T. D. Lama · Dhiman Burman ·
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H. S. Sen *Editors*

Transforming Coastal Zone for Sustainable Food and Income Security

Proceedings of the International Symposium of ISCAR on Coastal Agriculture, March 16–19, 2021

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Preface

The global coastline is about 440,000 km long and varies greatly around the world from frozen polar shorelines to tropical mangroves and beaches. Coastal regions include coastal seas on the continental shelf to a depth of 50 m, the coastline and the adjacent land that is routinely inundated with sea water and extends over approximately 2.3–7.0 million km^2. In general, the coastal and marine environment can extend up to 100 km inland and up to 50 m water depth in the ocean. Tropical and subtropical coastlines are dominated by mangroves, sandy beaches, coral reefs and seagrass beds, whereas tidal marshes, macroalgal forests and seagrass beds abound on higher latitude coastlines. While coastal areas cover only 4% of the earth's total land area and are equivalent to only 11% of the world's ocean area, they host one-third of the world's population and are twice as densely populated as inland areas.

In India, around 250 million population reside within 50 km of the 7500 km coastline that is shared by 9 states and 2 union territories comprising 77 towns and cities including 3 megacities, viz., Mumbai, Kolkata and Chennai. The coastline supports several economic activities that are vital for the nation's economy like oil and gas, ports and harbours, power plants, fishing, tourism and mining that keep affecting the coastal ecology and environment. At the same time, it is important to note that the coastal stretches are well endowed with highly productive ecosystems that support the coastal human population in numerous ways, ranging from alleviating their poverty by offering a variety of coastal resources, to protecting them from natural and manmade hazards like erosion, cyclones, storm surges, tsunamis, pollution, etc.

Despite the multitude of services that coastal ecosystems provide us, their degradation and the subsequent loss of biodiversity continue at an unprecedented rate. This undermines coastal ecosystem functioning and resilience and thus threatens the ability of coastal ecosystems to continuously supply the flow of services for present and future generations.

Agriculture is the major occupation of the people in the rural areas of coastal regions of the country, but it is highly complex, risk-prone and entirely dependent on the vagaries of nature.

Thus, farmers primarily grow low-yielding long-season traditional varieties of rice during the wet season and much of the land lies fallow during the dry season.

Changing rainfall patterns and increased frequency of extreme events attributed to climate change proceeding unabated are inflicting added vulnerabilities to livelihoods and resources in the region. A range of ecosystem services critical to the ecological and economic security of the region needs attention for its sustainable uses. There are opportunities for intensification through efficient use and optimal management of fresh surface and groundwater resources, careful planning of the crop calendar and efficient agronomic practices that maximize water use efficiency.

The Indian Society of Coastal Agricultural Research (ISCAR), established in 1983, is a pioneer scientific body in India engaged with international associations in establishing linkage among the scientists, academicians, research institutes, universities and NGOs, for coordination of overall research activities related to agriculture in coastal areas of India and abroad. It publishes regularly a research journal *Journal of the Indian Society of Coastal Agricultural Research* and holds meetings, workshops, seminars, etc., to keep close exchange of views among the farmers and research workers working on different problems of agriculture and allied sectors in coastal areas. The society has already organized twelve national seminars/symposiums and one international symposium in various parts of the country. In the Annual General Body (AGM) held on March 31, 2019 under the chairmanship of Dr. H. S. Sen, President of ISCAR, it was decided that the forthcoming symposium would be held during November 5–8, 2020 at Kolkata as the Second International Symposium of ISCAR. Due to the COVID pandemic, the symposium was postponed, and finally, it was decided that the Second International Symposium would be held on March 16–19, 2021 in virtual mode. Along with COVID, two devastating recent cyclones *Bulbul* during November 2019 and *Amphan* during May 2020 as well as frequent storm surges in coastal India raised concern about the very existence of the coastal region. Suitable policies are to be evolved to protect the vested interest of different stakeholders of the coastal region with particular focus on multiple uses of coastal resources. Exceptions are India, Bangladesh, Philippines, Thailand, Sri Lanka, Vietnam, Cambodia, Egypt, Australia, Latin America and possibly a few other countries paying concerted attention to the coastal ecosystem for improvement in the agricultural front in particular. The problems of livelihood in these areas are compounded manifolds owing to a series of technological, administrative and socio-economic constraints, which need to be addressed on a common platform. It was important in the same context to draw instances and research progress from other countries, sharing significant coastal areas, like USA, Italy, Canada, New Zealand, Kenya, Poland, etc., for global upkeep of the research recommendations that we strive for in this symposium. Keeping in view of the above issues, the Indian Society of Coastal Agricultural Research (ISCAR), Canning Town, West Bengal, India, in collaboration with ICAR-Central Soil Salinity Research Institute, Karnal, India, organized this International Symposium on Coastal Agriculture (ISCA Webinar): Transforming Coastal Zone for Sustainable Food and Income Security during March 16–19, 2021 in a virtual mode.

One National Advisory Board and one International Advisory Board under the chairmanship of Prof. M. S. Swaminathan always guided the society to chalk out the entire programme of the symposium. The symposium was attended by more than

250 delegates comprising researchers, academicians and students from Australia, UK, USA, Bangladesh, Canada, Kenya, Ghana, Thailand, Malaysia, Poland, Italy, Philippines, New Zealand and various parts of the coastal states of India. A total of 274 abstracts were received out of which 182 abstracts were voluntary contributions. There were 11 plenum lectures and 86 invited talks during the symposium. Those 78 full-length articles were evaluated and are presented in this book under five major theme areas on coastal region development like (a) system approach to address abiotic and biotic stresses, (b) resource management and technological innovations in fisheries and animal husbandry, (c) assessment and management of natural resources, (d) climate change trend and its impact and (e) socio-economic issue and value chain. We hope this book has collected all the know-how available with researchers, academicians and various other stakeholders for addressing the complex problems of coastal regions and to draw out strategies for resilient agricultural technologies and improving livelihood security in coastal agro-ecosystem and preparing a road map taking into consideration the value addition and market intelligence under changing global environment.

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On behalf of the Indian Society of Coastal Agricultural Research (ISCAR), the editors would like to express their gratitude to the Indian Council of Agricultural Research (ICAR), New Delhi, National Jute Board, Government of India, and National Bank for Agriculture and Rural Development (NABARD) for sponsoring the International Symposium on Coastal Agriculture: Transforming Coastal Zone for Sustainable Food and Income Security organized in collaboration with ICAR-Central Soil Salinity Research Institute, Karnal, India, during March 16–19, 2021. The proceedings comprises a compendium of selected papers that were presented by eminent scientists, researchers and students during the symposium.

The editors are thankful to all the authors for having given their valuable time in the preparation of contributed chapters. Sincere thanks are also due to the reviewers and editors for their valuable comments and feedback.

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Inaugural Address by DG ICAR

My special thanks to Dr. H. S. Sen, President of the Indian Society of Coastal Agricultural Research; our Special Guest, Dr. Shaikh Mohammad Bokhtiar, Executive Chairman, Bangladesh Agricultural Research Council; our Special Guest, Dr. Luke York, Counsellor Agriculture, Australian High Commission, New Delhi; my valued colleague Dr. S. K. Chaudhari, Deputy Director General (Natural Resource Management), Indian Council of Agricultural Research; Dr. P. C. Sharma, Director of Central Soil Salinity Research Institute, Karnal; Dr. Burman, Organizing Secretary of the International Symposium on Coastal Agriculture; other colleagues from various countries who are participating in this particular webinar; my own colleagues from the Indian Council of Agricultural Research and the State Agricultural Universities and State Governments; and all delegates, ladies and gentlemen. It is a great pleasure on my part to be associated with this International Symposium. Thanks to Dr. H. S. Sen for being very persistent and very particular about me participating in this international symposium, though I was reluctant and explained that probably I do not know much about the coastal agriculture in terms of research conducted by me and therefore may not be befitting on my part to speak about it. But anyway in such webinars and conferences, they are supposed to be addressed by some person and he has chosen me. I know him for pretty long time when he was Director of Central Research Institute for Jute and Allied Fibres, Barrackpore. I have regards and very deep regards for him, so I agreed and I am here. Thanks Dr. Sen once again profusely for continuing and insisting that I should be here.

I am extremely happy to see online Dr. Bokhtiar. He has been a good friend for a quite long time and that we know each other. Not only that he visited here, he also invited me to Dhaka and we had very good interaction, when he was with the SAARC Agriculture Centre and moreover our friendly relationship between the two countries gets further cemented through these relationships. Opportunities are further provided through such international conferences and symposia where we sit together in a common platform to deliberate on issues and problems of relevance to our countries. So, Dr. Bokhtiar, a very happy welcome on my own personal behalf to you and to your other colleagues who are there. Also, I welcome Dr. Luke York Counsellor Agriculture, Australian High Commission, New Delhi. I am sure the kind of situation

Australia faces due to the fact that the whole country is surrounded by the ocean causes coastal agriculture and its relevance for Australia as huge. And rightly Dr. Luke has highlighted, and very importantly again India and Australia have been interacting on various facets of agriculture including coastal agriculture. I am happy to see Dr. Luke York and to listen to him. To my own colleague Dr. Chaudhari and to all of you from my own behalf and on behalf of the Indian Council of Agricultural Research and Department of Agriculture Research and Education, a very hearty welcome. Congratulations to Dr. Sen and his colleagues, the Indian Council of Agricultural Research and my colleagues there for having this international symposium organized which has been planned over a pretty long time. Dr. S. K. Chaudhari did inform me that we have here Dr. A. K. Singh, former DDG Natural Resource Management and former Vice Chancellor of one of our agricultural universities. We have also heard Dr. A. R. Khan, CGM from NABARD Kolkata and many others whom I cordially welcome on my own behalf. For this symposium, since time available with me is very limited, I will not be able to deal deeper into it.

The symposium has chosen the topic *Transforming Coastal Zone for Sustainable Food and Income Security*. This is something which is a very challenging one. Transforming coastal zone and coastal agriculture for food and income security is a huge challenge. Indian agriculture was focusing on enhancing production. Core production brings in more return to the farmers and that is how it was emphasized in view of the deficit situation that was quite relevant. Over the years, global agriculture and Indian agriculture have moved quite far, and today, we have here in India and other countries in the neighbourhood food self-sufficiency. In many fronts, we have quite a bit satisfactory development. Indian agriculture has done pretty well, and for this year prediction and assessment is that we will be crossing 300 million tonnes mark for the food grains, 20 million tonnes mark for horticultural crops, so on and so forth. So, agriculture is moving at a faster rate. Our growth rate has been close to 4%, and it has been quite a significant growth despite COVID-19. In fact, in case of milk production, our growth is close to 6% fisheries sector even more than 10%. So that is a kind of remarkable growth rate that you see in Indian agricultural sectors.

But coming to the challenges that we face, we have small marginal land holdings, 85% of our farmers being small and marginal. When we talk of the coastal agriculture, IPCC says in its Fourth Report that more than 2.4 billion people are staying in coastal region, within about 100 km from the sea shore, and it is a huge number close to little more than 40% of the total population at the global level. It is quite a dense region at the same time with regard to population density. Obviously, the anthropogenic activities in the coastal zone are quite huge and that put pressure on the ecology. That is a very serious challenge to sustainable production systems and increased income for the farmers. Today in India, Hon'ble Prime Minister of India has given a call for doubling farmers' income. When we look on the challenges, they are so formidable, and it is not just population density in the coastal regional but the climate change as well. The climate change is a serious threat, and when it is temperature rise, we are already 1 °C more than what we had in the pre-industrial era, and it is going to reach 1.5 °C by the turn of the century. Some prediction says that even earlier by 2050 we might reach there because we are increasing temperature @ 0.2 °C per decade, quite a fast increase in temperature. So, this is a very serious threat and is associated with reduced productivity in wheat. It said that 10% yield reduction will be there for every 1 °C rise in temperature. In case of rice, rise in carbon dioxide is supposed to increase rice yield particularly the biomass, while the temperature rises, which are concomitant with yield increase, but tends to increase sterility in grains. This will finally counterbalance, and in the process, you will not have much gain particularly in *kharif* season.

This is an important area in the coastal zone where the population density being high has positive anthropogenic activities with negative impacts, and the temperature rise poses a big challenge. Temperature rise is again associated with sea-level rise leading to inundation and intrusion of the sea water with all kinds of problems associated with them. In fact, during 1900–2010 sea level has risen by 19 cm and that is what I am told that it is going to rise further. By the end of this century, we might be crossing 50 cm increase in the sea level and some say it might go up to 98 cm. Salinity is concomitantly increasing. The coastal areas are getting submerged which is one kind of problem, and getting frequent flooding is another problem, but yet the other one being the kind of salinity increasing. It is predicted and assessed that by 2050 about 50% of the fallow land in the world would be rendered saline.

That is something which is very frightening. When you describe all these, you see that where are those rays of hope for us? Where can we pin our hope? What is that should we be doing? Certainly, the symposium of this kind I mentioned is very well planned and I believe you will be covering most aspects which are relevant. Anthropogenic pressure, and how do we really minimize the pressure, mangrove ecology and the mangrove forest—they are all very important. Almost 5 million hectares of mangrove forest area has been reduced over the past 30–40 years. And it is all because of the anthropogenic pressure, and of course, the tidal effects were always there. In addition, tsunami effects are there. So how do we really counterbalance these changes in case of climate and in terms of anthropogenic pressure, and move forward. I think it is a long way to go. Fortunately for us, the coastal ecosystem is positive for carbon and has plenty of carbon sequestration taking place and methane emissions are relatively low. So, these coastal wetlands and shallow lowland ecosystem are actually cropped where rice is grown in two seasons. Our own study at CRRI has revealed that the system is a carbon sink, so this is something which is positive with regard to the coastal system. How do we really enrich this further? What all should we be doing to enrich and strengthen our activities?

First of all, we should start building institution, because without that you cannot succeed. India took note of all these probably long times ago since India has a very long coastline stretching for more than 7500 km including the island ecosystems. Nine states, two islands—Andaman and Nicobar Islands, altogether it is a huge ecosystem, which is actually there for India. That is the reason why the government recognized the importance and built institution that is Central Coastal Agricultural Research Institute way back in 1976 at Goa. Before that recognizing that salinity would increase not only for inlands but also the coastal areas, the Central Soil Salinity Research Institute was established way back in 1969 and 1971 to address the issues related to inland and coastal salinity, respectively. Central Island Research Institute at Port Blair was established in 1978. So, the institutional framework is very essential to understand what is actually happening and this is all the more significant in today's context. Across nations, this has to be our emphasis that we must build institutions of relevance and intensify our efforts in these institutions to work on coastal zones and agriculture in the regions. When I say agriculture, agriculture includes allied sector activities, so that we build information and build science-based decision support system for helping this ecosystem. Coastal areas represent very fragile ecosystems, as I highlighted earlier, and this is very essential to consider. So, I am sure that we should be able to build networks, international networks across the nation as a crucial strategy. Institutions can do their own work individually but what is more important is building network across institutions. To understand very fragile nature of the coastal ecosystem, the threats to this ecosystem opportunities which are available and steps as to how we can capitalize on the existing strength to take advantage of, our expertise scattered across nations may be utilized. Can we really build it as a part of our deliberations during this symposium? In order to be a part of the international networks across nations, I think it would be very crucial and rewarding for all of us. Whatever we are discussing we must check the gaps at the global level and ensure participatory approach in addressing the farmers, since they are mostly small and marginal in the coastal ecosystem. This participatory approach is of crucial relevance. I remember some years ago we visited Bali Island in Sundarbans of West Bengal and we could clearly see how vulnerable agriculture was in that part of the country and that required participatory approach. Probably that is a very important component of our activity while we are trying to address the risk, minimize the risk and build sustainable agriculture production system to enhance income in this zone.

I will touch upon a few points as to how do we use more and more technologies. This coastal region is quite advanced in certain segments, but in other segments particularly in island ecosystem and some of the coastal regions in the main land we do see quite a bit of weakness with regard to technology use. For the farmers belonging to low-income groups, situation in this region is a big challenge. I strongly believe that given the emphasis on that kind of infrastructure, with access to fund and the kind of government schemes, there are scope and need for accelerated technology use. I should also emphasize here that India planned for mainstreaming technology use through climate-resilient platform, and while planning for this, we did think of the coastal region and its fragile nature and almost 8–10 of our climate-resilient villages are there in this ecosystem. For instance, in 24 Parganas (S) of West Bengal we find climate-resilient villages present. From the kind of lessons, we learnt with regard to technology interventions we find that these need to be really mainstreamed for helping the farmers for addressing the challenges. Similarly, in Kendrapara in Odisha, which is highly cyclone prone, tsunami impacts were severely observed in the past, and also in Ramanathapuram in case of Tamil Nadu. I was citing a few examples only that how these climate-resilient villages in this region are providing deeper technology mainstreaming, which is so essential to address the facts of climate change. In this region and particularly in the coastal ecosystem, how do we really go further with regard to today's use of technologies. I remember during my days at CRRI, Cuttack, we were promoting 'Swarna Sub-1' resistant to flash flood. I visited Bangladesh, and I saw 'Binadhan 8' and 'Binadhan 10' were getting popularity there as salt-tolerant varieties. We introduced them in India and then a few other lines were developed/identified in the institute and introgressed to develop salt-tolerant, drought-tolerant and flood-resistance varieties, and these traits were getting pyramided. CR Dhan 801 and 802 from CRRI, Cuttack, again got a big step in the direction of putting multiple genes of drought and submergence, and in certain instances, the salinity is also getting added. So, we have this kind of technologies developed and International Rice Research Institute is conducting works in India and Bangladesh in a big way.

Technology demonstration, handholding and participatory mode with farmers, as we are doing in climate-resilient village system, are thus very important for us. Use of technology in the form of drones or even remote sensing to map and build decision support system with regard to use of appropriate soil and land systems for various cropping patterns and integrated farming systems is another very crucial area, where, I think, we are lagging tremendously. So, this requires immediate international collaboration. Another issue is how do we use our artificial intelligence system, which will be very effective to use data from large data pool available in the respected regions and countries, and they build decision support system to use in all modern tools and technologies. Gender in this region is again a very sensitive point. How do we really mainstream gender and bring them to the front? There are plenty of opportunities as well as challenges. By handholding, we can make entrepreneurs in small and medium scale of tomorrow. Entrepreneurship is very important.

If agriculture has to be remunerative, and if agriculture has to be lucrative, this has to be built as a business model in the coastal zone. I strongly believe that women need to be trained and incubated to be entrepreneurs. India is trying in a small way, we have built centres, and we are building in fact start-ups. More than 500 start-ups we have built over the past few years, but there is plenty of opportunity to go in this direction.

Fishery is extremely important. The marine fishery catch is declining particularly in few nautical miles from the coast. Deep-sea fishing is essential, and so, we can go in fact to address the marine aquaculture system. How do you really build that platform so that we have sustainable and responsible fishery system developed? It should be a responsible fishery system built up. Nitrogen when applied through river systems is reaching the coastal zone and polluting it. That is a serious threat today in another area. How do we really purify this region, the coastal region? Reduced use of nitrogen in the inland will help this ecosystem further, and that is a big challenge.

Similarly, a kind of problem we face with regard to the mangrove ecology as I stated. Can you really strengthen the wetlands of coastal ecologies—the flora and fauna and the biodiversity getting extinct in the coastal zones—which are serious concerns? In fact, it is said that thirty per cent of the animal and plant species would be wiped out because of this global temperature rise which is happening very fast. By 2050, if we reach 1.5 degrees, and more increase in temperature probably by end of this century, you can imagine what would happen to the flora and fauna in the coastal zones. How do you really protect the biodiversity in this region? I mean that is another serious challenge to sustainability of the coastal ecosystem.

While I talked of the mainland of coastal region, the ocean system particularly the coral reefs and coral reef ecosystem, it is in fact getting negatively impacted and is very significant worldwide. It is not just in the Indian peninsula but worldwide. In fact, carbon dioxide levels in sea water particularly increase and have adverse impact on the microbes and microalgae, and that is again impacting this ecosystem particularly the coral reef ecosystem. This is again a very serious challenge and what we all can do to protect it? Can we do something? Deep sea water studies are lacking actually in this region, and what is happing in ocean unless we understand the temperature profile, the kind of tides, the volcanic eruptions taking place under sea, etc. Unless we understand all those phenomena, we will not be able to address what is happening there.

In terms of the anthropogenic activities, I referred to several times earlier, and these are to be minimized as the central key point in order to save the ecological disaster. So, who would be doing this and creating awareness is very essential in this context?

Through these symposia and conferences and beyond this, the activities of this society, I believe, are very praiseworthy and I am sure this would create more and more of awareness, for instance, on afforestation and strengthening of the kind of mangrove ecosystem in the coastal ecosystem. Sustainable and responsible fishery in the oceans is also very important, so also the marine ecosystem is also important—and all these need to be really promoted through extensive awareness programmes along with the agricultural system where clinical use is very extensive and needs to be again addressed through creating awareness and proper education to the farmers. So, we have tremendous responsibility for our future generations. I am sure the deliberations in this symposium would be quite rewarding. This common platform would provide countries in the region to deliberate on issues and concerns to address them by way of network programmes which would be very helpful in defining our future course of action. Developing new pathways, finding resources, building resources, taking care of natural resources which are available in this region, protecting biodiversity, using newer technologies which are there at this point of time for precision systems to be effectively utilized, and working with the farmers mainstreaming with gender-neutral programmes are some of the pathways suggested. I am sure you will go beyond these points which I mentioned because you are more knowledgeable than what I am because I have not worked in this particular area. So, I take this opportunity once again to thank profusely Dr. Sen, Dr. Chaudhari and all my colleagues for inviting me to be part of this symposium and also listen to many erudite speakers to learn from them many new facts and enrich myself. So, thank you Prof. Sen for giving me this opportunity and I wish this programme a grand success. Wishing you all the very best and thank you Dr. Bokhtiar for joining us from Bangladesh and also Dr. Luke York for being with us in this inaugural session. Thanks to all of you and thanks delegates. Thanks to press and media who are here today in this particular programme. Thank you very much.

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Part III Assessment and Management of Natural Resources

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Dr. Dhiman Burman is Head and Principal Scientist (Soil Science) at ICAR-Central Soil Salinity Research Institute, Regional Research Station, Canning Town. He received his Ph.D. in Agricultural Physics from IARI, New Delhi. Since 1995, he is engaged in research at various scientific positions at ICAR institutes (Indian Grassland and Fodder Research Institute and Central Soil Salinity Research Institute) on sustainable management of problem soils in semiarid and coastal region for augmenting agricultural production. He has 18 years of research experiences on soil and water management for agricultural development in the coastal salt-affected region. He has developed many agricultural technologies especially for small and marginal farmers of the salt-affected coastal region. During his research career, he has handled many in house research projects and international projects funded by GEF, CGIAR under CPWF, BMGF, IRRI and ACIAR as Principal Investigator/Co-principal Investigator. He received Jawaharlal Nehru Award of ICAR and Young Scientist Award of Indian Science Congress Association. He was awarded Fellow of Indian Society of Coastal Agricultural Research. He has several publications in national and international journals.

Dr. Uttam Kumar Mandal is Principal Scientist in Soil Physics at ICAR-Central Soil Salinity Research Institute, Regional Research Station, Canning Town. He holds a doctorate in Agricultural Physics from IARI, New Delhi. He was awarded Post Doctoral Fellow at ARO Israel and was conferred Lal Bahadur Shastri Young Scientist Award in the field of natural resource management. He received the Golden Jubilee Young Scientist Award from Indian Society of Soil Science. His research interests are soil water balance, sustainable land management in watershed, soil quality assessment, climate change, soil carbon sequestration. He is associated with ICAR network project National Innovations in Climate Resilient Agriculture (NICRA) where the team is looking after the spatio-temporal dynamics due to climate variability in Sundarbans region. He has several publications in national and international journals.

Dr. Sukanta Kumar Sarangi is Principal Scientist in Agronomy at ICAR-Central Soil Salinity Research Institute, Regional Research Station, Canning Town. He holds a doctorate in Agronomy from Banaras Hindu University (BHU), Varanasi. He received Gold Medal in bachelor's degree in Agriculture and University Gold Medal during master's degree in Agronomy. He was awarded national scholarship during graduation studies, Junior and Senior Research Fellowships of ICAR for master's and Ph.D. studies. He worked at M. S. Swaminathan Research Foundation for conservation of rice biodiversity. He has about 20 years of experience on farming system research in hill and coastal ecologies of India. His research interests are improving productivity of rice-based farming system through efficient management of natural resources in salt-affected coastal areas. He has more than 80 research papers published in peer-reviewed national and international journals and more than 25 chapters/conference proceedings published by renowned publishers. Presently, he is Editor-in-Chief of the *Journal of the Indian Society of Coastal Agricultural Research* (https://www.iscar.org.in/publications) and Editor of the *Indian Journal of Agronomy*.

Dr. H. S. Sen Former Director, Central Research Institute for Jute and Allied Fibres (CRIJAF, a unit under Indian Council of Agricultural Research or ICAR under the Ministry of Agriculture, Government of India), located at Barrackpore, West Bengal, has retired from regular service on superannuation from the institute, which was his last official posting, on 31 January 2008. He did his M.Sc. and Ph.D., both from the Division of Agricultural Physics, Indian Agricultural Research Institute, New Delhi.

After completing his Ph.D., he joined the ICAR service in various capacities, which he continued with until joining the last posting as Director, CRIJAF, Barrackpore, in July 2002. Broadly, his nature of experience can be divided into two parts, viz. (i) research and (ii) research management and administration. He was devoted to research in various capacities especially in the fields of 'water management and soil salinity and ecology related to coastal ecosystem' during 1971–1976 and 1982–2002 at Central Soil Salinity Research Institute, Regional Station, Canning Town, West Bengal, which was in the heart of Sundarbans, and in the field of 'water management and ecology under rice-oriented cropping system' at Central Rice Research Institute, Cuttack, Odisha, during 1976 to 1982. He was devoted to Research Management and Administration at CRIJAF, during his last posting, having its mandate on 'Productivity and Quality Improvement of Jute and Allied Fibres' with emphasis on ecology of the environment. He has devoted considerable attention for planning for future research strategies and livelihood securities in tidal dominated lower Ganges delta covering India and Bangladesh and authored a book on this topic published by Lap Lambert Publishing Academy in Germany, besides writing a few chapters on similar topics published by others. He has been Guest Lecturer at postgraduate level in the University of Calcutta for 25 years. He guided 5 students so far for Ph.D. degree. He has so far published more than 160 research papers in various forms. He has earned the national 'Vasantrao Naik Award' conferred by ICAR on his contribution to rainfed agriculture in coastal ecosystems in 1998. He is Fellow of two professional societies and Honorary Member of a number of other national and international societies and organizations. He is also President of two societies of national and international repute. He has authored a book on Sundarbans which has been published by Springer International in 2019.

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Part I
Systems Approach to Address Biotic and Abiotic Stresses

Chapter 1
Agricultural System Transformation for Food and Income Security in Coastal Zones

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Abstract Long-term and seasonal variations in weather conditions, salt intrusion, waterlogging, and/or freshwater availability are some of the major factors that made coastal zones highly diverse, fragile, and vulnerable. Weather disturbances are common and are further aggravated by climate change. Competition among resource users usually leads to environmental and social challenges that need to be addressed at local and regional levels. These areas support dense human populations, with the prevalence of poverty and food insecurity, causing low and unstable agricultural productivity, driven by several abiotic stresses—floods in the wet season, soil salinization in the dry season, acidity, and high organic matter and nutritional toxicities or deficiencies throughout the year. Despite these challenges, these areas hold considerable opportunities for food production, though they still remain highly underutilized. Agriculture and aquaculture dominate the livelihood options in coastal tropical zones. Promising technologies together with access to knowledge had evolved considerably in the recent past, with packages of relevant technologies available to maximize the use of these areas. Major investments in infrastructure to control floods and salt intrusion demonstrated positive impacts in some areas, but this entails proper planning and policies for monitoring and adjustments, and large capital investments, beyond the reach of smallholder farmers. High rainfall during the wet season causes

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excessive wetting, positioning rice farming as the preferred agricultural activity. Several rice varieties with tolerance to salinity and floods or a combination of both have been developed and some deployed in affected areas over the past two decades, with remarkable impacts. These varieties provided opportunities for designing better stress- and variety-specific management options and more confidence and assurance for farmers to invest in input use and good crop husbandry, besides flexibility for higher cropping intensity and diversity to enhance their nutrition and household income. More efforts, however, are needed to fully exploit the potentials of these areas for food and nutrition security through large-scale adoption of validated technologies, human and infrastructure development, enabling and empowering policies, along with concomitant access to information via digital tools and to markets. Enhancing the productivity and profitability of rice-based cropping systems in these coastal areas with assured quality management services through proper harvest, postharvest processing, and value addition will significantly improve smallholder farmers' livelihood, thereby contributing to national food security and to reach several of the targets of the United Nation's Sustainable Development Goals.

Keywords Abiotic stresses · Agronomic management · Asian mega deltas · Coastal ecosystems · Food security · Rice · Salt tolerance

1.1 Introduction

Coastal ecosystems represent a transition between land and water (ocean, sea, river) systems, forming different landforms such as deltas, estuaries, creeks, lakes, and lagoons, including the shoreline environment, upland watersheds that flow into coastal waters, and sub-littoral habitats that are affected by land-based activities. Globally, the coastal ecosystem is a rich reservoir of agro-biodiversity and natural resources. Agriculture and allied sectors, including forestry and aquaculture, provide a livelihood for millions of people living within a few kilometers from the seashore (Schneider and Asch 2020). High rainfall, diverse soil types, and mangrove forests provide a heterogeneous system of natural resources; however, the high population density, land erosion and degradation, and remoteness are some of the weaknesses of this ecosystem. The prevalence of poverty in these coastal areas is higher compared to other ecosystems (Ismail and Tuong 2009).

Rice consumption provides about 20% of daily calories uptake and 12% of protein intake for four billion people around the globe, and Asian countries alone produce and consume more than three-fourths of the world's total rice (Mackill et al. 2012; Ismail et al. 2013). Based on Food and Agriculture Organization (FAO) estimates, rice production must be increased by 25% to feed the growing human population by 2030 (FAO 2017). Tropical coastal rainfed environments provide ample opportunities for sustainable food production, especially rice; however, the prevailing complex array of abiotic stresses prevents exploiting this capacity. During the wet season, partial or complete flooding and/or long-term waterlogging (stagnant flooding, SF) occurs during rice vegetative phase due to heavy rainfall. At a later stage, when freshwater availability decreases with the gradual decline in rainfall, it leads to salinity build-up in topsoils (Bhowmick et al. 2020; Ismail et al. 2010; Sarangi et al. 2011). During the wet season, waterlogging and excessive wetting of lowland fields make it difficult to grow crops other than rice; however, the availability of freshwater minimizes soil salinity impact, but yields are mostly low and unstable because of the ecological complexity of the system, use of old varieties and landraces, and limited access to new technologies (Ismail and Tuong 2009; Sarangi et al. 2020a).

High soil salinity and lack of freshwater for irrigation are major constraints during the dry season, where rice occupies only about 10–20% of the arable lands, with the others (80–90%) remaining unutilized for lack of good quality water, increase in soil salinity, seawater intrusion, and shallow saline water table (Kumar et al. 2018). Recent developments in research and innovations brought considerable opportunities for productive agriculture by introducing abiotic stress-tolerant rice varieties (STRVs), tailored management practices, integrated farming systems, crop diversification, and more recently, the use of information technology for monitoring and access to knowledge. However, climate-change-related natural calamities and disastrous weather events still remain the major constraints in coastal zones.

Globally, around 600 million people reside in coastal areas, representing 10% of the world population, where the mean sea level is less than 10 m (UN 2017). About 27 million hectares (m ha) of land are influenced by coastal salinity in South and Southeast Asia (Bhowmick et al. 2020). India's coastal ecosystem covers around 10.78 m ha, stretching over 8129-km coastline along the Arabian Sea on the West Coast and the Bay of Bengal on the East Coast (Velayutham et al. 1999). About 3 m ha of the coastal ecosystem has been identified as the most vulnerable in the Ganges delta in South Bangladesh, where soil salinity has increased by around 26% over the past 35 years, expanding into non-coastal areas (Hossain and Hasan 2017).

El-Niño had a more pronounced influence on rice production as well as food security in tropical delta areas, with Myanmar and Vietnam considered most vulnerable. Agricultural productivity was severely affected in the Mekong river and Ayeyarwady deltas due to the El-Niño of 2015/2016 (FAO 2016). These habitats are highly vulnerable, dynamic, and complex due to these diverse natural hazards and extensive human activity. However, these coastal areas still hold enormous potential for agriculture and are well-suited to diverse food production systems in which agriculture and aquaculture coexist and support livelihoods.

1.2 Rice Production Trends and Constraints in Delta Areas

Several tropical mega-deltas in East, South, and Southeast Asia are dominated by rice production as the backbone of agriculture. Mega-deltas in Bangladesh, Myanmar, and Vietnam (Table 1.1) are extremely important and play major roles in rice production and food security (Schneider and Asch 2020) of these countries. These deltas produce about 57, 53, and 71% share of the total annual rice production of 35, 26, and 44

Table 1.1 Mega deltas of Asia (adopted from Schneider and Asch 2020)

Delta	Country	Delta area (1000 km^2)	AARD[a] (max./min.) m^3 s^{-1}
Indus	Pakistan	1120	2644 (10,128/189)
Tigris-Euphrates	Iraq	880	1966 (3299/849)
Godavari	India	127	3079 (11,567/122)
Ganges–Brahmaputra	Bangladesh	106	29,692 (80,984/6041)
Changjiang (Yangtze)	China	67	25,110 (47,300/9261)
Mekong	Vietnam	39	10,314 (21,872/1505)
Huanghe (Yellow)	China	37	2571 (2858/543)
Ayeryawady (Irrawaddy)	Myanmar	21	12,564 (36,000/[b]ns)
Song Hong (Red River)	Vietnam	15	3300 (14,000/1000)
Chao Phraya	Thailand	10	883 (2838/50)
Fly	Papua New Guinea	6.2	6000 ([b]ns/ns)
Mahakam	Indonesia	1.5	2300 (5000/1800)

[a]*AARD* Average annual river discharge, [b]*ns* Not specified

million tonnes (mt), respectively, in these countries. Submergence (complete short-term inundation) and waterlogging/stagnant flooding (SF, partial long-term floods of up to 60 cm for most of the season) due to excessive rainfall in the wet season, and soil and water salinity due to scarcity of fresh water in the dry season are significant challenges for intensive rice production in these deltas.

Several factors have constrained the productivity of rice in these areas. Natural disasters (cyclones, typhoons, and coastal storms), degraded soils with high salinity, and scarcity of freshwater for irrigation adversely affect the production of rice and other crops. High population density and socio-economic factors also exert pressure on natural resources and the environment (Bhowmick et al. 2020). Waterlogging at the early vegetative stage and high salinity due to tidal activities and reduced rainfall at the reproductive phase, together with occasional drought at any stage, are commonly encountered during the wet season, leading to unstable productivity. During the dry season, the major challenges for rice production are high soil salinity, freshwater scarcity, salt intrusion, which is progressively worsening because of sea-level rise caused by climate change, and biotic stresses, including pest and disease pressure and weeds (Bhowmick et al. 2020; Sarangi et al. 2014). The Mekong delta in Vietnam has been reported with a mean elevation of ~0.8 m above sea level (Minderhoud et al. 2019), making it more vulnerable to climate change and changes in sea level than previously thought. The underestimation of the actual elevation of this delta is likely to be the case across other tropical deltas and coastal regions throughout Asia.

Recent data showed that these coastal tropical deltas are subsiding faster than initially thought, mainly because of excessive groundwater extraction. The Mekong delta sank by an average of ~18 cm during the past 25 years (Minderhoud et al.

2017). Water management for agricultural and urban use, water-saving technologies, and careful land-use planning are direly needed to mitigate these impacts and more effectively deal with climate change adversities. Integrated interventions like well-planned irrigation schemes, climate-resilient varieties with tailored management practices, and scale-appropriate mechanized operations need to be in place to improve and sustain system productivity. Understanding the dependencies and individual components of improved technological innovations, their penetration with strong extension support, knowledge access, and sharing should be explored to deploy effective adaptation and mitigation strategies.

1.3 Tapping into Coastal Zones for Food Production and Security

Overexploitation and mismanagement fueled by dense and mostly impoverished populations have placed tropical mega deltas under a great deal of pressure, leading to the degradation of natural resources. Majority of the world's poor farmers live in these zones and are mostly affected by climate change and other human-induced adversities. Indigenous varieties and traditional production systems with mostly single cropping are dominant. These areas also missed the benefits of the green revolution that focused on technologies and varieties suitable for favorable areas, yet these areas hold significant potential that can be explored by bridging knowledge gaps between lab and land for increasing productivity and resilience. Addressing the current constraints of coastal zones will help prepare for future climate change adversities through resilient crops and production systems (Ismail et al. 2010). Tropical coastal zones are rich in water and land resources. Good weather conditions provide ample scope for year-round farming. Rice, aquaculture, and value-added products can all be integrated with farming system models that use modern interventions and technologies. Seasonally diversified production systems can generate more employment and create opportunities for rural entrepreneurship, with higher income and fewer risks than monoculture systems (Schneider and Asch 2020).

1.4 Transforming Rice-Based Agri-food Systems in Coastal Zones

Farmers in most coastal zones are still using traditional varieties to just meet their subsistent food needs, though the yield of these varieties is low and they do not respond to inputs like chemical fertilizers. These varieties were kept in use for a long time because of their partial adaptation to recurring stresses, especially floods and salinity. More recently, farmers started using popular rice varieties developed for favorable areas, together with blanket crop and nutrient management recommendations. This shift results in a noticeable increase in productivity during favorable years, but carries the risk of low productivity or even complete losses during disastrous years, with the severe incidence of floods or salt intrusion due to drought spells or coastal storms. The recent progress made in developing and deploying resilient modern varieties that are tolerant to floods, salt stress, or multiple abiotic stresses is providing opportunities for transforming these areas for food production (Singh et al. 2011; Ismail et al. 2013; Ismail and Horie 2017). These new varieties are also more responsive to modern crop management systems that integrate proper nutrient, water, and pest management, facilitating the transition from old traditional production systems to modern, efficient, and more sustainable productive systems. Increasing adoption of stress-tolerant varieties (STVs) with improved management practices, including shifting from blanket to stress- and variety-specific recommendations, is gradually being witnessed in these coastal areas. The introduction of farm machinery and modern production and postharvest technologies, and access to input and output markets are increasingly enhancing productivity and farmers' income. Together with enabling policies and empowerment for partnerships, faster deployment of modern innovations, equity, and income-generating value addition activities, and empowerment of women and youth, these interventions will transform coastal zones and raise their productivity to levels similar to that being witnessed in favorable areas (Fig. 1.1).

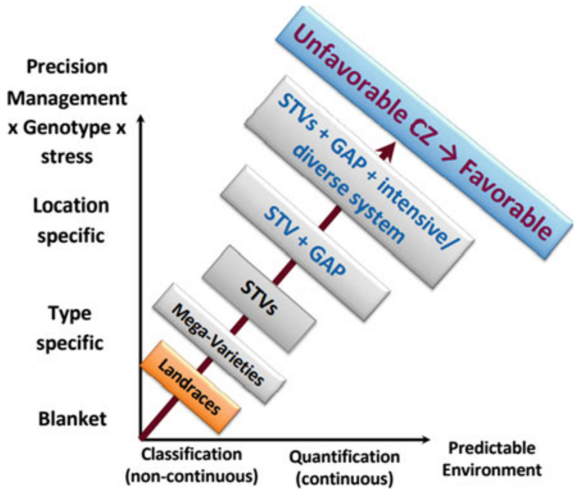

Fig. 1.1 Transforming unfavorable coastal zones into favorable areas through modern technologies for sustainable food production (adopted from Yadav et al. 2017). *CZ* coastal zone, *GAP* good agricultural practice, *STVs* stress-tolerant varieties

1.4.1 Development and Deployment of Stress-Tolerant Rice Varieties

In coastal regions, flash floods (FF, complete flooding/submergence for 1–2 weeks) and/or SF can occur any time during the wet season. FF occurs for a short period, whereas SF is common in the saucer-shaped lowlands with high annual rainfall (>1800 mm), and usually persists for more than a month. Submergence affects over 22 m ha of farmland in the rainfed lowland of Asia. The affected areas are usually inhabited by small, marginal, and resource-poor farming communities (Ismail et al. 2013). As a coping strategy, farmers cultivate traditional and old varieties that endure 5–7 days of complete submergence, though with a substantial loss in yield (Catling 1992). Productivity of these traditional varieties is less than 2 t ha^{-1}, considerably lower than that of advanced semi-dwarf varieties being used under the input-intensive irrigated systems. After large-scale screening at the International Rice Research Institute (IRRI), FR13A, a local landrace from Odisha, was first identified by farmers for its submergence tolerance and was later extensively used in breeding programs to develop submergence tolerant varieties. The locus responsible for the tolerance of FR13A named *Submergence 1* (*SUB1*) was later mapped and cloned. DNA markers were developed and used for their incorporation into numerous varieties through Marker-Assisted Backcrossing (MABC). Most of these varieties are now being adopted in flood-prone areas of many countries in South and Southeast Asia and sub-Saharan Africa (Xu et al. 2006; Neeraja et al. 2007; Septiningsih et al. 2009; Ismail et al. 2013; Ismail and Atlin 2019). The first generation of these varieties includes popular varieties such as Swarna, IR64, Samba Mahsuri, BR11, Ciherang, and CR1009. The improved versions of these varieties can withstand 10–15 days of complete submergence (Ismail et al. 2013; Sarangi et al. 2020b). The *SUB1* version of these varieties can provide 1.0–2.5 t ha^{-1} additional yield after 7–16 days of flooding in farmers' fields, with no yield penalty in years with no incidence of submergence. In recent years, extensive field studies confirmed the effectiveness of Sub1 varieties, such as Swarna-Sub1, CR1009-Sub1, and BR11-Sub1 under FF conditions (Mackill et al. 2012, Ismail et al. 2013, Sarangi et al. 2020b) (Table 1.2).

In SF-prone areas, rice fields are flooded with water depths that typically do not exceed 50–60 cm but last for a few weeks to few months. SF at depths higher than 25 cm hampers the growth of rainfed lowland rice in medium-deep to deepwater areas (30–100 cm) even when the plants are not completely submerged, due to poor tillering ability, smaller panicles with fewer spikelets, high sterility, and increased lodging (Singh et al. 2011; Vergara et al. 2014). Growth, phenology, and yield responses to SF are primarily determined by plant height and tillering ability. *SUB1* can be introgressed into the relatively taller varieties that have better SF tolerance in areas with concomitant incidences of submergence (FF) and SF, either during the same season or in different seasons. Given the erratic nature and flood types, combining *SUB1* with SF tolerance for all genotypes developed for coastal zones is becoming unavoidable to ensure wider adoption and adaptation by the farmers (Singh et al. 2011). Amal-Mana, Gosaba 5, and Gosaba 6 are recently released as SF-tolerant varieties (Table

Table 1.2 Yield and farmers' preference scores of Sub1 varieties under stagnant and flash flood conditions in an on-station experiment conducted at ICAR-CSSRI, RRS, Canning Town, South 24 Parganas, West Bengal, India

Genotypes	Grain yield (t ha^{-1})			Preference score		
	SF*	FF**	Mean	SF*	FF**	Mean
BR 11-Sub1 (BRRI Dhan 52)	2.65	2.78	2.72	0.32	0.38	0.35
Ciherang-Sub1 (BINA Dhan 11)	1.53	2.64	2.08	−0.26	−0.29	−0.27
CR 1009-Sub1 (Savitri-Sub1)	3.27	4.11	3.69	0.31	0.63	0.47
IR 64-Sub1	0.79	1.55	1.17	−0.56	−0.62	−0.59
Samba-Sub1	1.95	2.10	2.03	−0.31	−0.34	−0.33
Swarna-Sub1	2.26	3.11	2.68	−0.26	0.20	−0.03
DRR Dhan 39	2.17	1.85	2.01	−0.06	−0.27	−0.17
Sabita (Check)	3.45	2.14	2.80	0.62	0.15	0.39
Mean	2.26	2.53	2.40	–	–	–
$LSD_{0.05}$ Flooding stress (*F*) Genotype (*G*) $F \times G$	ns# 0.35 0.52			–		

Data are means of the wet season, 2016 and 2017 (adopted from Sarangi et al. 2020b)
**SF* Stagnant flooding, ***FF* Flash flooding, # *ns* Non-significant
~40 days old seedlings were transplanted at a spacing of 15 cm × 15 cm. Fertilizers were applied at 75-20-10 kg N–P_2O_5–K_2O ha^{-1}, P and K were applied as basal before transplanting and N through neem coated urea in three equal splits at 7 days after transplanting (DAT), maximum tillering (35–45 DAT), and flowering (60–80 DAT) (adopted from Sarangi et al. 2020b)

1.3) (Sarangi et al. 2016; Bhowmick et al. 2020) and could be incorporated with *SUB1* to develop varieties that can tolerate both submergence and SF.

Rice production during the dry season is more challenging in coastal zones and depends largely on access to freshwater resources. The success of dry season rice also requires the deployment of salt-tolerant rice varieties and good management practices, particularly for salt-affected areas. The cost of rice cultivation is higher due to the high cost of irrigation, especially when shallow-tube wells are used. However, rice yields in the dry season are higher than in the wet season due to higher solar radiation, lower night temperatures at the early crop growth stages, favorable temperatures during grain filling and ripening stages, and lower risks of monsoon rains and storms. Therefore, dry season rice can boost and stabilize rice production in coastal zones, with potentially high net profits because of the high yield of newly released salt-tolerant varieties (4–5 t ha^{-1}) compared with that of the traditional or old varieties (2–3 t ha^{-1}) under natural farmers' fields (Sarangi et al. 2014).

Table 1.3 Stagnant flood (SF)-tolerant rice varieties released by the National Agricultural Research and Extension Systems (NARES) institutes and preferred by farmers in the coastal region of India (adopted from Bhowmick et al. 2020)

Varieties	Duration (days)	Plant height (cm)	Grain yield (t ha^{-1})	Grain characteristics
Amal-Mana	160–165	160–170	5.0–5.5	[a]LS
Chinsurah Nona 1 (Gosaba 5)	138–142	115–120	4.5–4.8	[b]MB
Chinsurah Nona 2 (Gosaba 6)	135–140	115–120	4.8–5.2	[c]MS
CSRC(D) 2-17-5	160–165	155–175	4.0–4.5	MS
CSRC(D) 7-0-4	160–170	160–175	4.0–4.5	MS
CSRC(D) 12-8-12	160–170	160–175	4.0–4.5	MS
CSRC(D) 13-16-9	160–170	160–175	4.0–4.5	MS
DRR Dhan 33 (Jarava)	140–145	115–120	4.5–5.0	MB
Lunishree	145–150	130–135	4.0–4.5	LS
Luna Sampad (CR Dhan 402)	135–140	120–125	3.5–4.0	[d]SB
Luna Suvarna (CR Dhan 403)	145–150	130–135	4.0–4.5	MS
Luna Barial (CR Dhan 406)	150–155	125–130	4.0–4.5	SB
NC 678	155–160	165–170	2.0–2.5	MS
Patnai 23	160–165	160–170	3.0–3.5	MS
Sabita	150–155	140–150	3.5–4.0	LS

[a]*LS* Long slender, [b]*MB* Medium bold, [c]*MS* Medium slender, [d]*SB* Short bold

1.4.2 Crop Establishment Methods and Site-Specific Management Practices

The introduction of STRVs and best bet management practices can boost both productivity and profitability of the rice-based cropping systems (RBCS) in fragile environments. Management interventions include optimal nutrition in the nursery, proper seeding/seedling density, green manuring, care during and after stress, pre-and post-submergence nutrient management, and use of slow-release nitrogen fertilizers. These options vary with the type of stresses (salinity/sodicity, submergence, drought, acidity) and the crop that precedes rice season. When transplanted at a spacing of 15 cm × 20 cm with 4 seedlings $hill^{-1}$, and fertilizer rate of 150-60-40-5 kg N–P_2O_5–K_2O–Zn ha^{-1} in sodic soils, the salt-tolerant variety ‘CSR 43’ produced 35% higher grain yield over farmers’ preferred varieties and management practices (Singh et al. 2016). Based on studies conducted in the Indian *Sundarbans* region, it is possible to stabilize rice yield and minimize the effect of waterlogging by deploying STRVs with

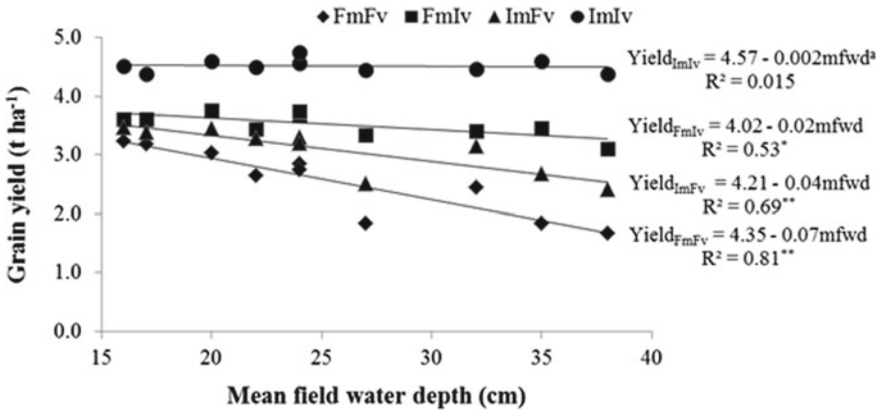

Fig. 1.2 Grain yield of rice varieties in the coastal flood-prone areas as influenced by management options under mean field water depth (from transplanting to harvest) in farmers' fields (adopted from Sarangi et al. 2016). *FmFv* farmer's management with farmer's variety, *FmIv* farmer's management with improved variety, *ImFv* improved management with farmer's variety, *ImIv* improved management with improved variety, [a]*mfwd* mean field water depth in cm, *significant at $P < 0.05$, **significant at $P < 0.01$.

tailored management practices. Association of grain yield with water depth (Fig. 1.2) was the strongest under farmer's management practice and using farmer's common variety ($R^2 = 0.81^{**}$) and the weakest when improved management was combined with improved variety ($R^2 = 0.015$), suggesting the resilience of the latter combination irrespective of water depth. Grain yield variation due to variable water depth was significantly narrowed down when improved management practices and the SF tolerant variety were combined (Fig. 1.2). Even with farmers' management practices, the yield of the tolerant variety (Amal-Mana) was higher and more stable than that of local varieties. The study clearly revealed that grain yields in these areas could be sustained with the combination of improved varieties and improved management practices, significantly mitigating the negative impacts of flooding and salinity in coastal areas (Sarangi et al. 2016).

1.4.2.1 Puddled Transplanted Rice

In coastal regions, adaptive rice varietal traits strikingly differ for the wet season compared with the dry season. Since rainfall is very high during the wet season, tall and long-duration varieties (usually 145 days or more) are preferred. In contrast, the dry season requires salt-tolerant varieties of shorter duration because of the usually high soil and water salinity and freshwater scarcity for irrigation. Transplanting rice in puddled soils (PTR) is the most common crop establishment method in these regions because puddling helps reduce soil salinity before planting and reduces the crop duration in the main field. Moreover, early rainfall causes waterlogging, restricting

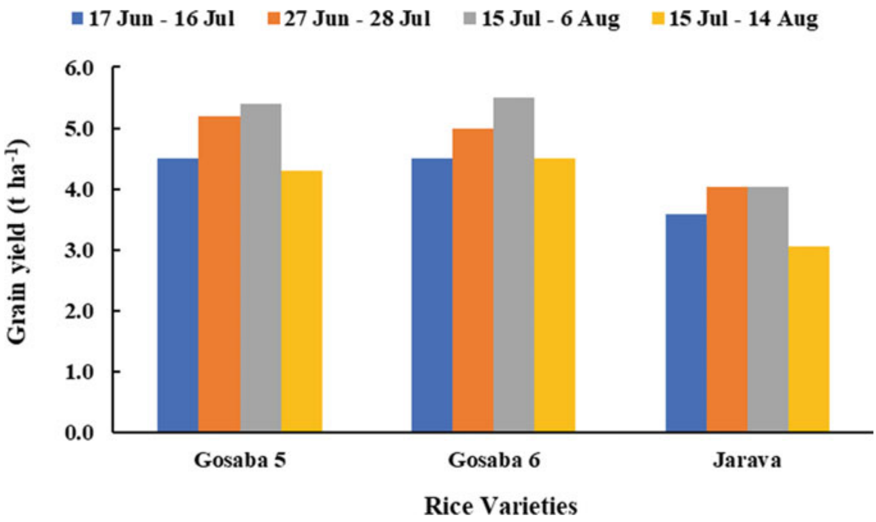

Fig. 1.3 Response of seed sowing and transplanting window (the first date is nursery sowing; the second is the date of transplanting) on grain yield of SF-tolerant rice varieties in the main field, using 30-day old seedlings for transplanting in an on-station experiment conducted at Salt and Flood Resistant Paddy Research Station, Gosaba, South 24 Parganas, West Bengal. Data are means of the wet season, 2014 and 2015 (adopted from Bhowmick et al. 2020)

seed sowing and reducing seed germination and seedling establishment, making it difficult to adopt direct seeding during the rainy season. Under PTR, soil compaction during land preparation reduces water seepage and helps in weed management. High soil salinization in the absence of rainfall or irrigation is a potential threat to seedling survival. Hence, the time of nursery establishment and transplanting are critical for good crop establishment and productivity. Transplanting of aged (30–35 days) seedlings in the first week of August can help escape the early high soil salinity and later stage waterlogging due to high rainfall (Fig. 1.3). Transplanting of aged seedlings leads to better seedling-vigor index and survival under complete submergence than younger seedlings due to higher vigor and high carbohydrate content in stems, which is essential for survival and recovery (Ella et al. 2003; Das et al. 2009; Bhowmick et al. 2020).

1.4.2.2 Unpuddled Transplanted and Direct Seeded Rice

Unpuddled transplanting of rice (UPTR) and/or dry-direct seeding (dry-DSR) are alternatives to conventional PTR during the wet season. Dry-DSR is beneficial in increasing yield with more economic returns than the PTR (Sarangi et al. 2020a), though there are hardly any varieties released specifically for dry-DSR conditions. Most rice breeding programs are focused on developing varieties suitable for transplanted rice systems, although some efforts on varietal testing for dry-DSR conditions have been made (Haefele et al. 2016; Panda et al. 2021). IRRI also initiated a direct-seeded rice consortium (DSRC) involving national programs in Asia and Africa, private sector companies, and other research and development partners (https://dsrc.irri.org/). The main aim of this consortium is to develop new varieties and technologies suitable for direct seeding, including land preparation, mechanization, weed management, and capacity-strengthening to facilitate shifting to, and large-scale adoption of DSR. However, wet-DSR (drum seeding of pre-germinated seeds) provided higher yields during the dry season (Sarangi et al. 2014; Bhowmick et al. 2016). Dry season crops like maize and rapeseed showed differential responses to various tillage practices and produced higher yields under raised bed systems (RBS) and zero-tillage, respectively. Hybrid maize is likely suitable as a post-wet season crop, but it requires 3.0 GJ ha^{-1} extra energy input and 25 cm more irrigation water than rapeseed-mustard. The study revealed a considerable saving (about 19 cm) of irrigation water during dry season maize by switching from the traditional practice of PTR to dry-DSR in the wet season, combined with partial (40%) crop residue retention in the rice-maize cropping system (Fig. 1.4). Thus, DSR crop in the wet season, followed by maize sowing on raised beds in the dry season, proved to be more productive and profitable in coastal rainfed lowland areas and could be promoted for large-scale adoption (Sarangi et al. 2020a).

Several nutritional and soil problems were also reported in coastal areas besides salinity, including acid sulfate soils, toxicities of iron and aluminum, deficiencies of

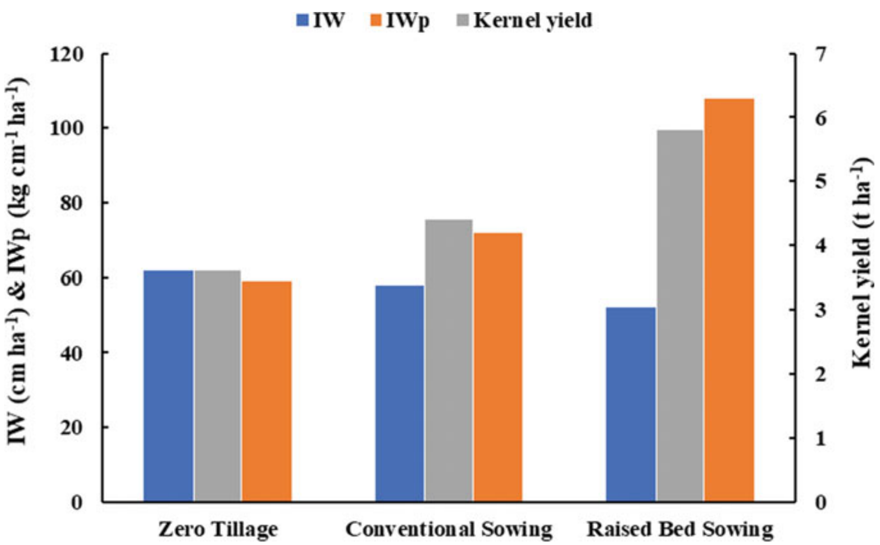

Fig. 1.4 Irrigation water use (IW) and irrigation water productivity (IWp) as influenced by different tillage practices in maize (variety Aditiya 303) during the dry season in an on-station experiment conducted at ICAR-CSSRI, RRS, Canning Town, West Bengal. Data are means of the dry seasons 2013–14 to 2015–16 (adopted from Sarangi et al. 2020a)

phosphorus, calcium, zinc, and potassium, and high level of exchangeable magnesium reported in the coastal zones of India (Sarangi et al. 2019), Vietnam, and Indonesia (Ismail et al. 2010). In these soils, green manuring using *Sesbania* spp. before rice transplanting and lime/rock phosphate application during the dry season increase soil pH and crop yield (Sarangi et al. 2019).

1.4.2.3 System of Rice Intensification

The System of Rice Intensification (SRI) was designed to be a climate-shrewd agro-ecological approach that increases rice yield, saves water, and improves the benefit–cost ratio following a set of production practices. It has recently been introduced in coastal areas to boost rice productivity with some deviations from its original principles to simulate best management practices that farmers can practically apply. The SRI principles applicable to normal soils are not as such suitable for coastal saline soils. In a study, 15–18 days old seedlings of a salt-tolerant rice variety were used for transplanting compared with the younger seedlings of 8–12 days recommended under SRI. Instead of soil saturation, extra irrigation water was applied to reduce salinity. The water-fern *Azolla*, microorganisms like *Azospirillum*, phosphate solubilizing bacteria, and *Trichoderma* were also applied to ensure sufficient nutrients, rather than relying on organic manure recommended for SRI (Sarangi et al. 2011). Based on soil characteristics, prevailing climatic conditions, water control, access to laborers, agrochemicals, and financial resources, farmers need to adjust their management practices to their local contexts in these highly variable coastal zones.

1.4.2.4 System of Assured Rice Production

Farmers generally use older seedlings when the onset of rainfall is delayed or due to the scarcity of irrigation water for timely transplanting. The System of Assured Rice Production (SARP) is an innovative methodology validated in rainfed ecosystems of West Bengal, India, during the wet season (Patra 2019). It increases the duration in the nursery before seedling uprooting and shortens the main field transplanting time, thus producing more vigorous and healthy seedlings. This practice appears to be ideal for adjusting to these difficult production conditions as well as to climate adversities. The nursery bed is supplied with farmyard and other organic manures (1.0–2.0 kg m^{-2}) and inorganic fertilizers; and low seeding density is used (15–20 g m^{-2}) to establish a healthy nursery. Based on weather conditions, variation in seedling age for main field transplanting makes the SARP methodology more attractive and suitable for coastal areas where vegetative-stage waterlogging and late-stage soil salinization are recurrent (Patra 2019; Patra and Bhowmick 2020).

1.4.2.5 Double Transplanting

Farmers often use double transplanting as a contingent plan in flood-prone areas when rainfall is delayed during the wet season or when floodwater is too deep for transplanting. This is a traditional method, popular in eastern India and Bangladesh, to ensure good crop establishment (Ram et al. 2009). In the first week of June, a wet nursery is initiated with a seed rate of 40–50 kg ha^{-1} under upland situation. The first transplanting is accomplished using high seedling density, with 12–14 seedlings $hill^{-1}$ at 15 cm × 15 cm spacing, using 25–30 days old seedlings. The seedlings are again uprooted at 30–35 days after the first transplanting and re-transplanted using the standard practices of 2–3 seedlings $hill^{-1}$ at a spacing of 20 cm × 20 cm in the main field (Verma et al. 2020). Through this approach, the early season flood can be managed effectively in the smaller nursery area before transplanting into the main field (Vijayakumar et al. 2019). Farmers in Sumatra (Indonesia) usually practice double and triple transplanting in uplands using high seeding densities. Final transplanting is then accomplished after water recession in the main field to lower levels at the end of the wet season (Ram et al. 2009). While it is labor-intensive, double and triple transplanting helps in managing excess water stress challenges early in the season in these fragile ecosystems.

1.4.3 Transition from Tillage-Intensive to Conservation Agriculture

Resource constraints such as water scarcity, labor shortage, and high cost of fertilizers and pesticides are common in most remote coastal areas. Even when available, these inputs are out of reach for resource-poor farmers. The choice of water productive cropping systems based on farmers' income and net returns is more effective as adaptation strategies to cope with these constraints. Rainwater harvesting and storage in farm ponds and/or canals, together with prudent use, is one option for farmers to consider during the succeeding cropping season. Medium ridges and shallow furrows, high ridges and deep furrows, broad beds and furrows, farm ponds, aquaculture ponds, and paddy-cum-fish cultivation could also be considered, based on farmers' available resources and socio-economic conditions. These choices are also largely dependent on farmers' immediate needs and market access, land types, and farm size and are effective in reclaiming the mostly degraded coastal soils, enhancing productivity, and improving their resilience against local vulnerabilities (Burman et al. 2013). Recycling crop residues in the RBCS reduces irrigation water requirements by over 30% and nitrogen requirements by 40 kg ha^{-1} in winter (*rabi*) maize (Sarangi et al. 2020c). Zero-tillage planting of potato in the dry season with paddy straw mulching has been reported to increase soil organic carbon by 0.39–0.44%, soil bulk density by 1.49–1.44 Mg m^{-3}, and soil moisture content by 4–8%; and reduce soil salinity (ECe) from 5 to 3 dS m^{-1} (Sarangi et al. 2020d).

1.4.4 Water Management

Proper water management reduces farm water requirements, improves system-scale water availability, and reduces soil salinity. Weather conditions, especially temperature and management practices, can influence groundwater capillary rise to the root zone. Shifting from flooded paddy fields to periodic flooding following improved water management practice(s) like alternate wetting and drying (AWD) and intermittent irrigation substantially reduces water use (Schneider et al. 2019). Freshwater scarcity and irrigation with saline water are major reasons for salinity building up in rice fields. Depending on local circumstances, selecting an effective irrigation technique is important to provide a balance between conserving water and maintaining low soil salinity to levels below the critical threshold for rice growth and yield. Water conservation strategies such as AWD can also minimize greenhouse gas emissions from flooded paddy fields; however, its use in coastal areas needs to be carefully assessed and modified. More research is needed to investigate the effectiveness of these water-saving technologies to avoid secondary soil salinization and the accumulation of toxic ions in the root zone (Schneider and Asch 2020).

1.4.5 Assuring Quality Through Proper Postharvest Processing and Value Addition

Sustainable development of the predominantly smallholder farmers' system in coastal zones requires efficient and cost-effective crop production practices, competitive markets, well-functioning value chains, and empowering and enabling policies (Parappurathu 2021). For an effective rice-based cropping system in these areas, timely harvesting of rice and land preparation is critical to establishing subsequent crops. Use of equipment like reapers can help preserve rice straw in the field similar to manual harvesting while shortening the time required for subsequent land preparation. Moreover, mechanical harvesting reduces grain losses, harvest duration, and labor requirements and preserves grain quality. Drum threshers are common, using a wheel system, and can be followed by drying using solar bubble dryers at reduced costs. For efficient storage, hermetic bags and cocoons are available to safely store grains and seeds from a few weeks to months. The income of the smallholder farmers in these areas can be increased through value addition to enhance the value of farm products based on consumer needs. Food processing is an important sector in coastal agriculture, covering diverse products such as fruits, vegetables, fish, milk, and marine products. Investments to boost food and agro-processing industries to better use these diverse food products will benefit both producers and consumers. In selected niche areas, organic production of quality rice varieties will increase farmers' income and profits.

1.4.6 Alternative Land Use

Alternative land use options based on season and soil and water salinity, including rice-shrimp and rice-non rice crop rotations, provide farmers with assurance options against changing environments and minimize income losses when severe weather incidences are encountered. Smajgl et al. (2015) proposed a change in agricultural production systems, primarily towards rice-upland crop rotations or rice-aquaculture to adjust to a 30 cm sea-level rise. During the dry season, shrimp can be grown under higher salinity (5–40 ppm). The arrival of monsoon during the wet season provides ideal conditions for fields to drain, reducing salt concentration sufficiently to start preparing for rice transplanting. The shrimp-rice rotation system could lead to 50% more earnings than the rice-rice cropping system. Thus, shrimp farming has been extensively promoted to farmers in semi-coastal areas considering the higher net returns (Smajgl et al. 2015), especially in areas where water becomes brackish during the dry season. However, precious freshwater is lost in the rice-shrimp cultivation system due to salinity build-up in the cultivated areas early in the season, owing to an expected shift in rainfall patterns (Schneider and Asch 2020). As a result, the intensity of rainfall during the remaining season is an important driver for the long-term viability and sustainability of this system. The rice-shrimp system also brings other challenges including the long-term impact of building of higher soil salinity, together with effluents filled with environmentally sensitive substances, besides vulnerability of the shrimp farming to viruses and other diseases (Clarke et al. 2015). Even though diversified technologies have positive impacts, these production models must be assessed for explicit spatial suitability, as well as long-term and large-scale impacts on the ecosystem and the environment (Schneider et al. 2019).

1.5 Policy Issues and Interventions

Being an integral part of river basins, the coastal zones in many countries hold considerable potential for food production and other industrial uses, transitioning the exchange between marine and terrestrial ecosystems (Coccossis 1997; Ismail and Tuong 2009). For example, the Ganges–Brahmaputra-Meghna river system is one of the largest freshwater outlets to the world's oceans (Rahman et al. 2020). Major challenges in these basins include the difficulty in developing an integrated basin management system, climate change impacts, continued threats from overexploiting natural resources, unsustainable interventions, disaster risks, and natural hazards, excessive fishing, habitat fragmentation, and degradation, human interventions, land erosion, massive flooding, and establishing effective transboundary cooperation.

Major investments in infrastructure for controlling flooding and salinity intrusion demonstrated huge impacts on rural livelihoods in some coastal areas, as in the Mekong Delta, when judicious interventions are carefully planned and properly backed with appropriate policies and strategies to accelerate the transformation of these areas (Ismail and Tuong 2009). Integrated coastal area and river basin management policies and strategies should address different issues like water rights, transboundary water conflicts, and watershed management at upper catchments among countries sharing the same basin, conflicting water uses for agriculture versus aquaculture, brackish water for shrimp vs. freshwater for crop production, etc. These are all important issues that impact downstream water use, with major effects on farmers in the coastal deltas. Even the issues for managing boulders sometimes cause problems in coastal zones, with conflicting water use options among farmers. Large boulders (mega-blocks) are sometimes displaced by storm events or tsunamis causing considerable damage (Evelpidou et al. 2020). A comprehensive policy dialog between beneficiaries usually helps in resolving these issues, improving the transboundary water governance, and ensuring the principles of equity and fairness in the coastal deltas are in place and rigorously implemented.

1.6 Conclusions

Despite a multifaceted array of soil-, climate-, and water-related issues, coastal rainfed areas in South and Southeast Asia are sustaining the livelihood of millions of people. These areas are inherently vulnerable to edaphic and weather factors, agroecologically diverse, with differential land use options, and subject to various abiotic stresses such as submergence, long-term waterlogging, and salt intrusion. The areas are dominated by small and marginal landowners who are often exposed to various climate risks and uncertainties, resulting in poor and unpredictable food production with a fair chance of complete crop failure in years when the stress is severe. Agricultural research and development options can substantially contribute to exploring these underutilized areas for more sustainable food production. Many of these regions are overpopulated with underdeveloped communities, with weak extension networks that allow limited access to improved varieties and modern production technologies. High humidity and waterlogging or excessive wetting do not favor crops other than rice during the wet season. Long-term SF or short-term complete submergence compounded by saltwater intrusion and poor crop and water management results in significant yield losses. During the last decade, several stress-tolerant rice varieties have been developed, deployed, and disseminated in areas challenged by submergence, waterlogging, and high soil and water salinity. The seeds of these varieties are available in the public domain for further deployment. These varieties can fit well in the rice-based systems to enhance and sustain productivity and profitability in these fragile ecosystems. We conclude that introducing STRVs, appropriate dry season crops for diversified nutrition and income sources, together with validated agronomic packages, would maintain higher productivity, making farming in these less favorable areas more appealing and robust. A better prediction system of weather conditions, rainfall patterns, and related floods and drought spells will contribute to farmers' preparedness and resilience. Aligning these interventions with the governments' plans and international governance addressing '*riparian state*' water rights would surely sustain food production, improve the livelihoods and the income of the resource-poor farmers in these vulnerable and fragile areas.

References

Bhowmick MK, Duary B, Bhattacharyya P et al (2016) Drum seeding technology: a viable option for resource-poor farmers toward profitable rice production in West Bengal. In: Mondal B, Sarkar D, Mukhopadhyay SD et al (eds) Family farming: challenges and opportunities. Renu Publishers, New Delhi, India, pp 125–130

Bhowmick MK, Srivastava AK, Singh S et al (2020) Realizing the potential of coastal flood-prone areas for rice production in West Bengal: prospects and challenges. In: Rakshit A, Singh HB, Singh AK et al (eds) New frontiers in stress management for durable agriculture. Springer Nature, Singapore, pp 543–577

Burman D, Bandyopadhyay BK, Mandal S et al (2013) Land shaping—a unique technology for improving productivity of coastal land. CSSRI/Canning Town/Bulletin/2013/02, ICAR-Central Soil Salinity Research Institute, Regional Research Station, Canning Town, West Bengl, India, p 38

Catling D (1992) Rice in deep water. MacMillan Press Ltd., London, p 542

Clarke D, Williams S, Jahiruddin M et al (2015) Projections of on-farm salinity in coastal Bangladesh. Environ Sci Processes Impacts 17(6):1127–1136. https://doi.org/10.1039/c4em00682h

Coccossis H (1997) Integrated coastal area and river basin management (ICARM). ICARM technical report series no. 1. United Nations Environment Programme, Water Branch, Priority Actions Programme, RegionaI Activity Centre, University of the Aegean Mitilini, Greece, p 13

Das KK, Panda D, Sarkar RK et al (2009) Submergence tolerance in relation to variable floodwater conditions in rice. Environ Exp Bot 66:425–434

Ella E, Kawano N, Yamauchi Y et al (2003) Blocking ethylene perception enhances flooding tolerance in rice seedlings. Functional Plant Biol 30:813–819

Evelpidou N, Zerefos C, Synolakis C et al (2020) Coastal boulders on the SE coasts of Cyprus as evidence of palaeo-tsunami events. J Mar Sci Eng 8:812. https://doi.org/10.3390/jmse8100812

FAO (2016) 2015–2016 El Niño early action and response for agriculture, food security and nutrition (http://www.fao.org/emergencies/resources/documents/resources-detail/en/c/340660/)

FAO (2017) FAOSTAT statistical database. Food and Agriculture Organization, Rome, Italy

Haefele SM, Kato Y, Singh S (2016) Climate ready rice: augmenting drought tolerance with best management practices. Field Crops Res 190:60–69. https://doi.org/10.1016/j.fcr.2016.02.001

Hossain MAR, Hasan MR (2017) An assessment of impacts from shrimp aquaculture in Bangladesh and prospects for improvement. FAO fisheries and aquaculture technical paper no. 618, Food and Agriculture Organization, Rome, Italy. https://reliefweb.int/report/bangladesh/climate-change-induced-salinity-affecting-soil-across-coastal-bangladesh. Accessed 23 Apr 2021

Ismail AM, Atlin G (2019) Incorporating stress tolerance in rice. In: Zeigler R (ed) Sustaining global food security: the nexus of science and policy, part 3, modern plant breeding; redesigning crop plants. CSIRO Publishing, Clayton, Australia, pp 224–246

Ismail AM, Horie M (2017) Genomics, physiology, and molecular breeding approaches for improving salt tolerance. Ann Rev Plant Biol 68:405–434

Ismail AM, Singh US, Singh S et al (2013) The contribution of submergence tolerant (Sub 1) rice varieties to food security in flood-prone rainfed lowland areas in Asia. Field Crops Res 152:83–93

Ismail AM, Thomson MJ, Vergara GV et al (2010) Designing resilient rice varieties for coastal deltas using modern breeding tools. In: Hoanh CT, Szuster BW, Suan-Pheng K et al (eds) Tropical deltas and coastal zones food production, communities and environment at the land-water interface. CAB International, Wallingford, UK, pp 154–165

Ismail AM, Tuong TP (2009) Brackish water coastal zones of the monsoon tropics: challenges and opportunities. In: Haefele SM, Ismail AM (eds) Natural resource management for poverty reduction and environmental sustainability in fragile rice-based systems, Limited proceedings no. 15. International Rice Research Institute, Los Baños, Philippines, pp 113–122

Kumar R, Mishra JS, Hans H (2018) Enhancing productivity of rice–fallows of eastern India through inclusion of pulses and oilseeds. Indian Farming 68:7–10

Mackill DJ, Ismail AM, Singh US et al (2012) Development and rapid adoption of submergence tolerant (Sub1) rice varieties. Adv Agron 115:299–352

Minderhoud PSJ, Coumou L, Erkens G et al (2019) Mekong delta much lower than previously assumed in sea-level rise impact assessments. Nat Commun 10:3847. https://doi.org/10.1038/s41467-019-11602-1

Minderhoud PSJ, Erkens G, Pham VH et al (2017) Impacts of 25 years of groundwater extraction on subsidence in the Mekong delta Vietnam. Environ Res Lett 12:064006. https://doi.org/10.1088/1748-9326/aa7146

Neeraja C, Maghirang-Rodriguez R, Pamplona A et al (2007) A marker-assisted backcross approach for developing submergence-tolerant rice cultivars. Theor Appl Genet 115:767–776

Panda A, Majhi PK, Anandan A et al (2021) Proofing direct-seeded rice with better root plasticity and architecture. Int J Mol Sci 22:6058. https://doi.org/10.3390/ijms22116058

Parappurathu S (2021) Strengthening agricultural and allied produce value chains for income and livelihood security in coastal ecosystems. In: Sarangi SK, Mahanta KK, Raut S et al (eds) Book of abstracts, international symposium on coastal agriculture: transforming coastal zone for sustainable food and income security, Indian Society of Coastal Agricultural Research, ICAR-Central Soil Salinity Research Institute, Regional Research Station, Canning Town, West Bengal, India, 16–19 Mar 2021, pp 288–289

Patra SR (2019) Climate-smart agriculture towards improving livelihood security and farmers' income in West Bengal. In: Souvenir of the national seminar on sustainable resource management for enhancing farm income, nutritional security and livelihood improvement, Department of Agronomy, Palli Siksha Bhavana (Institute of Agriculture), Visva-Bharati, Sriniketan, Birbhum, West Bengal, India, 1–3 Feb 2019, pp 37–38

Patra SR, Bhowmick MK (2020) System of assured rice production in *kharif*: a resource-conserving and climate-resilient methodology for higher productivity and profitability. In: Rakshit A, Singh HB, Singh AK et al (eds) New frontiers in stress management for durable agriculture. Springer Nature, Singapore, pp 645–660

Rahman MM, Ghosh T, Salehin M et al (2020) Ganges-Brahmaputra-Meghna delta, Bangladesh and India: a transnational mega-delta. In: Nicholls RJ, Adger WN, Hutton CW et al (eds) Deltas in the anthropocene, Palgrave Macmillan, Springer Nature, Switzerland AG, pp 23–51. https://doi.org/10.1007/978-3-030-23517-8_2

Ram PC, Mazid MA, Ismail AM et al (2009) Crop and resource management in flood-prone areas: farmers' strategies and research development. In: Haefele SM, Ismail AM (eds) Proceedings natural resource management for poverty reduction and environmental sustainability in fragile rice-based systems. International Rice Research Institutem Los Baňos, Philippines, pp 82–94

Sarangi SK, Maji B, Digar S et al (2019) Acid saline soil management in coastal region. Technical bulletin ICAR-CSSRI/Canning Town/Folder/2019/9, ICAR-Central Soil Salinity Research Institute, Regional Research Station, Canning Town, West Bengl, India

Sarangi SK, Maji B, Sharma PC et al (2020d) Potato (*Solanum tuberosum* L.) cultivation by zero tillage and paddy straw mulching in the saline soils of the Ganges delta. Potato Res 64:277–305. https://doi.org/10.1007/s11540-020-09478-6

Sarangi SK, Maji B, Singh S et al (2014) Crop establishment and nutrient management for dry season (boro) rice in coastal areas. Agron J 106:2013–2023. https://doi.org/10.2134/agronj14.0182

Sarangi SK, Maji B, Singh S et al (2016) Using improved variety and management enhances rice productivity in stagnant flood-affected coastal zones. Field Crops Res 190:70–81. https://doi.org/10.1016/j.fcr.2015.10.024

Sarangi SK, Mandal S, Mahanta KK et al (2011) Assessment of system of rice intensification (SRI) during rabi season in coastal salt-affected soils. J Indian Soc Coastal Agric Res 29:54–58

Sarangi SK, Singh S, Kumar V et al (2020a) Tillage and crop establishment options for enhancing the productivity, profitability, and resource use efficiency of rice-rabi systems of the salt-affected coastal lowlands of eastern India. Field Crops Res 247:1–15. https://doi.org/10.1016/j.fcr.2019.03.016

Sarangi SK, Singh S, Maji B et al (2020b) SUB1 varieties increased rice (*Oryza sativa*) yield in flood-prone rainfed lowlands of coastal regions. Indian J Agric Sci 90(11):2064–2070

Sarangi SK, Singh S, Srivastava AK et al (2020c) Crop and residue management improves productivity and profitability of rice–maize system in salt-affected rainfed lowlands of East India. Agron 10:2019. https://doi.org/10.3390/agronomy10122019

Schneider P, Asch F (2020) Rice production and food security in Asian mega deltas—a review on characteristics, vulnerabilities and agricultural adaptation options to cope with climate change. J Agron Crop Sci 206(4):491–503. https://doi.org/10.1111/jac.12415

Schneider P, Sanders BO, Wassman R et al (2019) Potential and versatility of WEAP model (Water evaluation and planning system) for hydrological assessments of AWD (Alternate wetting and drying) in irrigated rice. Agric Water Manag 224:105559. https://doi.org/10.1016/j.agwat.2019.03.030

Septiningsih EM, Pamplona AM, Sanchez DL et al (2009) Development of submergence-tolerant rice cultivars: the sub1 gene and beyond. Ann Bot 103:151–160

Singh S, Mackill DJ, Ismail AM (2011) Tolerance of longer-term partial stagnant flooding is independent of the SUB1 locus in rice. Field Crops Res 121:311–323. https://doi.org/10.1016/j.fcr.2010.12.021

Singh YP, Mishra VK, Singh S et al (2016) Productivity of sodic soils can be enhanced through the use of salt tolerant rice varieties and proper agronomic practices. Field Crops Res 190:82–90. https://doi.org/10.1016/j.fcr.2016.02.007

Smajgl A, Toan TQ, Nhan DK et al (2015) Responding to rising sea levels in the Mekong Delta. Nat Clim Change 5(2):167–174. https://doi.org/10.1038/nclimate2469

UN (2017) The ocean fact sheet. The ocean conference, United Nations, New York, 5–9 June 2017. https://www.un.org/sustainabledevelopment/wp-content/uploads/2017/05/Ocean-fact-sheet-package.pdf. Accessed 15 Apr 2021

Velayutham M, Sarkar D, Reddy RS et al (1999) Soil resource and their potentialities in coastal areas of India. J Indian Soc Coastal Agric Res 17:29–47

Vergara GV, Nugraha Y, Esguerra MQ et al (2014) Variation in tolerance of rice to long-term stagnant flooding that submerges most of the shoot will aid in breeding tolerant cultivars. AoB-PLANTS 6:plu055. doi:https://doi.org/10.1093/aobpla/plu055

Verma DK, Giri SP, Verma S et al (2020) Impact of double-transplanting (Sanda) on yield and profitability of rice in eastern Uttar Pradesh. Int J Cur Microbiol Appl Scie 10:222–228

Vijayakumar S, Nayak AK, Satapathy BS et al (2019) Double transplanting—a contingent strategy for rice cultivation in low-lying areas. Indian Farming 69(5):36–38. https://krishi.icar.gov.in/jspui/handle/123456789/32179. Accessed 10 Apr 2021

Xu K, Xu X, Fukao T et al (2006) *Sub1A* is an ethylene-response-factor-like gene that confers submergence tolerance to rice. Nature 442:705–708. https://doi.org/10.1038/nature04920

Yadav S, Kumar V, Singh S et al (2017) Growing rice in eastern India: new paradigms of risk reduction and improving productivity. In: Mohanty S, Chengappa P, Hedge M et al (eds) The future rice strategy for India. Academic Press, Canbridge, USA, pp 221–258.https://doi.org/10.1016/B978-0-12-805374-4.00008-7

Chapter 2
Dhani (*Oryza coarctata*): A Wild Relative of Rice is a Potential Source of Coastal Salinity Tolerance Genes Suitable for Rice Breeding

Swati Mishra, Soni Chowrasia, and Tapan Kumar Mondal

Abstract Coastal salinity stress is one of the major growth limiting factors for the cultivation of rice. The wild species are known to be an excellent source of tolerant genes against various biotic as well as abiotic stresses. Therefore, the stress-tolerant varieties can be developed by the introgression of these tolerant genes of wild species into cultivar crops. *Oryza coarctata* is a halophytic wild species of rice that grows in the coastal regions of South Asian countries and can withstand high saline as well as submergence conditions for quite a long period to such an extent which is lethal for any tolerant genotypes of rice. It is triploid in nature and propagates vegetatively. This wild species of rice has several unique morphological, anatomical and physiological features which help it to thrive well under different abiotic stress conditions. Moreover, several coding and non-coding genes, as well as metabolites, were also found to play an important role in salt-tolerance mechanisms in *O. coarctata*. Being a model halophytic plant, several important findings related to *O. coarctata* have been published recently such as genomic information, molecular markers and evolution towards C4 mode of photosynthesis which will draw the attention of agronomists for transferring agronomically important genes from this species into cultivar rice.

Keywords Abiotic stress · Coastal salinity · Genome · Genes · Photosynthesis · Wild species

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2.1 Introduction

Plants encounter several abiotic stresses due to changes in climatic conditions (Chowrasia et al. 2018). Moreover, these environmental stresses affect the growth as well as yield of several agronomically important plants. Salinity stress is one of the major abiotic stresses which causes damages in plants such as ionic toxicity, osmotic stress and nutritional deficiencies that ultimately hamper growth and development (Hussain et al. 2017). Moreover, about 20% of cultivated land is affected by soil salinity due to lack of a proper irrigation system and increase in sea level (Shrivastava and Kumar 2015). However, some of the plant species, especially wild type and land races were found to be tolerant against salinity stress. Therefore, it is imperative for plant biologists to identify the salinity-tolerant genes from these tolerant species and their introgression into cultivated crops either through conventional breeding methods or by genetic engineering approach.

Oryza genus includes 27 species, out of which two species such as *O. sativa* and *O. glaberrima* are cultivated. Rice is a glycophyte, and few landraces of rice have been reported to grow in saline soil (electrical conductivity, EC_e—12 dS m^{-1}) (Mondal et al. 2018). *O. coarctata* is an obligate hydro-halophytic wild species of rice found in coastal regions of Southeast Asian countries. Therefore, it is named as Asian wild rice and is also locally known as Uri-dhan or dhani (Chowrasia et al. 2018). *O. coarctata* has the ability to withstand both high saline (EC_e—40 dS m^{-1}) as well as submerged (12 h) conditions (Mondal et al. 2018; Chowrasia et al. 2019). Previously, *O. coarctata* was known to be a tetraploid (Jelodar et al. 1999), but recently, it was reported to be a triploid (Chowrasia et al. 2021). The genome sequence of this wild species of rice has been decoded, and the genome size was estimated as 665 Mb (Mondal et al. 2018).

Several stress-tolerance genes and metabolites were found to synthesis in *O. coarctata* under salinity stress to provide stress tolerance (Sengupta et al. 2008; Mondal et al. 2015). Thus, in this article, we have discussed the genome assembly, cytological and biochemicals studies that have been conducted in our laboratory recently.

2.2 Genome Assembly of *O. coarctata*

In 2016, only a few genomic resources were available for this species which was a bottleneck to discover the salinity/submergence tolerant genes. Although, few genes were cloned and characterized in a heterologous system (Majee et al. 2004; Mahalakshmi et al. 2006; Sengupta et al. 2008). Therefore, we decided to decode the genome of *O. coarctata* which is a prerequisite in many aspects such as (i) for cloning and characterization of tolerant and novel genes, (ii) generation of markers for markers assisted breeding and (iii) to study the evolutionary relationship with other plant species. Thus, we decoded for the first-time draft genome sequence of

O. coarctata (Mondal et al. 2018) which help to reveal many abiotic stress-specific genes. Genome size of *O. coarctata* was determined as 665 Mb where garden pea was used as a standard by FACS (fluorescence-activated cell sorting) (Mondal et al. 2018) which is against the previous report of 1283 Mb (Zuccolo et al. 2007). This is because Zuccolo et al. (2007) estimated the genome size based on K-mer of the genome from the BAC (bacterial artificial chromosome) sequence data available for related tetraploid *Oryza* species. The genome assembly of *O. coarctata* was performed by employing HiSeq4000 platform (Illumina, San Diego, CA) and MinION Mk1b (Oxford Nanopore Technologies, Oxford, UK) platforms. Thus, the draft genome of this wild species has a sequencing depth of 250.66 X, which accounts for the genome coverage of 85.71%. It is also noteworthy to mention that the repeat regions were found to be 19.89% which is the lowest among the other sequenced *Oryza* genome. From the phylogenetic study, the tree topology was derived from 1:1 single-copy orthologous genes by using other sequenced *Oryza* genomes, and it was observed that *O. coarctata* is closely related with *O. brachyantha* (Fig. 2.1). Syntenic analysis among the *Arabidopsis thaliana,* rice and two other halophytic

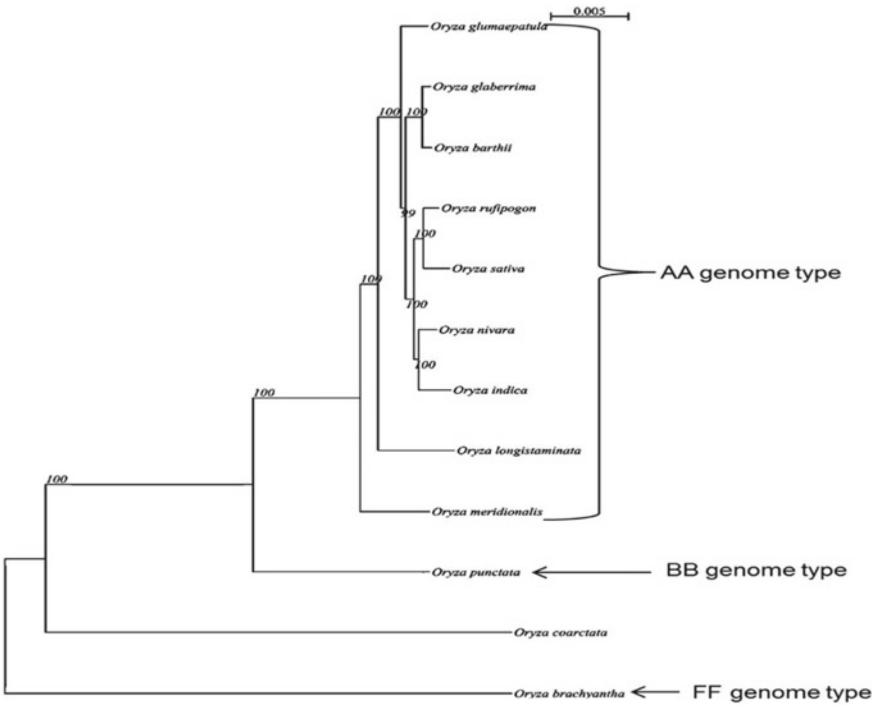

Fig. 2.1 A total of 194,069 unique clusters were formed with a cut-off of 90% for coverage and similarity from their protein sequences. The cluster analysis resulted in a total of 170 putative single copy gene clusters. These single copy proteins from the 12 genomes were considered for phylogenetic analysis (*Source* reproduced from Mondal et al. 2018 under creative common license)

species such as *Eutrema salsugineum*, *Thellungiella parvula* indicated that 8 scaffolds of *O. coarctata* showing no collinearity or synteny with *O. sativa* ssp. *Japonica* indicating that these scaffolds, which account for 12.52 *Mb*, i.e. 2.19% of *O. coarctata* genome which might have some possible roles in its adaptation under such harsh environmental conditions.

Further, about 33,627 protein coding genes were estimated which constitute 3.32% (1938 bp) of the total scaffolds. The length of these protein coding genes ranged from 180 to 1926 bp. Moreover, several genes were found to be involved in salinity tolerance mechanisms in this wild species, for example, transcription factors, osmoprotectant and metabolites synthesizing genes. The genome size of it was found to be approximately 1.7 times larger than the genome size of *O. sativa* ssp. *Japonica*. The genome sequence of *O. coarctata* consisted of around 50,562 genes in 5511 (62%) scaffolds which represents approximately 134 Mb (23.4%) of genome assembly, and the average size of genes was found to be around 1037 bp in length (Mondal et al. 2018; Bansal et al. 2020) (Table 2.1). The mitochondrial and chloroplast genome of *O. coarctata* were also decoded for the first time which were found to be 491.06 kb and 134.75 kb, respectively. While, the chloroplast genome contained 82 genes and the mitochondrial genome contained 91 genes (Mondal et al. 2018). Further, the assembly of genome completeness of *O. coarctata* was determined by referring the presence of core genes by CEGMA (Core Eukaryotic Genes Mapping Approach) and BUSCO (Benchmarking Universal Single-Copy Orthologs) analysis. CEGMA accounts for 92.34% completeness of genome assembly which raised up to 98.70% when normalized with respect to reference genome of *O. sativa* spp. *Japonica* Nipponbare-IRGSP-1.0. Moreover, BUSCO accounts for 97.08%

Table 2.1 Statistics of genome assembly and predicted genes (*Source* Reproduced from Mondal et al. 2018 under creative common license)

Assembly statistics	
Estimated genome size (Mb)	665
Genome-sequencing depth (X)	250.66
Assembled genome (Mb)	569.9
Genome coverage (%)	85.71
Number of scaffolds	58,362
Longest scaffold (bp)	7,855,609
Average scaffold length (bp)	9766.5
Percentage of non-ATGC characters	0.63
N50 of scaffolds (bp)	1,858,627
Repetitive region	19.89%
Gene annotation	
Number of gene models discovered	33,627
Gene length in the genome (%)	6.77%
Average gene length (bp)	1147
Largest gene length (bp)	14,926

completeness having a normalized value of 99.43% indicating that the present genome assembly was good (Mondal et al. 2018). However, further improvement of the genome sequence at the chromosome level is underway using the Hi-C data.

2.3 Characterization of Salinity Responsive Genes of *O. coarctata*

The salinity mechanisms till today are mainly focussed on model plant species such as rice and Arabidopsis. However, the major drawback of these model systems is that they are glycophytic species with a very low ability to endure salt stress. However, the genome sequence of few halophytes such as *E. salsugineum*, *T. salsuginea* and *T. parvula* have been decoded which help to identify salt responsive mechanisms (Wu et al. 2012; Yand et al. 2013) but none of them is a monocot. Thus, *O. coarctata* is one of the important halophytic models in monocot for exploring salt-tolerance mechanisms. Moreover, many stress responsive genes were also found with an increased number of paralogs such as *SOS1* (*salt overly sensitive 1*) genes with eight number of paralogs (Mondal et al. 2018). Phylogenetic analysis of *SOS1* genes of *O. coarctata* revealed that one out of eight paralogs might be responsible for coding plasma-membrane Na^+/H^+ antiporters while the rest seven clusters might be associated with vacuolar Na^+/H^+ antiporters. Interestingly, all these homologs were found closely related to *SOS1* homologs of *O. sativa ssp. Japonica.*

The analysis of transcriptomic data of leaves of *O. coarctata* under salt stress conditions revealed the presence of around 118 differentially expressed transcription factors such as WRKY, NAC and MYB/MYB-related families (Garg et al. 2013). Out of the 118 transcription factors, the expression of 30 genes was downregulated while that of 88 genes was upregulated. Genes involving in the biosynthesis of stress-related hormones were also found to be upregulated under salinity stress, for example, biosynthetic genes of abscisic acid, ethylene and jasmonic acid (Garg et al. 2013; Mondal et al. 2018; Mangu et al. 2019). Therefore, in order to further characterize these stress-related genes, it is necessary to identify stable references genes in *O. coarctata* for normalization of real-time PCR data. The attempt was made for the first time to identify stable reference genes in this orphan plant where it was found that ACT (*actin*) and *eIF4-α* (*eukaryotic initiation factor-4-alpha*) were the most stable reference genes out of eight selected reference genes (Chowrasia et al. 2019). Recently, in our lab, 11 novel genes have been identified and the expression level of these genes was observed under different stress conditions. Further, several tolerant genes and their promoter regions need to be identified for their functional characterization by using genomic information of *O. coarctata.*

2.4 DNA Markers of *O. coarctata*

In the rice breeding programme, very limited success has been gained to incorporate genes of this wild species into rice despite their immense potential (Jena 1994; Islam et al. 2017). Thus, large-scale discovery of DNA-based molecular markers is very important. Several SSRs (simple sequence repeats) markers were also identified across the whole genome of *O. coarctata* having an average frequency of one SSR per 2.46 *kb*. From the genome sequence of *O. coarctata*, it was observed that total 12,926 (22.15%) SSRs were present in 58,362 scaffolds; in addition, many trinucleotides (26.66%), mono- (19.99%), di- (16.79%), penta- (5.92%) and hexanucleotides (3.00%) were also found. For monotype of SSRs, A/T were the motifs with the percentage of 16.86%, and for di- and tri-types of SSRs, AT/TA, CCG/CGG were the motifs with percentages of 10.28% and 7.54%, respectively (Mondal et al. 2018). The decoding of the genome sequence could help to generate a total of 230,968 SSRs. Later, these markers were used by several other workers (Dalai et al 2021). In the case of wide hybridization, STMS (sequence-tagged microsatellite) markers are preferred due to their easy identification feature (Dalai et al. 2021). A set of molecular markers from the genome of *O. coarctata* has been identified for pre-breeding with *O. sativa*. Around 23,499 STMS markers of rice were used for genome sequencing of 9 *Oryza* species, in which 77 STMS markers were common with *O. sativa* complex and 359 of those were cross-transferable to *O. coarctata*. In *O. coarctata*, the repeat numbers of different motif and the numbers of microsatellite motifs were much lesser compared to AA genome species which leads to a high level of polymorphism. However, the STMS marker, RM11508 serve as a unique fingerprint for *O. coarctata* which helps in species and interspecific hybrid identification. RGNMS3515 is another unique marker that will also be helpful for the identification of particular species (Dalai et al. 2021). Therefore, identification of hybrids produced from a cross between *O. coarctata* and *O. sativa* with these STMS markers will be helpful.

2.5 Cytological and Physiological Studies of *O. coarctata*

The morphology of *O. coarctata* is unique from other Oryza species. It has an underground pseudo-taproot with a fibrous root at the tips and widely spread internodes which are called soboles. The new plantlets were developed from this soboles (Latha et al. 2004). There is the presence of a relatively higher number of mechanical tissues in *O. coarctata* as compared to other *Oryza* species (Sengupta and Majumder 2010). Some of the roots of *O. coarctata* remain above the soil which might provide sufficient aeration just similar to pneumatophores of mangroves. Unlike cultivated rice, the leaves of *O. coarctata* are waxy in nature to check the transpirational water loss, and the cross section of leaves showed the presence of alternate furrows and ridges (Chowrasia et al. 2021). This wild species of rice thrives well in its native habitat, i.e. coastal marsh land with tidal waves twice a day. Although this plant had been found to grow in non-saline soil, the addition of saltwater (EC_e—14 dS m^{-1}) was required for its survival under control conditions. Moreover, *O. coarctata* exhibits a comparatively better performance in terms of chlorophyll content, growth and photosynthetic efficiency than other compared rice varieties under different salt concentrations (Sengupta and Majumder 2009). This wild species of rice propagates vegetatively only, and seeds were recalcitrant in nature (Chowrasia et al. 2018).

The salt exudation in *O. coarctata* occurs through micro-hairs which are finger-shaped, unicellular, bi-or-trifurcated and bilobed with flattened head (Flowers et al. 1990). Scanning electron microscopy revealed the presence of hairs with plasmodesmata connections with nearby epidermal cells of *O. coarctata* leaves (Flowers et al. 1990). Interestingly, under salt stress conditions, micro-hairs of the upper leaf surface secrete salt, whereas micro hairs of the lower surface ruptured for salt exudation (Sengupta and Majumder 2010). In this way, *O. coarctata* maintains a relatively low Na^+/K^+ ions ratio in cells and thereby decreasing sodium toxicity (Bal and Dutt 1986).

The pollen of *O. coarctata* was found to be sterile when compared to the IR-29. Additionally, leaves of *O. coarctata* was found to possess Kranz anatomy with increased vein density and higher value for the ratio of bundle sheath/mesophyll cell area. Mesophyll cells of *O. coarctata* contain well-developed grana, whereas chloroplasts of bundle sheath cells lack grana (Chowrasia et al. 2021). Further, bundle sheath cells contain chloroplasts and mitochondria which were arranged centripetally (Fig. 2.2). Recently, these wild species have been found to bear several unique anatomical features in leaves which indicates that this plant is in the early stage of evolving towards C4 photosynthesis (Chowrasia et al. 2021).

O. coarctata is known to be KKLL genome type which was revealed by cytogenetics analysis of zygotene stage of inter-specific hybrids (Ge et al. 1999; Lu et al. 2009). However, the earlier studies based on the phylogenetic study of the chloroplast gene *matK* (*maturase K*) and two nuclear genes, i.e. *alcohol dehydrogenase gene 1*(*adh1*) and (*adh2*) revealed that the genome type of *O. coarctata* is HHKK. *O. coarctata* was believed to be a tetraploid from earlier reports; however, the cross involving this wild species (male parent) and rice (female parent) produces a very less number of viable hybrids (Jelodar et al. 1999; Islam et al. 2017). Recently through karyotype analysis of *O. coarctata*, we revealed that it is triploid ($2n = 3x = 36$) (Fig. 2.3). The triploid nature of *O. coarctata* was determined by flow cytometry, karyotype analysis of root tips and chromosomal abnormalities in meiotic I and II phases of flower buds (Chowrasia et al. 2021). The chromosomes of *O. coarctata* were found to be smaller in size. Further, the study revealed that *O. coarctata* has primitive and symmetrical karyotype which consisted of sub-median and median chromosomes. In addition, several unique characteristics of *O. coarctata* such as seed production, low pollen viability and vegetative mode of propagation further support the fact that *O. coarctata* is a triploid in nature (Chowrasia et al. 2021).

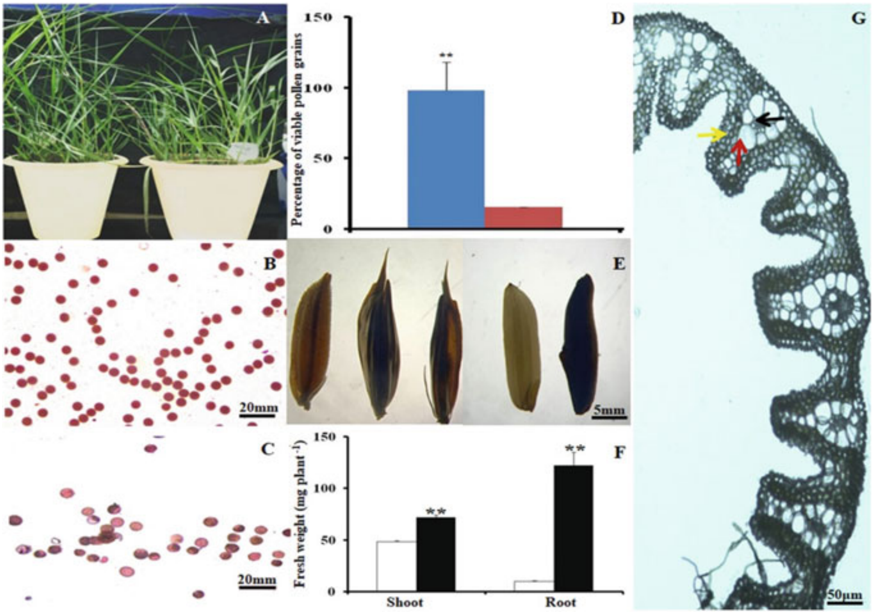

Fig. 2.2 Anatomical study of leaves of *O. coarctata* and IR-29. Analysis of leaf vein density under a light microscope in **a** *O. coarctata* and **b** IR-29. Longitudinal section of leaf blade of **c** *O. coarctata* and **d** IR-29. **e** ultrastructure of leaf of *O. coarctata* under transmission electron microscope showing centrifugal arrangement of the chloroplast in bundle sheath and mesophyll cells. **f** *O. coarctata* bundle sheath cells contain chloroplast which lacks granal stacking and mesophyll chloroplast exhibit extensive granal stacking (black arrow). **g** Ultrastructure of *O. coarctata* leaves depicting centrifugal arrangement of the chloroplast in bundle sheath and mesophyll cells as well as the chloroplast of bundle sheath is larger than mesophyll chloroplast. The bundle sheath cell wall is thicker (black arrow). **h** The bundle sheath cell wall showing suberin lamella (blue arrow). LLV—large longitudinal vein; SLV—small longitudinal vein; TV—transverse vein; C—chloroplast; M—mesophyll; BS—bundle sheath; Mi—mitochondria and SL—suberin lamella (*Source* Reproduced from Chowrasia et al. 2021 with permission from Elsevier)

2.6 Metabolite Analysis of *O. coarctata*

The salinity stress induces the production of many stress-protectant metabolites such as proline, inositol, allantoin and glucose (Kaur et al. 2021). In eukaryotic cells, inositol is an important secondary messenger (Gillaspy 2011). L-myo-inositol-1-phosphate synthase (PINO1) an enzyme that synthesizes inositol was found to have higher specific enzymatic activity under salt stress (Majumder et al. 2003). Further, in vivo study revealed that salts have less electrostatic interactions with PINO1 protein thus found to be stable under salinity stress. Over expression of *PINO1* gene in transgenic tobacco showed better photosynthetic efficiency and growth under salt stress (Majee et al. 2004).

Under salinity stress, a cytosolic sugar pinitol (o-methylated inositol), accumulation increased in leaves of *O. coarctata* (Sengupta et al. 2008). The metabolic

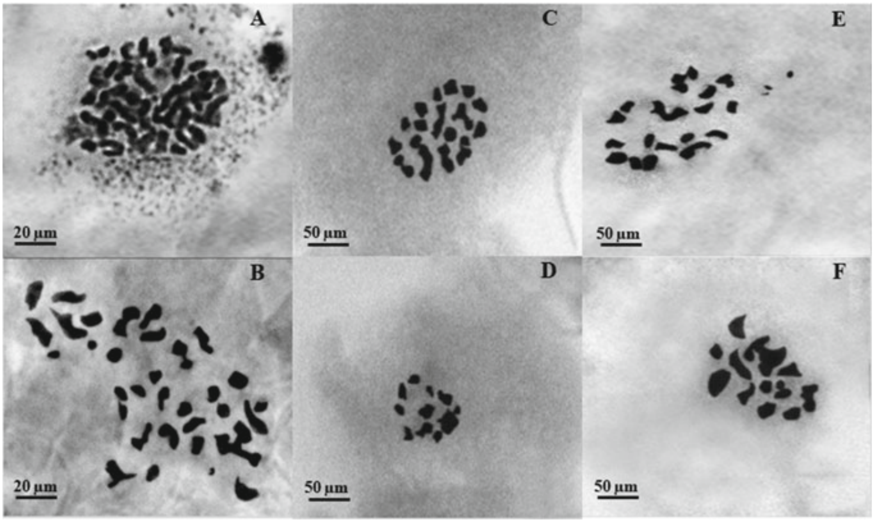

Fig. 2.3 Chromosomal study of *O. coarctata*. **a**, **b** Two independent metaphase plates from root tips showing $2n = 3x = 36$. **c** MI stage of *O. coarctata* showing 24 chromosomes. **d** The PMC at MI stage showing 12 univalent. **e** The PMC at MI stage consisting of 20 chromosomes. **f** The PMC at MI stage showing 16 chromosomes. MI—Metaphase I and PMC—Pollen mother cell (*Source* Reproduced from Chowrasia et al. 2021 with permission from Elsevier)

pathway for the biosynthesis of pinitol was found to be specific in *O. coarctata* absent in rice. Pinitol was found to maintain the cell membrane and enzymes integrity under osmotic stress and hence acts as an osmoprotectant (Ishitani et al. 1996). The pinitol is synthesis from inositol in presence of the enzyme inositol methyltransferase enzyme. There is an inverse relationship found between pinitol and inositol under salinity stress conditions, the level of pinitol is more than inositol (Sengupta et al. 2008).

Recently, our lab is working on the ureide pathway under salinity stress in *O. coarctata*. Allantoin is an important intermediate product of the purine catabolism pathway that was found to acts as a regulatory compound to activate different tolerance mechanisms (Kaur et al. 2021). The accumulation of allantoin in *O. coarctata* (especially in root) under salinity stress was found to be higher compared to other rice varieties such as IR29 (salt sensitive) and Pokkali (salt tolerant) (data unpublished). Presently, two important genes of this pathway such as *uricase* (924 *bp*) and *allantoinase* (665 *bp*) have been cloned from *O. coarctata* and over expressed in transgenic *Arabidopsis* which are in the process of various phenotyping characterization under salinity stress.

2.7 MiRNA of *O. coarctata*

The gene regulation at post-transcriptional level involved several genomic resources including microRNAs (miRNAs) which are single-stranded, small and non-coding RNAs (Devi et al. 2018). The length of the mature miRNAs is generally ranged from 21 to 24 nucleotides which involved in the degradation of specific mRNAs (Kidner and Martienssen 2005). Target genes of miRNAs are enzymes or transcription factors that are involved in abiotic stress including salinity stress (Sunkar et al. 2012). miRNA sequencing of leaves of *O. coarctata,* under salt stress, revealed 3219 target transcripts (non-coding and coding) and 168 unique miRNAs which were involved in many biological processes containing abiotic stress responses. Using bisulphite genome sequencing, it was reported that *O. coarctata* has around 19–48% methylcytosines throughout the genome, helping to understand the effect of methylation on gene expression (Bansal et al. 2020).

In addition, in silico analysis of this transcriptomics data of *O. coarctata* revealed the presence of around 95 novel, 338 known and 48 conserved miRNAs in addition to their pre-miRNA. Under salinity stress, 7 novel and 36 known miRNAs were found to be upregulated while 7 novel and 12 known miRNAs were downregulated. Further, 14 novel and 48 known differentially regulated miRNAs with 154 and 233 target genes were predicted, respectively (Mondal et al. 2015). Gene ontology analysis of these target genes was found to be involved in various important biological functions including salinity tolerance. These results revealed that *O. coarctata* contain novel miRNAs which regulate the salt tolerance mechanism.

2.8 Conclusions

Oryza coarctata is a wild species of rice, which serves as a good resource for candidate genes responsive for salinity as well as submergence stress tolerance (Garg et al. 2013; Mondal et al. 2015). This wild species of rice is amphibian in nature, thus able to survive in both aquatic and terrestrial conditions; this adaptation also helps in understanding the mechanisms of evolution from aquatic to terrestrial transition of ancient plants. *O. coarctata* has distinct anatomical, morphological and physiological features that are required for its survivability under saline submerged conditions. The transcriptomic studies revealed that this plant possesses several novel as well as conserved genes and miRNAs which regulate salt tolerance mechanisms. Further, proteomic and metabolites analyses support the transcriptomic data as well as depict the higher accumulation of stress-protectant proteins and metabolites, respectively, in *O. coarctata* under abiotic stress conditions. Besides, these features *O. coarctata* possess unique leaf anatomical characteristics such as the presence of Kranz anatomy which indicates that this plant is evolving towards C4 mode of photosynthesis. Among the genus *Oryza,* this wild species is found to be a triploid in nature. Therefore, our studies will help to prepare the strategies of developing stress-tolerant rice varieties by transferring tolerant genes/alleles from this wild species through conventional breeding programme.

References

Bal AR, Dutt SK (1986) Mechanism of salt tolerance in wild rice (*Oryza coarctata* Roxb). Plant Soil 92(3):399–404. https://doi.org/10.1007/BF02372487

Bansal J, Gupta K, Rajkumar MS et al (2020) Draft genome and transcriptome analyses of halophyte rice *Oryza coarctata* provide resources for salinity and submergence stress response factors. Physiol Plant. https://doi.org/10.1111/ppl.13284

Chowrasia S, Kaur H, Mujib A et al (2019). Evaluation of *Oryza coarctata* candidate reference genes under different abiotic stresses. Biol Plant 63(1):496–503. https://doi.org/10.32615/bp.2019.054

Chowrasia S, Rawal HC, Mazumder A et al (2018). *Oryza coarctata* Roxb. In: Mondal TK, Henry RJ (eds) The wild *Oryza* genomes. Springer, Cham, pp 87–104. https://doi.org/10.1007/978-3-319-71997-9

Chowrasia S, Nishad J, Pandey R et al (2021) Oryza coarctata is a triploid plant with initial events of C4 photosynthesis evolution. Plant Sci 308:110878. https://doi.org/10.1016/j.plantsci.2021.110878

Dalai D, Chakraborti M, Mondal TK et al (2021) The core set of sequence-tagged microsatellite sites markers between halophytic wild rice *Oryza coarctata* and *Oryza sativa* complex. Euphytica 217(4):57. https://doi.org/10.1007/s10681-021-02790-3

Devi KJ, Saha P, Chakraborty S et al (2018) Computational identification and functional annotation of microRNAs and their targets in three species of kiwifruit (*Actinidia* spp.). Indian J Plant Physiol 23(1):179–191. https://doi.org/10.1007/s40502-018-0353-0

Flowers TJ, Flowers SA, Hajibagheri MA et al (1990) Salt tolerance in the halophytic wild rice, *Porteresia coarctata* Tateoka. New Phytol 114(4):675–684. https://doi.org/10.1111/j.1469-8137.1990.tb00439.x

Garg R, Verma M, Agrawal S et al (2013) Deep Transcriptome sequencing of wild halophyte rice, *Porteresia coarctata*, provides novel insights into the salinity and submergence tolerance factors. DNA Res 21(1):69–84. https://doi.org/10.1093/dnares/dst042

Ge S, Sang T, Lu BR et al (1999) Phylogeny of rice genomes with emphasis on origins of allotetraploid species. Proc Natl Acad Sci 96(25):14400–14405. https://doi.org/10.1073/pnas.96.25.14400

Gillaspy GE (2011) The cellular language of myo-inositol signaling. New Phytol 192(4):823–839. https://doi.org/10.1111/j.1469-8137.2011.03939.x

Hussain S, Zhang J, Zhong C et al (2017) Effects of salt stress on rice growth, development characteristics, and the regulating ways: a review. J Integr Agric 16(11):2357–2374. https://doi.org/10.1016/S2095-3119(16)61608-8

Ishitani M, Majumder AL, Bornhouser A et al (1996) Coordinate transcriptional induction of myo-inositol metabolism during environmental stress. Plant J 9(4):537–548. https://doi.org/10.1046/j.1365-313x.1996.09040537.x

Islam T, Biswas S, Mita U et al (2017) Characterization of progenies from intergeneric hybridization between *Oryza sativa* L. and *Porteresia coarctata* (Roxb.) Tateoka. Plant Tissue Cult Biotechnol 27(1):63–76. https://doi.org/10.3329/ptcb.v27i1.35013

Jelodar NB, Blackhall NW, Hartman TPV et al (1999) Intergeneric somatic hybrids of rice [*Oryza sativa* L. (+) *Porteresia coarctata* (Roxb.) Tateoka]. Theor Appl Genet 99(3):570–577. https://doi.org/10.1007/s001220051270

Jena KK (1994) Production of intergeneric hybrid between *Oryza sativa* L. and *Porteresia coarctata* T. Curr Sci 67(9/10):744–746. http://www.jstor.org/stable/24095851

Kaur H, Chowrasia S, Gaur VS et al (2021) Allantoin: emerging role in plant abiotic stress tolerance. Plant Mol Biol Rep. https://doi.org/10.1007/s11105-021-01280-z

Kidner CA, Martienssen RA (2005) The developmental role of microRNA in plants. Curr Opin Plant Biol 8(1):38–44. https://doi.org/10.1016/j.pbi.2004.11.008

Latha R, Salekdeh GH, Bennett J et al (2004) Molecular analysis of a stress-induced cDNA encoding the translation initiation factor, eIF1, from the salt-tolerant wild relative of rice Porteresia Coarctata. Funct Plant Biol 31(10):1035–1042. https://doi.org/10.1071/FP03233

Lu F, Ammiraju JSS, Sanyal A et al (2009) Comparative sequence analysis of MONOCULM1-orthologous regions in 14 *Oryza* genomes. Proc Natl Acad Sci 106(6):2071–2076. https://doi.org/10.1073/pnas.0812798106

Majee M, Maitra S, Dastidar KG et al (2004) A novel salt-tolerant L-myo-inositol-1-phosphate synthase from *Porteresia coarctata* (Roxb.) Tateoka, a halophytic wild rice: molecular cloning, bacterial overexpression, characterization, and functional introgression into tobacco-conferring salt tolerance. J Biol Chem 279(27):28539–28552. https://doi.org/10.1074/jbc.M310138200

Majumder AL, Chatterjee A, Ghosh DK et al (2003) Diversification and evolution of L-*myo*-inositol 1-phosphate synthase. FEBS Lett 553(1):3–10. https://doi.org/10.1016/S0014-5793(03)00974-8

Mangu VR, Ratnasekera D, Yabes JC et al (2019) Functional screening of genes from a halophyte wild rice relative *Porteresia coarctata* in Arabidopsis model identifies candidate genes involved in salt tolerance. Curr Plant Biol 18:100107. https://doi.org/10.1016/j.cpb.2019.100107

Mondal TK, Ganie SA, Debnath AB (2015) Identification of novel and conserved miRNAs from extreme halophyte, *Oryza coarctata*, a wild relative of rice. PLoS ONE 10(10):1–27. https://doi.org/10.1371/journal.pone.0140675

Mondal TK, Rawal HC, Chowrasia S et al (2018) Draft genome sequence of first monocot-halophytic species *Oryza coarctata* reveals stress-specific genes. Sci Rep 8(1):13698. https://doi.org/10.1038/s41598-018-31518-y

Sengupta S, Patra B, Ray S et al (2008) Inositol methyl tranferase from a halophytic wild rice, *Porteresia coarctata* Roxb. (Tateoka): regulation of pinitol synthesis under abiotic stress. Plant Cell Environ 31(10):14421459. https://doi.org/10.1111/j.1365-3040.2008.01850.x

Sengupta S, Majumder AL (2009) Insight into the salt tolerance factors of a wild halophytic rice, *Porteresia coarctata*: a physiological and proteomic approach. Planta 229(4):911–929. https://doi.org/10.1007/s00425-008-0878-y

Sengupta S, Majumder AL (2010) *Porteresia coarctata* (Roxb.) Tateoka, a wild rice: a potential model for studying salt-stress biology in rice. Plant Cell Environ 33(4):526–542. https://doi.org/10.1111/j.1365-3040.2009.02054.x

Shrivastava P, Kumar R (2015) Soil salinity: a serious environmental issue and plant growth promoting bacteria as one of the tools for its alleviation. Saudi J Biol Sci 22(2):123–131. https://doi.org/10.1016/j.sjbs.2014.12.001

Sunkar R, Li YF, Jagadeeswaran G (2012) Functions of microRNAs in plant stress responses. Trends Plant Sci 17(4):196–203. https://doi.org/10.1016/j.tplants.2012.01.010

Wu HJ, Zhang Z, Wang JY et al (2012) Insights into salt tolerance from the genome of *Thellungiella salsuginea*. Proc Natl Acad Sci 109(30):12219–12224. https://doi.org/10.1073/pnas.1209954109

Zuccolo A, Sebastian A, Talag J et al (2007) Transposable element distribution, abundance and role in genome size variation in the genus *Oryza*. BMC Evol Biol 7(1):152. https://doi.org/10.1186/1471-2148-7-152

Chapter 3
SSR Marker Analysis for the Identification of the Elite Rice Variety Lavanya with Its Parent VTL-3 and DNA Fingerprinting

Veena Vighneswaran, A. K. Sreelatha, and Deepa John

Abstract Indigenous rice varieties of Kerala possess several adaptable features like resistance to various abiotic and biotic stresses. Farmers, however, experience heavy crop loss due to the tall stature of majority of these varieties, as they are prone to lodging. Mutagenesis has proved to be a very effective tool for improving specific characterstics of existing rice varieties. Several researchers have reported successful uses of induced mutations to improve characters like plant height, maturity period, and grain characteristics. A tall high yielding rice variety VTL-3 which is popularly cultivated in the Pokkali ecosystem was subjected to mutagenesis by gamma irradiation to generate semi-tall mutant lines. Gamma irradiation with 40 kR dose was effective in inducing semi-dwarfism in Pokkali rice genotype VTL-3. The selected seven mutant lines were screened with SSR markers linked to *Saltol* QTL, along with parental variety VTL-3 and check varieties to confirm whether the *Saltol* region is unaffected in the mutant lines. Culture 51.5 selected after comparative yield trials of the mutant lines and screening with *Saltol* markers, which was later released as Lavanya, was further screened with 48 SSR markers to generate DNA fingerprinting of the selected mutant line and the parental variety. Molecular profiles were generated with 14 SRR markers linked to *Saltol* QTL, which confirms that the *Saltol* QTL is retained in the mutant lines and induced mutagenesis of VTL-3 to generate semi-tall lines did not affect the salinity tolerance trait. DNA fingerprinting with a total of 48 SSR markers covering all the 12 chromosomes of rice revealed the polymorphism in eight markers between Lavanya and its parent, VTL-3. The number of alleles per locus ranged from 1 to 3 and the size of PCR products ranged from 110 to 300 bp with Polymorphic Information Content (PIC) from 0 to 0.5.

Keywords DNA fingerprinting · Pokkali · Saltol · SSR markers · Rice

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3.1 Introduction

Kerala is having a unique practice of rice cultivation with a wide range of agro-ecological zones. In Kuttanad, it is cultivated in below mean sea level condition with pumping out of water from the fields during the cropping period, and in the high ranges of Wayanad it is cultivated in the terraced lands across the contour. These varied cultivation practices, as well as diverse agroecological zones, reflect on the rich genetic diversity and several adaptable features like resistance to various abiotic as well as biotic stresses. But, due to the tall nature of these varieties, they are prone to lodging and thus result in heavy crop loss for the farmers (Haghdoost et al. 2014; Lang et al. 2012; Sharma et al. 2017). Plant breeders often depend on mutation breeding to induce favorable variations viz. for reducing plant height, duration, etc. and the same has proved to be a very effective tool for improving specific characters of local rice varieties (Shadakshari et al. 2001; Wu et al. 2005; Domigo et al. 2007; Jain 2010; Wei et al. 2013; Yang et al. 2013; Wang et al. 2013).

In the present investigation, physical mutagen Gamma-rays (γ-rays) are used for induced mutagenesis. Though various levels of gamma irradiation were tried, 40 kR dose was found effective in reducing the plant height of the variety VTL-3. Since mutations cause random changes in the genetic structure, the main objective of the work was to check the salinity tolerance character of the variety with its parent. A major Quantitative Trait Locus (QTL) for salt tolerance, *Saltol* was mapped on chromosome1 (Bonilla et al. 2002). Hence the molecular markers linked to this major QTL can be used to screen the mutant lines to confirm the presence of *Saltol* QTL. Single sequence repeats markers (SSR) are the most powerful markers they are co-dominant, hypervariable, abundant, and well distributed throughout the rice genome (Temnykh et al. 2001), *Saltol* linked SSR markers were used to screen the mutant lines for confirmation of salinity tolerance. The study also aimed to distinguish the variety Lavanya from its parent VTL 3, this was done by carrying out an SSR-based DNA fingerprinting with markers covering the whole rice genome.

3.2 Materials and Methods

The tall highyielding rice variety, VTL-3, and its mutant variety VTL 10 (Lavanya) developed by Rice Research Station, Vyttila were used for SSR marker analysis. Pokkali and FL-478 were used as saline tolerant check varieties. VTL-3 (Vytilla-3) is developed through Pedigree selection from a cross between VTL-1 X T(N)-1 (Taichung Native-1).

3.2.1 Genomic DNA Isolation

Total genomic DNA was extracted from young leaves of three-week old plants following the simple CTAB method (Doyle and Doyle 1987) and dissolved in 1X TE buffer. The quality and quantity of extracted DNA samples were determined using spectrophotometer NanoDrop 2000c (Thermo Scientific). The samples were then diluted with 1X TE buffer to make a final concentration of 25 μl^{-1} for use in polymerase chain reaction (PCR).

3.2.2 PCR Amplification

PCR amplification was carried out in a total volume of 20 µl containing a final concentration of 25 ng of genomic DNA and 2XPCR Master Mix (Thermo Scientific), comprising of 1X Taq Buffer with 4 mM $MgCl_2$, 0.4 mM of each dNTPs and 0.05U μl^{-1} Taq polymerase enzyme. The PCR program involved an initial denaturation at 94 °C for 5 min followed by 31 cycles of denaturation (94 °C for 5 min), annealing at 55–65 °C depending on the GC content of the primers for 40 s and extension at 72 °C for 40 s. PCR reactions were carried out in Thermocycler (Applied Biosystems, Veriti 96 well thermocycler). For the SSR markers assay, a total of 14 SSR markers lined to *Saltol* QTL were used to screen the mutant lines for salinity tolerance at molecular level and 48 SSR markers were used to fingerprint the selected culture and its parent variety. The PCR amplified products were separated by electrophoresis on 8% polyacrylamide gels. The bands were visualized by Silver Staining (Benbouza et al. 2006) and gel images were documented in a gel documentation instrument (BioRad Gel Doc XR+).

3.2.3 Data Analysis

Scoring of alleles for each SSR marker was done to find out the total number of alleles and the allelic data was converted into binary data. Polymorphic information content (PIC) value for each SSR marker was calculated as per Anderson et al. (1993) in order to identify the informative SSR marker. $\mathrm{PIC} = 1 - \sum_{i=1}^{k} P_i 2$.

Where, k denotes the total number of alleles (bands) detected for each SSR locus and P_i is the frequency of the ith allele in the set of genotypes investigated.

3.3 Results and Discussion

Rice variety VTL-3, which was developed by Rice Research Station, Vyttilain 1987 is a high-yielding variety popularly cultivated in the Pokkali ecosystem. However, farmers frequently experienced a yield loss of about 40–50%, due to its lodging nature. Hence, in the present study, this variety was subjected to mutagenesis by gamma irradiation to develop a semi-tall non lodging variety. Gamma irradiation with 40 kR dose was found effective in plant height in VTL-3. The selected seven mutant lines were screened with SSR markers along with parental variety VTL-3 and check varieties.

3.3.1 Molecular Analysis Using SSR Markers Linked to Saltol QTL

In the pokkali ecosystem, soil salinity is the most important abiotic stress experienced by farmers. A major Quantitative Trait Locus (QTL) for salt tolerance named *Saltol* was originally mapped on chromosome1 using Pokkali/IR29 RILs. This region was roughly lies between 11.2 and 12.7 Mb (Thomson et al. 2010). There are different markers linked to *Saltol* QTL, which are being used by several breeders for screening rice varieties for salt tolerance. The markers used in our current study to confirm the presence of *Saltol* QTL in the mutant lines were already validated by many researchers (Ali et al. 2014; Chowdhury et al. 2016; Singh et al. 2018; Adak et al. 2020).

Molecular profiles were generated with 14 SRR markers linked to *Saltol* QTL (Table 3.1), out of which only three markers showed variations in the banding pattern with respect to their parent, all the others exhibited the same banding pattern.

Figures 3.1, 3.2, 3.3 and 3.4 shows the molecular profile of mutant lines and parental variety VTL-3 with three of the key *Saltol* markers. These figures clearly indicate the presence of *Saltol* QTL-linked markers in all the mutant lines screened and also indicates that they possess the same alleles as that of the parent rice variety VTL-3. This in turn confirms that the induced mutagenesis of VTL-3 to generate semi- tall lines did not affect the salinity tolerance trait.

3.3.2 DNA Fingerprinting with SSR Markers

Simple Sequence Repeats (SSR) markers are widely used for discriminating rice varieties from each other (Ruizhen et al. 2004; Hasnaoui et al. 2012; Ren et al. 2014; Bora et al. 2016; Satturu et al. 2018). The selected mutant line of VTL-3, which is released as VTL 10 (Lavanya) was screened with a total of 48 SSR markers covering all the 12 chromosomes of rice along with its parent VTL-3 and check varieties. A

Table 3.1 Molecular profiles generated with 14 SRR markers linked to *Saltol* QTL

Sl. No	Primer	Forward sequence	Reverse sequence
1	RM10720	gcaaacgtctacgtgagaaacaagc	gcatgtggtgccttaacatttgg
2	RM493	gtacgtaaacgcggaaggtgacg	cgacgtacgagatgccgatcc
3	RM3412b	tcatgatggatctctgaggtg	gggaggatgcactaatctttc
4	RM8094	aagtttgtacacatcgtataca	cgcgaccagtactactacta
5	RM10793	gacttgccaactccttcaattcg	tcgtcgagtagcttccctctctacc
6	RM10701	gagacacggcacaatatacaacg	ttctatctccgacctcttctcaagg
7	RM10711	gcttcgatcgatgagaaagtagagg	gaatctcccatccttcccttcc
8	RM1287	ggaagcatcatgcaatagcc	ggccgtagttttgctactgc
9	RM10694	tttccctggtttcaagcttacg	agtacggtaccttgatggtagaaagg
10	AP3206	ttctcatcgcaccatctctg	ggaggaggagaggaagaag
11	RM140	tgcctcttccctggctcccctg	ggcatgccgaatgaaatgcatg
12	RM10713	atgaacccggcgaactgaaagg	ctggctccctcaaggtgattgc
13	SKC10	ataggggatattggctgcac	caaccaagcgtgactaaaaaga
14	RM10745	tgacgaattgacacaccgagtacg	acttcaccgtcggcaacatgg

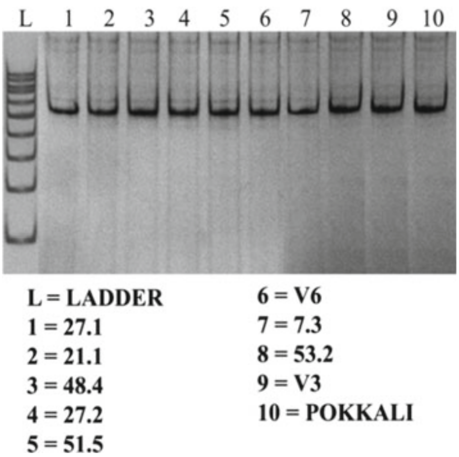

Fig. 3.1 Molecular profile with SSR marker AP3206

total of 55 bands were detected across the varieties used. The number of alleles per locus ranged from 1 to 3 with an average of 1.14 (Table 3.2). PIC values ranged from 0 to 0.5. Out of the 48 SSR markers used in the present study, a set of 8 markers viz. RM3362, RM600, RM279, RM85, RM7, RM149, RM144, and RM1880 exhibited unique alleles and could be used to distinguish the semi-tall mutant Lavanya from VTL-3 (Fig. 3.5). The PIC values of these markers were found to be 0.35 (RM1880) to 0.38 (RM3362, RM600, RM279, RM85, RM7, RM149, RM144). Therefore, these eight markers can be effectively used to distinguish mutant line Lavanya from the parent variety.

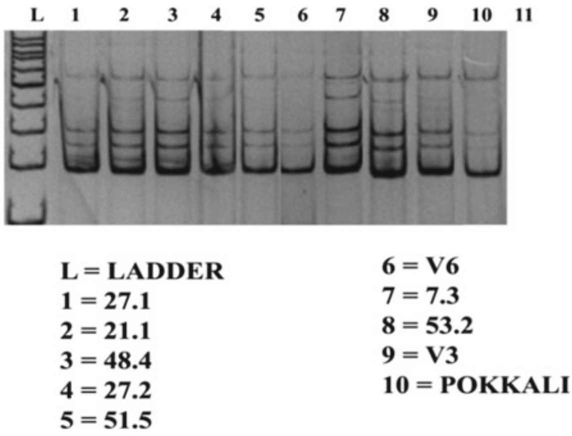

Fig. 3.2 Molecular profile with SSR marker RM493

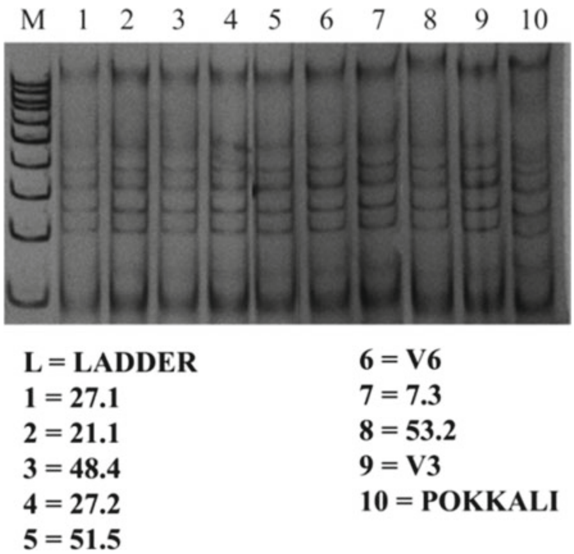

Fig. 3.3 Molecular profile with SSR marker RM8094

3.4 Conclusions

A semi-tall, non-lodging mutant of popularly cultivated saline tolerant rice variety, VTL-3 was developed using gamma radiation and released as VTL 10 (Lavanya). The variety Lavanya is short in stature and on screening with key markers linked to *Saltol* QTL. The salinity tolerance was found to be unaffected due to the induced mutagenesis. The variety was analyzed with genome-wide markers and a SSR-based DNA fingerprint was generated to distinguish the new variety from its parental variety. Eight SSR markers can be effectively used to distinguish mutant line Lavanya from the parent variety.

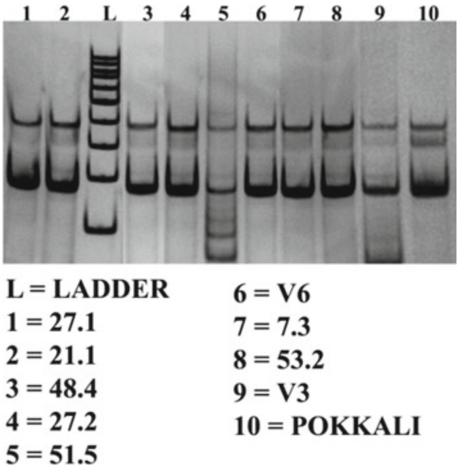

Fig. 3.4 Molecular profile with SSR marker RM10713

Table 3.2 Allele number, allele size, and frequency of the selected mutant line and parental variety with 48 SSR markers

Sl. No.	Primer	Chromosome no	Number of amplified bands	No. of polymorphic bands	Allele size range (bp)	PIC value
1	RM246	1	1	0	120–140	0
2	RM212	1	1	0	110	0
3	RM323	1	1	0	230	0
4	RM3362	1	2	2	200–180	0.38
5	RM600	1	2	2	120–150	0.38
6	RM221	2	1	0	200	0
7	RM279	2	2	2	160–190	0.38
8	RM5812	2	1	0	120	0
9	RM498	2	1	0	200	0
10	RM60	3	1	0	180	0
11	RM85	3	2	2	110–120	0.38
12	RM338	3	1	0	200	0
13	RM7	3	2	2	140–150	0.38
14	RM168	3	1	0	160–190	0
15	RM307	4	1	0	140	0
16	RM348	4	1	0	140	0
17	RM559	4	1	0	200	0
18	RM185	4	1	0	180	0

(continued)

Table 3.2 (continued)

Sl. No.	Primer	Chromosome no	Number of amplified bands	No. of polymorphic bands	Allele size range (bp)	PIC value
19	RM188	5	1	0	200	0
20	RM507	5	1	0	250	0
21	RM509	5	1	0	140	0
22	RM133	6	1	0	200	0
23	RM162	6	1	0	200	0
24	RM494	6	1	0	190	0
25	RM527	6	1	0	220	0
26	RM427	7	1	0	180	0
27	RM172	7	1	0	180	0
28	RM420	7	1	0	200	0
29	RM560	7	1	0	250	0
30	RM337	8	1	0	140	0
31	RM149	8	2	2	240–280	0.38
32	RM264	8	1	0	180	0
33	RM25	8	1	0	150	0
34	RM296	9	1	0	120	0
35	RM215	9	1	0	150	0
36	RM434	9	1	0	150	0
37	RM474	10	1	0	220	0
38	RM5689	10	1	0	150	0
39	RM590	10	1	0	150	0
40	RM294A	10	1	0	150	0
41	RM27173	11	1	0	120	0
42	RM116	11	1	0	300	0
43	RM144	11	2	2	290–300	0.38
44	RM457	11	1	0	300	0
45	RM101	12	1	0	280	0
46	RM6396	12	1	0	280	0
47	RM1880	12	2	1	140–150	0.35
48	RM1227	12	1	0	190	0

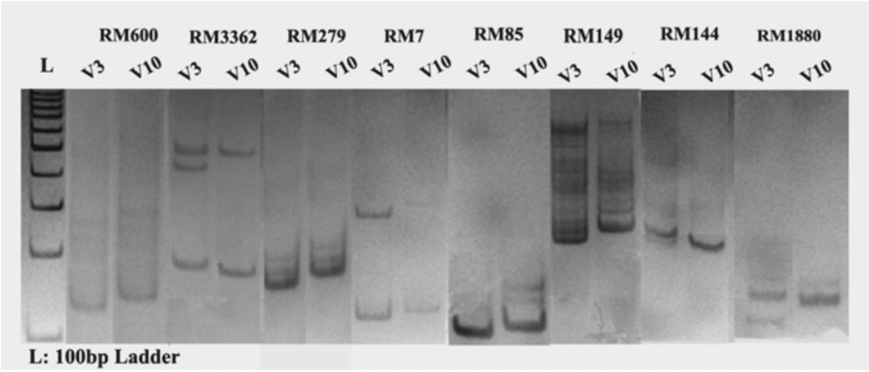

Fig. 3.5 Molecular profile with polymorphic genomewide markers

References

Adak S, Datta S, Bhattacharya S et al (2020) Diversity analysis of selected rice landraces from West Bengal and their linked molecular markers for salinity tolerance. Physiol Mol Biol Plants 26(4):669–682

Ali MN, Yeasmin L, Gantait S et al (2014) Screening of rice landraces for salinity tolerance at seedling stage through morphological and molecular markers. Physiol Mol Biol Plants 20(4):411–423

Anderson JA, Churchill GA, Autrique JE et al (1993) Optimizing parental selection for genetic linkage maps. Genome 36(1):181–186

Benbouza H, Jacquemin J, Baudoin J et al (2006) Optimization of a reliable, fast, cheap and sensitive silver staining method to detect SSR markers in polyacrylamide gels. Biotechnol Agron Soc Environ 10:77–81

Bonilla P, Dvorak J, Mackill D et al (2002) RLFP and SSLP mapping of salinity tolerance genes in chromosome 1 of rice (*Oryza sativa* L.) using recombinant inbred lines. Philipp Agric Sci 85:68–76

Bora A, Choudhury PR, Pande V et al (2016) Assessment of genetic purity in rice (*Oryza sativa* L) hybrids using microsatellite markers. Biotech 6(1):50

Chowdhury AD, Haritha G, Sunitha T et al (2016) Haplotyping of rice genotypes using simple sequence repeat markers associated with salt tolerance. Rice Sci 23(6):317–325

Domingo C, Andres F, Talon M (2007) Rice cv Bahia mutagenized population; a new resource for rice breeding in the Mediterranean Basin. Spanish J Agr Res 5(3):341–347

Doyle JJ, Doyle JL (1987) A rapid DNA isolation procedure for small quantities of fresh leaf tissue. Phytochem Bull1 9:11–15

Haghdoost P, Daliri MS, Mohamadian M et al (2014) The study of lodging occurrence stages on grain yield damages and agronomical traits of two rice cultivars (Tarom and Shiroodi). Adv Environ Biol 8:914–918

Hasnaoui N, Buonamici A, Sebastiani F et al (2012) Molecular genetic diversity of Punicagranatum L (pomegranate) as revealed by microsatellite DNA markers (SSR). Gene 493(1):105–112

Jain SM (2010) Mutagenesis in crop improvement under the climate change. Rom Biotechnol Lett 15(2):88–106

Lang YZ, Yang XD, Wang Zhu QS (2012) Effects of lodging at different filling stages on rice yield and grain quality. Rice Sci 19(4):315–319

Ren X, Jiang H, Yan Z et al (2014) Genetic diversity and population structure of the major peanut (*Arachis hypogaea* L) cultivars grown in China by SSR markers. PLoS One 9(2):e88091

Ruizhen HF, Zhangying X, Talukdar A et al (2004) Genetic diversity of different Waxy geneotypes in rice. Mol Plant Breed= Fen zizhiwuyuZhong 2(2):179–186
Satturu V, Rani D, Gattu S et al (2018) DNA fingerprinting for identification of rice varieties and seed genetic purity assessment. Agric Res 7(4):379–390
Shadakshari YG, Chandrappa HM, Kulkarni RS et al (2001) Induction of beneficial mutant in rice (*Oryza sativa* L). Indian J Genet 61(3):274–276
Sharma D, Das BK, Kumar V et al (2017) Identification of semi-dwarf and high yielding mutants in Dubraj rice variety of Chhattisgarh through gamma ray based induced mutagenesis. Int J Genet 9(9):0975–9158
Singh VK, Singh BD, Kumar A et al (2018) Marker-assisted introgression of Saltol QTL enhances seedling stage salt tolerance in the rice variety "Pusa Basmati 1". Int J Genomics. https://doi.org/10.1155/2018/8319879
Temnykh S, DeClerck G, Lukashova A et al (2001) Computational and experimental analysis of microsatellites in rice (*Oryza sativa* L): frequency, length variation, transposon associations, and genetic marker potential. Genome Res 11(8):1441–1452
Thomson MJ, Ismail AM, McCouch SR et al (2010) Marker assisted breeding. In: Pareek A, Sopory SK, Bohnert HJ et al (eds) Abiotic stress adaptation in plants: physiological, molecular and genomic foundation. Springer, New York, pp 451–469
Wang N, Long T, Yao W et al (2013) Mutant resources for the functional analysis of the rice genome. Mol Plant 6(3):596–604
Wei FJ, Droc G, Guiderdoni E et al (2013) International consortium of rice mutagenesis: resources and beyond. Rice 6(1):39. https://doi.org/10.1186/1939-8433-6-39
Wu JL, Wu C, Lei C et al (2005) Chemical-and irradiation-induced mutants of indica rice IR64 for forward and reverse genetics. Plant Mol Biol 59(1):85–97
Yang Y, Li Y, Wu C (2013) Genomic resources for functional analyses of the rice genome. Curr Opin Plant Biol 16(2):157–163

Chapter 4
Field Evaluation of Submergence Tolerant Rice Lines in a Coastal Ecosystem of Kerala

K. V. Arya and K. S. Shylaraj

Abstract Submergence is the third important abiotic stress affecting the rice crop in the coastal ecosystem of Kerala due to heavy showers of the South-West monsoon. The most probable solution to overcome this problem is to introgress submergence tolerant genes into high yielding rice varieties. Hence, the study was undertaken to introgress submergence tolerant gene into the rice variety Jaya through marker assisted backcross breeding. Selected BC_3F_2 lines were field evaluated during Kharif 2017 to assess their field performance along with the parents. After polymorphism assay, we could select three foreground, five recombinant and 76 background polymorphic markers. The segment size of *Sub1* region into the selected BC_3F_2 progenies was estimated to be 3.1–5.1 Mb. The percentage recovery of the recurrent parent genome in the best BC_3F_2 progeny was 95.3%. Five superior BC_3F_2 lines viz., BC_3F_2-3-2-6-8, BC_3F_2-5-21-5-2, BC_3F_2-3-5-4-6, BC_3F_2-3-5-4-2 and BC_3F_2-3-5-4-7 selected were further field evaluated to prove the conformity of superior performance. Agro-morphological characters like 50% flowering duration, crop duration, total grain number per panicle and filled grain number per panicle were found to be significantly correlated with the grain yield. The best performing lines viz., BC_3F_2-3-2-6-8, BC_3F_2-5-21-5-2 from the selected lines have the potential to be released as a new variety after assessing their performance in two or more comparative yield trials.

Keywords Agro-morphological characters · Introgression · Marker assisted backcross breeding · Rice genotypes · Submergence tolerance

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4.1 Introduction

Rice (*Oryza sativa* L.) is the major staple food crop of Asia. Submergence is the third important abiotic stress affecting the rice crop in the coastal ecosystems of Kerala due to heavy showers received during the South-West monsoon season. To overcome this problem introgression of submergence tolerant genes into high yielding rice varieties is a possible option. The basis of a marker assisted backcross breeding (MABB) approach is to transfer a specific allele at the target locus from a donor line to a recipient line. The use of molecular markers, permit the genetic dissection of the progeny at each backcross generation, increased the speed of the selection process, thus increasing the genetic gain per unit time (Tanksley et al. 1989; Hospital 2003). The main advantages of MABB are (1) efficient foreground selection for the target locus, (2) minimization of linkage drag surrounding the target locus (3) efficient background selection for the recurrent parent genome recovery and (4) rapid breeding of new genotypes with favourable traits of interest.

The microsatellites/Simple sequence repeats (SSR) markers have been utilized most extensively because they can be readily amplified by polymerase chain reaction (PCR) and a large amount of allelic variation at each locus can be detected. Furthermore, these markers are readily accessible through published linkage maps and public databases, and they permit the differentiation between homozygous and heterozygous individuals (McCouch et al. 2002; Caixeta et al. 2009). Overall, the speed, reliability and cost-effectiveness of acrylamide gel-based microsatellite analysis make this method an attractive tool for MABB (Fuentes et al. 2008). Considering the advantages of SSR markers, in the present study microsatellites/SSR markers were chosen for genetic tracking of the introgressed *Sub1* gene and for regaining the recurrent parent genome background.

At present, the flood-prone paddy fields are increasing due to unpredicted cyclonic rains and due to the adverse effect of global warming and consequent climate change. Hence, submergence is becoming a serious problem as far as the rice farmers in the coastal agroecosystems of Kerala and south India are concerned. The most ideal strategy to combat this problem is the development of *Sub1* introgressed submergence tolerant lines of already developed popular high yielding elite rice varieties. The present study was undertaken to introgress submergence tolerant gene into the rice variety Jaya through marker assisted backcross breeding. Our work focused on (i) the potential application of MABC for the improvement of rice varieties (ii) introgression of target QTL along with attaining maximum background recovery like that of the recurrent parent and (iii) Field evaluation of BC_3F_2 progenies and the performance of these introgressed lines.

4.2 Materials and Methods

4.2.1 Plant Materials

Rice seeds of variety Jaya obtained from ICAR-Indian Institute of Rice Research, Hyderabad was used as the recurrent parent and Swarna *Sub1* from IRRI, Philippines was used as donor parent. Fourteen-day old seedlings were raised in pots for breeding. Manuring, pesticide application and watering were followed as per the recommended package of practices (KAU 2011).

4.2.2 Polymorphism Assay and Genotypic Screening

Polymorphism assay was conducted using 625 SSR markers (Neeraja et al. 2007; Septiningsih et al. 2009) to find the polymorphic markers among the parents. Recurrent parent (RP) and donor parent (DP) crossed to raise F_1 seeds and these F_1 plants were backcrossed with the recurrent parent to raise BC_1F_1 generation. In the same way, BC_2F_1 and BC_3F_1 generations were raised. The selection of tolerant plants in each generation was done using the selected polymorphic foreground, recombinant and background markers. The selected introgressed BC_3F_1 plants were selfed to raise BC_3F_2 generation which was subjected to background screening to select the best introgressed line with maximum background recovery.

4.2.3 Field Evaluation of Sub1 Introgressed BC_3 Lines

The *Sub1* introgressed BC_3F_2 lines (20 lines) along with donor parent Swarna *Sub1* and recurrent parent Jaya were evaluated in the field under natural flash flood conditions during Kharif 2017 at the Rice Research Station, Kerala Agricultural University, Vyttila, Kochi. There was a flash flood of about 2 weeks, out of which the plants were under complete submergence for 6 days. The comparative yield trial was done in randomized block design with three replications. One month old seedlings were transplanted in the laid out plots with 1–2 seedlings per hill at a spacing of 20 cm × 15 cm. Observations of yield attributes were recorded in *Sub1* introgressed BC_3F_2 lines. The replicated values of various morphological observations were subjected to analysis of variance using Web-Based Agricultural Statistics Software Package (WASP 2.0 2004) software developed by ICAR-Central Coastal Agricultural Research, Goa, India. Correlation analysis was also carried out to find out the association between the yield and yield contributing characters.

4.3 Results and Discussion

4.3.1 *Polymorphism Assay and Genotypic Screening*

Polymorphism assay using 625 SSR markers could select three foreground markers viz., ART-5 (6.3 Mb), Sub1BC2 (6.3 Mb), RM23788 (4.2 Mb), five recombinant markers viz., RM23770 (3.7 Mb), RM8303 (2.3 Mb), RM23917 (7.3 Mb), RM23922 (7.4 Mb), RM23958 (7.9 Mb) and 76 background polymorphic markers (Arya and Shylaraj 2018). The genotypic selection of heterozygous plants was made in F_1, BC_1F_1, BC_2F_1 and BC_3F_1 generations and in selfed progenies homozygous plants were selected using the selected foreground and recombinant markers. The segment size of the introgressed donor *Sub1* region into the selected twenty BC_3F_2 progenies was estimated to be 3.1–5.1 Mb whereas Neeraja et al. (2007) reported 2.3–3.4 Mb. In this study, the percentage of recurrent parent genome recovery in the BC_3F_2 generation ranged from 80.0 to 95.3% of which BC_3F_2 -3-2-11-9 had the highest recurrent parent genome recovery of 95.3% followed by BC_3F_2 -3-5-4-7 (94.4%) and BC_3F_2 -3-2-6-4 (93.7%), respectively. Five superior BC_3F_2 lines viz., BC_3F_2-3-2-6-8, BC_3F_2-5-21-5-2, BC_3F_2-3-5-4-6, BC_3F_2-3-5-4-2 and BC_3F_2-3-5-4-7 were selected for further evaluation to prove the conformity of superior performance.

4.3.2 *Field Evaluation of BC_3F_2 Lines*

The *Sub1* introgressed BC_3F_2 lines were field evaluated to assess the yield and other morpho- physiological quantitative characters using experimental design RBD during *Kharif* 2017 in the experimental field of Rice Research Station, Kerala Agricultural University, Vyttila. The yield attributing characters recorded were statistically analysed using (WASP 2.0 2004) software, (Table 4.1) and the performance of the *Sub1* introgressed lines was compared with the parental line Jaya rice variety under flash flood field conditions.

4.3.2.1 50% Flowering Duration

The mean value of 50% flowering duration of the *Sub1* introgressed BC_3F_2 lines ranged from 88.7 to 95.0 days. The line BC_3F_2-5-21-5-7 had the least flowering duration of 88.7 days whereas the line BC_3F_2-3-4-7 expressed the maximum duration of 95 days. Five *Sub1* introgressed BC_3F_2 lines had the flowering duration of 89 days similar to the recurrent parent and seven lines had almost similar duration (89.3–89.7 days) which were statistically on par with Jaya. But seven lines had significantly higher flowering duration (93.3–95.0) which may be because the donor parent Swarna *Sub1* which was a long duration variety with 50% flowering duration of 115 days which is also acceptable in the Pokkali ecosystem. The 5 days

Table 4.1 Agro-morphological traits of selected *Sub1* introgressed BC_3F_2 lines of Jaya

Plant no	DFF (days)	CD (days)	TN	PTN	PL (cm)	GNPP	FGNPP	GFP	GL (mm)	GW (mm)	TGW (g)	GY (t ha^{-1})
BC_3F_2-3-2-6-2	89.7^{c}	119.7^{c}	9.00^{c}	9.00^{c}	24.9^{c}	134.1^{c}	98.3^{c}	73.2^{b}	8.1^{b}	2.9^{b}	24.7^{a}	4.7^{c}
BC_3F_2-3-2-6-4	94.7^{b}	124.7^{b}	9.43^{c}	9.43^{c}	25.4^{c}	130.9^{c}	96.9^{c}	74.2^{b}	8.0^{c}	3.0^{a}	26.1^{a}	4.9^{c}
BC_3F_2-3-2-6-8	94.0^{b}	124.0^{b}	11.63^{b}	11.53^{b}	24.2^{c}	129.6^{d}	88.5^{c}	68.4^{b}	8.1^{b}	3.0^{a}	26.0^{a}	7.5^{b}
BC_3F_2-3-2-6-10	93.3^{b}	123.3^{b}	11.33^{b}	11.33^{b}	26.9^{a}	132.5^{c}	93.8^{c}	70.6^{b}	8.1^{b}	3.0^{a}	25.9^{a}	4.4^{c}
BC_3F_2-3-2-11-5	89.0^{c}	119.0^{c}	8.33^{c}	8.33^{c}	26.1^{b}	104.3^{e}	82.7^{d}	79.1^{a}	8.0^{c}	2.9^{b}	24.3^{b}	3.2^{d}
BC_3F_2-3-2-11-9	89.0^{c}	119.0^{c}	10.67^{b}	10.67^{b}	24.8^{c}	135.5^{c}	105.2^{c}	77.7^{a}	7.9^{d}	2.9^{b}	23.8^{b}	4.5^{c}
BC_3F_2-3-2-11-10	94.0^{b}	124.0^{b}	9.33^{c}	9.33^{c}	25.0^{c}	131.3^{c}	96.4^{c}	73.3^{b}	8.0^{c}	3.0^{a}	25.2^{a}	3.9^{c}
BC_3F_2-3-5-4-2	94.3^{b}	124.3^{b}	10.70^{b}	10.70^{b}	26.2^{b}	119.8^{d}	104.1^{c}	87.2^{a}	8.1^{b}	3.0^{a}	24.8^{a}	6.4^{b}
BC_3F_2-3-5-4-6	94.0^{b}	124.0^{b}	10.90^{b}	10.90^{b}	26.7^{a}	169.8^{b}	123.0^{b}	71.8^{b}	8.0^{c}	2.9^{b}	23.9^{b}	6.8^{b}
BC_3F_2-3-5-4-7	95.0^{b}	125.0^{b}	9.20^{c}	9.20^{c}	25.4^{c}	147.8^{c}	126.9^{b}	86.1^{a}	8.2^{a}	3.0^{a}	26.2^{a}	6.1^{b}
BC_3F_2-3-5-7-2	89.7^{c}	119.7^{c}	11.10^{b}	11.10^{b}	25.9^{b}	125.8^{d}	95.7^{c}	75.6^{b}	8.1^{b}	2.9^{b}	24.3^{b}	4.3^{c}
BC_3F_2-3-5-7-6	89.0^{c}	119.0^{c}	8.00^{d}	8.00^{d}	24.7^{c}	140.2^{c}	94.8^{c}	67.6^{b}	7.9^{d}	2.9^{b}	23.4^{b}	3.4^{d}
BC_3F_2-3-5-7-7	89.0^{c}	119.0^{c}	10.57^{b}	10.57^{b}	26.1^{b}	133.4^{c}	100.1^{c}	75.0^{b}	8.0^{c}	2.8^{c}	24.4^{b}	3.9^{c}
BC_3F_2-5-21-1-3	89.3^{c}	119.3^{c}	11.20^{b}	11.00^{b}	24.4^{c}	135.0^{c}	96.1^{c}	71.0^{b}	7.9^{d}	3.0^{a}	24.6^{a}	5.2^{c}
BC_3F_2-5-21-5-1	89.7^{c}	119.7^{c}	9.23^{c}	9.23^{c}	25.9^{b}	159.6^{b}	112.9^{b}	70.6^{b}	7.8^{e}	2.8^{c}	22.5^{c}	6.0^{b}
BC_3F_2-5-21-5-2	89.0^{c}	119.0^{c}	12.10^{a}	12.00^{a}	26.9^{a}	159.9^{b}	120.2^{b}	75.1^{b}	7.9^{d}	2.9^{b}	22.7^{b}	7.4^{b}
BC_3F_2-5-21-5-4	89.7^{c}	119.7^{c}	9.57^{c}	9.57^{c}	24.7^{c}	132.5^{c}	99.7^{c}	75.2^{b}	7.8^{e}	2.8^{c}	21.2^{c}	4.8^{c}
BC_3F_2-5-21-5-5	89.7^{c}	119.7^{c}	11.57^{b}	11.57^{b}	26.3^{b}	154.7^{b}	105.8^{c}	68.4^{b}	7.9^{d}	2.8^{c}	22.0^{c}	5.8^{b}
BC_3F_2-5-21-5-7	88.7^{c}	118.7^{c}	10.10^{c}	10.10^{c}	22.0^{d}	127.8^{d}	89.9^{c}	69.9^{b}	7.9^{d}	2.8^{c}	22.7^{b}	3.7^{c}
BC_3F_2-5-21-5-9	89.3^{c}	119.3^{c}	11.70^{b}	11.47^{b}	25.1^{c}	139.8^{c}	82.7^{d}	59.7^{c}	7.9^{d}	2.9^{b}	22.9^{b}	4.3^{c}
Jaya	89.0^{c}	119.0^{c}	10.40^{b}	10.27^{b}	25.6^{b}	120.5^{e}	101.2^{c}	84.0^{a}	8.0^{c}	3.0^{a}	25.0^{a}	6.5^{b}

(continued)

Table 4.1 (continued)

Plant no	DFF (days)	CD (days)	TN	PTN	PL (cm)	GNPP	FGNPP	GFP	GL (mm)	GW (mm)	TGW (g)	GY (t ha^{-1})
Swarna*Sub1*	115.0^{a}	145.0^{a}	11.10^{b}	11.00^{b}	24.2^{c}	192.9^{a}	163.3^{a}	84.7^{a}	7.6^{f}	2.8^{c}	19.2^{d}	8.5^{a}
CD (0.01)	2.228	2.228	2.598	2.610	2.093	23.1	28.1	12.8	0.07	0.10	2.24	2.29
CD (0.05)	1.668	1.668	1.948	1.959	1.562	17.2	21.0	9.6	0.05	0.07	1.6	1.71

DFF—Days to 50% flowering, *CD*—Crop duration, *TN*—Tiller number, *PTN*—Productive tiller number, *PL*—Panicle length (cm), *GNPP*—Total grain number per panicle, *FGNPP*—Filled grain number per panicle, *GFP*—Grain filling percentage (%), *GL*—Grain length (mm), *GW*—Grain width (mm), *TGW*—1000 grain weight (g), *GY*—Grain yield (t ha^{-1}). Values followed by same lowercase letters in superscript within a column are not significantly different.

enhancement in duration would definitely add to the grain yield. Ahmed et al. (2016) stated that there was a significant difference between *Sub1* introgressed BC_2F_2 lines of MR219 and most of the lines were statistically similar to the value of recurrent parent MR219.

4.3.2.2 Crop Duration

The mean crop duration of the introgressed lines varied from 118.7 to 125 days. The recurrent parent Jaya had a duration of 119 days in the evaluation slightly earlier than the reported duration of 120–125 days (KAU 2011). According to Ahmed et al. (2016), a significant difference was observed among the *Sub1* introgressed BC_2F_2 lines of MR219 but not significantly different to the recurrent parent MR219. The crop duration of thirteen *Sub1* introgressed BC_3F_2 lines was statistically on par with the recurrent parent Jaya which correlates with 50% flowering duration. The plant BC_3F_2-5-21-5-7 showed the shortest crop duration of 118.7 days. Seven introgressed lines had a significantly higher period of maturity (123.3–125.0 days) compared to recurrent parent Jaya. The plant BC_3F_2-3-5-4-7 showed 125 days of longest duration followed by plants BC_3F_2-3-2-6-4 and BC_3F_2-3-5-4-2 with 124.7 and 124.3 days. The longer duration of the donor parent Swarna *Sub1* might have caused this variation in duration. However, these lines had the acceptable crop duration amenable for cultivation in the Pokkali ecosystem.

4.3.2.3 Number of Tillers per Hill

Tillering in rice is an important agronomic trait that determines the panicle number per unit land area as well as grain production (Moldenhauer et al. 2003). The mean tiller number per hill of the introgressed lines varied from 8.0 to 12.1. The plant BC_3F_2-5-21-5-2 expressed the maximum tiller no. of 12.1 which was significantly higher than the tiller number of both the parents which were statistically on par. Apart from this, ten more *Sub1* introgressed BC_3F_2 lines had more number of tillers (10.57–11.7) compared to the recurrent parent Jaya (10.4), whereas 9 lines had less number of tillers which ranged from 8.0 to 10.1. A similar variation was also reported by Ahmed et al. (2016) in his study where a significant difference was observed between the introgressed lines.

4.3.2.4 Productive Tillers per Hill

The number of productive tillers per hill plays an important role in determining the rice grain yield. The mean productive tillers per hill of the *Sub1* introgressed BC_3F_2 lines varied from 8 to 12 numbers. The plant number BC_3F_2-5-21-5-2 had the maximum productive tillers per hill (12 nos.) which was significantly higher than both the parents (RP and DP). The plant nos. BC_3F_2-5-21-5-5 and BC_3F_2-3-2-6-8 also had higher productive tiller numbers of 11.57 and 11.53, respectively compared to both the parents. The productive tiller numbers of both the parents (RP and DP) were statistically on par. Eleven *Sub1* introgressed BC_3F_2 plants had more number of productive tillers than the RP Jaya (10.27 nos.), whereas seven *Sub1* introgressed BC_3F_2 lines had equal or more productive tillers than the DP (11.0 nos.). Nine *Sub1* introgressed BC_3F_2 lines expressed less productive tillers per hill than both the parents and the least number was shown by the plant BC_3F_2-3-5-7-6. Similar observations were also made earlier by Ahmed et al. (2016), whereas some of the introgressed lines had more productive tillers than the recurrent parent.

4.3.2.5 Panicle Length

Panicle length (PL) is an important character for improving panicle architecture and grain yield in rice crop. The RP Jaya had a significantly higher panicle length of 25.6 cm compared to the DP Swarna *Sub1* (24.2 cm). The introgressed lines differed significantly with respect to panicle length and the lines BC_3F_2-3-2-6-10 and BC_3F_2 5-21-5-2 had the maximum panicle length of 26.9 cm followed by BC_3F_2-3-5-4-6 (26.7 cm) which were statistically on par and significantly superior to both the parents. Eight introgressed lines expressed higher panicle length and eleven lines showed lesser panicle length than the RP Jaya. The least panicle length of 22.0 cm was recorded in the line BC_3F_2-5-21-5-7 which was significantly inferior to both parents. This result was supported by the findings of Ahmed et al. (2016) who reported that there were significant differences in panicle length among the *Sub1* introgressed lines compared to the recurrent parent MR219.

4.3.2.6 Grain Number per Panicle

The grain number per panicle is an important attribute contributing to final grain yield. The DP Swarna *Sub1* recorded a significantly higher grain number per panicle (192.9 nos.). Among the introgressed lines, the line BC_3F_2-3-5-4-6 recorded the maximum grain number of 169.8 per panicle which is significantly higher than the RP Jaya but statistically on par with three other introgressed lines. The RP had an average of 120.5 grains per panicle which was statistically on par with the other eleven introgressed lines. Five introgressed lines expressed significantly less grain number per panicle than the RP Jaya.

4.3.2.7 Filled Grains per Panicle

In this study, the donor parent Swarna *Sub1* is a late duration variety and had a significantly higher number of filled grains per panicle (163.3 nos.) compared to RP Jaya (101.2 nos.) and the developed *Sub1* introgressed lines. Four *Sub1* lines recorded a significantly higher number of filled grains (112.9–126.9 nos.) than the recurrent parent Jaya which were statistically on par. The line BC_3F_2-3-5-4-7 recorded the maximum filled grain number per panicle (126.9). The filled grain numbers of fourteen lines ranged from 88.5 to 105.8 which were statistically on par with the RP Jaya. Two lines had significantly less number of filled grains (82.7) per panicle.

4.3.2.8 Percentage of Filled Grains per Panicle

Percentage of filled grains per panicle is an important yield parameter that expresses the difference between total grain number and filled grain number per panicle. The range of percentage of filled grains per panicle in the *Sub1* introgressed BC_3F_2 lines varied from 59.7 to 87.2, whereas the DP Swarna *Sub1* had 84.7% and RP Jaya had 84.0% fertility. The grain filling percentage of four *Sub1* introgressed lines were statistically on par with RP Jaya though two lines expressed higher grain filling percentage. The maximum percentage of grain filling (87.2%) was expressed by the line BC_3F_2-3-5-4-2 followed by the line BC_3F_2-3-5-4-7 (86.1%) which were higher than both the parents (RP and DP). According to Ahmed et al. (2016) most of the *Sub1* introgressed lines were found to be statistically similar to the recurrent parent MR219 in fertility percentage. But in this study, sixteen *Sub1* introgressed BC_3F_2 lines had significantly lesser grain filling percentage than the RP Jaya.

4.3.2.9 Grain Length

The grain length of *Sub1* introgressed BC_3F_2 lines ranged from 7.8 to 8.2 mm. The line BC_3F_2-3-5-4-7 had a significantly higher grain length of 8.2 mm over both RP and DP and all other introgressed lines. Apart from this, five other *Sub1* introgressed BC_3F_2 lines of Jaya had significantly higher grain length than the recurrent parent Jaya, whereas five other *Sub1* introgressed lines had grain length statistically on par with RP Jaya. Nine *Sub1* introgressed lines had statistically less grain length than RP Jaya (7.8–7.9 mm). The DP Swarna *Sub1* had the least grain length which is statistically inferior to RP and all the introgressed lines.

4.3.2.10 Grain Width

The range of grain width of *Sub1* introgressed BC_3F_2 lines varied from 2.8 to 3.0 mm. The grain width of seven *Sub1* introgressed lines was similar to RP Jaya (3.0 mm) and was statistically on par. Maximum grain width of 3.0 mm was observed in plant nos. BC_3F_2-3-2-6-4, BC_3F_2-3-2-6-8, BC_3F_2-3-2-6-10, BC_3F_2-3-2-11-10, BC_3F_2-3-5-4-2, BC_3F_2-3-5-4-7 and BC_3F_2-5-21-1-3. Contrary to this, Ahmed et al. (2016) reported in their study that there was no statistical difference between the *Sub1* introgressed lines of MR219. Eight *Sub1* introgressed lines (2.9 mm) expressed significantly less grain width than the RP Jaya and the grain width of five *Sub1* introgressed lines were similar to DP Swarna *Sub1* (2.8 mm) and were statistically at par.

4.3.2.11 1000 Grain Weight

The RP Jaya had a significantly higher 1000 grain weight of 25.0 g compared to the DP Swarna *Sub1* (19.2 g). The thousand grain weight of *Sub1* introgressed BC_3F_2 lines of Jaya ranged from 21.2 to 26.2 g. The thousand grain weight of eight *Sub1* introgressed lines of Jaya were statistically at par with the recurrent parent Jaya and twelve *Sub1* introgressed lines had significantly less 1000 grain weight than the RP Jaya. Maximum 1000 grain weight of 26.2 g was observed in plant no. BC_3F_2-3-5-4-7 followed by BC_3F_2-3-2-6-4 (26.1 g) and BC_3F_2-3-2-6-8 (26.0 g) while the minimum 1000 grain weight was observed in BC_3F_2-5-21-5-4 (21.2 g).

4.3.2.12 Grain Yield

It is a complicated trait that is determined directly by three main components including the number of panicles per plant, the number of grains per panicle and grain weight (Huo et al. 2017). The range of grain yield in *Sub1* introgressed lines ranged from 3.2 to 7.5 t ha^{-1}. Seven *Sub1* introgressed lines were statistically on par with the recurrent parent Jaya (6.5 t ha^{-1}). The DP Swarna *Sub1* had the highest grain yield of 8.5 t ha^{-1} which is attributed mainly to the longer duration of Swarna *Sub1*. This yield was significantly higher than the RP Jaya and all other *Sub1* introgressed lines. Thirteen *Sub1* introgressed lines had significantly less grain yield than both the parents (RP Jaya and DP Swarna *Sub1*). Plant no. BC_3F_2-3-2-6-8 expressed the highest grain yield of 7.5 t ha^{-1} which is 15.38% higher than Jaya followed by plant no. BC_3F_2-5-21-5-2 (7.4 t ha^{-1} which is 13.8% higher) and BC_3F_2-3-5-4-6 (6.8 t ha^{-1}). The lowest yield was observed in plant no.BC_3F_2-3-2-11-5 (3.2 t ha^{-1}).

From the field evaluation, it is evident that most of the introgressed lines performed equal or better than the RP Jaya though some of the lines were inferior. Five *Sub1* introgressed lines of Jaya viz., BC_3F_2-3-2-6-8, BC_3F_2-5-21-5-2, BC_3F_2-3-5-4-6, BC_3F_2-3-5-4-2 and BC_3F_2-3-5-4-7 were selected as the superior lines. Ahmed et al. (2016) also stated that there were significant variations of traits among the *Sub1* introgressed lines and also with the recurrent parent MR219. Similarly, Ullah et al. (2011) also noticed significant differences among the traits while studying ten Boro rice varieties of Bangladesh, considering ten morphological characters. Highly significant variations of traits among 40 rice accessions were also observed in another study conducted by Pandey et al. (2009).

After correlation analysis the morphological characters which had positive relationship with grain yield were 50% flowering duration ($r = 0.575$), crop duration ($r = 0.575$), tiller number ($r = 0.491$), productive tiller number ($r = 0.491$), total grain number per panicle ($r = 0.626$), filled grain number per panicle ($r = 0.715$), flag leaf length ($r = 0.552$) and flag leaf width ($r = 0.451$). On contrary, grain length ($r = -0.205$) and 1000 grain weight ($r = -0.233$) was inversely correlated with grain yield which is probably due to very small grain size of DR Swarna *Sub1* but higher grain yield reflected by 25 days extra duration. Among these morphological characters, 50% flowering duration, crop duration, total grain number per panicle and filled grain number per panicle were significantly correlated with grain yield. The character panicle length ($r = 0.142$), grain filling percentage ($r = 0.353$) and grain width ($r = 0.064$) had very weak correlation with grain yield.

4.4 Conclusions

The application of marker assisted selection along with the MABB programme accelerated the recovery of the recurrent parent genome, reducing the number of generations and the time for incorporating tolerance to submergence. Among the lines evaluated, BC_3F_2-3-2-6-8, BC_3F_2-5-21-5-2 were found to be the promising based on the performance of these selected lines in the farm trial and they have the potential to be identified as a new variety after assessing them in two or more comparative yield trials.

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References

Arya KV, Shylaraj KS (2018) Introgression of *Sub1* QTL (Submergence tolerant QTL) into the elite rice variety Jaya by marker assisted backcross breeding. J Trop Agric 56(2):114–128

Ahmed F, Rafii MY, Ismail MR et al (2016) The addition of submergence-tolerant *Sub1* gene into high yielding MR219 rice variety and analysis of its BC_2F_3 population in terms of yield and yield contributing characters to select advance lines as a variety. Biotechnol Biotechnol Equip 30(5):853–863

Caixeta ET, Oliveira ACB, Brito GG et al (2009) Tipos de marcadores moleculares. In: Borem A, Caixeta ET (eds) Marcadores moleculares, Editora UFV, Vicosa, Brazil, pp 11–93

Fuentes JL, Correa-Victoria FJ, Escobar F et al (2008) Identification of microsatellite markers linked to the blast resistance gene *Pi-1(t)* in rice. Euphytica 160:295–304

Hospital F (2003) Marker-assisted breeding. In: Newbury HJ (ed) Plant molecular breeding. Blackwell Publishing, Oxford, pp 30–59

Huo X, Wu S, Zhu Z et al (2017) *NOG1* increases grain production in rice. Nat Commun 8:1497. https://doi.org/10.1038/s41467-017-01501-8

KAU (2011) Package of practices recommendations: crops, 14th edn. Kerala Agricultural University, Thrissur, Kerala, p 360

Mccouch Sr, Teytelman L, Xu Y et al (2002) Development and mapping of 2240 new SSR markers for rice (*Oryza sativa* L.). DNA Res 9:199–207

Moldenhauer KAK, Gibbons JH (2003) Rice morphology and development. In: Smith CW, Dilday RH (eds) Rice: origin, history, technology, and production. Wiley, New Jersey, pp 103–128

Neeraja C, Maghirang RR, Pamplona A et al (2007) A marker—assisted backcross approach for developing submergence- tolerant rice cultivars. Theor Appl Genet 115(6):767–776

Pandey P, Anurag PJ, Tiwari D et al (2009) Genetic variability, diversity and association of quantitative traits with grain yield in rice (*Oryza sativa* L.). J Bio Sci 17:77–82

Septiningsih EM, Pamplona AM, Sanchez DL et al (2009) Development of submergence tolerant rice cultivars: the *Sub1* locus and beyond. Ann Bot 103(2):151–160

Tanksley SD, Young ND, Paterson AH et al (1989) RFLP mapping in plant breeding: new tools for an old science. Nat Biotechnol 7:257–264. https://doi.org/10.1038/nbt0389-257

Ullah M, Bashar M, Bhuiyan M et al (2011) Interrelationship and cause-effect analysis among morpho-physiological traits in Biroin rice of Bangladesh. Int J Plant Breed Genet 5(3):246–254

WASP 2.0 (2004) WASP 2.0-web based agricultural statistics software package, ICAR-Central Coastal Agricultural Research Institute (Formerly ICAR Research Complex for Goa), Goa

Chapter 5
Development of Ionome (Salt-Omic) for the Varietal Improvement and Food Security of the Coastal Region of India

Bidisha Mondal

Abstract Global agricultural productivity is regulated by soil salinity, one of the major abiotic constraints faced by the farmers, growers and breeders. The genomic, transcriptomics, proteomics and metabolomic salt profile of coastal plants could provide an insight into the mechanisms by which the differential performance is regulated in contrasting varieties of a single crop. This study proposes the construction of an ionome suitable for the coastal saline region for sustainable food security. This study focuses on functional genomic studies of saline belt crops and meta-analysis of the information for proposed ionome (Salt-omic) development. In the salt-genome segment, the appropriate genes were identified and categorized covering ion-transport-genes, senescence-associated genes, molecular-chaperones, dehydration-genes. Proteome provides additional information on protein coding sequences, endogenous small molecules. The identified genes, proteins and signalling pathways could form an ionome repository for molecular crop breeding programmes. The primary bioinformatics web source along with a customized database for several crops were found useful for identifying essential biomolecules. The study was able to assist in the formation of agri-ionome for the improvement of coastal crops. The sequential integration of agri-engineering model along with omic details could be utilized for the construction of an explicit repository for molecular plant breeders in a way similar to AMBAB, LIS, Pulsechip or RiceMetaSys.

Keyword Ionome (Salt-omic) · Molecular crop-improvement · Food security · Breeder focused-database

5.1 Introduction

Salinity problem creates massive impact on food security of our country. Enhanced crop productivity and area augmentation are the two focus area that could assist in sustainable food security. India requires 311 million food grains for its exceedingly

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growing population of approximately 1.43 billion in 2030. Intensive cropping, biodiversity loss, abundant fertilizer application, ground water depletion, deforestation, increased urbanization has led to an extraordinary increase in soil salinization in more than 6.74 million ha of land in the country. Advanced soil reclamation using novel technologies and strategies recovered and increased the crop area transforming the affected 2.18 million hectares of salt affected soil (Kumar and Sharma 2020). Inclusive technologies of gypsum-based treatment of sodic soil, subsurface drainage of saline soil, phytoremediation, bio-remediation, agro-forestry, novel breeding techniques could increase food security, income elevation and rural employability. The selection, retention and promotion of advanced breeding technologies could boost crop productivity aiding food security. The economically important varieties of rice, sunflower, sesame, moong, mustard, jute, vegetables and betel leaf grown in the coastal saline belt of West Bengal, India are susceptible to salinity stress. Plants can tolerate salinity stress by processes including salt exclusion or inclusion. The most predominant form of salt stress involving NaCl causes nutrient and metabolic imbalance. Increased salt stress leads to ion toxicity affecting the water retention capacity of the plant.

The breeders face constant challenges in development of new varieties resilient to extreme abiotic stresses including salinity. In such a condition unique breeding techniques will focus on expanding the gene pool or introspection of the present gene pool to identify some potential well performers. In recent times a comprehensive bioinformatics study involving inclusive approach covering all omic information could be applied for developing dynamic breeding strategies. The inclusion of high throughput techniques of DNA/RNA sequencing, microarray data and advanced proteomics could help the breeders to enter inside the unexplored territories of molecular crop advancement programme.

In salt and salinity management a number of agri-engineering computational models were already been invented and used. Scientists have analysed water flow and salt flow processes and developed scientific and engineering models for salinity management. On the basis of scope of application two models, basin model and field-scale models were developed by soil scientists, agri-engineers and agri-informatic professionals. LEACHC, SWAP, SOWACH, HYDRUS and UNSATCHEM were largely used for analysis of water flow, salt flow and plant performance. Among these models SWAP software package involves one-dimensional vertical transport of water, solute and heat and could predict crop yield. The SWAP model was effective in irrigation application and effective yield return studies in cotton (Pan et al. 2020).

SOWACH, a third generation salinity management model was written using QBASIC and runs under DOS and WINDOWS operating system. In a test, it was proved SOWACH model could effectively identify the rooting architecture ideal for increased yield (Alahmad et al. 2019). This model in alfalfa proved that across salinity treatments, final root length density was 24% higher in high fibrous root type and accordingly herbage yield of these root type superseded the low fibrous type by 14%.

The UNSATCHEM model was able to evaluate the efficacy of gypsum administered at different depths and able to suggest the feasibility of alternative management practises. Green manuring involving calcite could reclaim sodic field with less water or without addition of gypsum was proved by software application (Amini et al. 2016). The abundant application of agri-engineering computer software for analysing saline soil was invented for saving time, expense and accuracy of the growers, farmers and stakeholders.

The apparent abundance of soil engineering models could be surpassed if information on molecular crop databases could be utilized directly in salinity research. In reality, the employment of biological database in salinity research is meagre. The vast molecular resource available in public domain could be effectively used for ionome construction and allied research. In this aspect the application and performance of omic data have enormous potential. The available omic database related to salinity could be exploited by plant breeders and molecular biologists. The key information for plant ionome construction could be gathered from three main public repositories. GenBank, EMBL and DDBJ along with UniProt and Swissprot could provide initial data for salinity gene and protein sequence information. The major sequence repositories includes curated collections and provide holistic information on different domains (Lizumi and Sakai 2020). The individuality of these collections are maintained by their virtue of curation as well as unique approach of presentation of biological discoveries. A general plant database search could provide the detailed idea about available plant-omic information. Additionally, sequential exploration of the customized resources could assist in plant ionome construction. The identification of important salinity gene, protein, EST, biological pathways, conserved domains and other relevant information were discussed in this paper to emphasize the importance of crop ionome construction. Ionome (Salt-omic) could assist in the speedy selection and propagation of salt tolerant and resistant crops for the rejuvenation of the coastal and inland saline belts of developing countries ultimately ensuring food security for the human population.

5.2 Materials and Methods

In the present study two approaches were taken for omic data collection. In the first approach all the available primary bioinformatics resource were explored for development of proposed ionome relevant to crop improvement programme of saline belt of West Bengal, India. In this study mainly GenBank, DDBJ and EMBL, Uniprot and Swissprot repositories were searched for gathering omic information of the major crops grown in saline belt of West Bengal. Additionally several other customised public database for the above mentioned crops were investigated for gene and cDNA.

In second approach the open source research database Google Scholar was used for article searching using a search string of salt + omic + crop name consensus tab with only one variable (crop name). It yielded articles with a sample size of 9818. Only English articles published in last 5 years were included. The selected articles were screened on the basis of abstract and keywords. In initial selection grey literature, preprints, presentation, duplication and keynotes were excluded manually reducing the sample size to 303. In the next phase the study applied Voyant tool

Table 5.1 Selection and screening of salt-omic-based research articles

Crop	Extracted paper (*n*)	Initial selection	Selected full paper
Rice	5010	254	14
Lentil	1240	57	9
Mung	1480	62	9
Sunflower	748	74	11
Mustard	514	102	9
Sesame	384	37	10
Jute	462	117	8
Total	9818	703	70

(Sampsel 2018), an open source, web-based application for executing text mining and analysis, promoting rapid analysis of scholarly articles and interpretation of texts from the selected articles. It precisely extracted the frequencies of keywords from all selected published articles and ultimately 70 articles covering only salt-omic information were thoroughly studied and data was extracted (Table 5.1).

5.3 Results and Discussion

5.3.1 Exploitation of Computational Data Source for Ionome Construction

In the saline coastal belts of West Bengal apart from conventional rice cultivation moong, mustard, sunflower, sesame, betel leaf and jute were also cultivated. In this study, the unique dichotomous approach recorded major salt genes and proteins. A comparative study was made between the crop specific saline data source and omic associated papers. This study generated significant findings worthy to be applicable for ionome construction for coastal saline agricultural crops of West Bengal as well as other salt affected regions of India. Omic information was extracted from reported genes and proteins to be used as candidate or reference gene in abiotic stress tolerance. In rice a Google Scholar a search using Salt + omic + rice shows 5010 papers with 22 salt genes reported in gene repositories. Collectively, 1480 omic papers were found related to moong bean though there is no reporting of any gene. In NCBI database a search for salt omic of moong bean yielded only two results under the domain nucleotides. Additionally, the result was classified as an internal test-data record. One thousand two hundred forty papers were found for lentil salt genes with 5 proteins. Whereas a search with salinity genes in soybean extracts information from 10 databases out of which 8 could yield good result in reference omic study of moong bean and legume breeding. In sunflower 1480 omic papers are available with only one salt gene. NCBI covers a total of 22 bioinformatics database under which 10 were selected most suitable for the collection of ionome information. These information could be used by plant breeders for novel molecular studies with allied species or varieties and in integration could act as a valid resource for saline agricultural research. Crop specific useful salinity details under each database was recorded for salt breeding experiments. The database information of 10 cultivated saline belt crops were given in Table 5.2.

As rice is an important cereal the omic information were explored from several fields of publicly accessible databases like OryzaExpress (Kudo et al. 2017), Oryzabase (Kurata et al. 2006) and RiceXPro (Sato et al. 2013). The above domains were consulted for ionome study. Salinity related 22 genes were found to be reported in NCBI database. The reported genes mainly came from japonica subspecies of rice and the available data could be utilized for advance screening of promising rice genotypes for a new region before the commencement of field trials. In RiceMetaSys web interface differential gene expression studies integrated molecular data for rice abiotic and biotic stresses (Sandhu et al. 2017). The breeders could use the OryzaExpress or Oryzabase for the construction of primers and contribute towards rice omic study as well. These database information could be utilized by the breeders of any omic discipline in the elucidation of molecular experimental result in rice. These database information could be utilized for pan-genomic and comparative candidate salt related genetic performance analysis of different salt tolerant indigenous and hybrid rice varieties.

LIS or legume information system is a community resource utilized for legume improvement programme (Gonzales et al. 2005). The LIS contains legume mines integrating 8 individual mines covering bean mine, chickpea mine, cowpea mine, medic mine, lupin mine, soy mine, peanut mine and joint vetch mines combining genomic and expression data of the inter-mines. LIS has potential to be used for gene identification along with the primary data available in major public database. Pulsedb, a database mapping software (Humann et al. 2019) and KnowPulse a diversity based software (Sanderson et al. 2019) could be utilized for stress related classical and molecular genetic studies of pulse.

BASC is an integrated bioinformatics system for Brassica research is available for omic study of salinity tolerant and resistant brassica (Timothy et al. 2007). BASC is generated for browsing and mining of Brassica genetic, genomic and phenotypic data. Multinational Brassica Genome Sequencing Project is a collection of five distinct modules, ESTDB, Microarray, MarkerQTL, CMap and EnsEMBL. ESTDB is a microarray module hosting expressed gene sequences and related annotation derived from comparison with GenBank, UniRef and the genome sequence of Arabidopsis. In mustard 130 salinity genes were evidenced with 720 proteins and 21 EST from NCBI database. The Brassica database contains 47,555 unigenes made up of 17,939 consensus and 29,616 singleton sequences requires separation of stress genes of Brassica. Additionally, raw and normalized both types of data could be extracted from BASC.

In tomato different database extracts noteworthy information for genetic expression studies of tomato. Newly developed curated, open source integrated data resource including TGRD-Tomato Genomic Resources Database (Suresh et al.

Table 5.2 Omic details of essential salinity database of major crops of saline coastal zone of West Bengal obtained from NCBI public database (NCBI 2016)

Crop	Gene	Nucleotide	Protein	EST	Bio-projects	Geo dataset	Popset	dbGap	Conserved domain	SRA
Rice	22	358	224	203	49	80	4	0	2	4
Sunflower	0	8	5	18	1	1	0	0	0	0
Moong	1	4	10	0	1	0	0	0	0	0
Lentil	0	5	5	0	1	2	0	3	1	1
Betel leaf	0	0	10	0	0	0	0	0	0	0
Mustard	130	85	720	21	1	13	0	13	0	5
Grass pea	2	462	329	0	2	529	4	0	0	12
Sesame	36	14	268	1	2	29	0	5	0	6
Jute	0	1	168	2	2	0	0	0	0	1
Soybean	11	53	30	26	8	9	1	2	1	0

2014), TFGD-Tomato Functional Genomics Database (Tranchida-Lombardo et al. 2018), KaTomicsDB-Kazuka Tomato Genomics Database (Shirasawa et al. 2013), MoToDB-Metabolome Database (Grenan 2009) and COXPathDB (Narise et al. 2017) were of prime importance for tomato omic studies. Gramene (Tello-Ruiz et al. 2021) and MaizeGDB (Lawrence et al. 2008) portal was found equally effective in comparative functional genomic studies. The portal initially provided information for grass species but later the expansion of the portal made space for dicot species also. This portal hosts omic information of 93 reference genome of different plant species and 3.9 million genes covering 122,947 families with orthologous and paralogous details (Carson et al. 2016).

5.3.2 *Salt Gene and Protein for Ionome Construction*

In this study integrative meta-analysis efficiently identified several promising salinity genes. Twenty-five productive salt genes were identified in this study that could act as reference gene in virtual molecular breeding design. Bioinformatics tools could aid the breeder in initial design of a new crop related study revealing paralogous or ortholog gene function. The information presented in Tables 5.3 and 5.4 could be utilized for an inclusive study of sequence information, marker assay, trait association, locus details and biochemical path analysis of salinity tolerant important crops of West Bengal. This kind of bioinformatics data was utilized in testing of salinity responsive candidate gene in tomato for varietal performance testing (J'afar et al. 2018). In another paper two drought tolerant landraces were compared using 122 candidate gene studies. The approach identified high effect SNPs, structural variants and promising heat shock proteins and cation/H^+ antiporters. Additionally, pan-genomic studies using 753 accessions in tomato showed 4873 genes were diverse from the reference genome (Chaudhary et al. 2019). In case of betel leaf the recorded information in NCBI repository requires huge input and there is provision for omic study.

5.3.3 *Signalling Pathways for Ionome Construction*

To combat salt stress the plant maintains an equilibrium among carbon sink distribution, energy allocation and osmotic balance. Multiple signalling pathways become active for controlling salinity stress (Othman et al. 2017). Ionic stress signalling pathways along with osmotic stress signalling and detoxification pathways become operative in salt-stressed plants. A plethora of genes and proteins are related to this signalling cascades. SOS response, jasmonate pathway, tyrosine signalling, aquaporin regulation, ethylene synthesis, annexin mediated conductance, expression of asparagine synthetase, hydroxyl proline-rich glycoproteins, ROS and ABA related proteins expressions were vital in salt stress management. Along with the

Table 5.3 Essential genes identified for reference salt genomic studies

Gene	Crop	Gene ID	Function	References
SUV3	*Oryza sativa* ssp. *japonica*	4,334,089	Delayed senescence, ATP-dependent RNA helicase	Macovei et al. (2017)
KAT (4386)	Sunflower, rice, maize, potato	110,864,580	Cytosolic cation homoeostasis	DeLeon et al. (2015)
HKT1	Japonica rice	4,341,971	Regulation of Na toxicity under salt stress	Oda et al. (2018)
NHX	Barley	103,934,031	Na/H exchanger, Vacuolar transporter	Liangbo et al. (2018)
SOS family	Rice	4,341,015	SOS response peptidase	Rice Consortium (2003), Platten et al. (2013)
TIFY gene family	Brassicaceae	4,342,421	Jasmonate ZIM domain specific protein	Reddy et al. (2017)
CRY1b	Rice, Brassica	543,688 2,829,419	Cryptochrome 1b Melatonin biosynthesis	Hwang and Back (2021)
CDPK	Rice/Arabidopsis	819,282	Receptor kinase Ca/CaM	Reddy et al. (2017)
MAPK	Dicot/Monocot	541,618 (Maize)	Serine/threonine protein kinase, salt related oxidative stress	Kong et al. (2019)
GH3	Rice, Gossypium, Vitis	107,896,815 Gossypium	Lipid transporter protein, Tyrosine kinase signalling	Wong et al. (2019)
ERF4 OsSIRP1	Monocot, spinach, Arabidopsis	101,290,597 Triticum	Jasmonate, ethylene pathway	Zhang et al. (2020)
NAC	Wheat, rice, sorghum, sugarcane, mung	818,902 Arabidopsis	AtHB13 and JUB1 transcription regulator	Ebrahimian-Motlagh et al. (2018)
OBF1 (2021)	Maize, rice, Dendrobium	542,394 Maize	Zn finger ring domain, ocs element transcription factor	Alexandrov et al. (2009)

(continued)

Table 5.3 (continued)

Gene	Crop	Gene ID	Function	References
JcAP2/ERFs 2381	Rice, physic nut, Arabidopsis	844,348	Leucine rich repeat family, stomatal development	Tang et al. (2016)
OsFd1/Saltol	Red rice	3,974,662	Ferrodoxin 1 ETS, Na/K homoeostasis	He et al. 2020
RSS3	*Oryza sativa* ssp. *japonica*	4,350,435	Jasmonate induced gene expression	To et al. (2019), Toda et al. (2013)
OsGTv2	*Oryza sativa* ssp. *japonica*	4,330,612	Mitochondrial aldehyde dehydrogenase, Salinity adaptation	Xie et al. (2020)
AFP1,ninja family protein	Sunflower, tomato, rapeseed	110,920,831	putative ethylene responsive binding factor-associated repression, Ninja family	Badouin et al. (2017)
TaHAG1	Bread wheat. Barley, Arabidopsis	119,339,917	Modulating ROS production and salinity regulation	Zheng et al. (2021)
OsLEA	*Oryza sativa* ssp. *japonica*	4,339,745	ABA induced antioxidant stresses	Rice Consortium (2003)
OsPYL/RCAR7	*Oryza sativa* ssp. *japonica*	2,829,419	Glutaredoxin, ABA receptor	Bhatnagar et al. (2020)
TaOFP family	Triticum	3,760,030	Tillering, water stress	Wang et al. (2020)
ZmPTPN	Maize, Arabidopsis	AT5G50670	ABA signalling AsA biosynthesis	Zhang et al. (2020)
AQP (cDNA)	Chickpea, lathyrus, lentil	DY475124	Aquaporin regulation	Mantri et al. (2007)
ASNS (cDNA)	Chickpea, gram, lentil, grass pea	DY475477	Asparagine synthetase (glutamine hydrolysing)	Mantri et al. (2007)

Table 5.4 Essential proteins identified for reference proteomic studies from Uniprot repository

Protein	Accession	Length (AA)	Pathway	Crop	References
WRKY transcription factor WRKY71	Q6QHD1	348	Gibberellin signalling pathway	Rice	Zhang et al. (2020)
Jasmonate ZIM domain-containing protein 9	Q8GSI0	179	Jasmonic acid signalling pathway	Rice	Young et al. (2018)
SNF1-related protein kinase catalytic subunit alpha	Q38997	521	Serine/threonine protein kinase	Arabidopsis	Simon et al. (2018)
Bidirectional sugar transporter SWEET15	Q9FY94	292	Transmembrane transporter	Maize	Doidy et al. (2019)
Ascorbate oxidase	M4DUF2	570	Oxidoreductase, defense pathway	Rapeseed	Nudrat et al. (2017)
Mitogen activated protein kinase	ACJ31803	586	ABA signal transduction	Groundnut	Wang et al. (2016)
XERICO	KAG1363776	166	E3 ubiquitin-protein ligase	Coconut	Brugiere et al. (2017)
5MYB	ABI74688	348	Transcriptase	Cabbage	Wang et al. (2015)
JUNGBRUNNEN	Q 9SK55	375	TF, Central longevity regulator	Thalecress	Dudhate et al. (2021)
ABRC5	AAR06258	141	Ethylene responsive binding factor	Sunflower	Najafi et al. (2018)
RCAR3	5GWO_D	175	ABA receptor	Rice	Hyunmi et al. (2012)
DELLA	NP_001240948	523	Ethylene regulator	Tomato	Shohat et al. (2020)
SnRK2	AID23890	354	Sucrose non-fermenting 1-related protein kinase 2	Cotton	Liu et al. (2017)
ANAC017	EFH67341	547	Transcription regulator	Thale cress	Meng et al. (2019)
AKT	AT3G49850	693	AKT kinase telomeric DNA binding protein	Rice	Xu et al. (2020)

salt genes several important salt proteins were found impressive for comparative proteomic studies. In proteomics 2D gel electrophoresis, MALDI-TOF, mass spectroscopy (Moco et al. 2006) and western blot have proved effective in analysing stress response (Shinozaki et al. 2018). Differential response of 49 proteins was noticed under aluminium stress in tomato seedlings and 40 for silicon stress in tomato (Zhou et al. 2009; Muneer et al. 2015).

5.4 Conclusions

The web-based primary bioinformatics database provides abundant omic information for several crops assisting scientists and researchers in the construction of crop specific public or private databases. Salinity stress is regarded as one of the robust abiotic problems reducing global food productivity. The proper alleviation of salt stress requires an understanding of the activity or expression of mineral and trace elements forming an integrated database including agri-engineering-based plant modelling and multivariate omic information to provide a solution to farmers. The omic study could provide true insight into the physiological activity of plant organs, differential expression of genes and epigenetic regulations. The above study proposes the necessity of the construction of a breeder-focused standalone ionome (Salt-omic) database or crop specific customised database construction for ensuring global food security under ever changing environmental complications.

References

Alahmad S, El Hassouni K, Bassi FM et al (2019) A major root architecture QTL responding to water limitation in durum wheat. Front Plant Sci 10:436. https://doi.org/10.3389/fpls.2019.00436

Alexandrov NN, Brover VV, Freidin S et al (2009) Insights into corn genes derived from large-scale cDNA sequencing. Plant Mol Bio l69(1–2):179–94. https://doi.org/10.1007/s11103-008-9415-4

Amini S, Ghadiri H, Chen C et al (2016) Salt-affected soils, reclamation, carbon dynamics, and biochar: a review. J Soils Sediments 16:939–953. https://doi.org/10.1007/s11368-015-1293-1

Badouin H et al (2017) The sunflower genome provides insights into oil metabolism, flowering and asterid evolution. Nature 546(7656):148–152. https://doi.org/10.1038/nature22380

Bhatnagar N, Kim R, Han S et al (2020) Ectopic expression of OsPYL/RCAR7, an ABA receptor having low signaling activity, improves drought tolerance without growth defects in rice. Int J Mol Sci 21(11):4163. https://doi.org/10.3390/ijms21114163

Brugière N, Zhang W, Xu Q et al (2017) Overexpression of RING domain E3 ligase ZmXerico1 confers drought tolerance through regulation of ABA homeostasis. Plant Physiol 175(3):1350–1369. https://doi.org/10.1104/pp.17.01072

Carson MA, Ethalinda KC, John LP et al (2016) MaizeGDB update: new tools, data and interface for the maize model organism database. Nucleic Acids Res 44(D1):D1195–D1201. https://doi.org/10.1093/nar/gkv1007

Chaudhary J, Khatri P, Singla P et al (2019) Advances in omics approaches for abiotic stress tolerance in tomato. Biology (basel) 8(4):90. https://doi.org/10.3390/biology8040090

De Leon TB, Linscombe S, Gregorio G et al (2015) Genetic variation in Southern USA rice genotypes for seedling salinity tolerance. Front Plant Sci 6:374. https://doi.org/10.3389/fpls.2015.00374

Doidy J, Vidal U, Lemoine R (2019) Sugar transporters in Fabaceae, featuring SUT MST and SWEET families of the model plant *Medicago truncatula* and the agricultural crop *Pisum sativum*. Plos One 14(9). https://doi.org/10.1371/journal.pone.0223173

Dudhate A, Shinde H, Yu P et al (2021) Comprehensive analysis of NAC transcription factor family uncovers drought and salinity stress response in pearl millet (*Pennisetum glaucum*). BMC Genomics 22:70. https://doi.org/10.1186/s12864-021-07382-y

Ebrahimian-Motlagh S, Ribone PA, Thirumalaikumar VP et al (2018) JUNGBRUNNEN1 confers drought tolerance downstream of the HD-Zip I transcription factor AtHB13. Front Plant Sci 8:2118. https://doi.org/10.3389/fpls.2017.02118

Gonzales MD, Archuleta E, Farmer A et al (2005) The legume information system (LIS): an integrated information resource for comparative legume biology. Nucleic Acids Res 33(1):660–665. https://doi.org/10.1093/nar/gki128

Grenan AK (2009) Mo To DB A metabolic database of tomato. Plant Physiol 151(4):1701–1702. https://doi.org/10.1104/pp.109.900308

He L, Li M, Qiu Z et al (2020) Primary leaf-type ferredoxin 1 participates in photosynthetic electron transport and carbon assimilation in rice. Plant J 104(1):44–58. https://doi.org/10.1111/tpj.14904

Hwang OJ, Back K (2021) Suppression of rice cryptochrome 1b decreases both melatonin and expression of brassino steroid biosynthetic genes resulting in salt tolerance. Molecules 26(4):1075. https://doi.org/10.3390/molecules

Humann JL, Jung S, Cheng CH et al (2019) Cool season food legume genome database: a resource for pea, lentil, faba bean and chickpea genetics, genomics and breeding. In: Proceedings of the international plant and animal genome conference, January 2019, San Diego

Hyunmi K, Hyunsik H, Jung-WH et al (2012) A rice orthologue of the ABA receptor, OsPYL/RCAR5, is a positive regulator of the ABA signal transduction pathway in seed germination and early seedling growth. J Exp Bot 63(2):1013–1024. https://doi.org/10.1093/jxb/err338

J'afar U, Aliyu A, Kasimu S et al (2018) genetic diversity in tomato genotypes (*Solanum lycopersicum*) based on salinity responsive candidate gene using simple sequence repeats. Int Lett Nat Sci 72:37–46

Kong W, Zhong H, Deng X et al (2019) Evolutionary analysis of *GH3* genes in six *Oryza* species/subspecies and their expression under salinity stress in *Oryza sativa* ssp. *japonica*. Plants 8(2):30. https://doi.org/10.3390/plants8020030

Kudo T, Terashima S, Takaki Y et al (2017) Plant express: a database Integrating OryzaExpress and ArthaExpress for single-species and cross-species gene expression network analyses with microarray-based transcriptome data. Plant Cell Physiol 58:1. https://doi.org/10.1093/pcp/pcw208

Kumar P, Sharma PK (2020) Soil salinity and food security in India. Front Sustain Food Syst 4:174. https://doi.org/10.3389/fsufs.2020.533781

Kurata N, Yamazaki Y (2006) Oryzabase. An integrated biological and genome information database for rice. Plant Physiol 140(1):12–7. https://doi.org/10.1104/pp.105.063008

Lawrence CJ, Harper LC, Schaeffer ML (2008) Maize GDB: the maize model organism database for basic, translational, and applied research. Int J Plant Genomics. https://doi.org/10.1155/2008/496957

Liu Z, Ge X, Yang Z et al (2017) Genome-wide identification and characterization of SnRK2 gene family in cotton (*Gossypium hirsutum* L.). BMC Genet 18:54. https://doi.org/10.1186/s12863-017-0517-3

Liangbo F, Qiufang S, Liuhui K (2018) Metabolite profiling and gene expression of Na/K transporter analyses reveal mechanisms of the difference in salt tolerance between barley and rice. Plant Physiol Biochem 130:248–257. https://doi.org/10.1016/j.plaphy.2018.07.013

Lizumi T, Sakai T (2020) The global dataset of historical yields for major crops 1981–2016. Sci Data 7:97. https://doi.org/10.1038/s41597-020-0433-7
Macovei A, Sahoo RK, Faè M et al (2017) Over expression of PDH45 or SUV3 helicases in rice leads to delayed leaf senescence-associated events. Protoplasma 254(2):1103–1113. https://doi.org/10.1007/s00709-016-1017-4
Mantri NL, Ford R, Coram TE et al (2007) Transcriptional profiling of chickpea genes differentially regulated in response to high-salinity, cold and drought. BMC Genomics 8:303. https://doi.org/10.1186/1471-2164-8-303
Meng X, Li L, De Clercq (2019) ANAC017 Coordinates organellar functions and stress responses by reprogramming retrograde signalling. Plant Physiol 180(1):634–653. https://doi.org/10.1104/pp.18.01603
Moco S, Bino RJ, Vorst O (2006) a liquid chromatography-mass spectrometry-based metabolome database for tomato1. Plant Physiol 141:1205–1218
Muneer S, Jeong BR (2015) Proteomic analysis of salt-stress responsive proteins in roots of tomato (*Lycopersicon esculentum* L.) plants towards silicon efficiency. Plant Growth Regul 77:133–146
Najafi S, Sorkheh K, Nasernakhaei F (2018) Characterization of the APETALA2/Ethylene-responsive factor (AP2/ERF) transcription factor family in sunflower. Sci Rep 8(1):11576. https://doi.org/10.1038/s41598-018-29526-z
Narise T, Sakurai N, Obayashi T et al (2017) Co-expressed pathways database for tomato: a database to predict pathways relevant to a query gene. BMC Genom 18:437
NCBI Resource Coordinators (2016) Database resources of the National Center for Biotechnology Information. Nucleic Acids Res 44(D1):D7-19. https://doi.org/10.1093/nar/gkv1290
Nudrat AA, Fahad S, Muhammad A (2017) Ascorbic acid-a potential oxidant scavenger and its role in plant development and abiotic stress tolerance. Front Plant Sci 8:613. https://doi.org/10.3389/fpls.2017.00613
Oda Y, Kobayashi NI, Tanoi K (2018) T-DNA tagging-based gain-of-function of OsHKT1;4 reinforces Na exclusion from leaves and stems but triggers Na toxicity in roots of rice under salt stress. Int J Mol Sci 19(1):235. https://doi.org/10.3390/ijms19010235
Othman HC, Millar H, Taylor NL (2017) Connecting salt stress signalling pathways with salinity-induced changes in mitochondrial metabolic processes in C3 plants. Plant Cell Environ 40:2875–2905. https://doi.org/10.1111/pce.13034
Pan YX, Yuan CF, Jing SY (2020) Simulation and optimization of irrigation schedule for summer maize based on SWAP model in saline region. Int J Agric Biol Eng 13(3):117–122
Platten, JD, Egdane, JA, Ismail, AM (2013) Salinity tolerance, Na^+ exclusion and allele mining of *HKT1;5* in *Oryza sativa* and *O. glaberrima*: many sources, many genes, one mechanism?. BMC Plant Biol 13:32. https://doi.org/10.1186/1471-2229-13-32
Reddy INBL, Kim BK, Yoon IS et al (2017) Salt tolerance in rice: focus on mechanisms and approaches. Rice Sci 24(3):123–144. https://doi.org/10.1016/j.rsci.2016.09.004
Rice Full-Length cDNA Consortium (2003) Collection, mapping, and annotation of over 28,000 cDNA clones from japonica rice. Science 301(5631):376–379. https://doi.org/10.1126/science.1081288
Sampsel LJ (2018) Voyant tools. Music Ref Serv Q 21(3):153–157. https://doi.org/10.1080/10588167.2018.1496754
Sanderson LA, Caron CT, Tan R et al (2019) KnowPulse: a web-resource focused on diversity data for pulse crop improvement. Front Plant Sci 10:965. https://doi.org/10.3389/fpls.2019.00965
Sandhu M, Sureshkumar V, Prakash C et al (2017) RiceMetaSys for salt and drought stress responsive genes in rice: a web interface for crop improvement. BMC Bioinform 18:432. https://doi.org/10.1186/s12859-017-1846-y
Sato Y, Takehisa H, Kamatsuki K et al (2013) RiceXPro version 3.0: expanding the informatics resource for rice transcriptome. Nucleic Acids Res 41(Database issue):D1206–13. https://doi.org/10.1093/nar/gks1125
Shinozaki Y, Nicolas P, Fernandez-Pozo N et al (2018) High-resolution spatiotemporal transcriptome mapping of tomato fruit development and ripening. Nat Commun 9:364

Shirasawa K, Hirakawa H (2013) DNA marker applications to molecular genetics and genomics in tomato. Breed Sci 63(1):21–30. https://doi.org//10.1270/jsbbs

Shohat H, Illouz-Eliaz N, Kanno Y et al (2020)The tomato DELLA protein PROCERA promotes abscisic acid responses in guard cells by upregulating an abscisic acid transporter. Plant Physio l184 (1):518–528. https://doi.org/10.1104/pp.20.00485

Simon NML, Kusakina J, Fernandez-Lopez A et al (2018) The energy-signaling hub SnRK1 ais important for sucrose-induced hypocotyl elongation. Plant Physiol 176:1299–1310

Suresh BV, Roy R, Sahu K et al (2014) Tomato genomic resources database: an integrated repository of useful tomato genomic information for basic and applied research. PLoS ONE 9:e86387

Tang Y, Qin S, Guo Y et al (2016) Genome-wide qnalysis of the AP2/ERF gene family in physic nut and over expression of the *jcerf011* gene in rice increased its sensitivity to salinity stress. Plos One 11(3): https://doi.org/10.1371/journal.pone.0150879

Tello-Ruiz MK, Naithani S, Gupta P et al (2021) Gramene 2021: harnessing the power of comparative genomics and pathways for plant research. Nucleic Acids Res 49(D1):1452–1463. https://doi.org/10.1093/nar/gkaa979

Tranchida-Lombardo V, Aiese Cigliano R, Anzar I et al (2018) Whole-genome re-sequencing of two Italian tomato landraces reveals sequence variations in genes associated with stress tolerance, fruit quality and long shelf-life traits. DNA Res 25(2):149–160. https://doi.org/10.1093/dnares/dsx045

Timothy AE, Erica GJ, Christopher GL et al (2007) BASC: an integrated bioinformatics system for *Brassica* research. Nucleic Acids Res 35(1/1):870–873. https://doi.org/10.1093/nar/gkl998

To HTM, Nguyen HT, Dang NTM et al (2019) Unraveling the genetic elements involved in shoot and root growth regulation by jasmonate in rice using a genome-wide association study. Rice 12:69. https://doi.org/10.1186/s12284-019-0327-5

Toda Y, Tanaka M, Ogawa D et al (2013) RICE SALT SENSITIVE3 forms a ternary complex with JAZ and class-C bHLH factors and regulates jasmonate-induced gene expression and root cell elongation. Plant Cell 25(5):1709–1725. https://doi.org/10.1105/tpc.113.112052

Wang, Z, Tang, J, Hu, R et al (2015) Genome-wide analysis of the R2R3-MYB transcription factor genes in chinese cabbage (*Brassica rapa* ssp. pekinensis) reveals their stress and hormone responsive patterns. BMC Genom 16:17. https://doi.org/10.1186/s12864-015-1216-y

Wang H, Lei Y, Wan L et al (2016) Comparative transcript profiling of resistant and susceptible peanut post-harvest seeds in response to aflatoxin production by *Aspergillus flavus.* BMC Plant Biol 16:54. https://doi.org/10.1186/s12870-016-0738-z

Wang D, Cao Z, Wang W et al (2020) Genome-wide characterization of *OFP* family genes in wheat (*Triticum aestivum* L.) reveals that *TaOPF29a-A* promotes drought tolerance. Biomed Res Int7:9708324. https://doi.org/10.1155/2020/9708324

Wong LH, Gatta AT, Levine TP (2019) Lipid transfer proteins: the lipid commute via shuttles, bridges and tubes. Nat Rev Mol Cell Biol 20:85–101. https://doi.org/10.1038/s41580-018-0071-5

Xie X, Zhang Z, Zhao Z et al (2020) The mitochondrial aldehyde dehydrogenase OsALDH2b negatively regulates tapetum degeneration in rice. J Exp Bot 71(9):2551–2560. https://doi.org/10.1093/jxb/eraa045

Xu H, Li X, Zhang H et al (2020) High temperature inhibits the accumulation of storage materials by inducing alternative splicing of OsbZIP58 during filling stage in rice. Plant Cell Environ 43(8):1879–1896. https://doi.org/10.1111/pce.13779

Young UT, Yong LH, Sangyool L et al (2018) Jasmonate zim-domain protein 9 interacts with slender rice 1 to mediate the antagonistic interaction between jasmonic and gibberellic acid signals in rice. Front Plant Sci 9:1866. https://doi.org/10.3389/fpls.2018.01866

Zhang H, Xiang Y, He N et al (2020) Enhanced vitamin C production mediated by an ABA-Induced PTP-like nucleotidase improves plant drought tolerance in arabidopsis and maize. Mol Plant 13(5):760–776. https://doi.org/10.1016/j.molp.2020.02.005

Zheng M, Lin J, Liu X et al (2021) Histone acetyltransferase TaHAG1 acts as a crucial regulator to strengthen salt tolerance of hexaploid wheat. Plant Physiol 23:kiab187. https://doi.org/10.1093/plphys/kiab187

Zhou S, Sauvé R, Thannhauser TW (2009) Proteome changes induced by aluminium stress in tomato roots. Plant Signal Behav 60:1849–1857

Chapter 6
Agro-Morphological, Yield and Grain Quality Analysis of *Sub1* Introgressed Lines of Rice Variety Jyothi

J. Deepa and K. S. Shylaraj

Abstract In the current study, Marker-Assisted Backcross Breeding (MABC) was used to introgress *Sub1* QTL from submergence tolerant Swarna-Sub1 into the genetic background of Jyothi, the most popular high yielding rice variety of Kerala to produce submergence tolerant rice lines. The BC_3F_2 seeds from *Sub1* introgressed progenies were planted with three replications following Randomised Block Design (RBD) to evaluate the agronomic traits and grain yield and quality. The results suggested that developed lines were found to be more or less similar to recurrent parental characters in terms of certain agronomic traits. Some plants showing better performance than the recurrent parent based on the measured traits were also identified. All the progenies had significantly better yield than the recurrent parent. Grain dimension, kernel colour and cooking and eating quality parameters of the *Sub1* lines of Jyothi developed through MABC programme were analysed along with the parental lines to identify high yielding superior quality grains of introgressed lines. A total of four progenies were selected after field evaluation of the 20 Sub1 introgressed BC_3F_2 lines of Jyothi for agro-morphological traits.

Keywords Agro-morphological traits · Grain quality · Marker-assisted backcross breeding · Rice · Submergence tolerance · Sub1 QTL · Yield

6.1 Introduction

Asia produces more than 90% of the rice and it is the staple food for more than half of the world's population (FAO 2020). Among the various abiotic stresses, flood is one of the major abiotic stresses affecting rice productivity (Sahoo et al. 2018). India, Bangladesh and Nepal are the main countries in South Asia that are majorly

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affected by floods. In India, 30% of the total area under rice cultivation is prone to flash flooding (Bhowmick et al. 2014).

Submergence tolerance or quiescence strategy is expressed by rice varieties adapted to flash floods. These rice varieties conserve their energy for survival by limited shoot elongation under submergence and resume growth as soon as the water recedes (Das et al. 2005). Shoot elongation ability (escape mechanism) on the other hand is adopted by varieties capable of withstanding deepwater where water stagnates (>100 cm) for several months (Mommer et al. 2005). The major QTL *Sub1,* located on chromosome 9 is associated with submergence tolerance (Siangliw et al. 2003; Toojinda et al. 2003). This discovery led to the successful introgression of *Sub1* QTL into popular mega rice varieties through Marker Assisted Breeding (Mohanty et al. 2000; McCouch et al. 2002; Neeraja et al. 2007; Ray et al. 2014; Iftekharuddaula et al. 2016; Ray 2018; Rahman et al. 2018).

Marker Assisted Backcrossing was used to introgress *Sub1* QTL from submergence tolerant Swarna-Sub1 into the genetic background of Jyothi, the most popular high yielding rice variety of Kerala to produce submergence tolerant rice lines. Field level analysis is important to assess the adaptability, agronomic characteristics, yield-related traits, etc., along with the purpose for which these lines were developed. Therefore, the present investigation was undertaken to assess the performance of introgressed lines under field conditions to study the agromorphological and yield-related traits to identify promising lines with superior yield and desirable agronomic traits.

6.2 Materials and Methods

6.2.1 Experimental Design

Field-level screening of the 20 *Sub1* introgressed BC_3F_2 lines of Jyothi was carried out during kharif 2017 at the research farm of Rice Research Station, Kerala Agricultural University, Vyttila, Kochi. The selected BC_3F_2 progenies along with the donor and recurrent parental lines were treated with pseudomonas (20 g L^{-1}) overnight before germination. The seeds were then drained and kept under the dark for better germination. Sprouted seeds were sown in special plastic trays and seedlings were maintained until transplantation. The experimental plot was divided into three blocks. The 21-day old seedlings of the *Sub1* introgressed BC_3F_2 lines and parental varieties were transplanted in the field at a spacing of 20 cm × 15 cm in a Randomised Block design (RBD) with three replications. All the recommended package of practices was followed and every care was taken for better crop establishment.

6.2.2 Recording of Agro-morphological Traits

Ten plants were randomly selected from each replication of each of the genotypes for recording the respective observations. Observations on days to 50% flowering, days to maturity, plant height, panicle length, number of productive tillers per plant, number of filled grains per panicle, 1000 grain weight and grain yield per plant and total yield were recorded from the BC_3F_2 introgressed lines along with donor and recurrent parental lines. Grains were used to assess the grain quality parameters like kernel length, breadth, L/B ratio, grain colour and cooking properties like amylose content, gelatinization temperature, gel consistency and protein content.

6.2.3 Statistical Analysis

The mean values of observations taken from each replication were used for statistical analysis. The mean values were statistically analysed by Web Agri Stat Package (WASP) 2.0 (ICAR-Central Coastal Agricultural Research, Goa) and mean differences were compared at 5 and 1% levels of significance.

6.3 Results and Discussion

The data on agro-morphological, yield and quality parameters of the promising Sub 1 introgressed lines and their parents are given in Tables 6.1 and 6.2.

6.3.1 Days to Maturity

The recurrent parent had a duration of 120 days whereas, the donor parent took the longest days to maturity (144 days). Statistical analysis of days to maturity data for all the BC_3F_2 lines revealed significant variation among a few progenies and ranged from 115 to 122 days among the BC_3F_2 lines. However, none of the BC_3F_2 lines screened showed longer maturity days than that of the donor parent. Varieties with a duration of 110–135 days are more preferable as they produce a better yield than those maturing earlier or later under most of the agronomic and climatic conditions (Jennings et al. 1979).

Table 6.1 Agro-morphological traits of *Sub1* introgressed lines of Jyothi and parental varieties

BC_3F_2 progeny no	Days to 50% flowering	Days to maturity	Plant height (cm)	Total number of tillers plant^{-1}	No. of productive tillers plant^{-1}	Percentage of productive tillers (%)	Panicle length (cm)	Flag leaf length (cm)	Flag leaf width (cm)	Index leaf length (cm)	Index leaf width **(cm)**
32-57-8-1	84.67^{f}	114.67^{f}	96.33^{klm}	15.33^{bc}	15.00^{abc}	97.83^{a}	24.33^{abcde}	30.00^{bcd}	1.05^{jk}	33.67^{bcdefg}	1.00^{bcd}
32-57-8-4	89.00^{d}	119.00^{d}	98.50^{ijkl}	12.58^{defg}	12.50^{defgh}	99.37^{a}	24.083^{bcdef}	30.50^{bcd}	1.15^{fghij}	33.67^{bcdefg}	0.68^{f}
32-57-8-6	89.00^{d}	119.00^{d}	100.22^{efghi}	16.45^{abc}	15.56^{ab}	94.63^{abc}	23.28^{efgh}	20.67 ^{g}	1.50^{abc}	26.00 ^{h}	1.03^{bc}
32-57-8-8	90.00b^{cd}	120.00 ^{cd}	96.00 ^{lm}	14.44^{cde}	14.44^{bcde}	100.00^{a}	22.55^{hi}	28.89^{de}	1.07^{ijk}	32.55^{cdefg}	0.80^{ef}
32-57-9-1	88.33^{de}	118.33^{de}	100.22^{efghi}	14.33^{cdef}	13.89^{bcdefg}	97.42^{a}	25.28^{a}	31.33^{bcd}	1.47^{abcd}	32.00^{defg}	1.03^{bc}
32-57-9-3	89.67 ^{cd}	119.67 ^{cd}	102.56^{def}	16.44^{abc}	15.56^{ab}	94.53^{abc}	23.89^{cdefg}	30.00^{bcd}	1.30^{cdefgh}	33.33^{bcdefg}	0.85^{de}
32-57-9-5	90.00^{bcd}	120.00^{bcd}	99.22^{ghijk}	12.44^{efg}	12.44^{efgh}	100.0^{a}	23.56^{efgh}	31.33^{bcd}	1.47^{abcd}	32.67^{cdefg}	0.97^{bcd}
32-57-9-7	85.67^{f}	115.67^{f}	99.08^{hijkl}	12.21 ^{fg}	12.21^{fgh}	100.00^{a}	23.483^{efgh}	30.75^{bcd}	1.39^{bcde}	32.63^{cdefg}	0.94^{bcde}
32-57-9-9	89.33 ^{cd}	119.33 ^{cd}	99.22^{ghijk}	14.67 ^{cd}	13.11^{cdefgh}	89.28^{bc}	23.11^{fgh}	30.67^{bcd}	1.10^{hijk}	32.50^{cdefg}	1.00^{bcd}
32-57-18-1	90.00^{bcd}	120.00^{bcd}	106.01^{bc}	12.78^{defg}	12.22^{fgh}	96.04^{ab}	23.46^{efgh}	23.36 ^{fg}	1.09^{hijk}	26.63 ^{h}	0.94^{bcdef}
32-57-18-4	91.33^{bc}	121.33^{bc}	94.89 ^{m}	18.11^{a}	16.00^{ab}	88.54^{c}	22.89^{gh}	26.00^{ef}	1.00^{jk}	31.00^{efg}	1.00^{bcd}
32-57-18-5	86.33^{ef}	116.33^{f}	99.66^{fghij}	15.78^{bc}	15.55^{ab}	98.60^{a}	23.22^{fgh}	23.00 ^{fg}	1.23^{efghi}	35.33^{bcd}	1.00^{bcd}
12-3-3-3	90.00^{bcd}	120.00^{bcd}	96.17^{klm}	14.33^{cdef}	14.33^{bcdef}	100.00^{a}	24^{cdef}	33.33^{b}	1.00^{jk}	30.33^{fgh}	1.10^{b}
12-3-3-9	86.67^{ef}	116.67^{ef}	103.45 ^{cd}	15.44^{bc}	14.44^{bcde}	93.69^{abc}	24.89^{abc}	24.33^{f}	1.20^{efghij}	36.67^{bc}	1.00^{bcd}
45-65-1-1	88.33^{de}	118.33^{de}	96.92^{jklm}	15.33^{bc}	14.58^{abcd}	95.15^{abc}	23.29^{efgh}	29.25^{cde}	0.90 ^{k}	34.25^{bcde}	0.93^{cde}
45-65-1-4	92.00^{b}	122.00^{b}	102.33^{defg}	17.11^{ab}	16.67^{a}	97.35^{a}	23.78^{defg}	37.00^{a}	1.27^{defghi}	36.00^{bcd}	0.94^{bcde}
45-65-1-10	89.00^{d}	119.00^{d}	99.17^{ghijk}	14.58^{cde}	14.33^{bcdef}	98.33^{a}	24.08^{bcdef}	30.50^{bcd}	1.38^{bcde}	31.75^{defg}	0.64^{f}
12-6-2-1	89.67 ^{cd}	119.67 ^{cd}	107.11^{b}	15.11^{bc}	14.89^{abc}	99.04^{a}	24.83^{abcd} 24.83^{abcd}	30.67^{bcd}	1.37^{bcdef}	36.00^{bcd}	1.00^{bcd}

(continued)

Table 6.1 (continued)

BC_3F_2 progeny no	Days to 50% flowering	Days to maturity	Plant height (cm)	Total number of tillers plant^{-1}	No. of productive tillers plant^{-1}	Percentage of productive tillers (%)	Panicle length (cm)	Flag leaf length (cm)	Flag leaf width (cm)	Index leaf length (cm)	Index leaf width **(cm)**
12-6-2-7	89.67^{cd}	119.67^{cd}	103.17^{cde}	12.42^{efg}	12.17^{gh}	97.95^{a}	23.96^{cdefg}	26.00^{ef}	1.33^{cdefg}	37.50^{b}	1.00^{bcd}
12-6-2-8	89.67^{cd}	119.67^{cd}	102.00^{defgh}	15.67^{bc}	14.67^{abc}	93.37^{abc}	25.11^{ab}	26.00^{ef}	1.57^{ab}	26.00^{h}	1.00^{bcd}
Jyothi	90.00^{bcd}	120.00^{bcd}	95.97^{lm}	9.30^{h}	8.8^{i}	94.80^{abc}	21.63^{i}	26.03^{ef}	1.12^{ghijk}	29.37^{gh}	0.45^{g}
Swarna–Sub1	114.33^{a}	144.33^{a}	114.467^{a}	11.08^{gh}	11.08^{i}	100.00^{a}	25.33^{a}	32.33^{bc}	1.63^{a}	42.67^{a}	1.37^{a}
CV	1.51	1.12	1.89	9.38	9.35	4.41	2.81	7.19	10.79	8.05	10.88
CD (0.01)	3.02	2.97	4.19	2.97	2.85	NS	1.47	4.55	0.29	5.83	0.22
CD (0.05)	2.26	2.23	3.13	2.22	2.13	7.01	1.10	3.40	0.22	4.36	0.17

Means in the same column with same superscript letters are statistically on par at $p < 0.01$ and $p < 0.05$

Table 6.2 Yield contributing traits of *Sub1* introgressed lines of Jyothi and parental varieties

BC_3F_2 progeny no	Total no. of grains $panicle^{-1}$	No. of filled grains $panicle^{-1}$	Fertility (%)	1000 grain wt (g)	Plant wt (g)	Yield (kg $plot^{-1}$ (10 m^2))	Yield (t ha^{-1})
32-57-8-1	154.20^{b}	117.99^{bc}	76.55^{abcd}	24.23^{efg}	33.21^{ab}	11.63^{ab}	8.14^{ab}
32-57-8-4	136.33^{bcde}	104.33^{bcdefg}	76.53^{abcd}	24.95^{cdef}	32.98^{ab}	11.54^{ab}	8.08^{ab}
32-57-8-6	121.22^{defg}	91.89^{ghi}	76.02^{abcd}	24.99^{cde}	32.36^{ab}	11.33^{ab}	7.93^{ab}
32-57-8-8	125.33^{cdefg}	91.89^{ghi}	73.33^{bcde}	25.30^{cd}	33.53^{ab}	11.73^{ab}	8.21^{ab}
32-57-9-1	138.00^{bcd}	111.00^{bcdef}	79.94^{abc}	26.23^{ab}	32.21^{ab}	11.27^{ab}	7.89^{ab}
32-57-9-3	142.66^{bc}	120.00^{b}	83.96^{a}	25.41^{bcd}	33.44^{ab}	11.71^{ab}	8.19^{ab}
32-57-9-5	136.00^{bcde}	111.67^{bcde}	82.01^{a}	24.90^{cdef}	34.38^{a}	12.03^{a}	8.42^{a}
32-57-9-7	143.33^{bc}	104.78^{bcdefg}	73.28^{bcd}	25.25^{cd}	32.55^{ab}	11.39^{ab}	7.97^{ab}
32-57-9-9	113.22^{g}	93.89^{efghi}	82.88^{a}	25.53^{bc}	31.40^{abc}	10.99^{abc}	7.69^{abc}
32-57-18-1	139.00^{bcd}	117.11^{bcd}	84.31^{a}	23.42^{ghi}	34.36^{a}	12.03^{a}	8.42^{a}
32-57-18-4	127.11^{cdefg}	104.11^{bcdefg}	82.00^{a}	23.05^{hij}	33.72^{a}	11.80^{a}	8.26^{ab}
32-57-18-5	133.67^{cdef}	111.00^{bcdef}	83.01^{a}	24.09^{fg}	30.38^{abc}	10.63^{abc}	7.44^{abc}
12-3-3-3	138.33^{bcd}	100.89^{cdefgh}	73.33^{bcdef}	22.25^{j}	30.42^{abc}	10.65^{abc}	7.45^{abc}
12-3-3-9	121.11^{defg}	99.33^{defgh}	82.06^{a}	22.31^{j}	32.05^{abc}	11.22^{abc}	7.85^{abc}
45-65-1-1	117.67efg	82.89^{hi}	70.71^{de}	23.70^{gh}	28.59^{bc}	10.01^{bc}	7.00^{bc}
45-65-1-4	122.56^{defg}	80.44^{i}	65.64^{e}	24.67^{cdef}	33.01^{ab}	11.55^{ab}	8.09^{ab}
45-65-1-10	117.33^{efg}	92.67^{fghi}	78.34^{abcd}	24.63^{def}	34.02^{a}	11.90^{a}	8.33^{a}
12-6-2-1	116.33^{fg}	88.78^{ghi}	76.75^{abcd}	22.64^{ij}	30.01^{abc}	10.50^{bc}	7.35^{abc}
12-6-2-7	123.00^{defg}	88.56^{ghi}	71.96^{cde}	23.60^{gh}	27.08^{c}	9.48^{c}	6.63^{c}
12-6-2-8	120.33^{defg}	97.89^{efghi}	81.57^{ab}	24.98^{cdef}	33.12^{ab}	11.59^{ab}	8.11^{ab}
Jyothi	109.77^{g}	91.37^{ghi}	83.24^{a}	26.94^{a}	21.35^{d}	7.47^{d}	5.23^{d}
Swarna–Sub1	192.13^{a}	162.23^{a}	84.43^{a}	19.17^{k}	34.52^{a}	12.08^{a}	8.46^{a}
CV	9.007	10.872	10.872	2.245	9.903	9.899	9.910
CD (0.01)	26.053	24.653	24.653	1.197	6.929	2.424	1.698
CD (0.05)	19.487	18.440	18.440	0.895	5.182	1.813	1.270

Means in the same column with same superscript letters are statistically on par at $p < 0.01$ and $p < 0.05$

6.3.2 Plant Height

The mean plant height of recurrent parent was found to be 95.97 cm whereas in the case of donor parent it was found to be 114.47 cm. Mean plant height ranged from 94.89 to 107.11 cm with an average of 100.11 cm. Mean plant height of progenies like 32-57-18-4, 32-57-8-8, 12-3-3-3, 32-57-8-1 and 45-65-1-1, 32-57-9-7 and 32-57-8-4 did not differ significantly with the mean plant height of the recurrent parent. All the BC_3F_2 lines analysed have medium height. Farmers prefer rice varieties with medium height. Taller plants are susceptible to lodging and dwarf plants are difficult to harvest.

6.3.3 Number of Total Tillers and Productive Tillers per Plant

The total number of tillers in BC_3F_2 lines showed significant variations and ranged from 12.21 to 18.11 with an average of 14.78 compared to 9.30 tillers in recurrent parent and 11.80 tillers in the donor parent. It has been reported that the number of productive tillers and grain yield had a high positive correlation (Yaqoob et al. 2012).

6.3.4 Panicle Length

The mean panicle length showed significant variations among the *Sub1* introgressed BC_3F_2 lines and it varied from 22.55 to 25.28 cm. The recurrent parent exhibited the lowest value of panicle length (21.63 cm) whereas the donor parent had the longest panicle length (25.33 cm).

6.3.5 Leaf Length and Width

Flag leaf is the uppermost leaf below the panicle. Photosynthetic rate is affected by the size and shape of flag leaf which in turn negatively affect the production (Yue et al. 2006). It has been proved that there is a positive correlation between flag leaf length and panicle length and hence, a positive correlation to grain yield (Rahman et al. 2013). In the present study, the length and width of the topmost leaf known as flag leaf and the third leaf from the top known as index leaf were measured. Flag leaf length values were from 20.67 to 37.00 cm with an average of 28.68 cm among the *Sub1* introgressed BC_3F_2 lines. On the other hand, the flag leaf width among the introgressed lines ranged from 0.90 to 1.57 cm having an average of 1.23 cm. The flag leaf width recorded in the recurrent and donor parents was 1.12 cm and 1.63 cm, respectively.

Index leaf length also showed significant variations among the *Sub1* introgressed BC_3F_2 lines and varied from 26.0 to 37.5 cm with an average of 32.37 cm. Recurrent and donor parents exhibited a length of 29.37 cm and 42.67 cm, respectively. The lowest index leaf width was observed in the recurrent parent whereas the donor parent recorded the highest value. Index leaf width varied between 0.64 and 1.10 cm among the introgressed lines with an average value of 0.94 cm.

6.3.6 Number of Filled Grains and Unfilled Grains per Panicle

The total number of filled grains in recurrent parent Jyothi was found to be 91.37 whereas in donor parent it was found to be 162.23. The number of filled grains in the selected BC_3F_2 progenies varied between 80.44 and 120.00 with the highest value observed in plant no. 32-57-9-3 whereas the lowest value (80.44) was observed in 45-65-1-4.

6.3.7 Spikelet Fertility

Spikelet fertility which refers to the number of filled grains per panicle is a critical yield-determining trait considered during the development of improved lines. It is influenced by genetic background and environmental factors including rain, wind and temperature (Liu et al. 2013). Selected BC_3F_2 progenies exhibited spikelet fertility in the range of 65.64–84.31%. Only one of the progenies (plant no. 45-65-1-4) showed spikelet fertility lower than 70%.

6.3.8 Thousand Grain Weight

The thousand-grain weight among the BC_3F_2 lines varied from 22.25 to 26.23 g with an average of 24.31 g. The recurrent parent had the highest 1000 grain weight (26.94 g) whereas the donor parent had the lowest value (19.17 g). One of the progenies (32-57-9-1) had a thousand-grain weight (26 g) statistically similar to the recurrent parent.

6.3.9 Grain Yield

The recurrent parent recorded the lowest total yield 5.23 t ha^{-1} whereas the yield of the donor parent was 8.46 t ha^{-1}. All the *Sub1* introgressed BC_3F_2 lines had significantly better yield than the recurrent parent and it ranged from 6.63 to 8.42 t ha^{-1}. Eighteen out of the twenty screened progenies recorded statistically at par total yield as that of Swarna-Sub1.

6.3.10 Grain Quality Analysis

All the analysed BC_3F_2 progenies exhibited significant differences in kernel size ranging from 6.50 to 6.87 mm. However, all were classified as long grains similar to the recurrent parent. With respect to length breadth (L/B) ratio, the recurrent parent and donor parent were classified as medium having L/B ratios of 2.8 and 2.5, respectively. The *Sub1* introgressed lines were also classified as medium with L/B ratio ranging from 2.7 to 3.0 except for progenies 12-6-2-1 and 12-3-3-9 with L/B ratio of 3.1 and 3.2, respectively and classified as slender. For grain colour, the recurrent parent had red coloured grains whereas, the donor parent Swarna-Sub1 had white coloured grains. All the BC_3F_2 lines also showed red coloured grains.

The introgressed lines were found to have low and intermediate amylose content. Few lines exhibited an alkali value of 5 with intermediate gelatinization temperature whereas the majority of the progenies exhibited lower alkali value with higher gelatinization temperature. According to gel consistency measurement, all the introgressed lines except for two of the progenies were found to have a softer gel consistency. Rice varieties with softer gel consistency are the most preferred by rice consumers (Babu et al. 2013). Protein content in the selected BC_3F_2 lines and parental varieties were estimated by Kjeldhal method (Orlandini et al. 2009). The total protein content in the BC_3F_2 lines ranged from 7.63 to 9.56%.

6.4 Conclusions

Major QTL for submergence tolerance was introgressed into the elite rice variety Jyothi of Kerala through Marker-Assisted Backcross Breeding. The selected BC_3F_2 lines after foreground, recombinant and background selection with respective markers were subjected to field level analysis for agronomic trait analysis and grain quality analysis. Based on their performance, the four lines viz., 32-57-8-8, 32-57-18-1, 45-65-1-10 and 12-6-2-8 with improved yield and preferred grain quality were found to be the most promising lines which could be subjected to further proceedings necessary for the release of a new variety.

References

Babu RV, Shreya K, Singh DK et al (2013) Evaluation of popular rice (*Oryza sativa* L.) hybrids for quantitative, qualitative and nutritional aspects. Int J Sci Res Pub 3(1):1–8

Bhowmick MK, Dhara MC, Singh S et al (2014) Improved management options for submergence-tolerant (SUB1) rice genotype in flood-prone rainfed lowlands of West Bengal. Am J Plant Sci 5(1):14–23

Das KK, Sarkar RK, Ismail AM (2005) Elongation ability and non-structural carbohydrate levels in relation to submergence tolerance in rice. Plant Sci 168(1):131–136

FAO (2020) Food and Agricultural Organization (online report): land and water section. http://www.fao.org/faostat/en/#data/QC
Iftekharuddaula KM, Ahmed HU, Ghosal S et al (2016) Development of early maturing submergence-tolerant rice varieties for Bangladesh. Field Crops Res 190:44–53
Jennings PR, Coffman WR, Kauffman HE (1979) Rice improvements, p 97. International Rice Research Institute, Los Banos, Philippines
Liu W, Zhang D, Tang M et al (2013) THIS1 is a putative lipase that regulates tillering, plant height, and spikelet fertility in rice. J Exp Bot 64(14):4389–4402
McCouch SR, Teytelman L, Xu Y et al (2002) Development and mapping of 2240 new SSR markers for rice (*Oryza sativa* L.) DNA Res 9(6):199–207
Mohanty HK, Mallik S, Grover A (2000) Prospects of improving flooding tolerance in lowland rice varieties by conventional breeding and genetic engineering. Curr Sci 78(2):132–137
Mommer L, Visser EJW (2005) Underwater photosynthesis in flooded terrestrial plants: a matter of leaf plasticity. Ann Bot 96:581–589
Neeraja CN, Maghirang-Rodriguez R, Pamplona, et al (2007) A marker-assisted backcross approach for developing submergence-tolerant rice cultivars. Theor Appl Genet 115(6):767–776
Orlandini S, Lattanzi L, Paggi U et al (2009) Interlaboratory collaborative study on the kjeldahl reference method for nitrogen determination in goat milk according to ISO 8968–1/2 IF 20–1/2. Bull Int Dairy Fed 440:15–24
Rahman H, Dakshinamurthi V, Ramasamy S et al (2018) Introgression of submergence tolerance into CO 43, a popular rice variety of India, through marker-assisted backcross breeding. Czech J Genet Plant Breed 54(3):101–108
Rahman MA, Haque ME, Sikdar B et al (2013) Correlation analysis of flag leaf with yield in several rice cultivars. J Life Earth Sci 8:49–54
Ray BP (2018) Genetic analysis and development of submergence tolerance rice (*Oryza sativa* L.) lines through MAS. Int J Complement Alt Med 11(4): 244–249
Ray BP, Iftekharuddaula KM, Ghoshal S (2014) Marker assisted backcross for the development of submergence tolerant rice (*Oryza sativa* L.). J Biol Chem Res 31:01–05
Sahoo JP, Singh SK, Saha D (2018) A review of linkage mapping for drought stress tolerance in rice. J Pharmacogn Phytochem 7(4):2149–2157
Siangliw M, Toojinda T, Tragoonrung S et al (2003) Thai jasmine rice carrying QTL ch9 (Sub QTL) is submergence tolerant. Ann Bot 91(2):255–261
Toojinda T, Siangliw M, Tragoonrung S et al (2003) Molecular genetics of submergence tolerance in rice: QTL analysis of key traits. Ann Bot 91(2):243–253
Yaqoob M, Anjum R, Hussain M et al (2012) Genetic diversity analysis and character association in some Chinese hybrid rice under dry conditions. Pak J Agric Res 25(4):249–256
Yue B, Xue WY, Luo LJ et al (2006) QTL analysis for flag leaf characteristics and their relationships with yield and yield traits in rice. Acta Genet Sin 33(9):824–832

Chapter 7
Sahyadri Panchamukhi: A Red Rice Variety Identified for Lowland Situation of Coastal Karnataka

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Abstract Rainfed rice cultivation in lowland ecosystems of coastal Karnataka is largely dominated by the traditional varieties. They are characterized by tall plant types prone to lodging, poor responsive to fertilizer inputs and generally low yielding. Yearly, more than 500 ha area is being affected by flood, because of incessant rains in the region, and hence, farmers are unable to get high returns. To overcome the lodging and yield constraints, intensive efforts were made under the All India Coordinated Rice Improvement Project (AICRIP) at Zonal Agricultural and Horticultural Research Station, Brahmavar, and the outcome of the efforts led to identification of the red rice variety named Sahyadri Panchamukhi. It is a pure line selection from IRGA-318-11-6-9-2B (INGER, IRRI, Philippines) suitable for lowland situation in kharif (rainy) season. The variety recorded 16% increased yield over local check in field experiments conducted consecutively for three years. The farmers accepted the variety because of its overall characteristics covering medium bold size, red kernel colour with medium duration, semi-tall, non-lodging, submergence tolerance and higher grain yield with tolerance to gall midge, blast and major insect pests. The variety is also tastier with mild aroma, taking lesser cooking time and lesser water requirement and is highly suitable for parboiling.

Keywords Low yield · Parboiling · Rainfed lowland · Red rice · Submergence tolerant

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7.1 Introduction

Rice is a staple food for half the population of the world, and the rice diet meets more than half the calorie requirements of a person and his family in many places. Farmers in the world are small/marginal/poor often losing their rice crops during heavy rains mainly because of flooding. The erratic floods experienced in rainfed and flood-affected areas are usually caused by heavy rainfall, overflow of nearby rivers and canals or sometimes tidal movements as in coastal areas. These floods cause serious problems for rice, and hence, flooding is therefore considered a major challenge for rice production, and changing global climate reflected in local weather patterns has also affected the farming conditions adversely; farmers are looking for rice varieties that withstand flooding effectively. Although rice is traditionally grown in flooded soil, most rice cultivars die within days of complete submergence, often resulting in total crop loss (Mackill et al. 2012). These losses disproportionately affect rice farmers in rainfed and flood-affected areas where alternative livelihood and food security options are limited.

In the coastal region of Karnataka, rice covers a major area of nearly 0.21 m ha with a productivity of 2.9 t ha^{-1}. This area comprises the entire district of Udupi and Mangalore and a part of Uttar Kannada (Rajanna 2010). The region is characterized by a hot humid climate with heavy rains during kharif (June to September) and a dry period from November to May. Annually, this region receives an average rainfall of about 3900 mm. The southwest monsoon normally commences from the first week of June and during the first crop season, (May–June to September–October) 130–135 days maturity rice varieties (medium duration) are grown. Here, varieties with coarse grain and red kernels (most of the micronutrients are concentrated and a red tinge remains even after a high degree of milling) are generally preferred as they suit parboiling adequately. The iron and zinc content of red rice was also reported to be 2–3 times higher than that of white rice (Ramaiah and Rao 1953). The red rice variety also exhibited many other special attributes such as resistance to drought, flood and submergence tolerance, alkalinity and salinity (Chaudhary and Tran 2001). The bran layer contained polyphenols, anthocyanin and antioxidant properties. Proanthocyanidin pigments showed important deterrent effects on pathogens and predators (Bate-Smith 1973; Scalbert 1991).

Rice cultivation in rainfed lowland ecosystems of coastal Karnataka is largely restricted to growing traditional varieties, and they are prone to lodging, respond poorly to fertilizer inputs and generally are low-yielding genotypes. Medium bold red rice variety MO-4 is the predominant variety that is being grown (>25 years) in the Coastal Karnataka in kharif season but is susceptible to lodging in lowland areas leading to a drastic reduction in yield under week-long flooded conditions. Yearly, more than 500 ha area is being affected by the flood because of continuous rainfall in the region, and hence, farmers are unable to get high returns. Therefore, the development/identification of improved cultivars for the rainfed lowland ecosystem is bound to lead to a quantum leap in the production and returns of farmers. To overcome the lodging and yield constraints, concentrated efforts were made in the

All India Coordinated Research Project (AICRP) on Rice, at Zonal Agricultural and Horticultural Research Station, Brahmavar, and the outcome of the efforts led to the identification of the red rice variety named Sahyadri Panchamuki.

7.2 Material and Methods

7.2.1 Plant Material

The red kernelled rice with medium bold type and non-lodging genotype (IRGA-318-11-6-9-2B) later named Sahyadri Panchamukhi was identified and selected from the International Rainfed Lowland Rice Observational Nursery, Module-2 trial (INGER, IRRI, Philippines). The pure line selection of this entry was tested initially in station trial with the check variety (MO-4) in 10 m^2 plot area with two replications in RCBD design for three years (2016, 2017 and 2018) in kharif season at the Zonal Agricultural and Horticultural Research Station, Brahmavar, Udupi Dist. Karnataka, India, located at the 12° 54′ North latitude and 74° 54′ East longitude. All the necessary agronomic practices were followed to raise a healthy crop and pests/disease (leaf/neck blast, brown spot, false smut and gall midge) incidence scoring for the entry was made as per the Standard Evaluation System of Rice (IRRI 1995). In each kharif season, traits like days to 50% flowering, plant height (cm), tillers m^{-2}, panicle length (cm), 1000 grain weight (g), grain yield (kg ha^{-1}), duration (days) and straw yield (t ha^{-1}) and disease/pests score were recorded.

7.2.2 MLT, Farm Trial and IVT-IM Rice Trial

After the good performance of this entry, IRGA-318-11-6-9-2B, for grain yield, yield attributing traits, disease and pest incidence in the station trial, six multi-location trials (MLT) were conducted in 2017, 2018 and 2019 during the kharif season. Later, farm trial was proposed for 2 years (2017 and 2018), and simultaneously, this entry was nominated in the initial varietal trial (IVT-IM) of the AICRP on Rice, ICAR-Indian Institute of Rice Research (IIRR), Hyderabad, for kharif 2018 conducted across 32 locations for grain yield, disease and pest reaction. Large-scale demonstrations and field days were organized in 2019 and 2020 in Udupi and Dakshina Kannada Districts of Karnataka.

7.2.3 Assessment of Physio-chemical Characteristics of Seed

Rice grain quality has become an important issue affecting domestic consumption and international trade of rice. The marketing potential of red rice can be widened with the identification of the nutritional benefits among health conscious consumers. Physio-chemical characteristics of the seed were done as per Subba Rao et al. (2013) for the hulling percentage, milling, head rice recovery, amylose content, water uptake, elongation ratio, bulk density and leached out solids. For sensory (organoleptic) evaluation, the seed material along with check was submitted to the ICAR-National Rice Research Institute, Cuttack, Odisha, and AICRP-Food and Nutrition, University of Agricultural Sciences, Gandhi Krishi Vigyan Kendra, Bangalore, Karnataka, simultaneously.

7.2.4 Proximate Nutrients Composition of Seed

For nutrient profiling of IRGA-318-11-6-9-2B, the seed material along with that of check was submitted to pesticide residue and food quality analysis laboratory, University of Agricultural Sciences, Raichur, Karnataka. The moisture and total ash content of rice were determined according to IS 4333: 2017 (BIS 2017) and IS 1155:1968 (BIS 1968), respectively. The crude protein, crude fibre and crude fat of the rice were determined according to Latimer Jr (2016) using sub-components 984.13, 962.09, and 2003.06 respectively. The determination of carbohydrate content in the rice sample was determined according to the method described by IS 1656: 2007 (BIS 2007). The calcium, iron, magnesium and zinc contents of rice were determined by using the method as per Latimer Jr (2016).

7.3 Results and Discussion

7.3.1 Station, MLT and Farm Trial

The pure line selection of IRGA-318-11-6-9-2B was tested initially in the station trial with check MO-4 for grain yield, disease and pest incidence for three consecutive kharif seasons (2016, 2017 and 2018). The entry was exhibited significantly higher mean grain yield of 5858 kg ha^{-1} with a 16% increase over the local check (MO4) (Table 7.1).

The mean performance of this entry for the yield attributing characters was observed in three kharif seasons; IRGA-318 required 95–100 days to 50% flowering, whereas check variety (MO-4) took 100–105 days to 50% flowering; IRGA-318 is taller (90–95 cm) than MO-4 (80–85 cm); IRGA-318 recorded 320–350 tillers m^{-2} whereas in MO-4 380–400 tillers m^{-2} were observed. A 1 cm difference in panicle

Table 7.1 Performance of Sahyadri Panchamukhi (IET No.27670) for grain yield in station trial at ZAHRS, Brahmavar

Sl. No.	Genotypes	Kharif/Lowland			Mean grain yield (kg ha^{-1})	% increase over check
		2016	2017	2018		
1	Sahyadri Panchamukhi	5953*	5769*	5851*	5858	16
2	MO-4	4938	5108	5087	5044	
	Exp. mean	3184.33	2622.04	3745.53		
	SEM ±	150.31	243.43	242.93		
	CD @ 5%	430.70	657.72	736.86		
	CV	6.66	13.13	9.17		

*Significant at 5% probability level

length was observed between IRGA-318 (21–22 cm) and MO-4 (20–21 cm), while the test weight (1000 grain wt.) was slightly higher in IRGA-318 (24 g) as compared to MO-4 (23 g). Similarly, the IRGA-318 showed tolerance to submergence condition and non-lodging nature, whereas MO-4 is non-tolerant to the submerged situation and is lodging type. The IRGA-318 recorded a higher straw yield (6–6.5 t ha^{-1}) as compared to MO-4 (5–5.3 t ha^{-1}) in lowland areas. For leaf/neck blast and gall midge incidence, both the varieties showed tolerance reaction, but MO-4 was more affected by brown leaf spot and false smut diseases as compared to IRGA-318. Both varieties are medium bold, red kernelled and matured in 130–135 days (Table 7.2).

The performance of entry IRGA-318 was evaluated at six multi-location trials (Table 7.3) in Udupi and Mangalore districts of Karnataka during kharif 2016, 2017 and 2018 for grain yield, disease and pest incidence. The pooled mean grain yield was highest in this entry (5571 kg ha^{-1}), with 21% increase yield over local check MO-4 (4580 kg ha^{-1}). During the trial, no severe pests and diseases incidences were noticed.

The farm trials were conducted along with check variety for two kharif seasons (2017 and 2018) by the Karnataka State Department of Agricultural in Udupi and Dakshina Kannada districts and KVKs of Mangalore and Brahmavar. In 2017, the first year of farm trial, the entry IRGA-318 recorded significantly highest grain yields of 5690 kg ha^{-1} in KVK, Brahmavar, 4625 kg ha^{-1} in KVK, Mangalore, 5500 kg ha^{-1} in KSDA, Udupi and 5435 kg ha^{-1} in KSDA, Mangalore. In 2018 (second year farm trial), the entry showed consistently good performance and recorded significantly higher grain yields of 5750 kg ha^{-1} in KVK, Brahmavar, 5150 kg ha^{-1} in KVK, Mangalore, 5688 kg ha^{-1} in KSDA, Udupi and 5575 kg ha^{-1} in KSDA, Mangalore. The overall grain yield of IRGA-318 was 5426 kg ha^{-1}, accounting for 16.88% yield increase over the local check MO-4 (Table 7.4).

In large-scale demonstration, the entry again recorded the highest grain yield of 5546 kg ha^{-1}, with a 23.8% increase over local check MO-4 (4480 kg ha^{-1}) at three locations during kharif 2018 (Table 7.5).

Table 7.2 Performance of Sahyadri Panchamukhi (IET No.27670) for yield attributing characters and disease/pest reaction

Sl. No.	Character	Sahyadri Panchamukhi	MO-4
1	Days to 50% flowering	95–100	100–105
2	Duration (days)	130–135	130–135
3	Plant height (cm)	90–95	80–85
4	Tillers m^{-2}	320–350	380–400
5	Panicle length (cm)	21–22	20–21
6	1000 grain weight (g)	24	23
7	Grain type	Medium bold	Medium bold
8	Kernel colour	Red	Red
9	Submergence tolerance	Tolerant	Non tolerant
10	Lodging incidence	Non-lodging	Lodging
11	Grain yield (kg ha^{-1})	5000–5500	4500–4800
12	Straw yield (t ha^{-1})	6–6.5	5–5.3
13	Leaf and neck blast (scale 0–9)	2	2
14	Brown leaf spot reaction (scale 0–9)	1	2
15	False smut reaction (Scale 0–9)	1	2
16	Gall midge reaction (Scale 0–9)	0	0

Submergence is a serious problem and affects crop growth and ultimately reduces the yield drastically in the lowland areas of the coastal region of Karnataka. It was noticed that in the farm trials and large-scale demonstrations in lowland areas in farmers' fields during the first year, this entry showed tolerance to submergence conditions and non-lodging character.

7.3.2 IVT-IM Trial AICRP on Rice

In All India coordinated IVT-IM trial with 64 entries, over 32 locations during kharif 2018, IET27670 recorded significantly higher grain yield 7739 kg ha^{-1} with 17% increased yield over the check (Ratna) in Kota (Rajasthan). Similarly, in Ragolu (9226 kg ha^{-1}) and Warangal (7765 kg ha^{-1}) of Andhra Pradesh, the IET27670 recorded higher grain yield as compared to check RGL 2538, and furthermore, the same trend was observed in Pattambi, Kerala (7709 kg ha^{-1}), Patna (7030 kg ha^{-1}) and Katlagere (7000 kg ha^{-1}) compared to the local checks Sweta, Rajendra Sweta and JGL 1798, respectively. It showed consistently good performance in NRRI-Cuttack (ICAR) (5350 kg ha^{-1}), Jeypore (5210 kg ha^{-1}), Chiplima (5673 kg ha^{-1}) of Odisha state and Bikramganj (Patna) (5700 kg ha^{-1}) of Bihar state (Table 7.6).

In AICRIP, Brahmavar centre, also, the entry IET27670 exhibited the significantly higher yield (5975 kg ha^{-1}) with 30%, 68% and 16% increase yield over the National

Table 7.3 Performance of Sahyadri Panchamukhi (IET No.27670) for grain yield under multi-location trial

Sl. No.	Genotypes	Kharif/Lowland						Mean grain yield (kg ha^{-1})	% increase over check
		2016	2017			2018			
		Kota	Uchhila	Manur	Munddkin jaddu	Manipura	Surathkal		
1	Sahyadri Panchamukhi	5500*	5476*	5500*	5851*	5663*	5436*	5571	21
2	MO-4	4575	4837	4441	4665	4462	4500	4580	
	Exp. mean	3548	3615.25	3569.63	3228	3602.75	3622.67		
	SEM ±	325.01	264.46	268.13	189.58	256.39	249.45		
	CD @ 5%	1011.64	823.16	834.59	590.11	798.06	776.46		
	CV	12.95	10.34	10.62	8.30	10.06	9.74		

*Significant at 5% probability level

Table 7.4 The results of Sahyadri Panchamukhi (IET No.27670) for grain yield (kg ha^{-1}) in farm trial of 2 years (2017 and 2018) in Udupi and Dakshina Kannada districts

District	Year	Location name	Grain yield (kg ha^{-1})		
			Sahyadri Panchamukhi	MO-4 (Local check)	% increase over check
KVK, Brahmavar	2017	1. Belapu nademanege, Udupi tq 2. Keduru, Udupi taluk 3. Chantar	5690	4961	14
	2018	1. Mr. Ragavendra Bhat-Baidubettu 2. Mr. Chandrasekhar Kokkarne 3. Mr. Babu naik, Petri	5750	4893	17
KVK, Mangalore	2017	1. Kaliya village, Belthangadi Taluk 2. Kateel village, Mangalore taluk 3. Nada village, Belthangadi Taluk	4625	4300	8
	2018	1. Canute Arhna, Chenchanakerer, Mangaluru taluk, DK 2. Manik Raj Jain, Bantwala, DK	5150	4475	15
KSDA, Udupi	2017	1. RSK, Kota 2. RSK, Ajekar 3. RSK, Udupi	5500	4800	15
	2018	1. RSK, Byndoor 2. RSK, Kota 3. RSK, Karkala	5688	4413	28
KSDA, Mangalore	2017	1. RSK, Kokkada and Belthangadi 2. RSK, Surathakal 3. RSK, Bantwala	5435	4896	11
	2018	1. RSK, Kokkada and Belthangadi 2. RSK, Surathakal 3. RSK, Bantwala	5575	4400	26
Total/mean			5426	4642	16.88

Table 7.5 Performance of Sahyadri Panchamukhi (IET No.27670) for grain yield in large-scale demonstration during kharif 2018 in Udupi district

Sl. No	Place	No. of location	Grain yield (kg ha^{-1})	
			Sahyadri Panchamukhi	MO-4 (Local check)
1	Kota	1	5500	4441
2	Katpadi	1	5663	4462
3	Kapu	1	5476	4537
Mean			5546	4480
% increase over check				23.8

Table 7.6 National-level grain yield data of Sahyadri Panchamukhi (IET No.27670) in AICRIP trial

Entry No	IET No	Zone	Zone II	Zone III		Zone VII		
		States	RA	BI		KE	KA	
		places	KTA	BKG	PTN@	PTB@	BRM@	KTG
			Grain yield (kg ha^{-1})					
1513	27670		7739	5700	7030	7709	5975	7000
1525	NDR 359 (NC)		4734	5600	8470	7060	4588	6900
1546	Zonal check ZC)		6629	5550	4710	7087	3538	4700
1564	Local check		6576	5500	6450	6423	5151	5000
Exp. mean			6145	4967	6909	6116	3591	5630
CD%			1360	874	663	2351	514	816
CV%			11.07	8.8	4.79	20.97	7.15	7.25
Local check name			Ratna	Sabour shree	Rajendra Sweta	Swetha	MO-4	JGL 1798

BKG—Bikramganj (Patna); *BRM*—Brahmavar; *KTA*—Kota; *KTG*—Kathalgere; *PTB*—Pattambi; *PTN*—Patna
Source Progress report 2018, Vol 1, Varietal Improvement, AICRP on rice, ICAR-IIRR, Hyderabad

check (NDR 359), Zonal check (Jaya) and Local check (MO-4), respectively, in IVT-IM trial during kharif 2018 (Table 7.7).

7.3.3 AICRIP Screening Nurseries Trials for Disease and Pests

The incidence of pests (at 32 locations) and disease (at 16 locations) was also evaluated in the AICRIP screening nurseries trials. During kharif 2018, IET27670 showed a susceptibility index of 5.3 for leaf blast disease in Hyderabad, Coimbatore, Almora,

Table 7.7 Grain yield data of Sahyadri Panchamukhi (IET No.27670) in AICRIP trial at Brahmavar centre

Sl. No.	IET No	Kharif 2018 yield (kg ha^{-1})	% increase over check
1	IET27670	5975	
2	National Check (NC) (NDR 359)	4588	30% over NC
3	Zonal check (ZC) (Jaya)	3538	68% ver ZC
4	Local check (LC) (MO4)	5151	16% over LC
	Exp. Mean	3591	
	CD @ 5%	514	
	CV	7.15	

Source Progress report 2018, Vol 1, varietal improvement, AICRP on rice, ICAR-IIRR, Hyderabad

Nellore, Jagdalpur, Titabar and Ponnampet, which means IET27670 showed moderately tolerance reaction to leaf blast for both under artificial and natural screening. Similarly in Mandya, Ponnampet and Titabar, the IET27670 scored a susceptibility index of 7 for neck blast disease and, therefore, exhibited moderately tolerant to susceptible reaction for the disease under both artificial and natural screening conditions.

The susceptibility index for sheath blight in IET27670 was 7.2 in Raipur, Pantnagar, Patna and Moncompu which means that the entry was moderately tolerant to sheath blight both under artificial and natural screening. Similarly, in Gangavati, Varanasi, Aduthurai, Moncompu and Chatha, the entry IET27670 exhibited moderately tolerant to susceptible reaction for bacterial leaf blight both in artificial and natural screening with a susceptibility index of 7.0.

Similarly, IET27670 scored an 8.0 susceptibility index for sheath rot in Raipur, Aduthurai and Chatha, which means the entry was moderately tolerant to sheath rot only in artificial screening. Similarly, in natural screening at Coimbatore, Jagdalpur, Hazaribagh, Chatha and Mugad, the entry scored a susceptibility index of 6 for brown spot disease, indicating it was moderately tolerant. The IET27670 showed a resistant reaction against glume discolouration and moderately resistant reaction to rice tungro diseases (Tables 7.8 and 7.9).

In AICRIP pest screening nursery trials during kharif 2018, for stem borer damage, the IET27670 exhibited moderate resistance reaction in Chinsurah, Aduthurai, Chiplima, Ghaghrahat, Pantnagar and Titabar, and for leaf folder damage, it exhibited moderate reaction in Titabar, Jagdalpur, Gangavathi, Aduthurai, Pantnagar and Ghaghrahat. Similarly, for brown planthopper (BPH) and white-backed planthopper (WBPH), this red rice variety showed a resistant reaction in Gangavathi and Maruteru. Against gall midge, the entry IET27670 exhibited resistant reaction in Hyderabad, Chiplima, Aduthurai and Jagdalpur (Tables 7.10 and 7.11).

Table 7.8 Disease reaction of Sahyadri Panchamukhi (IET No.27670) in AICRIP screening nurseries trials during kharif 2018

P No	IET No	NSN-2 leaf blast													NSN-2 neck blast						NSN-2 brown spot					
	Locations	CUT	CBT	ALM	HYD	NLR	JDP	TTB	PNP	SI	HZB	REW	PTB	MGD	MND	PNP	TTB	SI	JDP	MGD	CBT	JDP	HZB	CHT	SI	MGD
	Screening	A	A	N	A	N	N	A	N		N	-	N	N	N/A	N	A		N	N	N	N	N	N		N
	LSI	7.4	6.4	5.2	5.1	5.1	4.8	4.4	4.3		3.9	3.7	3.7	1.2	7.0	6.5	4.6		2.7	2.3	7.7	5.1	4.8	4.6		1.6
451	27670	5	3	5	4	5	5	3	5	5.3	2	5	2	0	7	7	7	7.0	1	1	5	5	5	3	6.0	0

Table 7.9 Disease reaction of Sahyadri Panchamukhi (IET No.27670) in AICRIP screening nurseries trials during kharif 2018

P. No	IET No	NSN-2 sheath blight					NSN-2 BLB						NSN-2 sheath rot			RTD	GD
	Locations	RPR	PNT	PTN	SI	MNC	GNV	VRN	SI	ADT	MNC	CHT	RPR	SI	ADT	HYD	CHT
	Screening	A	A	N		A	A	A		A	A	N	A		-	A	N
	LSI	6.6	6.3	4.1		3.1	6.5	5.2		6.4	3.0	3.0	8.2		3.9	6.4	3.3
451	27670	5	5	5	7.2	0	5	5	7.0	3	1	3	7	8.0	–	5	–

A—artificial screening, *N*—natural screening, *LSI*—location severity index, *SI*—Susceptibility index
NSN-2—National screening nursery-2, *BLB*—bacterial leaf blight, *RTD*—rice tungro disease, *GD*—glume discolouration
ADT—Aduthurai, *ALM*—Allmora, *CBT*—Coimbatore, *CHT*—Chatha, *CUT*—Cuttack, *GNV*—Gangavati, *HYD*—Hyderabad
HZB—Hazaribagh, *JDP*—Jagdalpur, *MGD*—Mugad, *MNC*—Moncompu,*MND*—Mandya, *NLR*—Nellore, *PNP*—Ponnampet
PNT—Pantnagar, *PSA*—Pusa, *PTB*—Pattambi; *PTN*—Patna, *REW*—Rewa, *RPR*—Raipur, *TTB*—Titabar, *VRN*—Varanasi

Table 7.10 Insect pest reaction of Sahyadri Panchamukhi (IET No.27670) in AICRIP screening nurseries trials during kharif 2018

Entry No.	IET No.	Stem borer damage								Leaf folder damage				
		CHN	ADT	CHP	PNT	TTB	ADT	TTB	PNT	TTB	JDP	GVT	ADT	PNT
		30DT	53DT	50DT	56DT	50DT	72DT	102DT	118DT	30DT	30DT	32DT	53DT	76DT
		% Dead hearts					% White ears			% Damaged leaves				
451	27670	7.3	5.1	2.2	27.4	4.4	3.8	12.2	2.7	7.0	0.9	9.5	1.4	0.6

Table 7.11 Insect pest reaction of Sahyadri Panchamukhi (IET No.27670) in AICRIP screening nurseries trials during kharif 2018

Entry No	IET No	BPH + WBPH		GMB1	GMB1	GMB	GMB
		GVT	MTU	HYD	CHP	ADT	JDP
		64DT	80DT	GH	30DT	53DT	30DT
		Damage score	%DP	%DP	%DP	%SS	
451	27670	3.0	5.0	0.0	70.0	30.0	0.0

GH—green house reaction, *DT*—date of transplanting, *DP*—dead plant
SS—silver shoots, *GMB*—gallmidge biotype, *BPH* + *WBPH*—brown plant hopper + whitebacked planthopper
ADT—Aduthurai, *CHN*—Chinsurah, *CHP*—Chiplima, *GVT*—Gangavathi; *HYD*—Hyderabad
JDP—Jagdalpur, *MTU*—Maruteru, *PNT*—Pantnagar, *TTB*—Titabar

7.3.4 Physio-chemical Characteristics of Seed

Being a major cereal grain, evaluating the nutritional and cooking qualities of rice has been given the highest priority. Rice is the only cereal crop consumed mainly as whole grain, and quality considerations are much more important than any other food crop (Paramita et al. 2002; Hossain et al. 2009). Rice grain quality is influenced by various physico-chemical characteristics that determine the cooking behaviour as well as the cooked rice texture (Bocevska et al. 2009; Moongngarm et al. 2010). Intrinsic properties like amylose, gelatinization temperature and gel consistency determine the market quality of rice as well as its products (Lodh 2002).

Evaluation of physio-chemical characteristics and cooking quality of the entry IRGA-318 (IET No. 27670) was done at the Central Rice Research Institute, Cuttack. It was observed that the red kernelled medium bold IRGA-318 required less water uptake (175 ml 100 g^{-1}), less leached out solids (0.36 10 g^{-1}), less gel consistency (44) and gained higher bulk density after cooking (1.77), whereas in MO-4, water uptake was more (225 ml 100 g^{-1}), more leached out solids (0.99 10 g^{-1}), gel consistency (49) and less bulk density after cooking (0.95). Similar results were observed in both varieties such as alkali spreading value (7), volume expansion ratio (4), kernel length after cooking (10 mm), elongation ratio (1.90), hulling (77%), milling (67%), head rice recovery (48%) and kernel length (5.24 mm) (Table 7.12).

The organoleptic study done in AICRP-Food and Nutrition, UAS, GKVK, Bangalore, revealed that the IRGA-318 (IET No.27670) has got good appearance, taste, aroma and soft texture as compared to MO4 (Table 7.13).

7.3.5 Proximate Nutrient Composition of Seed

Rice with a red bran layer is called red rice. The red pigment in rice grains is due to the presence of proanthocyanidins, also called condensed tannins. Bran layer

Table 7.12 Physio-chemical characteristics of Sahyadri Panchamukhi (IET No.27670) in comparison with check variety MO-4

Sl. No	Name of variety	ASV	WU (ml/100 g)	VER	KLAC (mm)	ER	AC (%)	Gel consistency	Hulling (%)	Milling (%)	HRR (%)	Moisture (%)	KL (mm)	KB (mm)	L/B	Grain type
1	Sahyadri Panchamukhi	7	175	4	10	1.90	20.70	44	77	67	48	12.2	5.24	2.39	2.19	Medium bold
2	MO-4	7	225	4	10	1.90	20.77	49	77	67	48	12.6	5.24	2.46	2.13	Medium bold

ASV—alkali spreading value, *WU*—water uptake, *VER*—volume expansion ratio, *KLAC*—kernel length after cooking
ER—elongation ratio, *AC*—apparent amylase content, *HRR*—head rice recovery, *KL*—kernel length
KB—kernel breadth, *L/B*—length breadth ratio

Table 7.13 Sensory (organoleptic) evaluation of Sahyadri Panchamukhi (IET No.27670)

Varieties	Quality parameter					Description
	Appearance	Aroma	Texture	Taste	Overall acceptability	
Sahyadri Panchamukhi	5.80	5.90	5.00	5.60	5.50	Accepted
MO-4	5.50	5.50	5.00	5.00	5.20	Accepted

No. of samples—50; cooking was done in open condition

Table 7.14 Nutrient composition in Sahyadri Panchamukhi and MO-4

Nutrients	Sahyadri Panchamukhi	MO-4
Moisture (%)	12.66	12.63
Total ash (%)	1.56	1.39
Crude fat (%)	2.21	2.44
Fibre (%)	1.29	1.37
Protein (%)	9.18	8.57
Carbohydrate (%)	74.39	74.97
Calcium (mg/kg)	29.94	22.55
Iron (mg/kg)	16.95	8.07
Magnesium (mg/kg)	1540.30	1358.09
Zinc (mg/kg)	24.19	19.06

contains polyphenols and anthocyanin, which possesses antioxidant properties; zinc and iron content of red rice, is also 2–3 times higher than that of white rice (Desai Amruta 2012). The proximate nutrient composition of both the entries were tested at the Pesticide Residue and Food Quality Analysis Laboratory, UAS, Raichur, and the results revealed that IRGA-318 contained high values of zinc (24.19 mg kg^{-1}), protein (9.18%), magnesium (1540.30 mg kg^{-1}), iron (16.95 mg kg^{-1}) and calcium (29.94 mg kg^{-1}), whereas MO4 recorded, lower contents of zinc (19.06 mg kg^{-1}), protein (8.57%), magnesium (1358.09 mg kg^{-1}), iron (8.07 mg kg^{-1}) and calcium (22.55 mg kg^{-1}). The moisture, carbohydrates, crude fat, fibre and total ash content values in IET No.27670 are on par with MO4 (Table 7.14).

7.4 Conclusions

IET No.27670 had been tested in All India Coordinated varietal trail (IVT-IM) during kharif 2018 and tested in 32 locations across India and found superior grain yield in southern, northern and eastern India, and this entry also showed the tolerance reaction to leaf blast, neck blast, brown spot, sheath blight, sheath rot, bacterial leaf blight and rice tungro disease, and tolerance to major insect pests like stem borer, leaf folder, BPH + WBPH and gall midge damage.

This entry required less water uptake, gained higher bulk density after cooking and having less leached out solids and less gel consistency. IRGA-318 (IET No.27670) has got good appearance, taste, aroma and soft texture as compared to MO-4. The red rice variety (IET No.27670) had higher values of zinc, protein, calcium, iron and magnesium content so that it can be used for children and pregnant woman.

The farmers accepted this variety mainly because the new rice variety named "Sahyadri Panchamukhi" is red kernelled, medium bold, straight without awn and possessing good milling recovery with consumer preference. Apart from this, the variety has embodied desirable characteristics of the compactness, semi-tall plant height, non-lodging stature, submergence tolerance and maturity of 130–135 days. The variety also exhibited green foliage, strong and erect Culm, higher grain yield with tolerance to leaf and neck blast and to major insect pests—stem borer, gall midge and leaf folders. An average yield of this variety is 50–55 q ha^{-1} and higher zinc content compared to MO-4.

The 38th state seed sub-committee in 2019 accepted the variety for release in the name Sahyadri Panchamukhi for lowland situation of Zone 10 (Coastal Karnataka) during kharif season and the National Bureau of Plant Genetic Resources granted the National Identity number IC 630611 for this red rice variety (Table 7.14).

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References

Bate-Smith EC (1973) Tannins of herbaceous leguminosae. Phytochemistry 12:1809–1812

BIS (1968) Indian standard, specification for wheat atta, 2nd revision, IS 1155:1968. Bureau of Indian Standards, New Delhi, India, p 8

BIS (2007) Indian standard, milk-cereal based complementary foods—specification, 4th revision, IS 1656:2007. Bureau of Indian Standards New Delhi, India

BIS (2017) Indian standard, method of analysis for food grains—part 2: determination of moisture content, 2nd revision, IS 4333 (part 2):2017. Bureau of Indian Standards New Delhi, India

Bocevska M, Aldabas I, Andreevska D et al (2009) Gelatinization behavior of grains and flour in relation to physiochemical properties of milled rice (*Oryza sativa* L.). J Food Qual 32(1):108–124

Chaudhary RC, Tran DV (2001) Specialty rices of the world - a prologue. In: Chaudhary RC, Tran DV (eds) Specialty rices of the world: breeding, production, and marketing. FAO, Rome, Italy and Oxford IBH Publishers, India, pp 3–14

Desai Amruta S (2012) Molecular characterization of red rice genotypes (*Oryza sativa* L.). M.Sc. Thesis, Dept. of Agricultural Biotechnology B.A. College of Agriculture, Anand Agricultural University, Anand, Gujarat, India

Hossain HT, Seki H, Ariga J (2009) The texture of cooked rice. J Texture Stud 13(1):31–42

IRRI (1995) Standard evaluation system for rice (SES), IRRI, Manila, Philippines. www.knpwledgebank.irri.org

Latimer Jr GW (2016) Official methods of Analysis of AOAC International, 20th edition. Association of the Official Analytical Chemists International, Maryland
Lodh SB (2002) Quality evaluation of rice for domestic and international consumers. In: Khush GS, Coffman WR (eds) Genetic evaluation and utilization (GEU) in rice improvement. International Rice Research Institute, Philippines, pp 135–140
Mackill DJ, Ismail AM, Singh US et al (2012) Development and rapid adoption of submergence-tolerant (Sub1) rice varieties. Adv Agron 115:303–356
Moongngarm A, Saetung N (2010) Comparison of chemical compositions and bioactive compounds of germinated rough rice and brown rice. Food Chem 122(3):782–788
Paramita B, Rekha SS, Pushpa RK (2002) Basmati rice: a review. Int J Food Sci Technol 37(1):1–12
Rajanna MP (2010) Status paper on rice in Karnataka. Rice Knowledge Management Portal. http://www.rkmp.co.in
Ramaiah K, Rao MVBN (1953) Rice breeding and genetics. ICAR Science Monograph 19, Indian Council of Agricultural Research, New Delhi, India.
Scalbert A (1991) Antimicrobial properties of tannins. Phytochemistry 30:3875–3883
Subba Rao LV, Shobha Rani N, Chiranjevi M et al (2013) DUS characterization of rice varieties. DRR, ICAR

Chapter 8
Impact of Different Tillage Systems on the Dynamics of Soil Water and Salinity in the Cultivation of Maize in a Salt-Affected Clayey Soil of the Ganges Delta

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Abstract The effects of minimum and reduced tillage have been widely investigated in many climatic regions for a range of cereal crops, but limited research has been done for mechanized maize establishment, on wet clay-structured soils such as those that occur in the salt-affected Ganges Delta coastal zone. To identify the impacts of various tillage systems on the maize establishment and yield performance, and changing of soil properties, a field experiment was conducted in 2017 and 2018 seasons. The implemented tillage treatments were zero tillage (ZT), strip tillage (ST), shallow bed planting (BP), single-pass shallow rotary tillage (SPST) and double pass rotary tillage (DP). The results showed that reduced tillage treatments (BP, SPST and DP) had greater soil water content and lower soil salinity ($EC_{1:5}$) at 0–15 cm soil

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depth than minimum tillage treatments (ZT and ST) in both years. The increased soil disturbance produced the highest grain yield (10–15% improvement) relative to the minimum soil disturbance. The yield improvements were related to the improved soil solute potential under intensive soil disturbance which can be attributed to less soil water evaporation.

Keywords Minimum tillage · Reduced tillage · Solute potential · Wet soil

8.1 Introduction

In the salt-affected coastal region of Ganges Delta, dry season (*rabi*) crop establishment is constrained by waterlogging, soil salinity, and poorly structured soil (Mainuddin et al. 2019; Mondal et al. 2015a; Paul et al. 2016). Farmers usually grow long-duration wet season rice in puddled clay soil from July/August–December/January, which delays sowing time for dry season crop establishment (Paul 2020; Mondal et al. 2015b; Maniruzzaman et al. 2019). Some studies reported that intensive soil puddling by two-wheel tractor leads to the breakdown of soil aggregates, hardpan formation, soil compaction, and increased cracking tendency (Kirchhof et al. 2000; Wopereis et al. 1992). These soil physical constraints can reduce the internal drainage and infiltration and increase the soil penetration resistance, which results in poor crop emergence, growth, and development (So and Ringrose-Voase 2000). Moreover, the low-lying land and shallow water table in the coastal area slow down the surface water drainage from the field, which is a barrier for rabi crop establishment early because the soil is too wet for sowing (Paul et al. 2020a). The common practice for rabi crop establishment in this area is full rotary tillage (3–4 passes) a two-wheel tractor that is possible only when soil surface has dried enough. So, the establishment often occurs late in February or March when valuable soil water can be lost (Paul et al. 2020b). Moreover, the late sown of *rabi* crops are exposed to increased risk of drought and increased salinity as well as waterlogging from pre-monsoon rains at the end of the growing season, which results in low yield or often complete crop damage. Therefore, early sowing with a suitable tillage system and soil water and salinity management is crucial to overcome these constraints (Bell et al. 2019; Mainuddin et al. 2020, 2021).

Minimum and reduced tillage may enable early sowing into the moist soil for maximum utilization of soil water and avoidance of soil salinity. Some studies have reported that the benefits of minimum tillage (zero/no-tillage, i.e., less soil disturbance) include more stable aggregates in the surface soil layer (Lal et al. 2007), more soil water retention, increased infiltration because of higher macro-porosity (Pagliai et al. 2004), decreased fuel and labour requirement and earlier sowing time for *rabi* crops (Hobbs et al. 2007; Haque et al. 2017; Bonari et al. 1995). However, other studies have mentioned that minimum tillage increase soil bulk density, soil penetration resistance, and water loss by increasing evaporation, which is related to the reduction of root and shoot growth and yield (Ferreras et al. 2000; Opoku et al.

1997). Paul et al. (2020a) showed that minimum soil disturbance (zero and strip tillage) decreased soil water content, increased soil bulk density and soil salinity, and decreased yield of the relatively salt-tolerant sunflower compared to increased soil disturbance (bed planting and single-pass shallow tillage) in the salt-affected coastal region of the Ganges Delta. With these contradictory findings for minimum soil disturbance effects, the present study evaluated the different tillage systems on soil, water, and salinity dynamics, and the growth and yield of maize in heavy-textured soil in the salt-affected coastal zone of Bangladesh.

8.2 Materials and Methods

8.2.1 Study Site Description

The experiment was conducted in a farmer's field at Pankhali, Dacope, Khulna, Bangladesh (22° 60′ 12″ N and 89° 50′ 72″ E). A high-yielding medium duration wet season rice was transplanted in the last week of August and harvested in the last week of December. After harvesting, rice residue was removed from the field to allow the soil surface to dry. The climate is subtropical with hot and humid summer (March–June), cold and dry winter (December–February), and a monsoonal rainy season (June–October). During the study period, there was no rainfall during the early growing season (Fig. 8.1a, b), but from the second week of March and April, there was frequent rainfall until harvest; 205 mm in 2017 and 147 mm in 2018.

The minimum temperature was the lowest in January (9.5 and 8 °C in 2017 and 2018, respectively), and the maximum temperature was the highest in April (37.5 and 37 °C in the first and second year, respectively) (Fig. 8.1a, b). The experimental area is classed with the Ganges Tidal Floodplain agro-ecological zone (known as AEZ 13) (Paul et al. 2021a). The soil texture of the site varied from silty clay (0–30 cm) to clay (30–60 cm). At 0–15 cm depth, the soil had a bulk density of 1.56 Mg m^{-3}, a pH of 7.5, the total organic carbon content of 12 g kg^{-1} and nitrogen content of 1.3 g kg^{-1} (Paul et al. 2020b).

8.2.2 Experimental Design and Crop Management

The experiment was set-up in a randomized complete block design (RCBD) with three replications in plots measuring 6 m × 6 m. The experiment comprises five tillage treatments. These were: ZT (zero tillage), ST (strip tillage), BP (shallow bed planting), SPST (single-pass rotary shallow tillage), and DP (double pass rotary shallow tillage). Maize (viz., DON-111, Hybrid) was sown on 7 January and 11 January in 2017 and 2018, respectively, with a plant to plant spacing of 25 cm and

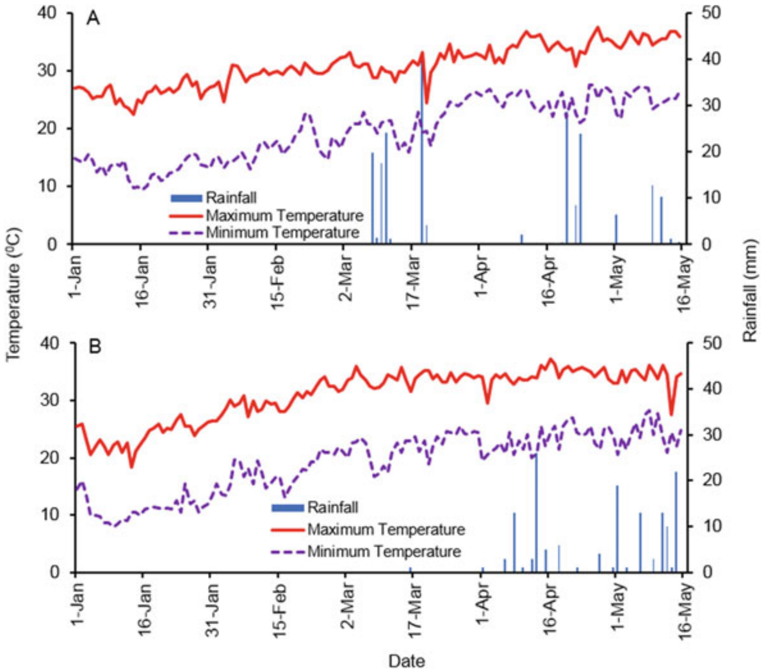

Fig. 8.1 Daily rainfall, minimum and maximum temperatures (**a**) in 2017 and (**b**) in 2018 growing season in Pankhali, Dacope, Khulna, Bangladesh

row to row spacing of 60 cm. Fertilizers applied were urea (550 kg ha^{-1}), triple superphosphate (260 kg ha^{-1}), muriate of potash (220 kg ha^{-1}), gypsum (260 kg ha^{-1}), zinc sulphate (15 kg ha^{-1}), and boric acid (10 kg ha^{-1}). Fertilizer, including one-fourth of urea, was applied during sowing time, and the remaining urea was broadcasted in three splits at 35 days after sowing (DAS), 50 DAS and 70 DAS. Irrigation water was sprayed through plastic hose pipe across the soil surface from the nearby canal, and volumetric water was measured. Preventive spraying of insecticide Nitro (Cypermethrin Chlorpyriphos) was applied three times to control pests. Two hand weeding were done at 35 DAS and 50 DAS, and 30 DAS and 50 DAS in the first and second year, respectively. Maize emergence and dates for tasseling, silking and milking period were recorded throughout the season. Physiological maturity was recorded when 80% of the kernels had a black layer. During harvest, yield, and yield-related parameters such as plant height, cob diameter, cob length, cob weight, number of kernels per cob, thousand seed weight, and yield were measured. Seeds were threshed manually from cobs and air-dried 1–2 days to calculate the final yield (t ha^{-1}) at an adjusted moisture content of 12%.

8.2.3 Soil Water Content Measurement

During the growing season, gravimetric soil water content was measured at 0–7, 7–15, 15–30, 30–45 and 45–60 cm depth at 30 days intervals between sowing to harvest for all tillage treatments. A hand-held auger was used to collect soil samples from each depth, and these were kept in sealed polyethylene bags. The wet weight of the samples was measured immediately, and they were then oven-dried to a constant weight. Gravimetric soil water content (SWC) was calculated from the difference between soil wet and dry weights.

8.2.4 Soil Electrical Conductivity ($EC_{1:5}$) and Solute Potential of Soil Solutions

The $EC_{1:5}$ was measured at 0–7, 7–15, 15–30, 30–45 and 45–60 cm depth at 30-day intervals between sowing and harvest. Measurements were made in 1: 5 soil–water suspension using a portable EC meter. A conversion factor was used to determine the electrical conductivity of soil saturated paste extracts (EC_e) from the $EC_{1:5}$ for clay texture (Slavich and Peterson 1993). The solute potential (SP) of the soil solutions was calculated according to Paul et al. (2020a).

$$\Psi_s = \frac{-22,580 \times EC_{1:5}}{W}$$

where, Ψ_s is the solute potential (kPa), $EC_{1:5}$ is the electrical conductivity (dS m^{-1}) of the 1:5 soil: water extract and W is the gravimetric SWC (%, w/w).

8.2.5 Statistical Analysis

The crop data were analyzed by single-factor ANOVA using STAR software (version 2.0.1.). The significance of effects of tillage on soil water content, $EC_{1:5}$ and solute potential were determined using a three-way factorial ANOVA model that also took account of the effects of tillage treatments, soil depth and date after sowing (time) as repeated measures. The differences between means were tested using the least significant difference (LSD) at the 95% confidence level.

8.3 Results

8.3.1 Maize Growth Observations

With the ZT and ST, most emergence occurred after 5–8 days but emergence was delayed to 10–12 days for SPST and DP, and to 10–15 days for the BP treatment in both years. At 25 DAS, plants per square meter was significantly lower in the BP treatments relative to the other tillage treatments (Fig. 8.2a, b). Tasseling of maize became visible at 78–80 DAS and silking commenced 3–4 days after tasseling in all tillage treatments. Plants matured 3–4 days earlier in ZT and ST than the other tillage treatments. The average growth duration was shorter by 4–5 days in the second year (120–124 days) than in the first year (124–129 days).

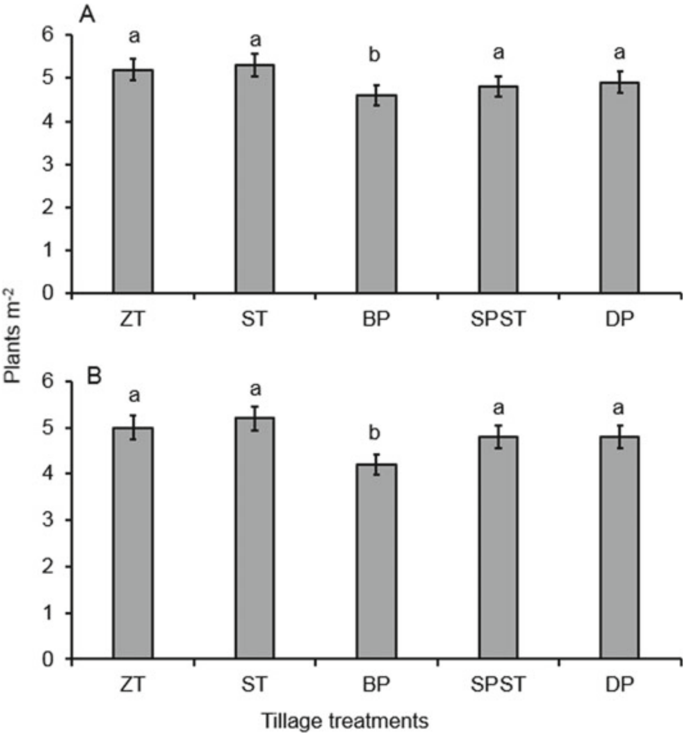

Fig. 8.2 Maize plant density per square metre under different tillage treatments in Pankhali, Dacope, Khulna during (**a**) 2017 and (**b**) 2018 growing season. Means with identical letters are not significantly different. Abbreviations: ZT = Zero tillage, ST = Strip tillage, BP = Shallow bed planting, SPST = Single-pass shallow tillage and DP = Double pass shallow tillage

Table 8.1 Yield and yield attributes of maize in five tillage treatments in Pankhali, Dacope, Khulna, Bangladesh in (*a*) 2017 and (*b*) 2018

Treatments	Seed yield (t ha^{-1})	Number of kernels per cob	1000 seed weight (g)	Cob length (cm)	Cob diameter (cm)
(*a*)					
BP	7.7	691	250	20	17.1
DP	7.5	667	251	18	16.8
SPST	7.4	664	249	19	17.3
ST	6.9	622	241	19	16.6
ZT	6.7	620	240	18	16.9
P-values	0.0001	0.008	0.02	NS	NS
$LSD_{0.05}$	0.28	37	7.0	–	–
(*b*)					
DP	7.0	678	220	18.6	16.6
BP	6.8	653	212	19.4	16.7
SPST	6.6	647	204	18.9	16.4
ST	5.9	555	193	17.4	15.3
ZT	5.8	548	188	17.3	15.6
P-values	0.0003	0.001	0.02	NS	NS
$LSD_{0.05}$	0.39	54	19.4	–	–

Abbreviations ZT-Zero tillage, *ST*-Strip tillage, *BP*-Bed planting, *SPST*-Single-pass shallow tillage and *DP*-Double pass tillage. LSD is the least significant difference at $P < 0.05$. *NS* = Non-significant

8.3.2 Yield and Yield Attributes

Tillage treatments had significant effects on yield and yield components (Table 8.1). The highest yield was with the greatest soil disturbance (BP, DP and SPST) and the lowest with the minimum soil disturbance (ZT and ST) in both years. The BP and DP treatments had almost 1 t ha^{-1} higher yield than ZT treatment in the first and second years. However, there was no difference in yield between BP, DP and SPST or between ZT and ST. The number of kernels per head and thousand seed weight was also higher with the increasing soil disturbance relative to the minimum soil disturbance in both years. No difference was found in cob length and cob diameter among the tillage treatments.

8.3.3 Variation in Soil Water Content (SWC)

In both seasons, tillage treatments significantly affected the SWC at different growth stages and soil depth. There was a significant interaction between tillage treatments and DAS (time), and tillage treatments and soil depth on SWC (Fig. 8.3). After

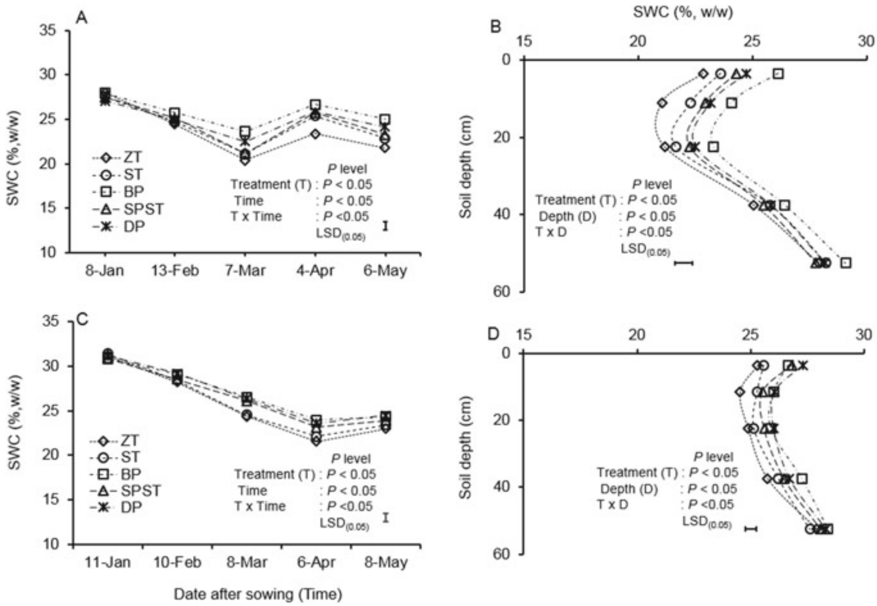

Fig. 8.3 Tillage treatments impact on soil water content in 2017 (**a** and **b**) and in 2018 (**c** and **d**) at 0–60 cm soil depth. ZT = Zero tillage, ST = Strip tillage, BP = Shallow bed planting, SPST = Single-pass shallow tillage and DP = Double pass shallow tillage. LSD bars indicate the least significant difference between treatments and Time interaction (**a** and **c**), and treatments and soil depth interaction (**b** and **d**)

sowing of maize under five tillage treatments, soil water decreased sharply with the progress of the season until 7 March in the first season (2017) and 6 April in the second season (2018), and after that SWC increased because of frequent rainfall (Fig. 8.3a, c). In both years, between sowing and harvest, BP, SPST and DP had higher SWC than ZT and ST. The surface soil at 0–30 cm dried faster than deeper soil at 30–60 cm throughout the season (Fig. 8.3b, d). Tillage treatments greatly altered the SWC at 0–15 cm depth and below this depth, there was a little change (Fig. 8.3b, c). At 0–7 cm depth, the BP increased the average SWC by 8–13% (w/w) compared to ZT and ST treatments in both years.

8.3.4 Variation in Soil Salinity ($EC_{1:5}$)

The $EC_{1:5}$ varied with progress of the dry season in all tillage treatments in both years (Fig. 8.4). The value of $EC_{1:5}$ was significantly influenced by tillage treatments, days after sowing (time) and soil depth. There was a significant interaction between treatments and time (Fig. 8.4a, c), and treatments and soil depth (Fig. 8.4d), but no interaction between treatments and depth in the first year (Fig. 8.4b). In 2017, during

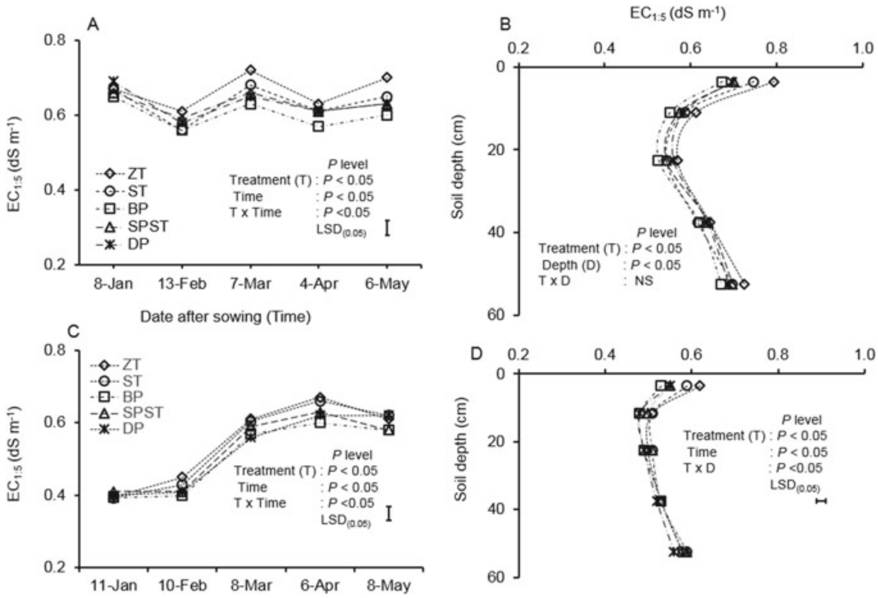

Fig. 8.4 Tillage treatments impact on soil salinity ($EC_{1:5}$) in 2017 (**a** and **b**) and in 2018 (**c** and **d**) at 0–60 cm soil depth. ZT = Zero tillage, ST = Strip tillage, BP = Shallow bed planting, SPST = Single-pass shallow tillage and DP = Double pass shallow tillage. LSD bars indicate the least significant difference between treatments and time interaction (**a** and **c**), and treatments and soil depth interaction (**b** and **d**). NS- non-significant

sowing, $EC_{1:5}$ varied from 0.52 to 0.85 dS m^{-1} up to depth 60 cm and decreased at 30 DAS, with values that ranged from 0.51 to 0.72 dS m^{-1} probably due to light irrigation on 21 and 29 January. The highest $EC_{1:5}$ was on 7 March (60 DAS), and afterward, it decreased because of rainfall. Whereas in 2018, $EC_{1:5}$ increased in all tillage treatments throughout the season. The highest $EC_{1:5}$ was on 6 April where BP, SPST and DP treatments maintained significantly lower salinity (0.6–0.62 dS m^{-1}) than ZT and ST treatments (0.66–0.68 dS m^{-1}). At any time, the average $EC_{1:5}$ was higher at 0–7 cm and 45–60 cm than at 7–15 cm and 15–30 cm.

8.3.5 Changes in Solute Potential (SP) of Soil Solutions

In both seasons, tillage treatments significantly altered the SP with some variations because of rainfall and irrigation. The SP significantly differed among tillage treatments and time (Fig. 8.5a, b) and tillage treatments and soil depth (Fig. 8.5b, d). In 2017, the SP was lower (become more negative) on 7 March (60 DAS) when the BP and DP treatments had greater SP (−654 and −708 kPa) than ZT, ST and SPST (−799 and −864 kPa) treatments (Fig. 8.5a). While in 2018, the SP was lowest on

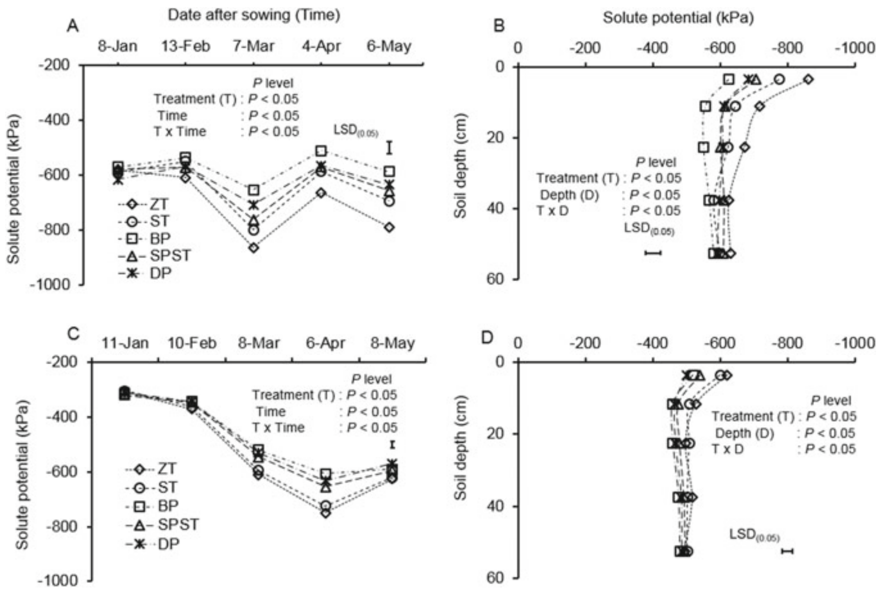

Fig. 8.5 Tillage treatments impact on solute potential (kPa) in 2017 (**a** and **b**) and in 2018 (**c** and **d**) at 0–60 cm soil depth. ZT = Zero tillage, ST = Strip tillage, BP = Shallow bed planting, SPST = Single-pass shallow tillage and DP = Double pass shallow tillage. LSD bars indicate the least significant difference between treatments and time interaction (**a** and **c**), and treatments and soil depth interaction (**b** and **d**)

6 April (90 DAS) in all tillage treatments, but the most soil disturbances at planting improved the SP relative to the less disturbed soil. Tillage treatments greatly affected the SP at 0–30 cm and below this depth, there was little effect (Fig. 8.5b, d). The SP was more negative at 0–7 cm than at the lowest depth to 60 cm.

8.3.6 *Plant Response to Solute Potential of Soil Solutions*

Maize yield was negatively correlated with the decreasing SP of soil solutions (Figs. 8.6 and 8.7). In 2017, the most significant correlation was from maximum vegetative to maturity at 0–7 and 7–15 cm depth with R^2 values between 0.56 and 0.92, and P-values < 0.01 and < 0.001 (Fig. 6a–h). Similarly, in 2018, the SP at 0–7 and 7–15 cm depth were negatively correlated with maize yield from maximum vegetative to milk stage with R^2 values between 0.44 and 0.88, and P-values < 0.01 and < 0.001 (Fig. 8.7a–f). In the first season, the highest effect was at maturity (6 May) ($R^2 = 0.99$ and $P < 0.001$), while in the second season, the highest effect was at the reproductive stage (at 60 DAS and 90 DAS) (8 March and 6 April).

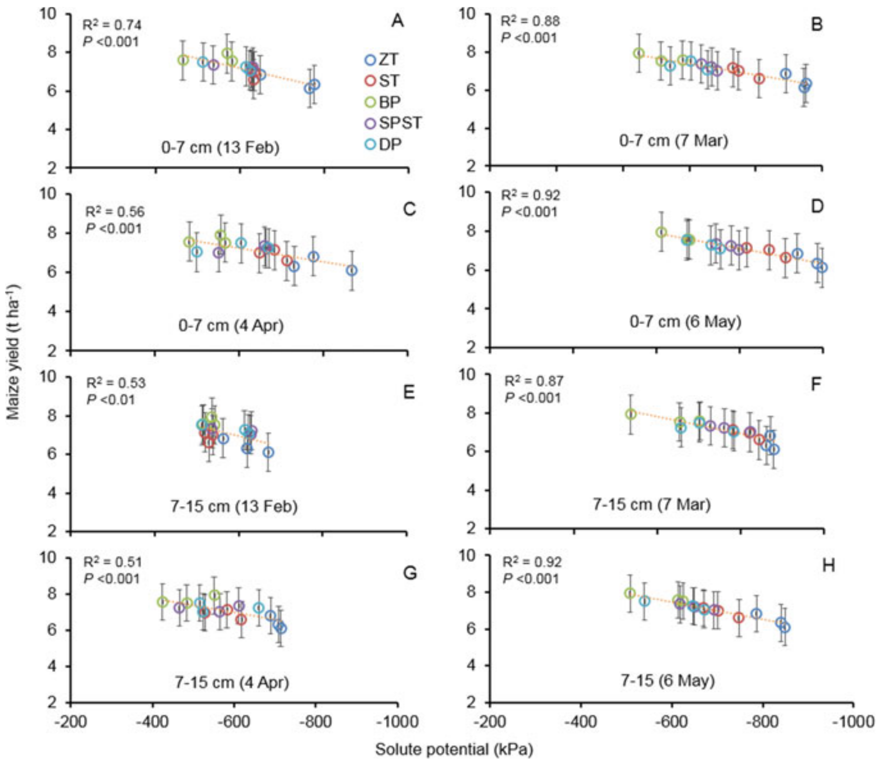

Fig. 8.6 Maize yield and soil solute potential relationship at various times for different soil depths in 2017. ZT—zero tillage, ST—strip tillage, BP—shallow bed planting, SPST—single pass shallow tillage, DP—Double pass shallow tillage

8.4 Discussion

The impact of levels of soil disturbance on soil physical and chemical properties, and on crop growth and yield, depends on several factors, including soil type, weather conditions, topography and crop species, and soil management. In many parts of the world, zero tillage (ZT) has a positive impact on soil properties and crop production. However, in this study, we have found contrary results. Zero and strip tillage (minimum soil disturbance) were the tillage systems that decreased soil water content, increased soil salinity and reduced solute potentials, thereby decreasing maize yield. In the same area, Paul et al. (2020a) found that sunflower which is relatively salt and drought tolerant also higher yielded if planted with intensive soil disturbance than with minimum soil disturbance. Mondal et al. (2015a) also showed that conventional tillage (3–4 passes) by two-wheel tractor produced higher maize yield (about 9.0 t ha^{-1}) than minimum tillage in the coastal area of Bangladesh.

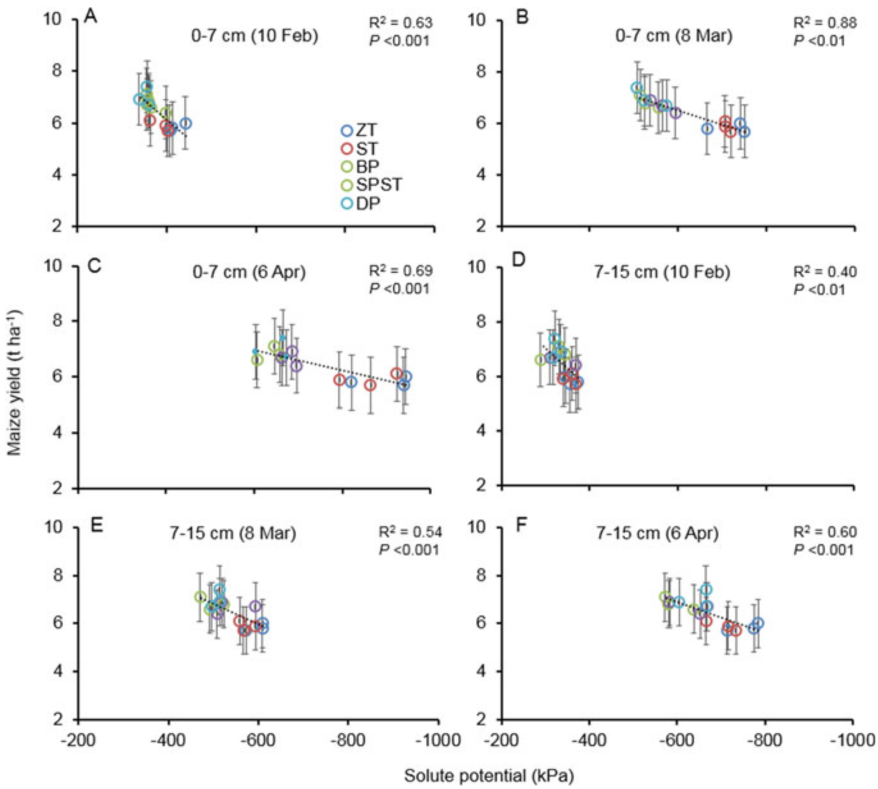

Fig. 8.7 Maize yield and soil solute potential relationship at various time for different soil depths in 2018. ZT—zero tillage, ST—strip tillage, BP—shallow bed planting, SPST—single pass shallow tillage, DP—Double pass shallow tillage

8.4.1 Maize Growth and Yield

Although the fastest emergence and highest plant density was obtained from ZT and ST treatments, the subsequent growth and yield of maize were restricted relative to BP, SPST and DP. In both seasons, the increased number of kernels per head and seed weight under the increased soil disturbance (BP, SPST and DP) contributed significantly to higher grain yield (11–15% in the first year and 8–14% in the second year) than the minimum soil disturbance (ZT and ST). The greatest yield with the increased soil disturbance was associated with the higher soil water content and lower soil salinity, which together resulted in the improved solute potential of soil solutions. In this study, there were significant linear relationships between maize yield and SP at different times and soil depths. These correlations were mostly related from maximum vegetative growth to harvesting in the first season and reproductive stage in the second season at 0–15 cm soil depths (Figs. 8.6 and 8.7), which indicates that plant available water was limited in the upper surface than deeper depths. The fact that seed weight was correlated with increased yield supports the conclusion that avoidance of crop stress due to less negative solute potentials later in the crop growth was a major determinant of crop response.

8.4.2 Change in Soil Water Content

The dynamics of SWC in the soil profile were influenced by irrigation and rainfall. Between sowing and harvest, the SWC was lower with ZT and ST than with the BP, SPST and DP treatments. The SWC mostly depleted at 60 DAS (7 March) before the tasseling period in the first year and at 90 DAS (6 April) before the milky stage; this was 20.4–21.5% (w/w) in ZT treatments and 22.5–23.7% in DP and BP treatments, respectively. Even though the SWC in the upper soil (0–30 cm) was close to the wilting point, the SWC was higher below at 30–60 cm depth, suggesting that plants could have extracted water from this deeper soil when surface soil water was restricted. A similar result was found by Paul et al. (2020a) for the heavy clay-textured soil in the coastal zone of Bangladesh. They mentioned that the lower SWC under ZT and ST treatments might be related to the rapid soil surface dryness, compaction and cracking, which promoted large vertical voids and accelerated water loss from the soil by evaporation. Xue et al. (2018) have found that more disturbance tillage (deep ploughing) increased soil water at 0–50 cm soil depth than with no-tillage practice for dryland winter wheat.

8.4.3 Change in Soil Salinity and Solute Potential

In the present work, the $EC_{1:5}$ was influenced by irrigation, rainfall and soil depth. At the early and later part of the growing season, $EC_{1:5}$ was mainly diminished by irrigation and rainfall. The highest $EC_{1:5}$ was at 60 DAS during the tasseling in the first season and at 90 DAS during the milky stage in the second season. Overall, the greatest change of $EC_{1:5}$ due to soil disturbance was at 0–7 cm where BP and DP treatments remained at lower salinity (0.67–0.70 dS m^{-1} in 2017 and 0.53–0.55 dS m^{-1} in 2018) than with the ZT and ST treatments (0.79–0.75 dS m^{-1} in 2017 and 0.59–0.62 dS m^{-1} in 2018). Paul et al. (2020a) also reported that the greatest soil disturbance (BP and DP) had lowered $EC_{1:5}$ than with the minimum soil disturbance (ZT and ST) in the saline clay soil of the coastal zone of Bangladesh. Other reports have shown that bed planting or raised bed effectively reduced the soil salinity in landscapes with shallow saline groundwater (Devkota et al. 2015; Slavich 2006; Bakker et al. 2010). The reason for higher soil salinity in ZT and ST treatments was associated with lesser soil disturbance, which accelerated soil evaporation water loss through capillary tubes and accumulated salt at the soil surface (Paul et al. 2020a). By contrast, the decreased soil salinity in BP and DP treatments was related to substantial soil disturbance with capillary breaks, which slowed down evaporation water loss and reduced the upward movement of salt to the surface (So and Ringrose-Voase 2000; Paul et al. 2020a). Another report showed that minimum tillage (ZT) without surface cover created soil cracking and compaction which is related to increased soil water loss (Paul et al. 2021a).

The effects of soil salinity on plant growth can be attributed to lower solute potential which limits water uptake by plants (Steppuhn et al. 2005; Rengasamy 2006). However, the SP is directly proportional to the concentration of salt in the soil and inversely related to the soil water content (Liu and Chi 2014). In this study, the SP changed with soil depth, rainfall and irrigation. Tillage treatments greatly affected the SP at 0–7 cm and 7–15 cm soil depth. Among the tillage treatments, the SP had become more negative at 0–7 cm, which varied from −500 to −861 kPa, and while these values are far greater than the wilting point (−1500 kPa). Throughout the season, minimum tillage (ZT and ST) decreased the SP than intensive tillage (BP, SPST and DP). The lower SP with the ZT and ST can be explained with the higher soil salinity and lower soil water caused by higher evaporation rate (Paul et al. 2020b). On the contrary, the increased SP with the BP and DP treatments plausibly accounted for the higher amount of soil water and the lower salt concentration because of reduced evaporation by the breakdown of capillary connectedness. This improvement of SP might be attributed to the increased yield and yield components of maize. Since mulch can also decrease evaporative loss of soil water in these soils in the rabi season (Paul et al. 2020b), it would be interesting to repeat the present study with 5–10 t of rice straw mulch per hectare. In addition, by applying effective drainage and sowing much earlier than the present study, the late-season crop stresses due to low SP can be alleviated (Paul et al. 2021b).

8.5 Conclusions

In clay-textured soil in the salt-affected coastal zone of the Ganges Delta, minimum soil disturbance (ZT and ST) accelerated the seedling emergence and plant density of maize, but subsequent growth and development were suppressed. The ZT and ST treatments reduced soil water availability, increased soil salinity and lowered the solute potential in the surface soil and these depressed maize yields. By contrast, tillage techniques that increased soil disturbance (BP, SPST and DP) also increased soil water content, minimized soil salinity and improved soil solute potential, thereby producing higher yield. Therefore, enhancing soil disturbance at planting was most effective in restricting soil drying and decreasing solute potential in clay-textured saline soil in the coastal zone of the Ganges Delta and this was most favourable for rabi season maize yield.

References

Bakker DM, Hamilton GJ, Hetherington R et al (2010) Salinity dynamics and the potential for improvement of waterlogged and saline land in a Mediterranean climate using permanent raised beds. Soil Tillage Res 110:8–24

Bell RW, Mainuddin M, Barrett-Lennard EG et al (2019) Cropping systems intensification in the coastal zone of the Ganges delta: opportunities and risks. J Indian Soc Coastal Agric Res 37(2):153–161

Bonari E, Mazzoncini M, Peruzzi A (1995) Effects of conventional and minimum tillage on winter oilseed rape (*Brassica napus* L.) in a sandy soil. Soil Tillage Res 33:91–108

Devkota M, Devkota KP, Martius C et al (2015) Managing soil salinity with permanent bed planting in irrigated production systems in Central Asia. Agric Ecosyst Environ 202:90–97

Ferreras L, Costa J, Garcia F et al (2000) Effect of no-tillage on some soil physical properties of a structural degraded Petrocalcic Paleudoll of the southern "Pampa" of Argentina. Soil Tillage Res 54:31–39

Haque ME, Islam AKMS, Hossain MM et al (2017) An innovative versatile multi-crop planter for crop establishment using two-wheel tractors. AMA Agric Mechanization Asia Africa Latin Am 48:33–44

Hobbs PR, Sayre K, Gupta R (2007) The role of conservation agriculture in sustainable agriculture. Phil Trans R Soc Biol Sci 363:543–555

Kirchhof G, Priyono S, Utomo WH et al (2000) The effect of soil puddling on the soil physical properties and the growth of rice and post-rice crops. Soil Tillage Res 56:37–50

Lal R, Reicosky DC, Hanson JD (2007) Evolution of the plow over 10,000 years and the rationale for no-till farming. Soil Tillage Res 93:1–12

Liu X, Chi C (2014) Estimating osmotic potential from electrical conductivity for solutions/extracts in salt-affected soils using an universal equation. J Food Agric Environ 12:1033–1035

Mainuddin M, Bell RW, Gaydon DS et al (2019) An overview of the Ganges coastal zone: climate, hydrology, land use, and vulnerability. J Indian Soc Coastal Agric Res 37(2):1–11

Mainuddin M, Karim MF, Gaydon DS et al (2021) Impact of climate change and management strategies on water and salt balance of the polders and islands in the Ganges delta. Sci Rep 11:7041. https://doi.org/10.1038/s41598-021-86206-1

Mainuddin M, Maniruzzaman M, Gaydon DS et al (2020) A water and salt balance model for the polders and islands in the Ganges delta. J Hydrol 587:125008

Maniruzzaman M, Kabir MJ, Hossain MB et al (2019) Adjustment in wet season rice planting for cropping intensification in coastal Bangladesh. J Indian Soc Coastal Agric Res 37(2):123–133

Mondal MK, Paul P, Humphreys E (2015a) Opportunities for cropping system intensification in the coastal zone of Bangladesh. In: Humphreys E, Tuong TP, Buisson Marie-Charlotte, Pukinskis I, Phillips M (eds) Proceedings of the CPWF, GBDC, WLE conference on revitalizing the ganges coastal zone: turning science into policy and practices, Dhaka, Bangladesh, 21–23 Oct 2015. Colombo, Sri Lanka: CGIAR Challenge Program on Water and Food (CPWF), 449–476

Mondal MK, Saha N, Ritu S et al (2015b) Optimum sowing window for boro cultivation in the coastal zone of Bangladesh. In: Humphreys E, Tuong TP, Buisson, Marie-Charlotte, Pukinskis I, Phillips M (eds) Proceedings of the CPWF, GBDC, WLE conference on revitalizing the Ganges Coastal Zone: turning science into policy and practices, Dhaka, Bangladesh, 21–23 Oct 2015. Colombo, Sri Lanka: CGIAR Challenge Program on Water and Food (CPWF), pp 342–36

Opoku G, Vyn TJ, Swanton CJ (1997) Modified no-till systems for corn following wheat on clay soils. Agron J 89:549–556

Pagliai M, Vignozzi N, Pellegrini S (2004) Soil structure and the effect of management practices. Soil Tillage Res 79:131–143

Paul P, Rashid M, Alam M et al (2016) Selection of profitable rice based cropping system under prevailing water environment in Satkhira district of Bangladesh. Acad J Agric Res 4:581–588

Paul PLC (2020) Agronomic practices increase sunflower yield in the rabi (dry) season in clay-textured, salt-affected soils of the coastal region of Bangladesh. PhD thesis, Murdoch University, Perth Australia

Paul PLC, Bell RW, Barrett-Lennard EG et al (2020a) Variation in the yield of sunflower (*Helianthus annuus* L.) due to differing tillage systems is associated with variation in solute potential of the soil solution in a salt-affected coastal region of the Ganges Delta. Soil Tillage Res 197:104489

Paul PLC, Bell RW, Barrett-Lennard EG et al (2020b). Straw mulch and irrigation affect solute potential and sunflower yield in a heavy textured soil in the Ganges Delta. Agric Water Manage 239:106211

Paul PLC, Bell RW, Barrett-Lennard EG, Kabir E (2021a) Impact of rice straw mulch on soil physical properties, sunflower root distribution and yield in a salt-affected clay-textured soil. Agriculture 11(3):264

Paul PLC, Bell RW, Barrett-Lennard EG, Kabi E, Gaydon DS (2021b) Opportunities and risks with early sowing of sunflower in a salt-affected coastal region of the Ganges Delta. Agron Sustain Dev 41(3):39

Rengasamy P (2006) World salinization with emphasis on Australia. J Exp Bot 57:1017–1023

Slavich P (2006) Reducing impacts of salinity on crops growing in tsunami-affected areas in Nanggore Aceh Darussalam Province, Indonesia. http://www.agric.nsw.gov.au/reader/salinity/reduce-salinity-tsunami-areas.pdf

Slavich P, Petterson G (1993) Estimating the electrical conductivity of saturated paste extracts from 1:5 soil, water suspensions and texture. Soil Res 31(1):73–81

So HB, Ringrose-Voase AJ (2000) Management of clay soils for rainfed lowland rice-based cropping systems: an overview. Soil Tillage Res 56:3–14

Steppuhn H, Van Genuchten MT, Grieve C (2005) Root-zone salinity. Crop Sci 45:209–220

Wopereis MCS, Stein A, Bouma J et al (1992) Sampling number and design for measurements of infiltration rates into puddled rice fields. Agric Water Manage 21:281–295

Xue JF, Ren AX, Li H et al (2018) Soil physical properties response to tillage practices during summer fallow of dryland winter wheat field on the Loess Plateau. Environ Sci Pollut Res 25:1070–1078

Chapter 9
Zero Tillage Potato Cultivation Following Rice in the Coastal Ganges Delta

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Abstract Zero tillage potato is attracting increasing attention for cropping system intensification in the saline coastal zone of the Ganges Delta. With the use of rice straw mulch, zero tillage potato appears to escape the worst effects of soil salinity, but the optimum sowing time in this environment has not been determined. An experiment was conducted at Tildanga during 2018–2019 and at Choto Chalna during 2019–2020, Dacope Upazilla, Khulna, Bangladesh during rabi seasons after harvest of T. aman rice. The experiment comprised three potato varieties, viz., BARI Alu-8, BARI Alu-41 and BARI Alu-72, and four sowing dates, viz., 15 December, 22 December, 29 December and 05 January, in a split-plot design with three replications. The maximum potato yield (17.1–17.3 t ha^{-1}) was obtained with 15 December sowing of BARI Alu-41 in both years during 2018–2019 and 2019–2020 followed by the same date of BARI Alu-72. The lowest yield was recorded in both years when BARI

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Alu-8 was sown on 5th January. From the two years results, it can be concluded that yield of BARI Alu-41 and BARI Alu-72 was optimized at 15 December but could be extended to December 22. So, early sowing is preferable for zero tillage potato in the salinity-affected southern coastal region of Bangladesh for higher yield.

Keywords Sowing date · Potato varieties · Coastal soil · Zero tillage · Yield

9.1 Introduction

Potato (*Solanum tuberosum* L.) is the fourth major food crop globally after rice, wheat and maize. Bangladesh produces and consumes large quantities of potatoes (Hossain and Abdulla 2016). Demand for potato as processed and fresh food is increasing in Asian countries as well as in Bangladesh (Brown 2005) for its nutritional impact. Whole year round demand of potato by consumers and the high perishable rate of other vegetables due to the lack of preservation facilities are also responsible for the higher production within the last few years through the cultivation of potato. The geographical suitability of Bangladesh is also responsible for the increased production of potato every year (Nunn and Qian 2011). Generally, lower-income people consume more potatoes rather than other vegetables (Pitt 1983; McCracken and Marotz 1989). On the other hand, the government of Bangladesh wants to promote potato consumption instead of rice, to reduce continuous pressure for increased rice production (Chowdhury and Chowdhury 2015).

Although potato is one of the important food crops in Bangladesh, its yield in this country is relatively lower than those of many leading potato-growing countries. The main reasons for such low yield include varieties with low yield potential, use of seed potatoes of inferior quality and inefficient crop management practices by the potato growers. Potato is a short-duration and labour-intensive crop. In fact, the short cycle of potato frees the land for cultivating other crops. Most farmers in Bangladesh produce potato at a subsistence level. They are vulnerable to climate change since the production of potato is highly sensitive to various abiotic stresses including temperature rise, soil salinity and disease severity due to unfavourable impact of climate change. Therefore, there is a need to develop technologies that will reduce the cost of cultivation, conserve soil moisture and increase yield and profitability.

Potato has the potential to be cultivated as a rabi season (November to March) crop in the fallow lands of coastal saline areas provided the existing constraints of delayed crop establishment and soil salinity are managed properly (Sarangi et al. 2018). In the later stages of the growing season, temperature raises quickly causing terminal heat stress for potato plants. Many parts of Bangladesh, especially in Barind areas (drought-prone) are also facing the problem of terminal heat stress (Karim et al. 1990). Rising soil salinity during the rabi season is another threat for crop production in the saline coastal zone of Bangladesh especially for potato (Miah et al. 2013). Developing heat, drought and saline-tolerant potato varieties will not only enhance production but may also impart resilience to climate change.

In the coastal and offshore areas of Bangladesh about 0.83 million hectares or 30% of land are arable lands. Agricultural land use in the coastal districts is very poor. The flood and tidal water recede from October to late December in the coastal area. Depending on the topographical position and drainage facilities, water recede from about 24% of land within October, from another 53% in November and mid-December and from the remaining 23% of land in late December. Most of the coastal areas are dominated by medium highlands, where flooding depth ranges from 0.3 to 0.9 m. This category of land is suitable for two crops per year and sometimes three crops. But only medium- to long-duration transplanted Aman (T. Aman) rice (monsoon rice) is the predominant cropping sequence in the region. The slow drying process after harvest of T. Aman rice delayed the time taken to attain the soil condition suitable for ploughing the land for dry season winter (rabi) and pre-monsoon crops. Generally, the situation leads to seeding of rabi crops during the first fortnight of February which is often affected by soil salinity. The cultivation of dry season crops in this worse situation requires suitable crops and agronomic options suitable for early planting in the excess moist soil, more than field capacity which is unable to plough to increase the productivity and cropping intensity.

Zero tillage potato cultivation is a promising technology for cropping system intensification in the rainfed low lands in coastal saline region, with limited use of irrigation water, less labour input and higher yield (Sarangi et al. 2018). Sustainable intensification of coastal saline land needs an improved package of practices which conserves soil moisture, facilitates early crop establishment, ensures profitability and has a positive effect on soil health (Sarangi et al. 2019). Mono-cropped soils of coastal region of Bangladesh can be converted into double and triple cropping through the adoption of zero tillage potato technology. In this practice, potato is sown in the wet field on the same day, the preceding monsoon or kharif rice is harvested (Sarangi et al. 2020). In Sundarbans region (the Ganges Delta) of West Bengal, cultivated lands are low lying (76%) and flat, and soils are heavy textured with drainage congestion in wet season (kharif), while soil salinity and lack of good quality irrigation water in dry season (rabi) result in mono-cropping (Mainuddin et al. 2019a). During the rabi season, the land remains fallow and less emphasis has been placed on investigating the ways in which these lands can be intensified (Krupnik et al. 2017; Bell et al. 2019; Mainuddin et al. 2019a). Yield difference in delayed planting dates is caused by reduction in the number of tubers per plant and shrinkage of leaves. Potato planting date can be determined based on its growth season duration in any region. Delayed planting dates cause yield reduction. The level of soil salinity in southern coastal region generally remains the minimum in the monsoon season but it attains the peak in March/April (Haque 2006). If the sowing time is delayed as compared to its optimum sowing time, the crop might encounter a higher level of soil salinity (>6 dS m^{-1}) during the active vegetative stage and onward that affects the plant growth as well as yield of potato (Maas 1990). Adjustment of sowing date or early sowing of potato just after harvest of previous T. aman rice might be able to escape the detrimental effect of soil salinity on this crop. Zero tillage potato cultivation with paddy straw mulching technology developed by Sarangi et al. (2018) under the Australian Centre for International Agricultural Research funded project on ‘Cropping System Intensification in the Salt-affected Coastal zones of Bangladesh and West Bengal, India (LWR/2014/073)’ is a promising eco-friendly technology. This technology has been introduced in Bangladesh, and it is proved to be highly successful for the salt-affected coastal regions (Sarangi et al. 2020). Planting of potato under zero tillage condition and just after harvest of T. aman rice could ensure the timely planting and increased yield of the crop. Therefore, this experiment was undertaken to find out the optimum sowing date for different potato varieties under zero tillage condition in salinity-affected coastal area of Bangladesh.

9.2 Materials and Methods

The field experiment was conducted at Tildanga during 2018–2019 and at Choto Chalna during 2019–2020, in Dacope Upazilla, Khulna, Bangladesh (Fig. 9.1) during the rabi season just after harvest of T. aman rice (rice variety was BR10). It is situated at 22°34′20″ north and 89°30′40″ east. As the whole Upazila is surrounded by an embankment, tidal water usually enters the land through sluice gates controlled by a committee authorized by the Bangladesh Water Development Board.

The two experimental areas are slightly to moderately drought and saline prone, and face rising soil salinity from February onwards. The soil of this area is calcareous, dark grey, silty clay loam. The initial soil chemical properties for experimental sites at Tildanga and Choto Chalna, Dacope, Khulna are given in (Table 9.1). The salinity

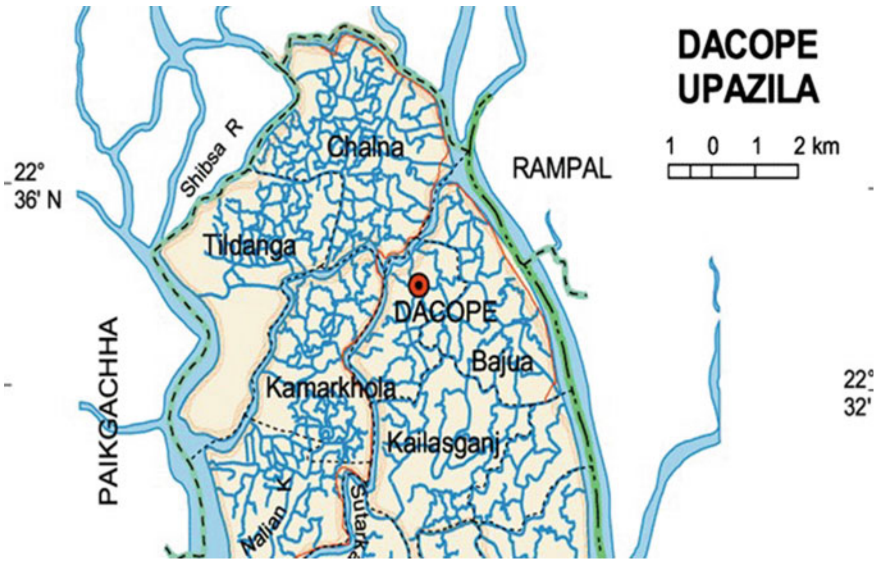

Fig. 9.1 Map showing the experimental site of Tiltanga and Choto Chalna, Dacope, Khulna, Bangladesh

Table 9.1 Initial soil chemical properties for experimental site at Tildanga and Choto Chalna, Dacope, Khulna

Soil depth (cm)	pH	OC (%)	Total N (%)	K (Cmol kg^{-1})	Na (Cmol kg^{-1})	P (mg kg^{-1})	S (mg kg^{-1})	B (mg kg^{-1})	Zn (mg kg^{-1})
Tildanga									
0–15	7.74	1.06	0.09	0.49	0.65	9.77	57.4	0.50	1.12
15–30	7.72	0.90	0.08	0.47	0.61	7.46	55.8	0.73	0.89
30–45	7.70	1.04	0.07	0.45	0.67	6.10	76.7	0.90	1.15
45–60	8.59	0.91	0.07	0.44	0.68	8.33	66.5	1.25	0.90
Choto Chalna									
0–15	7.51	1.12	1.70	0.50	0.66	6.57	57.5	0.41	1.27
15–30	7.88	0.95	0.92	0.50	0.60	5.50	55.8	0.69	0.91
30–45	7.86	1.05	0.87	0.48	0.68	5.22	75.7	0.90	1.22
45–60	8.36	0.98	0.80	0.45	0.70	6.18	68.2	1.25	0.89

of canal water and soil were recorded as given in Figs. 9.2 and 9.3. Weather data was also recorded during the crop growing period. Soil moisture level of the experimental fields was also collected (Fig. 9.4). The field experiment was arranged in a split-plot design with three replications where varieties were in main plot and sowing dates were in subplot. Factor-A consisted of three potato varieties, viz., BARI Alu-8, BARI Alu-41 and BARI Alu-72 and factor-B consisted of four sowing dates, viz., 15

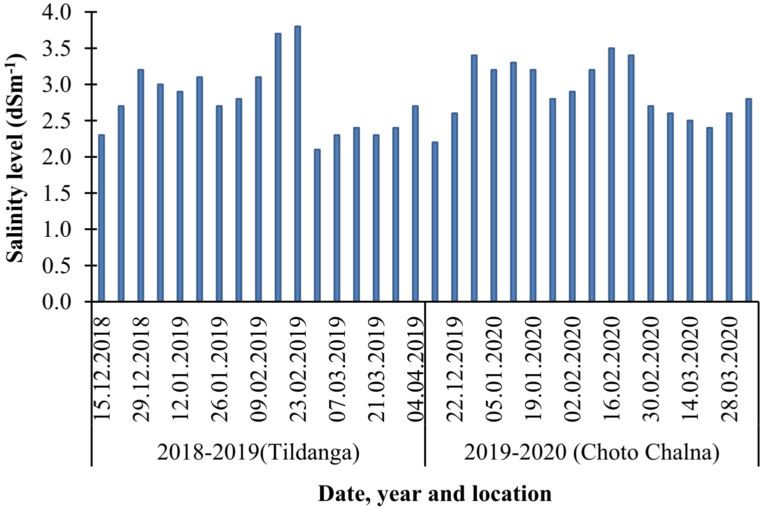

Fig. 9.2 Salinity of canal water by month as used for irrigation in crops during 2018–2019 and 2019–2020

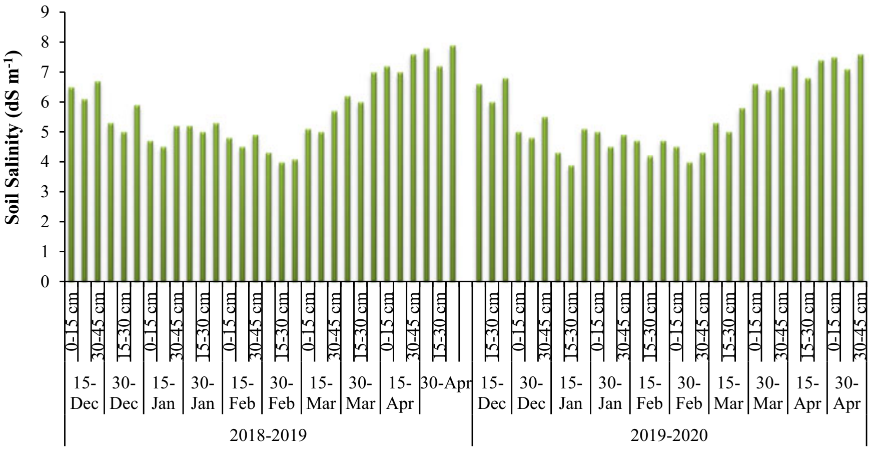

Fig. 9.3 Soil salinity level at different soil depths at 15 days interval during 2018–2019 and 2019–2020

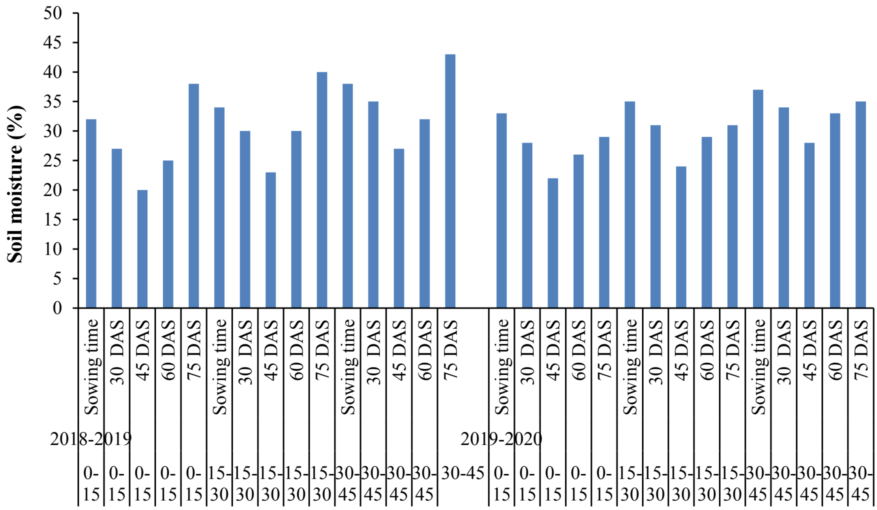

Fig. 9.4 Soil moisture content at 0–15, 15–30 and 30–45 cm depths at 15 days interval during 2018–2019 and 2019–2020

December, 22 December, 29 December and 05 January. The unit plot size was 5 m × 4 m. Immediately after T. Aman harvest, whole tubers (40–50 g) were sown in the wet field maintaining a distance of 50 cm between rows and 20 cm between plants. Before planting, seed potatoes were treated with Provex @ 2.5 g L^{-1} of water for 30 min. Fertilizers were applied according to FRG (2012). Full amount of TSP (150 kg ha^{-1}), MoP (250 kg ha^{-1}), Gypsum (130 kg ha^{-1}), Zinc sulphate (16 kg ha^{-1}), Boric acid (10 kg ha^{-1}) and half of the urea (250 kg ha^{-1}) as well as cowdung were applied during sowing time by broadcasting between rows. The remaining 50% of urea was applied at 30 days after planting followed by irrigation. Irrigation was applied from canal water for three times (25 DAS, 45 DAS and 65 DAS). Fungicide (Dithane M-45) was applied for preventing late blight disease of potato. Weeding, mulching and other intercultural operations were done as and when necessary following the production technology for potato as recommended by BARI (2017). The crops were harvested when the main products reached physiological maturity or harvestable stages. Data were recorded accordingly on different activities as well as parameters of the growing crops. All data were analysed statistically using R 3.5.0.

9.3 Results and Discussion

9.3.1 Effects of Sowing Dates on Mortality (%) of Different Potato Varieties Plantlets

The graph (Fig. 9.5) shows the effect of different sowing dates on the mortality rate of the plantlets of different potato varieties. The rate of mortality of plantlets of different potato varieties ranged from 2.67 to 15.56% during 2018–2019 and 3.12–16.78% during 2019–2020 (Fig. 9.5). Early sowing of potato varieties gave the lowest mortality of plantlet than the late sowing of potato. The lowest mortality rate was found in the combination of 15 December sowing with BARI Alu-41 (2.67%) during 2018–2019 and (3.12%) during 2019–2020 which is statistically similar to 15 December sowing with BARI Alu-72 for both years. The highest mortality rate was found in the interaction effect of 5th January sowing with BARI Alu-8 (15.56%) during 2018–2019 and (16.78%) during 2019–2020. Hossain (2013) observed 24–30% mortality rate of potato plantlets in Bangladesh. BARI Alu-41 and BARI Alu-72 varieties have salt-tolerant capacity, and these two varieties gave the lowest mortality rate from two years of experiments. Hence, these two varieties are suitable for the saline-affected area in Bangladesh. From the above results, it is revealed that the mortality rate was dependent on different environmental factors (salinity, drought, waterlogging condition, excess rainfall and pest management (rat problem)) in the saline area of Bangladesh.

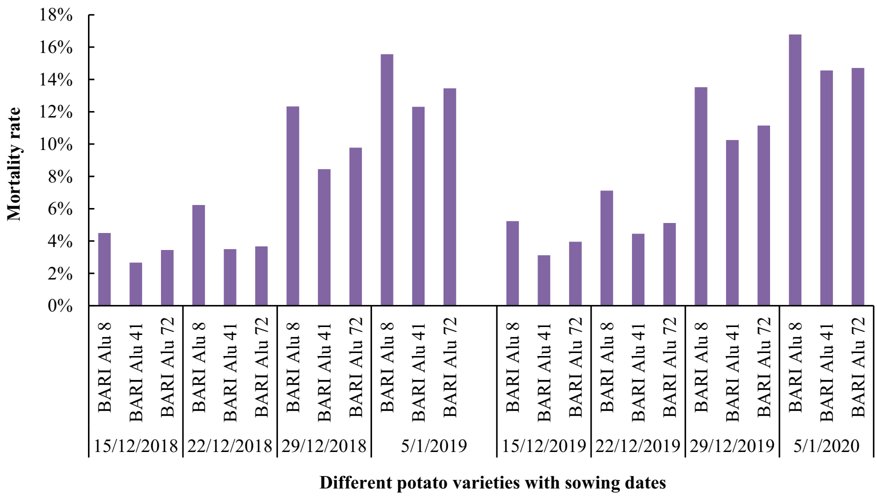

Fig. 9.5 Average mortality rate (%) of the plantlets of different potato varieties for the two years

9.3.2 Plant Phenological Response to Different Sowing Dates and Varieties

The plant emergence recorded after 30 days of planting was significantly affected by the treatments. Seedling emergence was greater at the early sowing dates and decreased in the subsequent sowing dates in both years. In 2018–2019, the highest emergence (95.5%) was occurred in the first sowing (15 December) with BARI Alu-41 and the lowest (82.3%) was recorded from the last sowing date on 05 January with BARI Alu-8. In 2019–20, the emergence was lower than the previous year, ranging from (94.0–80.1%). From Tables 9.2 and 9.3, it was observed that all the phenological stages of potato, viz., vegetative stage, maximum bulking stage and maturity stage depended on the variety and sowing date. It was observed that early sowing of potato took more time for physiological maturity which resulted in higher yield of potato but late sowing reduced the tuber yield, mainly because of the short growing period.

9.3.3 Plant Height and Leaf Area Index

Varieties and sowing dates of potato resulted in significant differences in plant height at 45 DAS and 75 DAS for both years (Tables 9.2 and 9.3). Early planting on 15 December with BARI Alu-41 gave the highest plant height (38.9 cm) at 45 DAS and (49.4 cm) at 75 DAS during 2018–2019. In the 2nd year, it was 37.6 cm at 45 DAS and 48.3 cm at 75 DAS. From the two years results, it was observed that delayed sowing caused decrease in plant height. The highest leaf area index (LAI) of 2.4 was observed with 15 December sowing of BARI Alu-41 at 45 DAS and for 75DAS, it was 2.9 while the lowest LAI (1.8) was obtained with January 05 sowing of BARI Alu-8 during 2018–2019. In the 2nd year, BARI Alu-41 with early sowing (15 December) gave the highest LAI (2.7) and the lowest (1.9) was observed from the interaction effect of 05 January sowing with BARI Alu-8. The delayed planting had an adverse effect on the leaf area index resulting in lower total dry matter accumulation and ultimately reduced yield (Shaheenuzzamn et al. 2015). Reduced leaf growth resulted in a smaller canopy and produced smaller tubers. Due to the difference in planting time, there is a synchronization of the internal and external parts, which affect the physiological process in plants and ultimately the yield of potato (Hossain et al. 2010).

9.3.4 Number of Tubers per Plant

It is revealed from the results that, the number of tubers per plant was significantly influenced due to the interaction effect of varieties and sowing dates (Table 9.4). The

Table 9.2 Interaction effect of variety and sowing date on growth parameters of potato during 2018–2019

Variety	Sowing date	Emergence % (30 DAS)	Days required			45 days after sowing		75 days after sowing	
			Vegetative stage	Maximum bulking stage	Maturity stage	Plant height (cm)	Leaf area index (LAI)	Plant height (cm)	Leaf area index (LAI)
BARI Alu-8	15 Dec	94.3	36	67	95	37.9	2.3	45.5	2.6
	22 Dec	92.3	32	64	92	34.8	2.2	44.2	2.4
	29Dec	86.2	28	54	88	30.6	2.1	42.3	2.3
	05 Jan	82.3	25	46	86	29.3	1.8	34.3	1.9
BARI Alu-41	15 Dec	95.5	35	65	90	38.1	2.4	48.3	2.7
	22 Dec	93.6	30	64	90	36.8	2.3	47.4	2.5
	29Dec	88.5	26	55	87	32.5	2.1	45.2	2.4
	05 Jan	84.3	24	45	84	30.6	2.0	37.5	2.1
BARI Alu-72	15 Dec	95.3	35	65	90	38.1	2.4	48.3	2.7
	22 Dec	93.1	30	63	90	35.2	2.3	46.4	2.4
	29Dec	87.8	26	54	87	31.2	2.1	46.1	2.3
	05 Jan	82.6	25	46	85	30.0	1.8	36.3	2.0
CV (%)		8.56	6.8	8.56	13.27	14.58	9.14	10.64	11.62
LSD (0.05)		1.18	NS	NS	1.23	2.46	3.12	2.41	3.56

Table 9.3 Interaction effect of variety and sowing date on growth parameters of potato during 2019–2020

Variety	Sowing date	Emergence % (30 DAS)	Days required			45 days after sowing		75 days after sowing	
			Vegetative stage	Maximum bulking stage	Maturity stage	Plant height (cm)	Leaf area index (LAI)	Plant height (cm)	Leaf area index (LAI)
BARI Alu-8	15 Dec	93.1	35	65	94	36.0	2.3	46.2	2.5
	22 Dec	90.4	33	63	92	32.1	2.2	43.3	2.3
	29Dec	84.2	28	54	89	28.8	2.1	42.4	2.2
	05 Jan	80.1	24	45	85	23.2	1.8	35.1	1.9
BARI Alu-41	15 Dec	94.0	34	64	92	37.6	2.4	48.3	2.7
	22 Dec	91.8	30	62	90	34.5	2.3	47.1	2.4
	29Dec	85.8	27	55	88	31.2	2.2	45.4	2.3
	05 Jan	82.3	23	46	83	25.1	1.9	38.5	2.1
BARI Alu-72	15 Dec	93.6	34	64	92	36.7	2.3	46.4	2.6
	22 Dec	91.4	30	63	90	34.1	2.3	45.7	2.3
	29Dec	84.3	27	54	88	30.4	2.11	45.1	2.3
	05 Jan	80.7	24	46	84	24.4	1.8	37.3	2.0
CV (%)		12.47	8.5	10.56	14.27	13.18	8.34	11.64	9.12
LSD (0.05)		2.45	NS	NS	2.53	1.78	2.12	2.76	2.44

Table 9.4 Interaction effect of varieties and sowing dates on yield contributing characters of potato during 2018–2019 and 2019–2020

Variety	Sowing date	2018–2019	2019–2020	2018–2019	2019–2020
		No of tubers plant^{-1}	Tuber weight (g plant^{-1})	No of tubers plant^{-1}	Tuber weight (g plant^{-1})
BARI Alu-8	15 Dec	8	283.2	7	280.8
	22 Dec	7	270.8	6	266.5
	29 Dec	6	251.2	5	218.8
	05 Jan	4	223.2	3	188.8
BARI Alu-41	15 Dec	10	304.6	9	289.9
	22 Dec	9	285.4	8	279.1
	29 Dec	7	268.2	7	238.2
	05 Jan	5	238.1	5	205.5
BARI Alu-72	15 Dec	9	294.9	8	285.3
	22 Dec	9	277.4	8	269.5
	29 Dec	7	259.2	6	232.2
	05 Jan	5	231.0	4	195.0
CV (%)		7.17	10.17	6.36	14.12
LSD (0.05)		1.21	5.87	1.45	6.37

maximum number of tubers (10) per plant was recorded in the variety BARI Alu-41 sown in 15 December and lowest (4) in 05 January sowing with BARI Alu-8 during 2018–2019. In 2019–2020, early sowing gave the highest number of tubers (9) per plant than the late sowing. A decrease in the tuber number under late plantings is probably because of moisture and temperature stress starting in late December which corresponds to the tuber initiation and bulking stage. Firman and Daniels (2011) and Khan et al. (2011) observed the same phenomenon.

9.3.5 Tuber Weight Per Plant

From Table 9.4, it was observed that the highest tuber weight per plant (304.6 g) was recorded from the interaction effect of 15 December sowing with BARI Alu-41 which is statistically similar to BARI Alu-72 with the same sowing date. The lowest (223.3 g) was seen from the late sowing date (05 January) with BARI Alu-8 during 2018–2019. In the second year (2019–2020), the interaction effect of 15 December sowing date with BARI Alu-41 gave maximum weight (289.9 g) and the lowest was observed in 05 January with BARI Alu-8 (188.8 g).

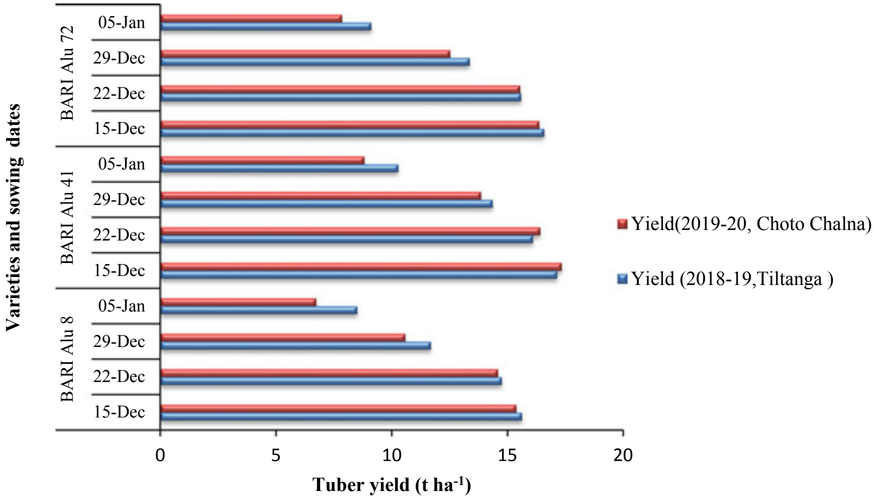

Fig. 9.6 Tuber yield of different potato varieties with four sowing dates during the years 2018–19 and 2019–20 in the salinity-affected coastal area of Bangladesh

9.3.6 Tuber Yield

From Fig. 9.6, it can be seen that potato yield was greater at the early sowing dates and decreased in the subsequent sowing dates in both years. In 2018–19, the yield of potato was highest (17.1 t ha^{-1}) in first sowing (15 December with BARI Alu-41) followed by the same date of BARI Alu-72. With the delay of sowing, the potato yield decreased and the lowest yield (8.5 t ha^{-1}) was found in fourth sowing date (5th January, 2019 with BARI Alu-8). In 2019–20, Fig. 9.6 shows that the interaction effect of 15 December with BARI Alu-41 gave the highest yield (17.3 t ha^{-1}) while the last sowing date (05 January) with BARI Alu-8 gave the lowest yield (6.7 tha^{-1}). There was about 50% reduction in potato yield due to a delay in sowing. Delaying the date of sowing reduced the tuber yield, mainly because of the shortening growing period and different stress conditions of the environment (Kawakami et al. 2005).

9.3.7 Yield of Different Grade Tubers of Potato

From the two years results (Fig. 9.7), it is revealed that the interaction effect of varieties and sowing dates significantly influenced the yield of different grade tubers of potato. From Table 9.5, it can be seen that in 2018–2019, the highest marketable yield was recorded from BARI Alu-41 with the sowing date of 15 December with 4.8 t ha^{-1} in grade A (28–40 mm), 9.3 t ha^{-1} in grade B (40–55 mm) and 2.7 t ha^{-1} in over grade (<55 mm). This interaction effect gave the lowest non-marketable yield (0.3 t ha^{-1}) in under grade (>28 mm) tubers. The interaction effect of BARI Alu-8

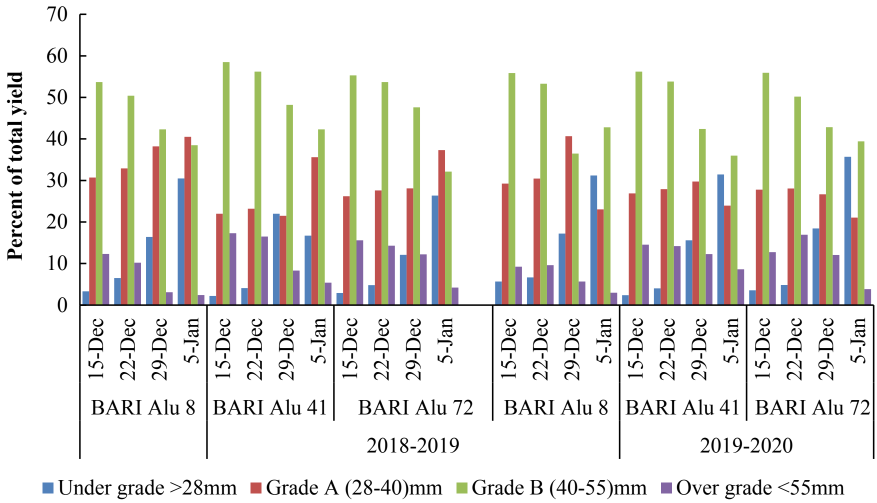

Fig. 9.7 Percent yield of different grades of potato varieties at respective sowing dates during 2018–2019 and 2019–2020

Table 9.5 Yield of different grades of potato tuber as influenced by variety and different sowing dates during 2018–2019

Variety	Sowing Date	Yield of different grade of potato (t ha^{-1})			
		Under grade >28 mm	Grade A (28–40) mm	Grade B (40–55) mm	Over grade <55 mm
BARI Alu-8	15 Dec	1.0	4.6	8.5	1.5
	22 Dec	1.0	4.5	7.8	1.5
	29 Dec	2.0	4.5	4.8	0.4
	05 Jan	3.3	2.8	2.2	0.2
BARI Alu-41	15 Dec	0.3	4.8	9.3	2.7
	22 Dec	0.7	3.7	9.1	2.6
	29 Dec	2.6	3.1	7.5	1.2
	05 Jan	2.4	3.0	4.4	0.6
BARI Alu-72	15 Dec	0.5	4.4	9.2	2.6
	22 Dec	0.8	4.3	8.3	2.2
	29 Dec	1.6	3.7	6.5	1.5
	05 Jan	2.4	3.7	2.7	0.4
CV (%)		7.25	9.57	12.43	8.45
LSD (0.05)		1.23	5.76	6.12	1.53

Table 9.6 Yield of different grades of potato tuber as influenced by variety and different sowing dates during 2019–2020

Variety	Sowing date	Tuber size			
		Under grade >28 mm	Grade A (28–40) mm	Grade B (40–55) mm	Over grade <55 mm
BARI Alu-8	15 Dec	0.9	4.5	8.6	1.4
	22 Dec	1.0	4.4	7.8	1.4
	29 Dec	1.8	4.3	3.9	0.6
	5 Jan	2.9	1.4	2.2	0.2
BARI Alu-41	15 Dec	0.4	4.7	9.7	2.6
	22 Dec	0.7	4.6	8.8	2.3
	29 Dec	2.2	4.1	5.9	1.7
	5 Jan	2.8	2.1	3.2	0.8
BARI Alu-72	15 Dec	0.6	4.6	9.2	2.1
	22 Dec	0.8	4.4	7.9	2.5
	29 Dec	2.3	3.3	5.4	1.5
	5 Jan	2.8	1.7	3.1	0.3
CV (%)		6.25	10.27	14.13	7.15
LSD (0.05)		1.21	4.86	5.37	1.03

with 05 January sowing gave the lowest yield of different grade tubers of potato (2.8 t ha^{-1} in grade A (28–40 mm), 2.2 t ha^{-1} in grade B (40–55 mm) and 0.2 t ha^{-1} in over grade (<55 mm). This interaction effect gave the highest non-marketable yield (3.3 t ha^{-1}) in under grade (>28 mm) tubers. In the second year (Table 9.6), the highest yield was observed from the interaction effect of BARI Alu-41 with 15 December sowing and BARI Alu-8 with 05 January gave the lowest marketable yield of different grade tubers of potato. After harvesting of potato, tubers were classified into four grades according to Karim et al. (2010), by measuring the diameter at the middle of the potato tubers. The grades were (i) Under grade (<28 mm), (ii) Grade A (28–40 mm), (iii) Grade B (41–55 mm) and (iv) Over grade (>55 mm). Among these grades, Grade A and Grade B together was considered as processable grade tuber and also called good quality tubers. Among the tuber grades, medium and large tubers are the most prized in the fresh tubers market due to peeling facilitation for both domestic and processing purposes. The present findings where medium to large tubers were observed significantly higher in early sowing and late sowing gave the lowest medium to large tubers.

9.4 Conclusions

From the two years results, the yield of potato, BARI Alu-41 and BARI Alu-72, was found to be optimum with 15 December sowing but reasonable yield could be possible up to December 22. Late sowing strongly reduced potato yield because it shortened the duration of tuber bulking by 5–8 days and decreased tuber number per plant by about 50%. Early sowing maintained plant mortality by <5% for BARI Alu-41 and BARI Alu-72 compared to over 10% with later sowing. So, it may be concluded that early sowing is suitable for zero tillage potato and BARI Alu-41, BARI Alu-72 are sufficiently salt-tolerant to produce satisfactory yields of 17 t ha^{-1} in the salinity-affected southern coastal region of Bangladesh.

References

Bell RW, Mainuddin M, Barrett-Lennard EG et al (2019) Cropping systems intensification in the coastal zone of the Ganges delta: opportunities and risks. J Indian Soc Coast Agri Res 37(2):153–161

Brown CR (2005) Antioxidant in potato. Am J Potato Res 82:163–172

Chowdhury MD, Chowdhury AH (2015) Problems and prospects of potato cultivation in Bangladesh. Asi Bus Rev 5(10):28–32

FRG (2012) Fertilizer recommendation guide-2012, 6th edn. In: Hassan AA, Jahiruddin M, Noor, Shamsun et al (eds) Bangladesh agricultural research council. Dhaka, Bangladesh

Firman DM, Daniels SJ (2011) Factors affecting tuber numbers per stem leading to improved seed rate recommendations. Potato council report no: 2011/2, pp 27–39

Haque SA (2006) Salinity problems and crop production in coastal regions of Bangladesh. Pak J Bot 38(5):1359–1365

Hossain MM, Abdulla F (2016) Forecasting potato production in Bangladesh by ARIMA model. J Adv Stat 1(4):191–198

Hossain MM, Rahman MM, Rahman, et al (2010) Photosynthetic potential and grain growth study in different boro rice cultivars. Int J Sustain Agric Technol 6(9):26–32

Karim MR, Hanafi MM, Hanafi, et al (2010) Virus free seed potato production through sprout cutting technique under net-house. African J Biotech 9:36

Karim Z, Ibrahim AM, Iqbal A et al (1990) Drought in Bangladesh agriculture and irrigation schedules for major crops, Bangladesh Agricultural Research Council (BARC). Soils Publ 34:11

Kawakami J, Iwama K, Jitsuyama Y (2005) Effects of planting date on the growth and yield of two potato cultivars grown from micro tubers and conventional seed tubers. Plant Prod Sci 8(1):74–78

Khan AA, Jilani MS, Khan MQ et al (2011) Effect of seasonal variation on tuber bulking rate of potato. J Anim Plant Sci 21(1):31–37

Krupnik TJ, Schulthess U, Ahmed ZU et al (2017) Sustainable crop intensification through surface water irrigation in Bangladesh. A geospatial assessment of landscape-scale production potential. Land Use Policy 60:206–222

Mainuddin M, Bell RW, Gaydon DS et al (2019) An overview of the Ganges coastal zone: climate, hydrology, land use, and vulnerability. J Indian Soc Coastal Agri Res 37(2):1–11

Maas EV (1990) Crop salt tolerance. In Tanji KK (ed) Agricultural salinity assessment and management, ASCE manuals and reports on engineering practice, American Society of Civil Engineers, Reston, VA, USA

McCracken VA, Marotz CC (1989) Consumer potato demand. J Food Dist Res 20(2):1–12

Miah MM, Hossain TMB, Hossain S et al (2013) Farmers perception about variety development and abiotic stresses on potato cultivation in Bangladesh. Bangladesh J Agri Res 38(3):401–416
Nunn N, Qian N (2011) The potato's contribution to population and urbanization: evidence from a historical experiment. Quar J Econ 126(2):593–650
Pitt M (1983) Food preferences and nutrition in rural Bangladesh. Rev Econ Stat 65(1):105–114
Sarangi SK, Maji B, Digar S et al (2018) Zero tillage potato cultivation–an innovative technology for coastal saline soils. Indian Farming 68(04):23–26
Sarangi SK, Maji B, Sharma PC et al (2019). Zero tilled-paddy straw mulched potato (*Solanum tuberosum*) cultivation in the coastal saline soils reduce soil salinity, increase yield and profitability. Proceedings 36(1):147. https://doi.org/10.3390/proceedings2019036147
Sarangi SK, Maji B, Sharma PC et al (2020) Potato (*Solanum tuberosum* L.) cultivation by zero tillage and paddy straw mulching in the saline soils of the Ganges Delta. Potato Res 64(2):277–305. https://link.springer.com/article/10.1007%2Fs11540-020-09478-6
Shaheenuzzamn M, Saha RR, Saha, et al (2015) Green cob and fodder yield of sweet corn as influenced by sowing time in the hilly region. Bangladesh J Agric Res 40(1):61–69

Chapter 10
Customized Nutrient Management Strategies for Acid Saline Soils (Orumundakan Tract) of Kerala

V. Mini and G. Suja

Abstract Acid saline soils of Kerala comprise rice-growing soils of Pokkali, Kaipad and Orumundakan tracts. Acid saline soils of Onattukara sandy plain (agroecological unit 3) known as Orumundakan soils covering an area of 2000 ha are distributed in Alappuzha and Kollam districts of Kerala. Rice cultivation in this area is declining due to soil fertility constraints. High soil acidity, salinity and nutritional disorders are the major problems faced during rice cultivation. To revive the rice cultivation in this area, the soil fertility constraints have to be identified and soil-based nutrient management strategies have to be developed so that farmers can take up profitable crops. Hence, the present study has been undertaken to develop a soil-based nutrient management plan for the acid saline soils (Orumundakan soils) of Kerala. To characterize the fertility status of soils, 100 soil samples were collected from paddy fields of Orumundakan tract and analysed for various soil fertility parameters. The data generated were used for assessing soil fertility and preparing customized nutrient management strategies for the region. Based on the new nutrient management plan, field demonstrations were conducted using medium duration rice varieties from Pokkali and Kaipad areas. Soil fertility evaluation of the Orumundakan tract revealed that acidity, salinity and nutritional disorders are the major soil fertility constraints. The soil pH ranged from 2.16 to 5.99 and electrical conductivity (ECe) from 1.5 to 17.5 dS m^{-1}. Widespread deficiencies of Ca, Mg and B and toxicities of Fe and Mn were also observed. Soil test-based recommendation of lime, N, P, K, Mg and foliar application of N-P-K:19-19-19 (1%) at the maximum tillering stage and foliar application of N-P-K:13-0-45 (1%) and Solubor (0.2%) at panicle initiation stage were found to be promising in field demonstrations. The customized nutrient management plan will help the farmers for profitable crop production in this region.

Keywords Acid saline soils · Customized nutrient management · Orumundakan tract · Soil fertility

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10.1 Introduction

The acid saline soils of Kerala comprise the rice-growing soils of Pokkali, Kaipad and Orumundakan tracts. Soils with high acidity, salinity and nutritional constraints are the major problems faced by the farmers in these areas. Acid saline soils of Onattukara sandy plain (AEU 3) are known as Orumundakan soils. The low lands of the Onattukara sandy plain nearer to the coast are susceptible to periodic inundation by seawater (Padmaja et al. 1994). These lands and the cultivation of rice in these lands are often referred to Orumundakan. The sandy or sandy loam, imperfectly drained, and acid saline soils are submerged during southwest and northeast monsoons. These soils are cropped once a year when the salinity level of surface soil is brought below the critical limit of 4 dS m^{-1} with the flush of monsoon water (KSPB 2013). The Orumundakan tract comprises 17 panchayats covering an area of 2000 ha distributed in Alappuzha and Kollam districts. During the monsoon season when rainwater and freshwater from rivers enter the field, salinity is partially washed off. Under such conditions, the inherent acidity of these soils becomes more dominant. Most of the saline soils of Kerala are acidic with a pH ranging from 3.0 to 6.8 despite high conductivity (Nair and Money 1972). Rice cultivation in this area is declining due to fertility constraints such as iron toxicity, salinity and nutritional problems. Poor crop stand due to high acidity, poor tillering and chaffiness of grains are the major yield-limiting problems in this area. To revive the rice cultivation in this area, the soil fertility constraints have to be identified and soil-based nutrient management strategies have to be developed so that farmers can take up profitable crops. The possibility of growing medium duration salt-tolerant rice varieties with customized nutrient management strategies can be explored for profitable rice production in this area. Nutrient interactions in salt-affected soils may affect crop growth in many ways. Hence, the present study has been undertaken to develop a soil-based customized nutrient management plan for the acid saline soils (Orumundakan soils) of Kerala.

10.2 Materials and Methods

10.2.1 Soil Analysis

To characterize the fertility status of soils, 100 soil samples were collected from paddy fields of Orumundakan tract and analysed for 13 soil fertility parameters: soil reaction, electrical conductivity, organic carbon and available phosphorus, potassium, calcium, magnesium, sulphur, iron, manganese, copper, zinc and boron following standard analytical procedures (Jackson 1973). The data generated were used for assessing soil fertility and preparing customized nutrient management strategy for the region. Based on the new nutrient management plan, field demonstrations were conducted using medium duration salt-tolerant rice variety Vytila-6 from Pokkali and Ezhome-2 from Kaipad areas.

10.2.2 Crop Yield

The effect of customized nutrient management strategy and recommended package of practices on rice yield was evaluated in the farmer's field using rice varieties Ezhome-2 and Vytila-6 in randomized block design with four treatments and five replications. The yield data collected from the plots following the standard methods were statistically analysed.

10.3 Results and Discussion

10.3.1 Soil Fertility Parameters

Soil pH ranged from 2.16 to 5.99 and electrical conductivity from 1.5 to 17.5 dS m^{-1}. Based on the soil test values for organic C, available P, K, Ca, Mg, S, Fe, Cu, Mn, Zn and B, the soil samples were classified into three categories, viz., low, medium and high as per the ratings suggested by Dev (1997). Range and mean value of various soil test parameters in the region are given in Table 10.1.

Acidification of soils is a serious constraint to crop production in the region. The problem of acidity has aggravated to extreme levels in soils due to heavy inputs of acid-producing fertilizers, without regular application of lime to neutralize the acidity generated. Liming is essential for favourable soil reaction and to ensure the availability of essential nutrients. Liming is also required to reduce the inoculum load of harmful microbes in soils. The salinity level is very high in certain areas even

Table 10.1 Range and mean of soil fertility parameters

Sl. no.	Parameters	Range	Mean
1	pH	2.16–5.99	3.78
2	Electrical conductivity (dS m^{-1})	1.50–17.50	4.14
3	Organic carbon (%)	0.09–3.15	1.16
4	Available phosphorus (kg ha^{-1})	2.72–137.20	36.20
5	Available potassium (kg ha^{-1})	1.01–238.67	37.29
6	Available calcium (mg kg^{-1})	168.00–420.00	121.92
7	Available magnesium (mg kg^{-1})	8.12–14.37	10.28
8	Available sulphur (mg kg^{-1})	1.65–16.13	7.43
9	Available iron (mg kg^{-1})	77.07–294.00	170.56
10	Available manganese (mg kg^{-1})	1.40–16.88	3.40
11	Available zinc (mg kg^{-1})	1.05–36.63	7.53
12	Available copper (mg kg^{-1})	1.24–10.06	28.84
13	Available boron (mg kg^{-1})	0.04–2.25	0.49

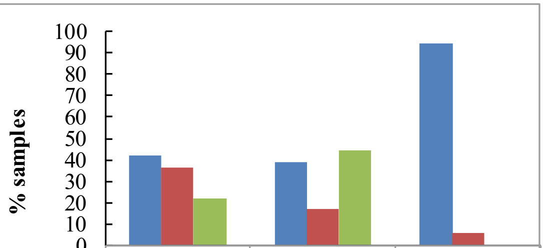
after the monsoon. Measures have to be taken to regulate the seawater intrusion in these areas by constructing physical barriers with the help of local self-government institutions.

10.3.2 Primary Nutrients

The organic carbon content of the soil is taken as an index for available nitrogen status in the soil. The available nitrogen status of the soils of this region revealed that 42% of the samples were low in available nitrogen. Fifty-eight percent of the samples had medium to high levels of organic carbon (Fig. 10.1). Optimum levels of organic matter not only serve as a slow release source of plant nutrients but also improve physico-chemical and biological properties of the soil. Correction of soil acidity can lead to better microbial activity and consequently to better utilization of applied nitrogen fertilizer and possibly reduction in their use.

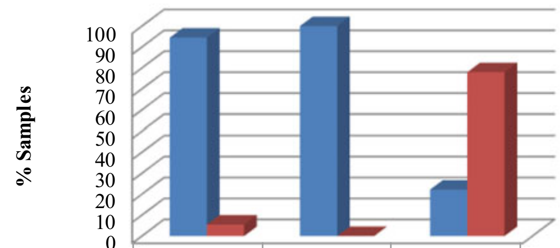
Plant available phosphorus was high in 44% of the soil samples tested (Fig. 10.1). A greater proportion of soil samples had high levels of available phosphorus suggesting considerable build-up of the nutrient. The result of the study points to the possibility for a reduction in the use of costly phosphatic fertilizers. Hence, it is recommended to get the soil tested regularly and apply fertilizers accordingly. High levels of available phosphorus can have a negative influence on the uptake of other nutrients especially zinc.

Among the major nutrients, potassium has a significant role in crop production as it contributes to the quality of the produce. A major part (95%) of the soils of Onattukara had low potassium status (Fig. 10.1). About 5% of samples have shown medium levels which may be due to the very strong acid condition and low CEC which do not permit any retention and rapid leaching loss of the element (Premachandran 1998).



	N	P	K
Low	41.7	38.9	94.5
Medium	36.1	16.7	5.5
High	22.2	44.4	

Fig. 10.1 Frequency distribution of available nitrogen, phosphorous and potassium classes



	Ca	Mg	S
Deficient	94.5	100	22.2
Sufficient	5.5	0	78

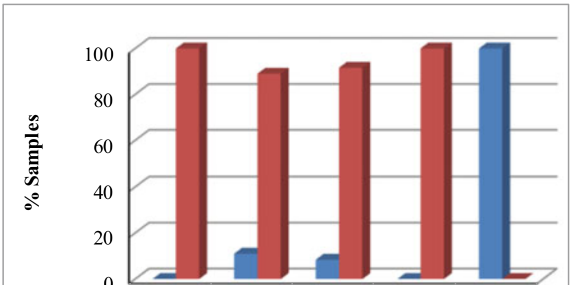
Fig. 10.2 Frequency distribution of available calcium, magnesium and sulphur classes

10.3.3 Secondary Nutrients

In the case of available calcium status, 95% of the samples were deficient (Fig. 10.2). The deficiency was more pronounced in areas with strongly acidic soil reaction. Use of the required quantity of lime for regulation of soil reaction can take care of calcium nutrition as well. Magnesium deficiency was observed in 100% of the soil samples (Fig. 10.2). Sulphur deficiency was observed only in 22% of the soil samples (Fig. 10.2). Most phosphatic fertilizers contain sulphur as an additional constituent and that may be responsible for satisfactory levels in soils. Application of magnesium sulphate can take care of the sulphur requirement of the crop.

10.3.4 Micronutrients

There was no deficiency of iron and manganese in any of the samples (Fig. 10.3). Zinc is a micronutrient required by the plant in very small quantities. Zinc and copper



	Fe	Cu	Zn	Mn	B
Deficient	0.0	11	8.4	0	100
Sufficient	100	89	91.6	100	0

Fig. 10.3 Frequency of available Fe, Cu, Zn, Mn and B classes

deficiency was noticed in 8% and 11% of the samples, respectively. High input of phosphatic fertilizers might have ensured an adequate level of zinc in these soils since zinc occurs as a contaminant in phosphatic fertilizers (Nair et al. 2013). The micronutrient copper needs to be applied only on the basis of soil test results that indicates copper deficiency.

Boron is another essential micronutrient required only in very small quantities by plants. Boron deficiency was found in 100% of soil samples tested in the region (Fig. 10.3). Boron deficiency is the major cause of the greater proportion of chaffiness in grains. This indicates the urgent need for boron fertilization in rice for enhancing the productivity.

Based on the soil analysis data and other observations and surveys, the soil fertility status was assessed and fertility constraints of the Orumundakan area were identified. Soil fertility evaluation of the Orumundakan tract revealed that acidity, salinity and nutritional disorders are the major soil fertility constraints. Widespread deficiencies of Ca, Mg and B and toxicities of Fe and Mn were also observed. Poor crop stand due to high acidity, poor tillering and chaffiness of grains were the major yield-limiting problems in this area. Based on the data generated, a customized nutrient management strategy for the region was prepared.

10.3.5 Customized Nutrient Management Strategy for Acid Saline Soils of Orumundakan Tract

Management of soil acidity is essential to ensure good crop stand in the initial stage and also for successful crop production in the region. Liming of soils in accordance with the soil test results is highly essential. Application of lime has to be done in two splits as 2/3rd dose at the time of land preparation and 1/3rd dose one week before the second dose of fertilizer application to manage the soil acidity at critical growth stages of the crops. Soil test-based fertilizer application has to be followed for N, P and K. Application of nitrogen and potassium fertilizers should be done in several splits to minimize the leaching losses. Application of magnesium sulphate @ 80 kg ha^{-1} is necessary to ensure adequate levels of magnesium and sulphur to crops. Foliar application of 19-19-19 (N-P-K foliar formulation) @ 10 g L^{-1} (1%) at maximum tillering stage is recommended to improve the crop growth and tillering. Foliar application of 13-0-45 (N-P-K foliar formulation) @ 10 g L^{-1} (1%) and boron containing foliar formulation Solubor @ 2 g L^{-1} (0.2%) at panicle initiation stage should be applied to reduce the chaffiness and also to ensure higher yield.

10.3.6 *Effect of Customized Nutrient Management (CNM) Strategy on Growth and Yield of Rice*

Field demonstrations were conducted using medium duration rice varieties Ezhome-2 and Vytila-6 (Fig. 10.4) using the customized nutrient management strategies and compared with recommended general package of practices (POP) for rice by the Kerala Agricultural University (KAU 2014) (Table 10.2).

Both the varieties Ezhome-2 and Vytila-6 performed well under customized nutrient management strategy compared to the recommended package of practices. The highest yield (2.98 t ha^{-1}) was recorded by Vytila-6 under customized nutrient management strategy and was at par with Ezhome-2 grown under similar practice. Soil test-based recommendation for lime, N, P, K, Mg and foliar application of N-P-K:19-19-19 (1%) at the maximum tillering stage and foliar application of N-P-K:13-0-45 (1%) and Solubor (0.2%) at panicle initiation stage were found to be promising in field demonstrations, and the yield was almost doubled with the new customized nutrient management strategy.

Ezome-2 Vytila-6

Fig. 10.4 Performance of rice varieties Ezhome-2 and Vytila-6 in field demonstrations

Table 10.2 Effect of customized nutrient management (CNM) strategy on yield of rice

Treatments	Yield (t ha^{-1})	
	Grain	Straw
Vytila-6 (POP)	1.16	1.57
Ezhome-2 (POP)	1.02	1.68
Vytila-6 (CNM)	2.98	4.12
Ezhome-2 (CNM)	2.75	4.53
CD (0.05)	0.245	0.590

10.4 Conclusions

Extensive soil acidity, salinity and wide spread deficiencies of potassium, calcium, magnesium and boron are the major limitations to crop production in this region. The problem of soil acidity has aggravated to extreme levels due to heavy inputs of acid-producing fertilizers, and the practice of liming to ameliorate soil acidity is either non-existent or ineffective. Very high levels of phosphorus in soils impair nutrient balance and affect micronutrient absorption by plants even when they are present in adequate levels in soils. Deficiency of potassium, calcium and magnesium seriously impair plant growth and productivity by affecting absorption of other nutrients and its effect on cellular functions**.** Deficiency of boron seriously affects seed development and yield. Nutritional stress during the critical growth stages can be overcome by supplementary foliar nutrition at these critical stages. A soil test-based nutrient management plan encompassing soil test-based lime and fertilizer recommendation including macro- and micro-nutrients and supplementary foliar nutrition at critical growth stages of the crop will help the farmers for profitable crop production in this region.

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References

Dev G (1997) Soil fertility evaluation for balanced fertilization. Fert News 42:3–34

Jackson ML (1973) Soil chemical analysis. Prentice Hall of India, New Delhi, pp 498–561

KAU (2014) Package of practices recommendations: crops, 15th edn. Kerala Agricultural University (KAU), Thrissur, Kerala, p 360

KSPB (2013) Soil fertility assessment and information management for enhancing crop productivity in Kerala. Kerala State Planning Board (KSPB), Thiruvananthapuram, Kerala, p 514

Nair PG, Money NS (1972) Studies on some chemical and mechanical properties of salt affected rice soils of Kerala. Agric Res J Kerala 10(1):51–53

Nair K, Saifudeen N, Suresh Kumar P (2013) Fertility of soils of Kerala. In: Soil fertility assessment and information management for enhancing crop productivity in Kerala. Kerala State Planning Board, Thiruvananthapuram, Kerala, pp 136–139

Padmaja P, Geethakumari VL, Harikrishnan NK, et al. (1994) A glimpse to problem soils of Kerala. Kerala Agricultural University, Thrissur, Kerala, pp 76–89

Premachandran PN (1998) Land evaluation and suitability rating of the major soils of Onattukara region. Ph. D. thesis, Kerala Agricultural University, Vellanikkara, Thrissur

Chapter 11
Effect of Phosphorus and Biofertilizers on Growth, Yield and Quality of Groundnut (*Arachis hypogaea* L.) in Coastal Region of Maharashtra

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Abstract Field trials over two consecutive rabi seasons of the year 2017–18 and 2018–19 were undertaken to find out the effect of phosphorus and biofertilizers levels on growth, yield and nutrients uptake by groundnut grown on Alfisols in the coastal region of Maharashtra. Two kinds of biofertilizers, i.e., vesicular-arbuscular mycorrhiza (VAM) and phosphate solubilizing bacteria (PSB) (*Pseudomonas*), were added alone or in combination (no biofertilizer application, VAM @ 10 kg ha^{-1}, PSB @ 10 kg ha^{-1}, VAM + PSB @ 5 kg ha^{-1} and VAM + PSB @ 5 kg ha^{-1} each) and were compared to different rates of phosphorus (P) fertilizer @ 15, 30, 45 and 60 kg ha^{-1} applied with recommended dose of nitrogen (N) and potassium (K). The factorial randomized block design was used with twenty treatment combinations which were replicated thrice. The results revealed that the application of phosphorus @ 60 kg ha^{-1} with the recommended dose of N and K combined with VAM + PSB @ 10 kg ha^{-1} biofertilizers realized higher biomass and yield than a lower dose of phosphorus and no biofertilizers application during the rabi season indicating the need of starter nutrients for hyphal growth and root colonization of VAM. The pod yield (3.59 t ha^{-1}), kernel yield (2.47 t ha^{-1}) and oil (50.23%) content were significantly the highest with the application of phosphorus @ 60 kg ha^{-1}. The co-inoculation of

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VAM + PSB @ 10 kg ha^{-1} each significantly increased the kernel yield (2.18 t ha^{-1}), test weight (63.46 g), shelling percentage (68.93%) as well as oil (48.52%) and protein (28.35%) content. The application of phosphorus @ 60 kg ha^{-1} with dual inoculation of VAM + PSB @ 10 kg ha^{-1} each indicated the highest plant height and number of rachis which results in higher pod yield, kernel yield (27.06 t ha^{-1}), test weight (68.33 g) and shelling percentage (72.70%). However, the application of phosphorus @ 45 kg ha^{-1} also showed beneficial results in respect of the other treatment combinations. Therefore, a combination of 60 kg P ha^{-1} and VAM + PSB @ 10 kg ha^{-1} can increase groundnut yield from 2.29 to 3.59 t ha^{-1}. The results realized the significance of arbuscular mycorrhizal fungi (AMF) in nutrient-depleted soils as starter nutrients.

Keywords Alfisols · Biofertilizers · Groundnut · PSB · VAM · Yield

11.1 Introduction

Groundnut (*Arachis hypogaea* L.), a native of South America (Brazil), is ranked as the 13th most important food and 4th oilseed crop; grown throughout the tropical, subtropical and warm temperate regions of the world (Hammons 1982). Groundnut kernel contains 40–55% oil, 22–30% protein and 10–20% carbohydrate (Narendra Kumar et al. 2017). The highest state average yield of 2.38 t ha^{-1} was estimated for Rajasthan which was followed by 1.88 t ha^{-1} for Gujarat, 1.38 t ha^{-1} for Maharashtra, 1.27 t ha^{-1} for Andhra Pradesh and the lowest of 0.87 t ha^{-1} for Karnataka (Anonymous 2018). In Maharashtra, groundnut is cultivated on an area of 0.33 M ha having 0.42 M tonnes of production with a productivity of 1.28 t ha^{-1} (Anonymous 2019), whereas in *Konkan* it is grown in about 20,000 ha area with 1.8 t ha^{-1} productivity (Waghmode et al. 2017).

Seed germination and seedling vigour are two important parameters that determine seed quality. Phosphorus is a vital component of ATP, the "energy unit" of plants. Taking into consideration, the experimental sites have major oxide content, viz., $SiO_2 > Al_2O_3$ and Fe_2O_3 in laterites derived from different parent rocks and established the stages of lateralization from the parent rock through kaolinization to true laterite. Therefore, the soil showed a deficiency of phosphate, accentuated by high phosphate-fixing capacity as Fe- and Al-phosphates (Sehgal 2015). For improving phosphorus nutrition, the focus is placed on the use of soil microorganisms endowed with the phosphorus solubilizing ability, which could be used as inoculants to mobilize P from poorly available sources in soil. In order to achieve the required production level of groundnut through higher productivity, in-depth analysis of groundnut production methods and adoption pattern of technology is necessary (Hruday Ranjan et al. 2014). Hence, the present study was conducted for optimizing P management and improving P-use efficiency, aiming at reducing consumption of chemical P fertilizer, maximizing exploitation of the biological potential of root/rhizosphere processes for efficient mobilization and acquisition of soil P by plants.

11.2 Materials and Methods

The experiment was conducted on terraced lateritic soil (sandy clay loamy texture), a member of fine, kaolinitic isohyperthermic family of *Typic Hapludalf* at Botany Farm, College of Agriculture, Dr. Balasaheb Sawant Konkan Krishi Vidyapeeth (DBSKKV), Dapoli, Maharashtra (17° 45′ 02″ N and 73° 10′ 55″ E with an altitude of 243.84 m above mean sea level) during the rabi seasons of 2017–18 and 2018–19 comprising four levels of phosphorus @ 15 (P_{15}), 30 (P_{30}), 45 (P_{45}) and 60 (P_{60}) kg ha^{-1} along with five levels of biofertilizer [no biofertilizer application (B_1), VAM @ 10 kg ha^{-1} (B_2), PSB @ 10 kg ha^{-1} (B_3), VAM + PSB @ 5 kg ha^{-1} each (B_4) and VAM + PSB @ 10 kg ha^{-1} each (B_5)] in groundnut Konkan Trombay Tapora variety released by DBSKKV, Dapoli. The experiment was laid out in a Factorial Randomized Block Design with three replications. The seed was dibbled by adopting spacing 30 × 15 cm, and all the recommended cultural practices were followed. The observations, viz., plant height, number of rachis, 100-kernel weight (test weight), shelling percentage, pod yield, kernel yield, were recorded. The nitrogen in the kernel was estimated by Micro-Kjeldahl method, and the per cent protein was obtained by multiplying per cent nitrogen by 6.25 (Harwitz and Latimer 1965). Methionine was estimated by Papain hydrolysis method (Gehrke and Neuner 1974). The obtained data were computed and analysed statistically (Panse and Sukhatme 1967).

11.3 Results and Discussion

11.3.1 Growth Parameters of Groundnut

11.3.1.1 Plant Height

The higher magnitudes of plant height were noted with the application of phosphorus @ 45 kg ha^{-1} and @ 60 kg ha^{-1} at peg initiation stage (22.59 cm) and at pod formation (33.85 cm) and harvest stage (35.34 cm) with the lower dose of phosphorus @ 15 kg ha^{-1}. Dual inoculation of VAM + PSB @ 10 kg ha^{-1} each recorded the highest and significantly superior plant height at pod formation stage and at harvest (34.09 and 35.08 cm, respectively). In case of interaction, the plant height was found to be significantly superior with phosphorus @ 15 kg ha^{-1} along with VAM + PSB @ 10 kg ha^{-1} each (B_4P_{15}) and phosphorus @ 15 kg ha^{-1} with no biofertilizer application (B_0P_{15}) during pod formation (40.31 cm) and at harvest stage (39.60 cm), respectively (Table 11.1).

Table 11.1 Effect of phosphorus and biofertilizers on plant height (cm) of groundnut (Pooled data of 2 years)

	Peg initiation						Pod formation						At harvest					
	B_0	B_1	B_2	B_3	B_4	Mean	B_0	B_1	B_2	B_3	B_4	Mean	B_0	B_1	B_2	B_3	B_4	Mean
P_{15}	17.20	19.10	17.73	21.96	20.32	19.26	32.47	33.58	33.66	29.22	40.31	33.85	39.60	39.71	30.72	30.72	35.96	35.34
P_{30}	23.54	20.71	22.46	21.58	20.57	21.78	29.89	29.22	30.90	22.50	30.90	28.68	30.72	30.54	36.31	22.13	33.04	30.55
P_{45}	21.93	20.35	24.66	22.07	21.09	22.02	33.59	28.88	28.54	31.90	35.60	31.70	32.02	31.67	31.44	33.82	35.86	32.96
P_{60}	22.69	21.91	22.78	21.64	23.95	22.59	29.55	33.25	32.08	33.53	29.55	31.59	34.99	30.86	29.90	33.85	35.44	33.01
Mean	21.34	20.52	21.91	21.81	21.48	21.41	31.37	31.23	31.29	29.29	34.09	31.46	34.33	33.20	32.09	30.13	35.08	32.97
			SEm ±		CD@5%				SEm ±		CD@5%				SEm ±		CD@5%	
	P		0.645		1.847		P		0.125		0.358		P		0.138		0.395	
	B		0.721		NS		B		0.140		0.400		B		0.154		0.442	
	Int (P x B)		1.442		NS		Int (P x B)		0.279		0.800		Int (P x B)		0.309		0.884	

11.3.1.2 Number of Rachis

The application of phosphorus and biofertilizers did not result in significant differences in the number of rachis plant^{-1} at peg initiation stage. The application of phosphorus @ 30 kg ha^{-1} recorded significantly the highest number of rachis plant^{-1} and found superior over all the treatments during pod formation (7.80) and at harvest stage (7.41), respectively. The inoculation of VAM @ 10 kg ha^{-1} during pod formation stage (7.21) and dual inoculations of VAM + PSB @ 10 kg ha^{-1} each (7.51) at harvest showed significantly highest number of rachis plant^{-1}. In interaction, the number of rachis plant^{-1} was found to be significantly highest with the application of phosphorus @ 30 kg ha^{-1} with the application of VAM + PSB @ 10 kg ha^{-1} during pod formation stage (9.92) and phosphorus @ 60 kg ha^{-1} with combined application of VAM + PSB @ 5 kg ha^{-1} each at harvest (8.63) (Table 11.2).

11.3.2 Yield and Yield Attributes

11.3.2.1 Pod Yield

The pod yield tended to increase significantly with increasing doses of phosphorus, and the highest pod yield was found with the application of phosphorus @ 60 kg ha^{-1} (P_{60}) (3.59 t ha^{-1}) but was at par with the application of phosphorus @ 45 kg ha^{-1} (P_{45}) (3.20 t ha^{-1}). The individual inoculation of biofertilizers and the interaction of phosphorus and biofertilizers were found to be non-significant. But numerically, the dual inoculation of VAM + PSB @ 10 kg ha^{-1} each with the higher dose of phosphorus @ 60 kg ha^{-1} (B_4P_{60}) showed the highest pod yield (37.16 t ha^{-1}) over all the treatment combinations (Table 11.3). The increase in growth parameters and pod yield of groundnut could be attributed due to better root proliferation, higher root development, increased availability and uptake of nutrients, energy transformation and metabolic processes in the plant.

The PSB is known to produce vitamins and indole acetic acid and gibberellins like substances also increase P availability through solubilization of insoluble inorganic phosphate, decomposition of rich organic compounds and production of plant growth-promoting substances (Gaur and Sunita 1999). The dual inoculation recorded higher grain yield might be due to the synergistic effect between PSB and VAM. This improvement in yield with increased supply of phosphorus might be due to profuse nodulation leading to an increase in nitrogen fixation which in turn had a positive effect on photosynthetic organs that resulted in higher grain yield (Pramanik and Bera 2013). Similar results were reported by Kausale et al. (2009) in groundnut and Nadeem et al. (2018) in cowpea crop.

Table 11.2 Effect of phosphorus and biofertilizers on number of rachis of groundnut (Pooled data of 2 years)

	Peg initiation						Pod formation						At harvest					
	B_0	B_1	B_2	B_3	B_4	Mean	B_0	B_1	B_2	B_3	B_4	Mean	B_0	B_1	B_2	B_3	B_4	Mean
P_{15}	6.65	6.88	6.99	6.68	10.44	7.53	6.60	7.37	6.60	5.88	6.50	6.59	7.06	7.05	5.49	7.05	6.44	6.62
P_{30}	7.92	8.17	7.62	6.79	6.72	7.44	7.67	9.92	7.05	7.33	7.04	7.80	8.38	7.50	6.78	7.42	6.97	7.41
P_{45}	7.78	7.70	7.74	8.44	6.24	7.58	6.97	5.99	6.97	6.63	8.03	6.92	6.47	6.29	7.06	5.89	8.63	6.87
P_{60}	8.49	6.82	8.37	8.12	8.34	8.03	4.04	5.54	7.69	8.79	5.50	6.31	4.88	6.66	8.63	8.63	8.01	7.36
Mean	7.71	7.39	7.68	7.51	7.93	7.64	6.32	7.21	7.08	7.16	6.77	6.91	6.70	6.88	6.99	7.25	7.51	7.06
			SEm ±		CD @ 5%				SEm ±		CD @ 5%				SEm ±		CD @ 5%	
	P		0.289		NS		P		0.144		0.411		P		0.100		0.285	
	B		0.323		NS		B		0.160		0.459		B		0.111		0.319	
	Int (P x B)		0.646		1.850		Int (P x B)		0.321		0.919		Int (P x B)		0.223		0.638	

Table 11.3 Effect of phosphorus and biofertilizers on yield of groundnut (Pooled data of 2 years)

	Pod yield (t ha^{-1})						Haulm yield (t ha^{-1})					
	B_0	B_1	B_2	B_3	B_4	Mean	B_0	B_1	B_2	B_3	B_4	Mean
P_{15}	2.20	2.25	2.25	2.42	2.33	2.29	5.21	4.29	5.20	4.48	4.44	4.72
P_{30}	2.48	2.60	2.47	2.89	3.15	2.72	4.80	5.14	5.03	4.44	4.81	4.84
P_{45}	3.19	3.20	2.88	3.29	3.42	3.20	5.14	5.04	4.67	5.28	5.40	5.11
P_{60}	3.55	3.42	3.57	3.67	3.72	3.59	5.19	4.95	5.01	5.07	5.07	5.06
Mean	2.85	2.87	2.79	3.07	3.16	2.95	5.08	4.86	4.98	4.82	4.93	4.93
			SEm ±		CD @ 5%				SEm ±		CD @ 5%	
	P		1.707		4.888		P		1.532		NS	
	B		1.909		NS		B		1.712		NS	
	Int (P x B)		3.818		NS		Int (P x B)		3.425		NS	

11.3.2.2 Kernel Yield

The highest kernel yield (2.47 t ha^{-1}) was found with the application of phosphorus @ 60 kg ha^{-1} (RDF), which was significantly superior over the lower doses of phosphorus and followed the order $P_{15} < P_{30} < P_{45} < P_{60}$. The co-inoculation of VAM + PSB @ 10 kg ha^{-1} (B_4) (2.18 t ha^{-1}) showed significantly the highest kernel yield and was found at par with B_3. The highest kernel yield was observed with application of phosphorus @ 60 kg ha^{-1} with dual inoculation of VAM + PSB @ 10 kg ha^{-1} (B_4P_{60}) (2.71 t ha^{-1}) and found at par with B_0P_{60}, B_2P_{60}, B_3P_{60} and B_4P_{45} (Table 11.4). The increase in kernel yield may be due to an increase in P availability through solubilization of insoluble inorganic phosphate, decomposition of phosphate-rich organic compounds and production of plant growth-promoting substances. Further, Balchandran et al. (2006) explained that the increase in grain yield of green gram might be due to the availability of N and P in the required amounts through fertilizers and PSB.

11.3.2.3 Test Weight

Application of phosphorus @ 30 kg ha^{-1} (62.02 g), 60 kg ha^{-1} (59.77 g) and 45 kg ha^{-1} (59.22 g) recorded on par test weight of groundnut. The dual inoculation of VAM + PSB @ 10 kg ha^{-1} each (B_4) (63.46 g) recorded significantly the highest test weight over all the treatment combinations. Phosphorus @ 60 kg ha^{-1} along with dual inoculation of VAM + PSB @ 10 kg ha^{-1} each (B_4P_{60}) significantly influenced the test weight (68.33 g) (Table 11.4). The increase in test weight might be due to a strong positive synergistic effect that caused to improving photosynthesis by increasing water and nutrients absorption and this leading to producing more assimilate and improving plant growth, as a result, 1000-seed weight increased (Pramanik

Table 11.4 Effect of phosphorus and biofertilizers on kernel yield, test weight and shelling percentage of groundnut (Pooled data of 2 years)

	Kernel yield (t ha^{-1})						Test weight (g)						Shelling percentage					
	B_0	B_1	B_2	B_3	B_4	Mean	B_0	B_1	B_2	B_3	B_4	Mean	B_0	B_1	B_2	B_3	B_4	Mean
P_{15}	1.38	1.43	1.44	1.57	1.70	1.46	6.32	4.87	6.35	4.68	6.34	5.71	62.9	63.6	64.2	64.6	65.0	64.1
P_{30}	1.84	1.92	1.89	1.77	1.92	1.85	5.92	6.59	6.56	5.45	6.49	6.20	65.8	66.3	66.9	67.4	67.9	66.9
P_{45}	1.99	2.03	2.07	2.37	2.40	2.12	5.46	5.45	6.70	6.28	5.73	5.92	68.5	71.4	71.8	72.0	70.1	70.8
P_{60}	2.51	2.36	2.45	2.57	2.71	2.47	6.68	5.67	5.32	5.38	6.83	5.98	70.6	69.0	69.1	69.8	72.7	70.2
Mean	1.93	1.94	1.96	2.07	2.18	2.02	6.10	5.64	6.23	5.44	6.35	5.95	66.9	67.6	68.0	68.5	68.9	68.0
			SEm ±		CD @ 5%				SEm ±		CD @ 5%				SEm ±		CD @ 5%	
	P		0.365		1.486		P		1.025		2.934		P		0.093		0.267	
	B		0.580		1.662		B		1.146		3.281		B		0.104		0.298	
	Int (P x B)		1.161		3.323		Int (P x B)		2.292		6.561		Int (P x B)		0.208		0.596	

and Bera 2013). Similar results were reported by Hadwani and Gundalia (2005) in groundnut.

11.3.2.4 Shelling Percentage

The application of phosphorus @ 45 kg ha^{-1} (70.76%) registered significantly higher and superior shelling percentage and followed the order $P_{15} < P_{30} < P_{60}$ and $< P_{45}$. The shelling percentage was found to be superior with co-inoculation of VAM + PSB @ 10 kg ha^{-1} each (68.93%) over no biofertilizers. The treatment consisting of application of phosphorus @ 60 kg ha^{-1} along with dual inoculation of VAM + PSB @ 10 kg ha^{-1} each, i.e., B_4P_{60} (72.70%) was found to be significantly highest in respect to shelling percentage in all treatment combinations (Table 11.4). This might be due to high dose of phosphorus fertilizer tends to form nutrient interaction and may affect the availability of other nutrients which are essential for growth of the groundnut (Sibhatu et al. 2016).

11.3.3 Quality Parameters

11.3.3.1 Oil Content

The highest oil content was recorded with the application of phosphorus @ 60 kg ha^{-1} (50.23%) in case of phosphorus levels; with dual inoculation of VAM + PSB @ 5 kg ha^{-1} each (48.57%) in case of biofertilizers and with the combined application of phosphorus @ 60 kg ha^{-1} with VAM + PSB @ 10 kg ha^{-1} each (B_4P_{60}) (50.62%) in case of interaction (Table 11.5). This may be due to the better availability of phosphorus through a readily available source (single super phosphate) caused better root development resulting in higher uptake of phosphorus and other nutrients and higher biological nitrogen fixation (Tanwar and Shaktawat 2003). The significant increase in oil content was also reported by Hadwani and Gundalia (2005) and Kamdi et al. (2014) in groundnut with higher doses of N, P and K.

11.3.3.2 Protein Content

The application of phosphorus @ 45 kg ha^{-1}, dual inoculation of VAM + PSB @ 10 kg ha^{-1} each and interaction of phosphorus @ 60 kg ha^{-1} with co-inoculation of VAM + PSB @ 10 kg ha^{-1} each recorded significantly highest protein content in groundnut (30.31, 29.67 and 31.93%, respectively) (Table 11.5). This may be because phosphorus has an important role in the formation of protein, particular amino acid, phosphate form, nucleic acid, phosphor-lipids, co-enzyme NAD, NADP,

Table 11.5 Effect of phosphorus and biofertilizers on quality of groundnut (Pooled data of 2 years)

	Oil content (%)						Protein content (%)						Methionine content (%)					
	B_0	B_1	B_2	B_3	B_4	Mean	B_0	B_1	B_2	B_3	B_4	Mean	B_0	B_1	B_2	B_3	B_4	Mean
P_{15}	45.44	45.10	45.56	46.73	47.14	45.99	22.51	23.10	23.80	24.21	24.51	23.63	0.18	0.21	0.24	0.26	0.27	0.23
P_{30}	49.01	48.25	47.91	47.67	45.91	47.75	25.04	25.98	26.45	26.63	27.16	26.25	0.29	0.31	0.32	0.35	0.37	0.33
P_{45}	45.95	44.60	49.71	50.08	50.40	48.15	30.28	30.81	31.46	29.16	29.81	30.31	0.49	0.40	0.40	0.47	0.48	0.45
P_{60}	50.48	49.80	50.48	49.80	50.62	50.23	27.81	28.40	28.52	31.70	31.93	29.67	0.38	0.46	0.43	0.44	0.45	0.43
Mean	47.72	46.94	48.41	48.57	48.52	48.03	26.41	27.07	27.56	27.93	28.35	27.46	0.34	0.34	0.35	0.38	0.39	0.36
			SEm ±		CD@5%				SEm ±		CD@5%				SEm ±		CD@5%	
	P		0.365		1.045		P		0.145		0.414		P		0.006		0.018	
	B		0.408		1.169		B		0.162		0.463		B		0.007		0.020	
	Int (P x B)		0.816		2.337		Int (P x B)		0.323		0.926		Int (P x B)		0.014		0.039	

ATP, cell growth, chromosome form and stimulate the root growth (Indriani et al. 2016); besides this, the synergistic interaction between VAM and PSB biofertilizers (Suri et al. 2011).

11.3.3.3 Methionine Content

Methionine content was 0.45% with application of phosphorus @ 45 kg ha^{-1}, 0.39% with application of VAM + PSB @ 10 kg ha^{-1} each and, 0.49% with application of phosphorus @ 15 kg ha^{-1} with no biofertilizers was registered and found to be significantly highest (Table 11.5). The results also find support with the investigation of Mhalshi (2013) who observed significant increase in methionine content with the dual inoculation of *Rhizobium* and PSB with different levels of phosphorus under groundnut (viz., 25 and 50 kg ha^{-1}).

11.4 Conclusions

Though the individual application of phosphorus or biofertilizers (alone or in combination) enhanced the growth, yield and quality of groundnut, the combined application of phosphorus @ 60 kg ha^{-1} with co-inoculation of VAM + PSB @ 10 kg ha^{-1} each positively influenced the yield attributing characters like pod yield, haulm yield, plant height, number of rachis and weight of 100-grains, oil, protein and methionine content.

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References

Anonymous (2018) Annual report 2018–19, ICAR-Directorate of Groundnut Research, Junagadh, Gujarat, India, 1–20

Anonymous (2019) Pocket book of agricultural statistics—2019. Department of economics and statistics, Directorate of Agriculture and Farmers Welfare, GOI, New Delhi, India, p 23–34

Balachandran S, Deotale RD, Hatmode CN et al (2006) Effect of biofertilizers (pressmud, *Rhizobium* and PSB) and nutrients (NPK) on chemical and bio-chemical parameters of green gram. J Soils Crop 16(1):176–179

Gaur AC, Sunita G (1999) Phosphate solubilizing microorganisms—an overview. Curr Trends Life Sci 23:151–164

Gehrke CH, Neuner TE (1974) The determination of methionine. J Asso Official Agric Chemist 57:683–689

Hadwani GJ, Gundalia JD (2005) Effect of N, P and K levels on yield, nutrient content, uptake and quality of summer groundnut grown on *Typic Haplustepts*. J Indian Soc Soil Sci 53(1):125–128
Hammons RO (1982) Origin and early history of the pea nut. In: Patte me HE, Young CT (eds) Peanut science and technology. American Peanut Research and Education Society, Yoakum, Texas USA, pp 1–20
Harwitz W, Latimer GW (eds) (1965) Official methods of analysis of the association of analytical chemists, 10th edn. Association of Analytical Chemists, Mary Land, USA, pp 59–60
Hruday Ranjan C, Satya Gopal PV, Sailaja V et al (2014) Extent of awareness, knowledge and adoption of different farm machinery by the groundnut farmers in Chittoor district of Andhra Pradesh. J Oilseeds Res 31(1):86–89
Indriani NP, Yuyun Y et al (2016) The role of vesicular arbuscular mycorrhiza (VAM) and rock phosphate application on production and nutritional value of centro legumes (*Centrosema pubescens*). Legume Res 39(6):987–990
Kamdi TS, Sonkamble P, Joshi S (2014) Effect of organic manure and biofertilizers on seed quality of groundnut (*Arachis hypogaea* L.). The Bioscan 9(3):1011–1013
Kausale SP, Shinde SB, Patel LK et al (2009) Effect of integrated nutrient management on nodulation, dry matter accumulation and yield of summer groundnut at south Gujarat conditions. Legume Res 32(3):227–229
Kumar N, Ajay BC, Rathanakumar AL et al (2017) Genetic variability for fresh seed dormancy in Spanish bunch advanced breeding lines of groundnut (*Arachis hypogaea* L.). J Oilseeds Res 34(3):119–124
Mhalshi RM (2013) Chemical and biological properties of soil as influenced by different levels of P and K with and without biofertilizers to cowpea. M.Sc. (Ag.) Thesis, Dr. B.S. Konkan Krishi Vidyapeeth, Dapoli, Maharashtra, India, pp 66–67
Nadeem MA, Vikas S, Dubey RK et al (2018) Influence of phosphorus and biofertilizers on growth and yield of cowpea [*Vigna unguiculata* (L.) Walp.] in acidic soil of NEH region of India. Legume Res 41(5):763–766
Panse VG, Sukhatme PV (1967) Statistical method for agricultural workers. 2nd edn, Indian Council of Agricultural Research, New Delhi, India, pp 157–165
Pramanik K, Bera AK (2013) Effect of biofertilizers and phytohormone on growth, productivity and quality of sunflower (*Helianthus annuus* L). J Crop Weed 9(2):122–127
Sehgal J (2015) Pedology—concepts and applications. Kalyani Publishers, New Delhi, India, pp 345–346
Sibhatu B, Tekle G, Harfe M (2016) Response of groundnut (*Arachis hypogaea* L.) to different rates of phosphorus fertilizer at Tanqua-Abergell district, Northern Ethiopia. Basic Res J Agric Sci Rev 5(1):24–29
Suri VK, Choudhary AK, Girish C et al (2011) Improving phosphorus use through co-inoculation of vesicular arbuscular mycorrhizal fungi and phosphate solubilizing bacteria in maize in an acidic Alfisol. Commun Soil Sci Plant Anal 42(18):2265–2273
Tanwar SPS, Shaktawat MS (2003) Influence of phosphorus sources, levels and solubilizers on yield, quality and nutrient uptake of soybean (*Glycine max*)-wheat (*Triticum aestivum*) cropping system in southern Rajasthan. Indian J Agric Sci 73(1):3–7
Waghmode BD, Navhale VC, Kamble AS et al (2017) Development of medium duration, high oil content and yield potential groundnut variety Konkan bhuratna for Konkan region of Maharashtra state India. Int J Curr Microbiol Appl Sci 6(12):999–1006

Chapter 12
Biodiversity of Vegetables: Sustainable Food and Nutritional Security in Coastal Areas

Pranab Hazra

Abstract Coastal agriculture is characterized by low-lying and saline-prone soils where spatial competition with urban growth coupled with food and nutritional security is an ever-increasing problem. Projections of the precise magnitude, frequency and regional patterns of the impacts from climate change on coastal agriculture are uncertain. Integrated Farming Systems (IFS) coupled with different technologies like different forms of floating garden and embankment cultivation need to be adopted for mixed cropping system that encompasses vegetables, fruits, plantation crops, spices, herbs, ornamental and medicinal plants as well as livestock that can serve as a supplementary source of food and income in the coastal areas. The concept of "biodiversity" has been linked with the emerging issue of "sustainable diets" in exploring solutions for the problems of malnutrition in its various forms, while addressing the loss of biodiversity and the erosion of indigenous and traditional food cultures. The purpose is to promote the development of new sustainable food production and consumption models. Urgent action is needed to develop and adopt different region-specific Integrated Farming Systems models utilizing available biodiversity and other natural resources scientifically to enhance food and nutritional security in the coastal areas.

Keywords Biodiversity · Coastal agriculture · Malnutrition · Vegetable crops

12.1 Introduction

Food availability is a crucial dimension of food security in an agrarian society. It is largely realized through the own food production of a specific society. Seasonality plays an important role in food security. Coastal areas are commonly defined as the interface or transition areas between land and sea, including large inland lakes. Overall, about 50–70% of the global population live within 100 km of the coastline covering only about 4% of earth's land, thereby drawing heavily on coastal and marine habitats for food, building sites, transportation, recreational areas and waste

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disposal. Coastal agricultural practices are less stable than upland agriculture because they need to cope with frequent changes in salinity, tidal processes, water stresses and waterlogging. Coastal ecosystems are greatly impacted by location-specific land use. Projections of the precise magnitude, frequency and regional patterns of the impacts from climate change on coastal agriculture are uncertain. However, the implications of these impacts will change the destiny of many generations to come and affect coastal communities in particular if no suitable action is taken. Given this growing concern, it is urgent that appropriate adaptation policies and strategies are developed and applied to mitigate the vulnerability of coastal agricultural systems to climate change. Biodiversity is the natural heritage of the planet and is one of the key factors of sustainable development, due to its importance not only for the environmental aspects of sustainability but also for the social and economic ones. The genetic diversity representing "Farmers' varieties" remains a vital resource for global food security and economic stability. FAO and Bioversity International for the first time linked the concept of "biodiversity" with the emerging issue of "sustainable diets" in exploring solutions for the problems of malnutrition in its various forms. The purpose was to promote the development of new sustainable food production and consumption models.

12.2 Hunger, Malnutrition and Hidden Hunger

At the beginning of this new millennium, we are still facing an alarming challenge. More than 820 million people in the world are still suffering from hunger while about 2 billion people experience moderate to severe food insecurity (FAO 2019). At the same time, about 2 billion are overweight and/or obese, and there is a steadily increasing number in all countries in the world (WHO 2011). This double burden is found in both poor developing countries as well as in Brazil, Russia, India and China. It is noteworthy that an important fraction of the population in industrialized countries is suffering from poverty too and inadequate food and nutrient intake. The trends for these patterns are quite alarming (CDC 2011), thus highlighting the overall inadequacy of food supply and dietary patterns during the last decades and present time worldwide. Micronutrient deficiencies, for instance, affect an estimated two billion people. Responding properly to the hunger and malnutrition problems requires urgent, resolute and concerted actions particularly in the coastal areas.

Hunger and malnutrition refer to the lack of macronutrients like carbohydrates and protein in the diet. Hidden hunger, unlike the usual forms of hunger like Protein Energy Malnutrition (PEM), is a disorder because of the lack of essential micronutrients in the diet that are absorbed by the body (Uchendu and Atinmo 2010). Micronutrients refer to vitamins and minerals essential for the body's physical and mental development, immune system functioning and various metabolic processes (Burchi et al. 2011). Vitamins are organic compounds needed to maintain health and sustain life. Minerals are inorganic micronutrients needed for metabolic reactions (Chavez et al. 2006). People suffering from hidden hunger may appear healthy and it is considered "hidden" due to the absence of the classic symptoms of hunger (i.e., starvation, "skin and bones" look, protruding abdomen) and to the "invisible" quantity of vitamins and minerals in the food people eat (Uchendu and Atinmo 2010; Burchi, et al. 2011). Even mild levels of micronutrient malnutrition may damage cognitive development, lower disease resistance in children and increase the incidence of childbirth mortality and diminish the quality of life (Pfeiffer and McClafferty 2007). The clinical and epidemiological evidence is clear that selected minerals (iron, calcium, selenium and iodine), and a limited number of vitamins (folate, vitamins E, B6, and A) play a significant role in the maintenance of optimal health and are limiting in diets and fortification of foods by the addition of specific micronutrients has high potential to provide health benefits (DellaPenna 2007). It calls for united efforts by all relevant sectors and at all levels.

12.3 Vegetables, the Functional Food

Vegetables are considered essential for well-balanced diets since they supply vitamins (C, A, B1, B6, B9, E), minerals, dietary fibre and phyto-chemicals (Dias and Ryder 2011). In the daily diet, they have been strongly associated with improvement of gastrointestinal health, good vision, and reduced risk of heart disease, stroke, chronic diseases such as diabetes, and some forms of cancer. A high vegetable diet has been associated with a lower risk of cardiovascular disease in humans (Mullie and Clarys 2011). Some phyto-chemicals of vegetables are strong antioxidants and are thought to reduce the risk of chronic disease by protecting against free radical damage by modifying metabolic activation and detoxification of carcinogens or even by influencing processes that alter the course of tumour cells.

12.4 Crop Genetic Diversity: A Critical Resource

Plant genetic resources have been defined as the "Genetic material of plants, which is of value as a resource for the present and future generations of people" (IPGRI 1993). The plants we use as crops (either directly as food or as fodder for animals) are dependent in terms of resilience and adaptability, on the broad genetic base of variation that exists both in the crops developed over millennia of farmer experimentation, and from their wild relatives (Maxted 2003). The foundation of the current world food supply is based on thousands of years of crop selection and improvement carried out on traits of wild species (Mc Couch 2004). Modern plant breeders and biotechnologists rely on genetic variation in landraces, primitive cultivars, obsolete cultivars, spontaneous mutants, induced mutants and crop wild relatives to produce better adapted, high yielding and high-quality crop varieties. Diversity among individual plants and animals, species and ecosystems provides the raw material that enables human communities to adapt to change—now and in future.

12.5 Biodiversity of Vegetable Crops

Biodiversity is the natural heritage of the planet and is one of the key factors of sustainable development, due to its importance not only for the environmental aspects of sustainability but also for the social and economic ones. Intensive agriculture has generally determined higher productivity, but also a decrease in agro-biodiversity, whose preservation represents a key point to assure adaptability and resilience of agro-ecosystems to the global challenge (to produce more and better food sustainably). Many components of agro-biodiversity would not survive without human interference, but human choices may also represent a threat to agro-biodiversity preservation (Elia and Santamaria 2013).

A study by Bioversity International in collaboration with the FAO revealed that a total 1097 vegetable species, with a great variety of uses and growth forms, are cultivated worldwide. Of the total of 1097 vegetable species cultivated worldwide, 495 species are used for leaves (leafy green and salad crop); 227 species are used for multiple vegetative parts (bulb, root tuber, stem, leaf, etc.); 204 species are used for roots (root crops); 90 species are used for fruits or seeds and 80 species are used for other plant parts like flowers, inflorescences and stems. But hardly, 80 species (less than 7% of the total species) are more familiar to us.

12.6 Farmers' Variety: Vital Resource for Food Security in Coastal Areas

Hard toil given by the farmers over centuries of selection has led to the creation of a plurality of local varieties starting from the domestication of wide agro-biodiversity forms, a precious heritage both from a genetic and a cultural–historical point of view. Therefore, the agro-biodiversity related to vegetable crops has assumed very articulated connotations. It is also important to specify that a "local variety" (also called a landrace, farmer's variety, or folk variety) is a population of a seed- or vegetative-propagated crop characterized by greater or lesser genetic variation, which is, however, well-identifiable and which usually has a local name (Elia and Santamaria 2013). There are still many millions of small farmers, particularly in the marginal agricultural environments and coastal ecosystems unsuitable for modern varieties, who practice traditional agriculture by cultivating a large number of indigenous varieties and landraces (Farmers' varieties or folk varieties) in a wide variety of vegetable crops. The genetic diversity represented in these "Farmers' varieties" remains a vital resource for global food security and economic stability. More than 80% of indigenous, tropical and tropicalized vegetable crops are grown in India with the farmers' varieties. Some Farmers' varieties or heirloom varieties have a higher quality nutritional and taste value than improved varieties and hybrids.

12.7 Biodiversity and Sustainable Nutrition

FAO and Bioversity International in 2010 for the first time, linked the concept of "biodiversity" with "sustainable diets" in exploring solutions for the problems of malnutrition in its various forms while addressing the loss of biodiversity and the erosion of indigenous and traditional food cultures. The purpose was to promote the development of new sustainable food production and consumption models. The alarming pace of food biodiversity loss and ecosystem degradation, and their impact on poverty and health makes a compelling case for re-examining food agricultural systems and diets. Globalization, industrial agriculture, rural poverty, population pressures and urbanization have changed food production and consumption in ways that profoundly affect ecosystems and human diets, leading to an overall simplification of diets. It is time to face the evidence of a worldwide unsustainable food system, particularly in the vulnerable coastal ecosystem. Its complexity makes it extremely fragile to any climatic, socio-economic, political or financial crisis. In that context, we need sustainable diets with low-input, local and seasonal agro-ecological food productions as well as short-distance production–consumption nets for fair trade. The "modern" trend and ways of life and culture are now clearly facing the challenge of sustainability, both in terms of land use for food production, farmers' income and poverty, water availability, pollution of the environment by chemicals and pesticide residues, fossil energy decline and cost, environment and biodiversity degradation, climate change and global warming. Despite an apparent opulence, the complexity of the present food supply system makes it extremely fragile to any climatic, socio-economic, political or as recently financial crisis (Brinkman et al. 2010).

12.8 Integrated Farming System in Coastal Areas

Integrated farming is defined as a biologically integrated system, which integrates natural resources in a regulated mechanism into farming activities to achieve maximum replacement of off-farm inputs and sustain farm income. It is a dynamic and whole farm management system that aims to deliver more sustainable agriculture. The goal of sustainable agriculture is to conserve the natural resource base, protect the environment and enhance prosperity for a longer period. In the Integrated Farming Systems (IFS) a judicious mix of one or more enterprises along with cropping has a complementary effect through effective recycling of wastes and crop residues and encompasses additional sources of income to the farmers. IFS activity is focused around a few selected interdependent, interrelated and interlinking production systems, based on crops, animals and related subsidiary professions. It is a rich source of species diversity, helps in soil building, preserve and improves the ecological condition, soil nutrient cycling essential to long-term sustainability. In all the ecosystems, IFS approach with location-specific models offers gainful employment and is highly profitable and sustainable. Several studies indicate that strategy of homestead vegetable farming with a wide diversity of vegetable crops in the "Integrated Farming System" approach is more successful than other types of agricultural interventions in improving nutritional security. It serves the purpose of household consumption and therefore improves supply and dietary diversity with, particularly vegetables thereby increasing micronutrient intake. Food and nutritional security of the ultra-poor can be significantly enhanced with household production of foods.

12.9 Adoption of Different Technologies for Vegetable Farming in Coastal Areas

12.9.1 Land Embankment Around Ponds in Low-Lying Areas of Sundarban

Most of the lands of Sundarban which is situated both in India and in Bangladesh are low-lying and inundated up to 3 ft during monsoon. Lands are saline and sticky due to high clay content which becomes very hard during winter and summer. Salinity goes down during the monsoon and it rises during summer. Poor drainage system is the characteristic of this region resulting waterlogged conditions during the monsoon. Most of the land is mono-cropped and remains fallow after the harvesting of paddy during the kharif season.

Nimpith Krishi Vignyan Kendra, 24 Parganas (South) conceptualized the "Land embankment system of vegetable farming". In this system, width and height of the land embankment (*Ails*) are raised upto that level where vegetables can be grown both in rainy and winter seasons. The transverse section of this modified land embankment should be like a trapezium, for strengthening the structure. Land embankment along the circumference of 1 ha (10,000 m^2) land having 400 running metre ridge requires 480 m^3 soil. This volume of soil is collected by making a trench surrounding the embankment or by digging a small-sized pond of about 24 m length, 10 m width and 2 m depth within the paddy field itself. The height of the land embankment is raised upto 1.0 m to overcome the inundation problem during the rainy season, keeping the low land paddy field aside. The width of the top of the embankment is made 90 cm where the base remains 150 cm. A wide variety of vegetable crops can be grown successfully on this land embankment in the both rainy and winter seasons (Fig. 12.1).

12.9.2 Floating Vegetable Farming in Bangladesh

Floating gardens are most common in the districts of Gopalganj, Barisal and Pirojpur of Bangladesh. In these areas, from July to October the water level can rise at least

Fig. 12.1 Vegetable farming on the land embankment in Sundarban, 24 Parganas (South), West Bengal, India

10 feet. When the fields flood, the farmers have no work. The concept of floating vegetable farming emerged from the kind of soil-free cultivation which exists in different parts of the world, such as Dal Lake in Kashmir, Loktak Lake in Manipur and Inle Lake in Myanmar where people have adapted to living on the water.

In this farming system, farmers stack several compact layers of aquatic weeds like water hyacinth, duckweed along with paddy stubble and place them on stagnant water, beating them into shape and making rafts. The weeds are allowed to rot and then mixed usually with cow dung and silt. Crop seeds are placed in small balls that are made out of peat soil, and wrapped in coconut fibre. After a week, when seedlings are about 15 cm high, they are transplanted to the floating garden beds. Traditionally, seeds of leafy vegetables, like red amaranth, are sown directly on the floating beds. They are then anchored with bamboo poles, so that they do not drift away. A typical floating bed is about 20ft long, but it can be as long as 180ft and provides enough food for the farmer and their family, and a source of income when the surplus is sold.

Another form of floating farm with a duck coop, fish enclosures and vegetable garden moored by rope to the river bank is very popular in the Pabna District of Bangladesh. The area is enclosed by a net so that fish cannot move beyond the boundary. The coop is attached to bamboo rods that make up two rows of fish enclosures where tilapia is farmed in blue plastic nets. The outer rails of bamboo support the garden. Old plastic containers cut in half and filled with soil and organic matter which float on the water are used to grow different vegetable crops particularly cucurbits like cucumber, pumpkin, bitter gourd and ridge gourd along with indeterminate varieties of beans (Fig. 12.2).

Fig. 12.2 Floating vegetable farming integrated with fishery and duckery in Pabna District of Bangladesh

12.10 Conclusions

The people of coastal zones depend mainly on low productive agriculture due to constraints such as prolonged waterlogging after the wet season, saline soils, and scarcity of good quality irrigation water in the dry season. In the coastal areas, adoption of several farming systems like floating garden and embankment cultivation need to be adopted for mixed cropping system that encompasses vegetables, fruits, plantation crops, spices, herbs, ornamental and medicinal plants as well as livestock that can serve as a supplementary source of food and income. Hence, it is urgently required to develop different models to utilize the agricultural biodiversity, resilient ecosystems and cultural heritage in the scientific method for producing fresh vegetables and fruits to meet up the food and nutritional security of the farmers of the coastal areas.

References

Brinkman HJ, de Pee S, Sanogo I et al (2010) High food prices and the global financial crisis have reduced access to nutritious food and worsened nutritional status and health. J Nutri 140:153S-S161

Burchi F, Fanzo J, Frison E (2011) The role of food and nutrition system approaches in tackling hidden hunger: review. Int J Environ Res Public Health 8:358–373

CDC (2011) Centre for disease control and prevention. United States Department of Health and Human Services, USA

Chavez LL, de Leon SY, Claudio VS (2006) Basic foods for Filipinos, in Jamorabo-Ruiz A (ed) Merriam and webster bookstore, Manila, Philippines
Della Penna D (2007) Biofortification of plant-based food: enhancing folate levels by metabolic engineering. Proc Nat Acad Sci 104:3675–3676
Dias JS, Ryder E (2011) World vegetable industry: production, breeding, trends. Hort Rev 38:299–356
Elia A, Santamaria P (2013) Biodiversity in vegetable crops, a heritage to save: the case of Puglia region. Ital J Agron 8:21–34
FAO (2019) The state of food security and nutrition in the world 2019. FAO, Rome
IPGRI (1993) Diversity for development. International Plant Genetic Resources Institute, Rome, Italy
Maxted N (2003) Conserving the genetic resources of crop wild relatives in European protected areas. Biol Conserv 113:411–417
Mc Couch SR (2004) Diversifying selection in plant breeding. PLOS Biol 2:e347. https://doi.org/10.1371/journal.pbio.0020347
Mullie P, Clarys P (2011) Association between cardiovascular disease risk factor knowledge and lifestyle. Food Nutr Sci 2:1048–1053
Pfeiffer WH, McClafferty B (2007) Harvest plus: breeding crops for better nutrition. Crop Sci 47:S88–S105
Uchendu FN, Atinmo T (2010) The silent and neglected crisis of malnutrition: scientific evidence for taking decisive action. Global J Health Sci 3:193–202
WHO (2011) World Health Organization United Nations, Switzerland, Geneva

Chapter 13
Managing Major Insect Pests of Mango in the Southern Coastal Belts of India

Abraham Verghese, B. R. Jayanthi Mala, and M. A. Rashmi

Abstract Mango has the potential to be a major horticultural crop of coastal lands of South India, which has a long coastline stretching from Karnataka in the west, way down southward to Kanyakumari, and further northwards to the east coasts up to Andhra Pradesh. Here, mango is found in perhaps two lakh hectares. Surveys were frequently being conducted to these areas in the last two decades mainly for augmenting mango through improved plant health. It was observed that mango could become a major crop here like in the Konkan region of Maharashtra provided plant health appropriate to the region is taken up. There are two types of mango 'systems' prevalent in these coastal areas: one, the small backyard 'orchards' of Kerala and Goa, and two, the large orchards in Tamil Nadu and Andhra Pradesh. The coastal climate is hot and humid supports a different flowering behaviour with flowering throughout the year especially on the west coast, from Thiruvanathapuram southwards to Kanyakumari. Along the coast, many major pests occur in mango. Managing pests scientifically not only bring income to farmers but also contribute to area expansion. With labour shortage producing residue-free mangoes for both local and export markets on the coasts is a worthwhile farm enterprise. As coastal areas are more prone to cyclones and stormy winds accompanied by heavy rains growing annuals and vegetables may be risky. Mango with deep planting and earthing-up will be less lodging prone. Mango is therefore a viable agrarian strategy on the coasts, and farmers can be encouraged to take it up provided a viable and economic and residue-free pest management is made available to the farmers. These are discussed in this paper integrating insecticidal and non-insecticidal methods.

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13.1 Introduction

Mango (*Mangifera indica*) has the potential to be a major horticultural crop in the coastal region of South India stretching from Karnataka in the west, way down southward to Kanyakumari, and further northwards to the east coasts up to Andhra Pradesh. In this region, there are about two lakh hectares under mango. Mango could become a major crop here, like in the Konkan region of Maharashtra. There are two types of mango 'systems': one, the small backyard 'orchards' of Kerala and Goa, to large orchards in Tamil Nadu and Andhra Pradesh. In the former, there would be a single tree to a dozen, often scattered. The coastal climate is hot and humid and supports a different flowering behaviour with flowering throughout the year from Thiruvanathapuram southwards to Kanyakumari. Along the coast, five major pests occur in mango. These are mango hopper (*Idioscopus* spp), stone weevil (*Strenochetus mangiferae*), fruit fly (*Bactrocera* spp), the borer (*Deanolis albizonalis*—only in the eastern districts of Andhra Pradesh), thrips (*Scirtothrips dorsalis*) and mealybugs (*Rastrococcus iceryoides*). Managing these pests cannot only bring income to farmers but also contribute to area expansion. With labour shortage especially in Kerala, and less profitability of rice, producing residue-free mangoes in the coasts for both local and export markets is a worthwhile economic strategy. This is possible only if viable and economic pest management strategies that ensure residue-free fruits is made available to the farmers. Following is a brief treatise of the major insect pest of mango, their distribution, bioecology and management.

13.2 Mango Hoppers, *Idioscopus nitidulus* (= *I. niveosparsus*), *I. clypealis, Amritodus atkinsoni* and *Amrasca splendens* (Cicadellidae: Hemiptera)

Mango leafhoppers are the most economically important insect pests of mango during the flowering stage.

13.2.1 Distribution

In India, these hoppers are widely distributed in all the mango-growing regions including coastal areas. Among these, *I. nitidulus* is the dominant species.

13.2.2 Nature of Damage

The hoppers are found in abundance during November–February synchronizing with the flowering of mango trees. Both the nymphs and adults suck the sap from the inflorescence in large numbers causing withering and shedding of flower buds and flowers which result in heavy loss ranging from 25 to 60% of fruit setting. The honeydew excreted by them affords conditions for the development of sooty mould. Egg-laying also inflicts injury to the inflorescence. During the remaining part of the year, they occur in small numbers inside barks or on leaves of mango.

13.2.3 Identification (Srinivasa et al. 2017)

13.2.3.1 *A. atkinsoni*

Adults with yellowish-brown colour, face, yellow, two prominent round black spots on anterior margin of the face near to crown. Pronotum with two black somewhat triangular spots at the apex. Scutellum with two basal black triangle patches. Attack inflorescence and shoots.

13.2.3.2 *I. clypealis*

Yellowish, face yellow colour. Two prominent round black spots apex of face. Pronotum without a spot. Scutellum with two basal dark triangle patches. Attack inflorescence (Fig. 13.1).

13.2.3.3 *I. nitidulus*

I. nitidulus is slightly smaller with three spots on the scutellum and a prominent white band across its light brown wings. Pronotum with diffused dark brown or black markings with an irregular pattern. Attack inflorescence and shoots (Fig. 13.1).

13.2.3.4 *Amrasca splendens*

Adults are greenish-yellow with brown markings on the head, thorax and tegmen. The female hopper inserts the eggs into a new flush. *A. splendens* attacks only new shoots mainly in March–April (Fig. 13.2). However, it can occur throughout the year (Verghese and Devi Thangam 2012).

Fig. 13.1 Leafhoppers, *I. nitidulus* and *I. clypealis*

Fig. 13.2 Damage symptoms by *Amrasca splendens*

13.2.4 Management Strategies

13.2.4.1 Cultural Control

- Avoid close planting, as the incidence is very severe in overcrowded orchards.
- Open the tree canopy from the centre to enable light penetration to reduce incidence.
- Orchards must be kept clean by ploughing and removal of weeds.

13.2.4.2 Mechanical Control

Monitor using yellow sticky sheet traps (2 × 3 sq ft). The sticky traps would be a useful tool in predicting the population outbreak and also bringing about an efficient management strategy. About 15 traps per acre can be used for surveillance (Verghese et al. 2012; Verghese and Devi Thangam 2012).

13.2.4.3 Chemical Control

- For effective management of mango leafhoppers, insecticidal sprays should be given at the time of panicle emergence during November–December months. It is recommended to avoid sprays at the full bloom stage of mango flowers to save pollinators.
- At low hopper density, spray Azadirachtin 3000 ppm @ 2 mL L^{-1} or Azadirachtin 10,000 ppm @1 mL L^{-1}. This is to be given at pre-bloom stage and is ideal for organic orchards (Verghese and Devi Thangam 2012).
- Spray imidacloprid 0.3 mL L^{-1} at the time of panicle emergence, and second spray if necessary after full bloom (Verghese 2000a).
- Field experiments conducted by Sharanabasappa et al. (2018) revealed that the population of leafhoppers before the first spray ranged from 26.00 to 31.00 nymphs and adults per panicle. However, on the 7th day after the first spray, dinotefuron 20 SG @ 300 g ha^{-1} recorded significantly the lowest number of nymphs and adults per panicle (0.33) followed by buprofezin 25 SC @ 200 ml ha^{-1} (1.00), thiamethoxam 25 WG 250 g ha^{-1}, acetamiprid 20 SP @ 500 g ha^{-1} and imidacloprid 70 WG @ 250 g ha^{-1} that recorded 1.00, 1.00, 1.17 and 1.50 nymphs and adults per panicle, respectively. The untreated check recorded 52.25 nymphs and adults per panicle.
- Different eco-friendly management options were tried against mango leafhoppers at Dharwad, Karnataka, India. The combined application of azadirachtin 10,000 ppm (1 mL L^{-1}) along with *Lecancillium lecanii* (2 g L^{-1}) was comparable to that of bufrofezin 25 EC (1.25 mL L^{-1}) (Manjunatha and Shashidhar 2015).
- Poornima et al. (2018) studied the management of mango hoppers under a high-density planting system with newer molecules. Their findings showed that

thiamethoxam 25% WG @ 0.3 g L^{-1} was found to be significantly superior in suppressing the mango hoppers (1.15 $\text{inflorescence}^{-1}$) after 14 days of third spray, while lambda-cyhalothrin 5EC @ 0.5 mL L^{-1} and imidacloprid 17.8% SL @ 0.25 mL L^{-1} were next best in reducing the hopper population to an extent of 4.75 $\text{inflorescence}^{-1}$ and 5.58 $\text{inflorescence}^{-1}$, respectively.

13.3 Mango Fruit Fly, *Bactrocera dorsalis, B. caryeae* (Tephritidae: Diptera)

The oriental fruit fly *Bactrocera dorsalis* (Hendel) (Diptera: Tephritidae) is a direct pest on mango, In India, the loss in fruit yield ranges from 1 to 31% with a mean of 16% (Verghese et al. 2002).

13.3.1 Distribution

Bactrocera is widely distributed in the Oriental region; hence, it is also called oriental fruit fly. On the west coast, *B caryeae* dominates while on the east coast, only *B dorsalis* is found.

13.3.2 Nature of Damage

The female flies lay eggs just below the fruit epidermis (1–4 mm deep) when the fruits are semi-ripe. On hatching, the maggots feed on the pulp of those fruits. As a result, a brown patch appears around the place of oviposition and the infested fruits start rotting. These affected fruits drop down prematurely and the maggots come out from these fallen fruits to pupate in the soil. Semi-ripe fruits are attacked usually by April–May.

13.3.3 Life History

The adult fly is light brown with transparent wings. A single female can lay 150–200 eggs in about a month. The eggs are laid in clusters of 2–15 eggs below the rind on semi-mature to mature fruits. The maggots on hatching pass through three instars inside the pulp. For pupation, the maggots come out of the fruit and drop to the ground. Pupation usually takes place 20–50 mm below the soil surface (Fig. 13.3a, b).

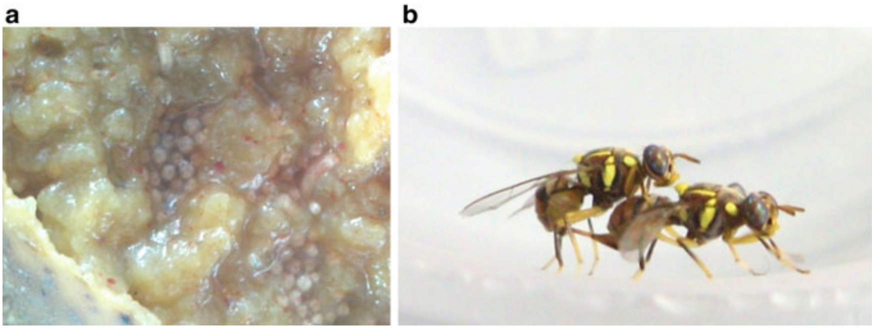

Fig. 13.3 **a** Maggots in infested fruit, **b** *Bactrocera dorsalis* mating

13.3.4 Management Strategies

13.3.4.1 Cultural Control

- The best way to avoid infestation of fruit flies is to harvest the fruits at 75–80% maturity.
- To check the carryover of the pest, collect and destroy all fallen fruits.
- Plough around the trees during winter to expose and kill the pupae.

13.3.4.2 Physical Control

- Post-harvest treatment of fruits with hot water for 1 h at 46 °C to kill the eggs and first instar present inside the fruits (Verghese et al. 2006).

13.3.4.3 Chemical Control

- Install at least eight para pheromone plywood traps per acre with two drops of Spinosad on the plywood before erecting the traps. Four traps may be placed in the borders of the orchard. These traps may cause male annihilation but normally are surveillance tools. If indicative populations are found in the traps, the following should be taken up:
- Three to four weeks before harvest 2–4 sprays with azadirachtin (3000 ppm) 2 mL L^{-1} should be given mainly on the trunks and canopy. Note: No chemical insecticides should be given.

13.4 Mango Nut Weevil or Stone Weevil, *Sternochaetus mangiferae,* (Curculionidae: Coleoptera)

The mango stone or nut weevil (MSW) *Sternochetus mangiferae* (Fabricius) (Coleoptera: Curculionidae) is a monophagous pest of mango. It is widely distributed in almost all mango areas of the world except the Canary Islands, Italy, Israel and Egypt (Tandon and Verghese 1985; IIE 1995).

13.4.1 Distribution

The pest is very common in the southern coasts of India, especially in Kerala, Kanyakumari, Visakhapatnam and Srikakulam. Incidence is more in late fruit-bearing varieties. It is a monophagous pest of mango. Neelam, Suvarna Rekha and Totapuri varieties are highly susceptible.

13.4.2 Biology

The adult is dark brown (about 6 mm long) weevil lays eggs under the rind or on the epicarp. On the seed coat, the larva initially mines in a zigzag manner and later enters the seed where it passes through five larval instars and a pupal stage in 35–54 days (Shukla and Tandon 1985; De and Pande 1988; Verghese 2000b). Grubs are creamy yellow, apodus and pupation occurs in the nut itself. The emerged adults usually remain inside the nut until they are thrown away after consuming. Occasionally, the weevil bores out of the fruit.

13.4.3 Nature of Damage

Eggs are laid singly on the epicarp of partially developed fruits (when they are marble or lime sized) or under the rind of ripening fruits by scooping the rind. The late appears in the shape of ‘T’ (Pradhan 1969). The grubs as soon as they hatch out from the eggs tunnel in a zigzag manner through the pulp, and the seed coat and finally reach the seeds. As the fruit develops the tunnels get closed up. The grubs feed on the cotyledons and destroy them and pupate there itself. The adults which emerge from the pupae also feed on the developing seed, and this may hasten the maturity of infested fruits and fall down. The adults hibernate in between the crevices on the tree trunks for nearly 7–8 months and remain inactive until the next flowering season (Balock and Kozuma 1964; De and Pande 1988). The weevil attacks only mango.

13.4.4 Symptoms of Attack

'T'-shaped resinous oviposition marking is observed on fruits of 2.5 or more diameter (Nagaraju 2005).

13.4.5 Management

- Collect and destroy all fallen fruits.
- Spray main trunk, primary branches and the junction of branches prior to flowering with chlorpyriphos @ 2 mL L^{-1} to control adult beetles hiding in the bark.
- The damage due to nut weevil can be minimized appreciably by spraying imidacloprid (recommended for hoppers) on the tree trunks and branches while spraying for hopper control.

13.5 Mango Stem Borer, *Batocera rufomaculata* (Cerambycidae*:* Coleoptera)

13.5.1 Distribution

Widely distributed all over India attacking apart from mango and other trees such as fig, rubber, jackfruit, eucalyptus and mulberry. The mango varieties, Alphonso and Malgoa, are highly susceptible to the attack of this insect.

13.5.2 Nature of Damage

Eggs are laid singly either in the slits of tree trunks or in the cavities in the main branches and stem. The grubs on hatching feed by boring through the bark of branches and cause wilting, though it is an occasional pest of importance, in case of severe attack the trees succumb. Normally, the attack goes unnoticed till the branches start drying up. Sometimes sap and frass may be seen exuding from the bored holes.

13.5.3 Life History

The adult beetle has two pink dots and lateral spines on the thorax and measures about 50 mm long. The eggs are laid singly on the bark or in crevices on the tree trunk or branches and hatch in about 1–2 weeks. Eggs are twice the size of a split red gram. The grub feeds for 3–6 months (7 instars) and pupates inside the tunnel itself. Pupation takes place in the tunnel and lasts for 20–25 days. The total life cycle takes 170–190 days, and adult longevity is 60–100 days.

13.5.4 Management Strategies

- The attacked portions should be chipped and cleaned and swabbed with sealer cum healer an invention of ICAR-Indian Institute of Horticultural Research (IIHR), Bangalore, now commercially available.
- The most effective treatment is sealer cum healer of IIHR. This powder formulation is mixed in water in a ratio of 400 g for every litre of water to bring it to a gel form or melted ice cream consistency. This is to be applied on the damaged portion of the mango stem using a 2 or 3 inch brush. The swabbed formulation is allowed to dry on the trunk so that it works as a repellent, and as well as curative treatment to neutralize the eggs, early instars of larvae and grubs living in the stem (Shivananda et al. 2012).

13.6 Mango Mealybug, *Rastrococcus iceryoides, R. invadens* and *R. mangiferae* (Psuedococcidae: Hemiptera)

13.6.1 Distribution

These are unevenly and sparsely distributed in the coastal areas.

13.6.2 Nature of Damage

They suck the plant-sap clustering in masses on young shoots, leaves, fruits. When they are in large number, they devitalize the plant and produce honeydew which encourages the growth of sooty mould, giving a very unhealthy look to the plant as a whole (Fig. 13.4).

13.6.3 Biology

The life stages of female mealybug consist of four instars, viz. first, second and third instars and adult. Males have an additional pupal stage from which they emerge as

Fig. 13.4 Mango mealybug, *Rastrococcus iceryoides*

delicate bi-winged insects with long-tailed filaments. Most of the mealybug species reproduce both sexually and parthenogenetically. Eggs are laid by the adult female among the filamentous secretion of the ovisac formed by pores on the adults' body (Borror et al. 1992). After 3–16 days, the eggs hatch into the first instar. First instars are always mobile, consist of three pairs of legs and are known as 'crawlers' because they crawl to a spot where they can feed and continue to mature. In this stage, they possess comparatively large legs and antennae when compared to other instars. First instar mealybugs spread through the wind. Once crawlers find a spot on a plant, settle to become immobile and sessile insects (Williams 2004).

The second instar nymph emerges through a slit exit in the medio-dorsum of the head and thorax of the first instar. In this stage, it is possible to differentiate between male and female mealybugs. Second instar males have more pores and ducts than second instar females (Williams and Watson 1988).

13.6.4 Management

13.6.4.1 Cultural Control

- Prune the affected area and bury in the soil.

13.6.4.2 Biological Control

- Release of ladybird beetle, *Cryptolaemus montrouzieri* @ 50 tree^{-1} will minimize the mealybug infestation (Mani et al. 1995; Nagalakshmi et al. 2017).

13.6.4.3 Chemical Control

- If necessary, in nurseries spray chlorpyriphos 20EC 2.5 mL L^{-1}.

13.7 Red Banded Mango Caterpillar, *Deonalis sublimbalis* (Crambidae: Lepidoptera)

The lepidopteran fruit borer, *Deanolis sublimbalis* Snellen (commonly called as red banded mango caterpillar), other synonyms are *Deonalis albizonalis* Hampson, *Noorda albizonalis* Hampson, *Autocharis albizonalis* Hampson (Royer 2008) is a specific pest of mango fruits distributed in the tropical regions of South and South-East Asia. Jha and Sarkar (1991) reported this pest from the Malda region of West Bengal. Subsequently, in the coastal region of Andhra Pradesh, it has become a serious pest on most mango varieties. The larval stage is quite destructive and feeds on all developmental stages of the mango fruit causing damage up to $\leq$55% and has become a major threat for mango cultivation (Zaheruddeen and Sujatha 1993).

13.7.1 Bioecology

The insect passes through five larval instars in 11–13 days. The incubation, pre-pupal and pupal period lasts for 2–3 days, 4.5–6 days and 9–11 days, respectively. Two to three overlapping generations were found only during the fruiting season and in the off-season, they hibernate as pre-pupae inside the cracks and crevices of the tree. Pupation was observed inside the dry branches and crevices of the bark of the mango plant. In the field, one to three mango fruits were found to be damaged by a single larva. On the other hand, more than one larva could also be recorded in one mango. The longevity of the adult was found to be 5–6 days in females and 1–2.5 days in males. The first-generation larvae attacked the fruits during the second to the third week of March, and peak infestation was observed during the first week of April and then the population was found to decline (Sahoo and Jhab 2009).

13.7.2 Management

This is a difficult pest to manage. Spraying the trunks with contact insecticides during off-season mitigates infestation the following year.

Fig. 13.5 Damage symptoms by thrips on leaves and fruits

13.8 Thrips: *Scirtothrips dorsalis* (Thripidae: Thysanoptera)

The thrips, *Scirtothrips dorsalis,* is the major pest of mango recorded in the Konkan region of Maharashtra. The nymphs and adults were found to lacerate the epidermis of tender leaves resulting in the development of brownish patches on the leaf surface resulting in leaf fall in a severe stage. The incidence of thrips was noticed on tender foliage during November for a shorter period; on inflorescence during December to January; and on fruits during January–February (Fig. 13.5).

13.8.1 Management

Spraying with Fipronil @1 mL L^{-1} during the new flush or inflorescence stage can minimize the damage at the early fruit maturation stage.

13.9 Mango Fruit Borer, *Citripestis eutraphera*

The mango fruit borer, *C. eutraphera*, a species of snout moth was described by Meyrick in 1933 and geographically distributed in Java, Indonesia, India and Northern Territory in Australia. However, in India, the only official record of *C. eutraphera* is from Andaman Islands (Bhumannavar 1991) and this is the first record from the country. It is believed to have spread from the Andamans to mainland perhaps through immature fruit movement (Soumya et al. 2016).

13.9.1 Nature of Damage

The larva bores and feeds on immature mango fruits causing extensive fruit damage. The infested fruits will have bored holes with frass and the fruit often blackened around the bored area. Several infested fruits also exhibit split. The young larvae scrape the fruit skin causing a characteristic scab-like patch, and the later stage larvae are found boring into the fruit. Even the adjacent fruits were found bored indicating that a single larva can damage several fruits. Premature fruit drop will be seen. This damage is easily detected in the field, and damaged fruits are unlikely to be harvested causing huge losses to farmers (Jayanthi et al. 2014).

13.9.2 Management

- Collection and destruction of all fallen fruits.
- Spray at marble size onwards with Deltamethrin 0.0028% or Azadirachtin 10,000 ppm @ 1 mL L^{-1} and repeat after two weeks in case of heavy infestation. Avoid all sprays from a fortnight prior to the harvest.

13.10 Conclusions

Mango pest management in the coasts is almost the same as elsewhere in South India. However, the threshold levels of pests, timing of spray, frequency of sprays, etc., differ. Humidity and rainfall spur new flush and staggered flowering, favouring pest multiplication. Specific management research should be initiated for mango in coasts as the area is expanding, justifying the need for more attention. Mango is replacing cereals, vegetables and even certain perennials like coconut on account of its cyclone resilience. There is also the issue of quarantine when fruits and mango grafts are to be moved or sold. Two important pests have to be mentioned: one the fruit fly *Bactrocera caryeae* exclusive to the west coast and *Deonalis altrizonalis* exclusive to the east coast must not be allowed to criss-cross the land in between. Local quarantining is also advocated as a part of the pest management protocol.

References

Balock TW, Kozuma TT (1964) Note on the biology and economic importance of the mango weevil, *Sternochetus mangiferae* (Fabricius), in Hawaii (Coleoptera: Curculionidae). Proc Hawaiian Entomol Soc 18:353–364

Bhumannavar BS (1991) Record of *Citripestis eutraphera* Meyrick (Pyralidae: Lepidoptera) on mango *Mangifera indica* in India. J Bombay Nat Hist Soc 88(2):299

Borror DJ, Triplehorn CA, Johnson NF (1992) An introduction to the study of insects. Saunders College Publishing, Florida

De K, Pande YD (1988) Bionomics and some behavioural aspects of the mango stone weevil *Sternochetus mangiferae* (Fab.) (Coleoptera: Curculionidae). Entomon 13:17–24

IIE (1995) Distribution maps of plant pests, vol 180. CAB International, Wallingford, UK

Jayanthi KPD, Verghese A, Shashank PR et al (2014) Spread of indigenous restricted fruit borer, *Citripestis eutraphera* (Meyrick) (Lepidoptera: Pyralidae) in mango: time for domestic quarantine regulatory reform. Pest Manag Hort Ecosyst 20(2):227–230

Jha S, Sarkar A (1991) Mango in Malda. Bidhan Chandra Krishi Viswavidyalaya, Mohanpur, West Bengal, India

Mani M, Krishnamoorthy A, Pattar GL (1995) Biological control of the mango mealybug, *Rastrococcus iceryoides* (Green) (Homoptera: Pseudococcidae). Pest Manag Hort Ecosyst 1(1):15–20

Manjunatha R, Shashidhar V (2015) Eco-friendly management of mango leafhoppers in organic production system. J Exp Zool 18(2):883–886

Nagalakshmi G, Verghese A, Thangam SD et al (2017) Advanced prediction to facilitate biocontrol of the mealybug *Rastrococcus iceryoides* (Green) in organic mango orchards. Can Entomol 150(1):116–119

Nagaraju DK (2005) Studies on the adult ethology life budget and growth models of mango stone weevil *Sternochetus mangiferae* (Coleoptera: Curculionidae) on mango. Ph.D. Thesis, Kuvempu University, Shimoga, Karnataka

Poornima MH, Gopali JB, Athani SI et al (2018) Impact of ultra high density, high density and conventional planting systems on major insect pests of mango. J Entomol Zool Stud 6(6):292–297

Pradhan S (1969) Insect pests of crops. National Book Trust India, New Delhi

Royer J (2008) Red banded mango caterpillar threat specific contingency plan. Department of Primary Industries and Fisheries, Queensland, Australia

Sahoo SK, Jhab S (2009) Bio-ecology of mango fruit borer, *Autocharis (=Noorda) albizonalis* Hampson. (Pyralidae; Lepidoptera) - a recent threat to mango growers in West Bengal. India. Acta Hortic 820:601–610

Sharanabasappa PHB, Maruthi MS, Nagarajappa A (2018) Efficacy of different newer insecticides against mango leaf hoppers. J Entomol Zool Stud 6(1):834–837

Shivananda TN, Verghese A, Hegde MR et al (2012) Management of mango trunk borers using sealer cum healer. Technical bulletin no. 72/12, ICAR-Indian Institute of Horticultural Research, Bangalore, Karnataka, India

Shukla RP, Tandon PL (1985) Bio-ecology and management of the mango weevil, *Sternochetus mangiferae* (Fabricius) (Coleoptera: Curculionidae). Int J Trop Agric 3:293–303

Soumya BR, Verghese A, Jayanthi PD et al (2016) Need to strengthen quarantine between Andaman and Nicobar Islands and mainland India. Curr Sci 111(11&10):1753–1756

Srinivasa N, Ramya N, Naresh MM (2017) Taxonomic studies of leafhoppers (Hemiptera: Cicadellidae) fauna associated with mango from India. Int J Curr Microbiol App Sci 6(10):2108–2124

Tandon PL and Verghese A (1985) World list of insect, mite and other pests of mango. Technical document no. 5, ICAR-Indian Institute of Horticultural Research, Bangalore, Karnataka, India

Verghese A, Devi Thangam S (2012) Mango hoppers and their management. Folder no 71–11, Atic Series 31–11, ICAR-Indian Institute of Horticultural Research, Bangalore, Karnataka, India

Verghese A, Devi Thangam S, Geetha GT (2012) Management of mango hoppers *Idioscopus* spp. and *Amritodus* spp. (Cicadellidae: Hemiptera). Paper presented at the XXIV international conference on entomology, Daegu, Korea, 19–24 August 2012

Verghese A, Madhura HS, Jayanthi KPD et al (2002) Fruit flies of economic significance in India, with special reference to *Bactrocera dorsalis* (Hendel). Proceedings of 6th international fruit fly symposium held between 6–10 May 2002, Stellenbosch, South Africa, pp 317–324

Verghese A, Sreedevi K, Nagaraju DK (2006). Pre and post-harvest IPM for the mango fruit fly, *Bactrocera dorsalis* (Hendel). In: Proceedings of the 7th international symposium on fruit flies of economic importance, Salvador, Brazil, 10–15 September 2006, pp 179–182

Verghese A (2000a) Effect of imidacloprid, lambda cyhalothrin and azadirachtin on the mango hopper, *Idioscopus niveosparsus* (Leth.) (Homoptera: Cicadellidae). Acta Hortic 509:733–736
Verghese A (2000b) Recent studies on the management of mango stone weevil *Sternochetus mangiferae* fab. (Coleoptera : Curculionidae) in South India. Acta Hortic 509:819–822
Williams DJ, Watson GW (1988) The scale insects of the tropical south Pacific region, part 2, the mealybugs (Pseudococcidae), CAB International, Wallingford, UK, p 260
Williams DJ (2004) Mealybugs of southern Asia. The Natural History Museum, London, UK, p 896
Zaheruddeen SM, Sujatha A (1993) Record of *Deanolis albizonalis* (Hampson) (Pyralidae: Odontinae) as mango fruit borer in Andhra Pradesh. J Bombay Nat Hist Soc 90(3):528

Chapter 14
Advances in Banana (*Musa acuminata, M. balbisiana* Colla) Production Technologies for the Coastal Ecosystems

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Abstract Banana (*Musa acuminata, M. balbisiana* Colla) forms a major component in coastal agroecosystems in tropical and subtropical zones. The major banana-growing countries and territories are analysed with respect to the area in the coastal zones. This chapter reviews the latest research work across the globe on banana in coastal agroecosystems. The constraints and opportunities for banana production in coastal ecosystems with reference to suitable cultivars, agroforestry systems, poly-house cultivation, biotic and abiotic stress factors are described in brief. Grand Nain and other Cavendish cultivars are found suitable at the coastal locations. Dwarf banana cultivars are found to perform well in agroforestry systems. The chapter also highlights the strategies for handling various challenges in the banana crop. Research on the protected cultivation of banana in the subtropical coastal zone is emphasized to augment banana production to meet the local requirements. Wind, salinity, potassium deficiency and shade are the major constraints in the cultivation of banana in coastal ecology. The impact of salinity stress in banana cultivation and the reduction in fruit yield due to salinity is discussed. A new rapid method for measuring foliar sodium, potassium contents is highlighted. The climate change vulnerability is also experienced in the banana crop which can shift the banana growing areas. The predicted increase in air temperature in future and possible impacts on banana crop and shifts in the suitable area under cultivation, simple strategies to mitigate the impacts are discussed which include high-density planting to provide mutual shade, increasing the banana area under agroforestry systems especially under coconut, arecanut, coffee, cocoa and Inga tree crops.

Keywords Agroforestry · Climate change · High-density planting · Musaceae · Plantains

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14.1 Introduction

The top five banana (*Musa acuminata, M. balbisiana* Colla) producing countries (India, China, Philippines, Brazil and Ecuador) grow banana in coastal ecosystems. Coastal districts of India especially in Andhra Pradesh (Guntur, East Godavari, West Godavari, Vizhianagaram), Gujarat (Anand, Bharuch, Surat), Tamil Nadu (Cuddalore, Kanyakumari, Tuticorin, Pudukkottai, Thanjavur, Tirunelveli) produce more than 0.1 million tonnes of banana bunches per year. Hainan island of China, Island of Mindanao, Soccskargen, Davao, of Philippines, Bahia, Rio de Janeiro of Brazil and Gauyas of Ecuador are the major banana producing regions of the coastal world. Other coastal banana ecosystems include the Coastal Alabama of USA, Columbia, Canary Islands, Malaysia, Bangladesh and Australia (https://www.promusa.org/).

Nearly 15–16% area or production of banana in India is in the coastal ecosystem (Table 14.1). The productivity of banana in coastal regions of India is one-half or one-third compared to the national average of India (Table 14.2). Yellow Sigatoka leaf spot, fusarium wilt, salt stress and heavy winds cause severe damage to banana plants of the coastal zone. Short-statured plants that can withstand moderate wind stress are most suited for growing in coastal areas. Banana is often grown as inter/mixed crop in coconut and arecanut gardens in the coastal zone. Salt stress causes significant yield reduction in the banana crop.

Table 14.1 Area and production of banana and plantains in coastal vis-à-vis entire country

	Area (ha)	Production (metric tonnes)
Coastal districts	134,442	4,554,298
India	830,000	29,780,000
%share	16.20	15.29

Source Directorate of Economics and Statistics (2012) from data.gov.in

Table 14.2 Productivity of banana in coastal India

	Productivity of banana (t ha^{-1})
National average	34.2
Coastal Tamil Nadu	24.5
Coastal Odhisa	16.3
Goa	25
Kerala	8.7

Source National Horticulture Board (2012)

14.2 Suitable Varieties

Banana varieties 'Pache Bontha Bathesa' (ABB), 'Udhayam' (ABB) and 'Grand Naine' (AAA) were found suitable for the West Coast of India (Sawant et al. 2016). Rasthali (AAB) was found to be the best banana variety with yield and quality for the South Karnataka coast of India (Uthaiah et al. 1992). NRCB Selection-10 and BRS Selection Popoulu cultivars are found suitable banana varieties for coastal Odisha in eastern India (Jena et al. 2020). Double, Grand Nain, and Cardaba cultivars of banana performed well under the cool coastal Alabama of USA (Vinson et al. 2018). Veinte Cohole is found to be a suitable short-cycle banana cultivar suitable for the cool subtropical region of Georgia coast of USA (Fonsah et al. 2010). In Puerto Rico coastal region with semi-arid climate, Ziv and Grand Nain banana cultivars are found suitable with drip irrigation (Irizarry et al. 1989).

Dwarf cultivars, Mas and Goroho dessert banana and plantain groups, respectively, are suitable for intercropping under coconut palm (Malia 2021) at North Sulawesi of Indonesia, whereas Dwarf Cavendish performed well under coconut gardens at Goa state, India (Devi et al. 2011). Banana varieties differed in their suitability as intercrop in areca gardens (Muralidharan and Nayar 1979).

14.3 Crop Management

Banana planted at 1600 plantains per hectare at two suckers per mat gave good yield in Nigeria (Obiefuna et al. 1982). The use of 250 g nitrogen and 200 g potassium per plant in coastal Odisha, India, gave a good yield of banana (Kumar et al. 2008). Time of desuckering (at 30 cm) is crucial in ensuring banana yield at the river coast of Kampala Uganda (Odeke et al. 1999). Banana is the most preferred mid-tier intercrop in agroforestry systems. The major other component perennial crops include coconut, arecanut, grevillea, inga, coffee, cocoa (Norgrove 1998). Intercropping of banana in coconut (Devi et al. 2011) or areca (Muralidharan and Nayar 1979) gardens are common in India and in the juvenile rubber plantation of Sri Lanka (Rodrigo et al. 2005). Banana is a preferred companion crop for coffee (van Asten et al. 2011) and cacao (Niether et al. 2019)-based agro-forestry systems. Greenhouse cultivation is emerging as a source of banana supply in subtropical coastal locations (Galán Saúco et al. 2004). Greenhouse offers advantages by providing the required number of hours above 20^0C, the suitable temperature for banana cultivation. Cultivation of banana under protected structures is practised to protect the crop from the low temperature in Turkey (Gubbuk and Pekmezci 2004).

14.4 Biotic and Abiotic Stress

14.4.1 Biotic Stress

Fusarium wilt is a serious problem in banana cultivation across the globe (Viljoen et al. 2019). Use of *Trichoderma viride* and *Pseudomonas fluorescens* in soil are useful in managing fusarium wilt of banana in coastal Odisha India (Pushpavathi et al. 2015). Sigatoka leaf spot is a serious biotic stress in coastal Brazil (Quirino et al. 2014). Nematode pests cause serious damage to banana cultivation especially *Pratylenchus coffea* in Tanzania (Luambano et al. 2019).

14.4.2 Abiotic Stress

One-third to one-fifth of banana-growing soils are prone to damage due to salinity in the soil or irrigation water. The banana plant is highly sensitive to salt stress, and application of irrigation water with EC of 3.4 and 5.7 μS cm^{-1} results in 25 and 50% potential yield loss, respectively (Palaniappan and Yerriswamy 1996). The results from the study indicate that every additional 1 g of sodium chloride per litre of irrigation water (assuming 1 $dSm^{-1} = 600$ mg NaCl L^{-1}) led to nearly 12–15% reduction in banana fruit yield. Banana plants are also able to seclude the excess sodium ions (7 mg g^{-1}) by leaching to marginal veins (Shapira et al. 2009). Mixing of groundwater with seawater at 80:20 ratio for irrigation has been shown to benefit banana crop in Canary Islands (Álvarez-Méndez et al. 2021).

Potassium deficiency is a major limitation in banana cultivation (Kumar et al. 2006). Rapid measurement of potassium and sodium in banana leaves using ion metres aids the banana farmers, researchers in determining the potassium deficiency and salinity stress levels (Arunachalam et al. 2020). Heavy winds uproot the banana plants or cause sever reduction in yields. Wind with high air temperature cause leaf tearing in banana. The size of tears is directly proportional to the damage to the plant (Eckstein et al. 1996). Short-statured cultivars are able to withstand moderate wind stress. Planting windbreaks around the banana gardens and supporting the bunches with bamboo stems help to reduce the damage in mild wind stress.

Choke throat, a physiological disorder of banana, is a problem in coastal semi-arid subtropical Carnarvon, Western Australia. It is due to the low temperature, waterlogging, or deficiency of calcium and boron. Williams and Hsien Jen Chiao cultivars are tolerant to the disorder. Williams also records high yield at this location (Hill et al. 1992). Heat stress in banana plants at this location could be managed by high-density planting of 3000 plants ha^{-1} (Kesavan et al. 2000).

14.5 Impact of Climate Change

Due to the climate change, the suitable locations for banana production in Latin American countries are predicted to decrease greatly at Guatemala, Columbia and Honduras, whereas the same is expected to increase at Mexico and Ecuador (Machovina and Feeley 2013). The optimal temperature for banana cultivation is 20–30 °C (Van der Bergh et al. 2010) and for best productivity across globe 26.7 ± 0.04 °C (Varma and Bebber 2019). Hence, the average banana productivity increased till 1961 but can decrease by 0.19–0.59 t ha^{-1} by 2050 due to the climate change (Varma and Bebber 2019). Climate change impact on banana can be minimized by optimal high-density planting which provides mutual shading and reduces canopy air temperature, opting for agroforestry systems, adopting drip irrigation and mulching techniques.

14.6 Conclusions

Coastal agroecosystems offer a suitable location for successful banana cultivation in tropical and subtropical climates. A sizeable area is found under banana cultivation in coastal ecosystem across the globe. Suitable cultivars of banana for coastal zone include Cavendish group Grand Nain for sole crop and dwarf varieties for agroforestry systems. Banana plants grown in coastal zone are prone to various biotic and abiotic stress factors especially Fusarium wilt, wind, salinity stress. Banana in subtropical countries also suffers from low-temperature stress which is managed by protected cultivation or artificial shade. Climate change poses threats of shifting banana cultivation to areas with cooler air temperatures. Suitable interventions of high-density planting, adopting banana intercrop in agroforestry systems, irrigation and mulching help to mitigate climate stress. Mixing of seawater with freshwater in 1:5 proportion, role of potassium are emphasized in salinity stress management. Using dwarf cultivars, and planting windbreaks help in minimising heavy wind stress in banana crop.

References

Álvarez-Méndez SJ, Padrón-Armas I, Mahouachi J (2021) Irrigation management strategies through the combination of fresh water and desalinated sea water for banana crops in El Hierro Canary Islands. J Water Reuse Desalination 11(3):464–474. https://doi.org/10.2166/wrd.2021.078

Arunachalam V, Fernandes CM, Salgaonkar DC (2020) Quick method to quantify the potassium and sodium content variation in leaves of banana varieties. Anal Sci 36(10):255–1260

Devi PS, Thangam M, Ladaniya MS et al (2011) Evaluation of local banana cultivars under coconut shade in Goa. J Biol Chem Res 28:63–76

Eckstein K, Robinson JC, Fraser C (1996) Physiological responses of banana (Musa AAA; Cavendish sub-group) in the subtropics. Y. influence of leaf tearing on assimilation potential and yield. J Hort Sci 71(3):503–514

Fonsah EG, Bogortti B, Ji P, et al (2010) New banana cultivars trial in the coastal plain of South Georgia. J Food Distrib Res 41(856–2016–58039):46–50

Galán Saúco V, Ait-Oubahou A, Abdelhaq H (2004) Greenhouse cultivation of bananas. Chronica Hort 44(2):35–37

Gubbuk H, Pekmezci M (2004) Comparison of open-field and protected cultivation of banana (Musa spp. AAA) in the coastal area of Turkey. New Zealand J Crop Hort Sci 32(4):375–378

Hill TR, Bissell ARJ, Burt JR (1992) Yield, plant characteristics, and relative tolerance to bunch loss of four banana varieties (Musa AAA Group, Cavendish subgroup) in the semi-arid subtropics of Western Australia. Aust J Expl Agric 32(2):237–240

Irizarry H, Rivera E, de Caloni IB et al (1989) Performance of elite banana (*Musa acuminata,* AAA) cultivars in four locations of Puerto Rico. J Agric Univ Puerto Rico 73(3):209–221

Jena P, Swain S, Pradhan BK et al (2020) Evaluation of new banana (Musa spp.) genotypes under Odisha conditions. Int J Chem Stud 8(3):1091–1097

Kesavan V, Hill T, Morris G (2000) The effect of plant spacing on growth, cycling time and yield of bananas in subtropical Western Australia. Acta Hort 575:851–857

Kumar AR, Kumar N, Kavino M (2006) Role of potassium in fruit crops—a review. Agric Rev 27(4):284–291

Kumar D, Pandey V, Anjaneyulu K (2008) Effect of planting density and nutrient management on growth, yield and quality of micro-propagated banana Rasthali Pathkapoora (AAB). Indian J Hort 65(3):272–276

Luambano ND, Kashando BE, Masunga MM et al (2019) Status of *Pratylenchus coffeae* in banana-growing areas of Tanzania. Physiol MolPlant Pathol 105:102–109

Machovina B, Feeley KJ (2013) Climate change driven shifts in the extent and location of areas suitable for export banana production. Ecol Econ 95:83–95

Malia IE (2021) Intercropping of several cultivars of banana and plantain under coconut based in North Sulawesi, Indonesia. In E3S web of conferences, vol 232. EDP Sciences p 03007

Muralidharan A, Nayar TR (1979) Intercropping in arecanut gardens. Multiple cropping in coconut and arecanut gardens. CPCRI, Kasaragod, India, p 24–27

Niether W, Schneidewind U, Fuchs M et al (2019) Below-and aboveground production in cocoa monocultures and agroforestry systems. Sci Tot Environ 657:558–567

Norgrove L (1998) Musa in multistrata systems: focus on shade. Infomusa 7:17–22

Obiefuna JC, Majumder PK, Ucheagwu AC (1982) Spacing and sucker management in the commercial plantain production in the rainforest belt of Nigeria. Ann Appl Biol 101(2):391–396

Odeke M, Rubaihayo PR, Osiru DSO (1999) Effect of spacing, stage and method of desuckering on bunch size and yield of banana cultivar Kibuzi (AAA-EA). African Crop Sci J 7(4):349–353

Palaniappan R, Yerriswamy RM (1996) Effect of saline water irrigation on growth, yield, quality and nutrition of Robusta banana. J Indian Soc Soil Sci 44(1):143–146

Pushpavathi Y, Dash SN, Mishra MK, Triveni V (2015) Management of Fusarium wilt in banana under coastal Odisha conditions. Int J Farm Sci 5(4):241–247

Quirino ZBDR, Ledo ADS, Talamini V et al (2014) Response of banana genotypes to yellow Sigatoka in coastal tablelands of Sergipe Brazil. Revista Ciência Agronômica 45(1):209–213

Rodrigo VHL, Stirling CM, Silva TUK et al (2005) The growth and yield of rubber at maturity is improved by intercropping with banana during the early stage of rubber cultivation. Field Crops Res 91(1):23–33

Sawant GB, Dalvi VV, Bhave SG et al (2016) Genetic variability of banana (*Musa* spp.) in west coastal zone of India. Electronic J Plant Breed 7(4):1144–1150

Shapira OR, Khadka S, Israeli Y et al (2009) Functional anatomy controls ion distribution in banana leaves: significance of Na+ seclusion at the leaf margins. Plant Cell Environ 32(5):476–485

Uthaiah BC, Indiresh KM, Jayarama Reddy M et al (1992) Performance of banana cultivars under Indian west coast conditions. Agric Res J Kerala 30(2):84–88

Van Asten PJ, Wairegi LWI, Mukasa D et al (2011) Agronomic and economic benefits of coffee–banana intercropping in Uganda's smallholder farming systems. Agric Syst 104(4):326–334

Van den Bergh I, Ramirez J, Staver C et al (2010) Climate change in the subtropics: the impacts of projected averages and variability on banana productivity. Acta Hortic 928:89–99

Varma V, Bebber DP (2019) Climate change impacts on banana yields around the world. Nat Clim Chang 9(10):752–757

Viljoen A, Ma LJ, Molina AB (2019) Fusarium wilt (Panama disease) and monoculture banana production: resurgence of a century-old disease. In: Ristaino JB, Records A (eds) Emerging plant diseases and global food security, The american phytopathological society, USA. https://doi.org/10.1094/9780890546383.008

Vinson EL, Coneva ED, Kemble JM et al (2018) Prediction of flower emergence and evaluation of cropping potential in selected banana cultivars (*Musa* sp.) cultivated in subtropical conditions of coastal Alabama. Hort Sci 53(11):1634–1639

Chapter 15
Dhanvantari Vatika—A Model Herbal Garden for an Agro-Ecotourism Unit

S. R. Maneesha, Vidula Pitre, Aviprit V. Ubarhande, Rupesh Devidas, Sujeet Desai, and E. B. Chakurkar

Abstract An agro-ecotourism unit is a new dimension of conventional agriculture that merges the features of agriculture and tourism. In this concept, the farmland is considered as a tourism spot and agriculture and allied activities as entertainment and adventure. Visitors can learn and experience various farming activities and enrich their knowledge of biodiversity, tradition and culture. Foreign tourists, as well as urban dwellers and school children, will enjoy the experiences of an agro ecotourism unit. The establishment of an agro ecotourism unit improves the livelihood status of the farmers by imparting additional income and promoting conservation and sharing of knowledge and resources. A herbal garden is an integral part of an agro ecotourism since it makes the unit holistic and close to nature. *Dhanvantari vatika* a herbal garden of ICAR-CCARI agro-ecotourism centre has more than 100 plant species including medicinal trees, shrubs, climbers and herbs. It also has aromatic plants, fruit crops, vegetables, flower crops and spices with medicinal uses. Each species is labelled precisely with English and Hindi names, botanical name, botanical family, parts used and major medicinal uses. The unit is under organic production using vermicompost and livestock manures. Pest and disease problems are addressed by biopesticides such as neem oil and jeevamruth. Micro-sprinklers are installed to ensure adequate water supply. Plant propagation, minimal processing and sales of the produce are being done in the unit itself. Inclusion of new species, new planting

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systems, categorization and cataloguing and phytochemical characterization is under progress. Thus, *Dhanvantari vatika* acts as a model for replication in agro-ecotourism units across the country.

Keywords Agro ecotourism · Herbal garden · Medicinal and aromatic plants

15.1 Introduction

Agro-ecotourism units are the new dimensions of agriculture that showcases farmland as a tourist spot and farming as entertainment and adventurous activities. The farmer himself or herself acts as a guide and explains the components of the unit to the visitors. Crop diversity, production, propagation, protection, harvest, post-harvest and processing activities attract foreign as well as domestic tourists and school children. The main objectives of an agro-ecotourism unit are harmonious integration of diversified farming activities with tourism for sustainable economic returns and ecology, local employment generation, delivering aesthetic goods and services, environmental protection and management, ecotourism industry development, infrastructure development and community development leading to socio-economic transformation (Korikanthimath et al. 2005). It has three basic principles such as 'something new to see, something new to do and something new to buy' (Barbuddhe and Singh 2014). Agro-ecotourism can encourage rural youth and improve employment opportunities (Desai, 2016). In states like Goa, where foreign, as well as domestic tourists flow is high, agro-ecotourism units can be a successful venture (Singh et al. 2016).

Out of the 43,000 plant species available in India, 7500 plant species are mentioned in Indian folklore and about 1700 plant species are documented in ancient manuscripts (Ramakrishnappa, 2002). Western Ghat region is a biodiversity hotspot and the vast diversity needs to be conserved either in situ or ex situ. Agro-ecotourism centres are knowledge centres of biodiversity (Salvi and Sawant 2014) and local genetic resources and rural traditions, and culture can be conserved and displayed in such units. In the Konkan region of Goa and Maharashtra, traditional homestead farms (*kulagar*) have been converted as agro-ecotourism spots, where in situ conservation of local genetic resources are being done for a long time (Maneesha et al. 2019). The interspaces of coconut and arecanut palms are cultivated with local fruits, vegetables, spices, flowers and medicinal and aromatic plant species. A portion of the agro-ecotourism unit can be exclusively dedicated to a herbal garden. In this paper, the features of a model herbal garden are explained with an example of *Dhanavanatari vatika*, the herbal garden of the agro-ecotourism centre of ICAR-Central Coastal Agricultural Research Institute, Goa.

15.2 Dhanvanatari Vatika

‘*Dhanvanatari*’ is the ‘God of Ayurveda’ in Hindu mythology. ‘*Dhanvantari vatika’* is located in Agro-Eco Tourism (AET) block of ICAR-Central Coastal Agricultural Research Institute, Goa (15°29′58” N 73°55′02” E). The garden has an area of 1670 m^2. The major objectives for establishing this garden are collection, conservation and utilization of medicinal and aromatic plant resources, promotion of medicinal and aromatic plants cultivation by providing quality planting materials and establishment of a model herbal garden for an agro-ecotourism unit. The garden has 65 herb species, 25 shrub species, 20 climber species and 40 tree species, and the details of the plants are given in Tables 15.1, 15.2, 15.3 and 15.4.

15.3 Plant Production Strategies

Plants are cultivated by organic methods in the *Dhanvanati vatika.* Small plots of size (2 × 3 m or 3 × 3 m) are prepared for planting herbs. Shrubs and trees are planted along the boundaries. Planting is done in the month of May–June after proper layout and land preparation. Raised beds or ridges and furrows are followed based on the type of plant species. Small pandals are prepared for trailing the climber species. The garden has neutral-non saline red laterite soil (pH 6.62 and EC 0.07). This area has low organic carbon (0.2%), low available nitrogen (N, 112.90 kg ha^{-1}), medium available phosphorus (P_2O_5, 34.72 kg ha^{-1}) and available potassium (K, 204.26 kg ha^{-1}). Calcium (Ca, 3247 ppm), magnesium (Mg, 69.63 ppm), sulphur (S, 16.30 ppm and micronutrients such as iron (Fe, 105.60 ppm), manganese (Mn, 54.68 ppm), zinc (Zn, 4.67 ppm), copper (Cu, 6.75 ppm) and boron (B, 0.53 ppm) are available in the soil of the garden. Usually, animal manures and vermicompost are used for growing the different plants. Jeevamrut and panchagavya solutions are also used in the garden to improve the nutritional status.

Jeevamrut is prepared using the ingredients such as native cow’s dung (10 kg), native cow’s urine (7 L), jaggery (1 kg), gram flour (1 kg), fertile soil (1–2 handful) and water (200 L). All these ingredients are mixed in a big barrel, and the top is covered with a jute sack. This solution is stirred well for proper mixing. Jeevamrut will be ready after seven days. Ghana jeevamrut is prepared by making balls of the mixture by reducing the quantity of water. This solution can be drenched in soil, sprayed or mixed with irrigation water at a rate of 200 L per acre in 2–3 months for improved production.

For the preparation of panchagavya, cow dung (7 kg) and cow ghee (1 kg) are first mixed in a barrel and the top is covered with a jute sack. The mixture is stirred well in the morning and evening for 3 days. The cow urine (10 L) and water (10 L) are added, and the mixture is kept for 15 days with regular stirring in the morning and evening. After 15 days, mix cow milk (3 L), cow curd (2 L), tender coconut water (3 L), jaggery (3 kg), well-ripened Poovan banana (12 nos.) are added into this mixture.

Table 15.1 Herbal plants available in *Dhanvantari vatika*

Sl. no	English name	Hindi name	Botanical name	Family
1	Aloe vera	*Gheekumari*	*Aloe barbadensis*	Asphodelaceae
2	Ambrette/Musk mallow	*Lata kasturi*	*Abelmochus moschatus*	Malvaceae
3	Arrow root	*Tikhor*	*Maranta arundinacea*	Marantaceae
4	Balsam	*Gulmehendi*	*Impatience balsamina*	Balsaminaceae
5	Bermuda grass	*Durva*	*Cynadon dactylon*	Poaceae
6	Blood berry	*Blood berry*	*Rivina humilis*	Phytolaccaceae
7	Blue leadwort	*Nila Chitrak*	*Plumbago auriculata*	Plumbaginaceae
8	Butterfly lily	*Dolan champa*	*Hedychium coronarium*	Zingiberaceae
9	Canna	*Keli*	*Canna indica*	Cannaeceae
10	Centella	*Mandookaparni*	*Centella asiatica*	Apiaceae
11	Ceylon spinach	*Talinum*	*Talinum fruticosum*	Portulacaceae
12	Citronella	*Ganjan*	*Cymbopogon nardus*	Poaceae
13	Coleus	*Ajmapan*	*Coleus aromaticus*	Lamiaceae
14	Costus	*Kebu*	*Costus speciosus*	Zingiberaceae
15	Country gooseberry	*Rasbhari*	*Physalis minima*	Solanaceae
16	False daisy	*Bhringraj*	*Eclipta prostrata/E. alba*	Asteraceae
17	Fenugreek	*Methi*	*Trigonella foenum-graecum*	Leguminaceae
18	Giant reed	*Jivnal*	*Arundo donax*	Poaceae
19	Ginger	*Adrak*	*Zingiber officinale*	Zingiberaceae
20	Greater Galangal	*Bara kulanjan*	*Alpinia galangal*	Zingiberaceae
21	Green chireta/Creat	*Kalmegh*	*Andrographis paniculata*	Acanthaceae
22	Halfa grass	*Darbha*	*Desmostachya bipinnata*	Poaceae
23	Holy basil	*Krishna tulsi*	*Ocimum sanctum*	Lamiaceae
24	Indian ginseng	*Ashwagandha*	*Withania somnifera*	Solanaceae
25	Indian Purslane	*Baralunia*	*Portulaca oleracea*	Portulacaceae
26	Indian Sarsaparilla	*Anantamul*	*Hemidesmus indicus*	Asclepiadaceae
27	Insulin Plant	*Keukand*	*Costus igneus*	Costaceae
28	Kalanchoe	*Pather chutt*	*Bryophyllum pinnatum*	Crassulaceae
29	Kenaf	*San*	*Hibiscus cannabis*	Malvaceae
30	Leea	*Hathikana*	*Leea macrophylla*	Leeaceae
31	Lemon grass	*Ganjan*	*Cymbopogon citratus*	Poaceae
32	Leucas	*Chota halkusa*	*Leucas aspera*	Lamiaceae

(continued)

Table 15.1 (continued)

Sl. no	English name	Hindi name	Botanical name	Family
33	Lime basil	*Tulsi*	*Ocimum americanum*	Lamiaceae
34	Mango ginger	*Am-halad*	*Curcuma amada*	Zingiberaceae
35	Marvel of Peru/4 O' Clock plant	*Gul abbas*	*Mirabilis jalapa*	Nyctaginaceae
36	Mint	*Pudina*	*Mentha arvensis*	Lamiaceae
37	Mint	*Pudina*	*Mentha spicata*	Lamiaceae
38	Mustard	*Sarson*	*Brassica nigra*	Brassicaceae
39	Palmarosa	*Gandhbeal*	*Cymbopogon martinii*	Poaceae
40	Patchouli	*Pacholi*	*Pogostemon cablin*	Lamiaceae
41	Periwinkle	*Sadabahar*	*Catharanthus roseus*	Apocynaceae
42	Pigweed	*Jungli chaulai*	*Amaranthus viridis*	Amaranthaceae
43	Purple arrowroot	*Achira*	*Canna edulis*	Cannaeceae
44	Purple fleabane	*Bakuci*	*Vernoia cineria*	Asteraceae
45	Red bird cactus	*Nival*	*Pedilanthus tithymaloides*	Euphorbiaceae
46	Red flame ivy	*Vran ropani*	*Hemigraphis colorata*	Acanthaceae
47	Red leadwort	*Lal chitrak*	*Plumbago rosea*	Plumbaginaceae
48	Senna tora	*Charok*	*Cassia tora*	Fabaceae
49	Sida	*Bala*	*Sida cordifolia*	Malvaceae
50	Stevia/ Candy leaf	*Meeti pati*	*Stevia rebaudiana*	Asteraceae
51	Stone breaker	*Bhuiamla*	*Phyllanthus niruri*	Phyllanthaceae
52	Sweet basil	*Tulsi*	*Ocimum basilicum*	Lamiaceae
53	Sweet flag	*Vaikhand*	*Acorus calamus*	Acoraceae
54	Sweet sagewort	*Dhavana*	*Artemesia annua*	Asteraceae
55	Tarvine/Red spiderling	*Punarnava*	*Boerhavia diffusa*	Nyctaginaceae
56	Toothache plant	*Akarkara*	*Spilanthes acmella*	Asteraceae
57	Touch-me-not plant	*Lajjalu*	*Mimosa pudica*	Mimosaceae
58	Trichopus	*Jeevani*	*Trichopus zeylanicus*	Dioscoreaceae
59	Tridax daisy	*Khal-muriya*	*Tridax procumbens*	Asteraceae
60	Turmeric	*Haldi*	*Curcuma longa*	Zingiberaceae
61	Vetiver	*Khus*	*Vetiveria zizanioides*	Poaceae
62	Water hyssop	*Jal brahmi*	*Bacopa monnieri*	Scrophulariaceae
63	White leadwort	*Safed chitrak*	*Plumbago zeylanica*	Plumbaginaceae
64	Wild basil	*Van tulsi*	*Ocimum tenuifolium*	Lamiaceae
65	Wild onion	*Jungali pyas*	*Allium sp.*	Alliaceae

Table 15.2 Shrubs species available in *Dhanvantari vatika*

Sl. No	Name	Hindi name	Botanical name	Family
1	Adulsa	*Adosa*	*Adhatoda vasica*	Acanthaceae
2	Annatto	*Sindhur*	*Bixa orellana*	Bixaceae
3	Arabian jasmine	*Mogra*	*Jasminum sambac*	Oleaceae
4	Barleria	*Vajradanthi*	*Barleria prionitis*	Acanthaceae
5	Calotropis	*Madar*	*Calotropis gigantea*	Asclepiadaceae
6	Cape jasmine	Gandhraj	*Gardenia jasminoides*	Rubiaceae
7	Caricature plant	*Pandhra adulsa*	*Graptophyllum pictum*	Acantahceae
8	Castor	*Arandi*	*Ricinus communis*	Euphorbiaceae
9	Chasku	*Banar*	*Cassia abus*	Caesalpiniaceae
10	Chekkurmanis	*Surasarabi*	*Sauropus androgynus*	Euphorbiaceae
11	Curry leaf	*Curry patha*	*Murraya koenigii*	Rutaceae
12	Henna	*Mehendi*	*Lawsonia inermis*	Lythraceae
13	Indian oleander	*Kaner*	*Nerium oleander*	Apocynaceae
14	Justicia	*Kaalaadulsa*	*Justicia gendarussa*	Acanthaceae
15	Night jasmine	*Parijat*	*Nyctanthes arbor-tristis*	Oleaceae
16	Noni	*Ach*	*Morinda citrifolia*	Rubiaceae
17	Serpent wood	*Sarpagandha*	*Rauvolfia serpentina*	Apocynaceae
18	Serpent wood	*Sarpagandha*	*Rauvolfia tetraphylla*	Apocynaceae
19	Shoe flower	Gudhal	*Hibiscus rosa-sinensis*	Malvaceae
20	Soap pod	*Shikakai*	*Acacia concinna*	Mimosaceae
21	Trumpet flower	Piliya	*Tecoma stans*	Bignoniaceae
22	Turkey berry	*Bhurat*	*Solanum tarvum*	Solanaceae
23	Vitex	*Sambhalu*	*Vitex trifolia*	Lamiaceae
24	Wild pepper	*Jungli miri*	*Piper geniculatum*	Piperaceae
25	Yellow oleander	*Peeli kaner*	*Cascabela thevetia*	Apocynaceae

The panchagavya will be ready after 30 days. Panchagavya can be sprayed @3% to plants to improve health.

Most of the pest and disease problems were least in the garden and were managed by the application of biopesticides like neem oil (3%), neem garlic emulsion and garlic decoction. Timely cultural operations such as weeding, manuring, pruning, staking, etc. are also done in the garden as and when required. Bilingual display boards with English and Hindi common name, botanical name, botanical family, parts used and major uses are noted in the metallic display boards for every species. An automated irrigation system with 100 micro-sprinklers with 8 lph capacity and 4 m diameter is operated one hour every day.

Table 15.3 Climber species available in *Dhanvantari vatika*

Sl. No	Name	Hindi name	Botanical name	Family
1	Asparagus	*Shatavari*	*Asparagus racemosus*	Liliaceae
2	Basella—Green	*Basella*	*Basella alba*	Basellaceae
3	Basella—Red	*Basella*	*Basella rubra*	Basellaceae
4	Betel vine	*Paan patha*	*Piper betle*	Piperaceae
5	Black pepper	*Kaali mirch*	*Piper nigrum*	Piperaceae
6	Bone setter	*Hathjod*	*Cissus quadrangularis*	Vitaceae
7	Clitoria	*Aparajitha*	*Clitoria ternatea*	Fabaceae
8	Cyclea	*Raj patha*	*Cyclea peltata*	Menispermaceae
9	Garlic vine	*Lasoon latha*	*Adenocalymma alliaceum*	Bignoniaceae
10	Glory lily	*Agnisikha*	*Gloriosa superba*	Colchicaceae
11	Gymnema	*Gudmar*	*Gymnema sylvestre*	Asclepiadaceae
12	Holostemma	*Holostemma*	*Holostemmaada-kodien*	Asclepidaceae
13	Liquorice	*Jeshtimadhu*	*Glycyrrhiza glabra*	Fabaceae
14	Long pepper	*Pippali*	*Piper longum*	Piperaceae
15	Mucuna	*Kaunch*	*Mucuna pruriens*	Fabaceae
16	Passion flower	*Jhumka latha*	*Passiflora edulis*	Passifloraceae
17	Rosary pea	*Guchi*	*Abrus precatorius*	Fabaceae
18	Tinospora	*Giloe*	*Tinospora cordifolia*	Menispermaceae
19	Colubrinum pepper	*Colubrinum*	*Piper colubrinum*	Piperaceae
20	Spanish jasmine	*Chameli*	*Jasminum grandiflorum*	Oleaceae

15.4 Plant Propagation Measures

Commercially important medicinal and aromatic plants are propagated from seeds and cuttings. The propagules are kept in the nursery till they are ready to be transplanted in fields. Around fifty species of plants were propagated in the nursery for sale and distribution. In the year 2020, a total of 809 plants worth 24,270 were sold from the medicinal and aromatic plant nursery. There is demand for plant propagules throughout the year from the unit, but the sales reach a peak in the month of June. There is a high demand for propagules of lemon grass, aloe vera, brahmi, mint and tulsi.

15.4.1 Seed Propagation

Most of the herbal plants (tulsi, ashwagandha, etc.) are propagated in the nursery in pro trays, polybags or raised beds. The germinated seedlings are transplanted into the main field after 30 days.

Table 15.4 Tree species available in *Dhanvantari vatika*

Sl. No	Name	Hindi name	Botanical name	Family
1	African tulip tree	*Rugtoora*	*Spathodea campanulata*	Bignoniaceae
2	Areca nut	*Supari*	*Areca catechu*	Arecaceae
3	Arjun tree	*Arjun*	*Terminalia arjuna*	Combretaceae
4	Ashoka tree	*Ashoka*	*Saraca asoca*	Caesalpiniaceae
5	Bael	*Bael*	*Aegle marmelos*	Rutaceae
6	Bead tree	*Maha neem*	*Melia azedarach*	Meliaceae
7	Belleric myrobalan	*Bahera*	*Terminalia bellirica*	Combretaceae
8	Black Dammar	*Dhup*	*Canarium strictum*	Burseraceae
9	Bullet wood	*Maulsari*	*Mimusops elengi*	Sapotaceae
10	Bullock's heart	*Ram phal*	*Annona reticulata*	Annonaceae
11	Camphor	*Kapoor*	*Cinnamomum camphora*	Lauraceae
12	Cannonball tree	*Nagalinga*	*Couroupita guianensis*	Lecythidaceae
13	Chebulic myrobalan	*Harad*	*Terminalia chebula*	Combretaceae
14	Cluster fig	*Gulaar*	*Ficus racemosa*	Moraceae
15	Coconut	*Nariyal*	*Cocos nucifera*	Arecaceae
16	Custard apple	*Sita phal*	*Annona squamosa*	Annonaceae
17	Devil's tree	*Shaithan kajat*	*Alstonia scholaris*	Apocyanaceae
18	Drumstick	*Mungana*	*Moringa oleifera*	Moringaceae
19	Flame of the forest	*Palash*	*Butea monosperma*	Fabaceae
20	Golden champaca	*Champa*	*Michaelia champaka*	Magnoliaceae
21	Guava	*Amrud*	*Psidium guajva*	Myrtaceae
22	Indian butter tree	*Mahua*	*Madhuca indica*	Sapotaceae
23	Indian elm	*Chilbil*	*Holoptelea integrifolia*	Ulmaceae
24	Indian gooseberry	*Amla/Aonla*	*Emblica officinalis*	Phyllanthaceae
25	Indian laburnum	*Amaltas*	*Cassia fistula*	Fabaceae
26	Indian senna	*Senna*	*Cassia angustifolia*	Fabaceae
27	Jack fruit	*Kathal*	*Artocarpus heterophyllus*	Moraceae
28	Jamun	*Jamun*	*Syzygium cumini*	Myrtaceae
29	Kadamba	*Kadam*	*Anthocephalus cadamba*	Rubiaceae
30	Kokum	*Kokum*	*Garcinia indica*	Clusiaceae
31	Mast tree	*Ashoka*	*Polyalthia longifolia*	Annonaceae
32	Neem	*Neem*	*Azadirachta indica*	Meliaceae
33	Papaya	*Papita*	*Carica papya*	Caricaceae
34	Paradise tree	*Lakshmi tharu*	*Simarauba glauca*	Acanthaceae
35	Purple orchid tree	*Kaniar*	*Bauhinia purpurea*	Caesalpiniaceae
36	Red sandalwood	*Rakta chandan*	*Pterocarpus santalinus*	Pterocarpaceae

(continued)

Table 15.4 (continued)

Sl. No	Name	Hindi name	Botanical name	Family
37	Sandalwood	*Chandan*	*Santalum album*	Santalaceae
38	Saursop	*Ramphal*	*Annona muricata*	Annonaceae
39	Scarlet flame bean	*Lal zhumbar*	*Brownea coccinea*	Fabaceae
40	Soapnut tree	*Rita*	*Sapindus trifoliatus*	Sapindaceae

15.4.2 Propagation by Cuttings

Some of the medicinal herbs (vitex, bone setter, henna) can be vegetatively propagated by cuttings. Cuttings can be put in polybags or raised beds. Rooted cuttings may be transplanted to the main field after attaining sufficient growth. Rooting can be induced using growth regulators such as NAA or IBA.

15.5 Harvest and Minimal Processing

The useful plant parts were harvested upon correct maturity and minimally processed. Fresh produce such as fruits and green leaves are sold for fresh consumption. Drying and powdering of the leaves and bark are being done under hygienic conditions. Aloe vera gel extraction unit, aromatic oil distillation unit and grinding mill are available in the institute. Minimally processed products are sold out to the public and visitors of agro-ecotourism through the sales counter situated near the garden.

15.6 Technical Support for Establishment of the Herbal Garden

Apart from planting material supply, technical support including production, post-harvest, processing and marketing are also provided from the institute to the farmers and interested people. Bilingual leaflets on the production technology of aloe vera, kalmegh, stevia, chekkurmanis and lemon grass are also prepared for sales and circulation.

15.7 Future Thrust

The inclusion of new plant species can be done to enrich the diversity of the garden. In order to promote the cultivation of herbs in the urban region, terrace gardens, vertical farming, polyhouse/greenhouses and hydroponics units can be demonstrated. There is lot of scope for medicinal and aromatic plants production in the interspaces of plantations. Spice plantations can be modified as agro-ecotourism centres where the interspaces can be utilized for the cultivation of medicinal and aromatic plant species (Maneesha et al. 2020). The plants can be categorized and planted based on properties (anti-diabetic: gudmar, insulin plant; anti-obesity: kokum, etc.), organs influenced (jalbrahmi—brain, ginger—stomach, vajradanti—teeth, etc.). Available plants and their parts used can be documented in catalogues. Dry preservation and documentation of medicinal and aromatic plants can be done as a herbarium. The presence of secondary metabolites such as alkaloids, flavonoids, tannins, polyphenols and pigments can be extracted and quantified. Vermicompost or common compost can be prepared exclusively using the medicinal herb. Beekeeping units can also be established in the herbal garden which improves pollination in the garden and yields honey with the goodness of medicinal and aromatic plants.

15.8 Conclusions

India has a huge diversity of these plants, and there is an urgent need to conserve the plant species which are used for traditional medicine. They are a potential source of therapeutic, cosmetic and industrial ingredients; hence, the commercial cultivation of them is gaining momentum in the current scenario. Collection, conservation and utilization of these plants can be done in herbal gardens in public or private places. It can also be promoted as a part of an agro-ecotourism centre. In the agro-ecotourism centre of ICAR-Central Coastal Agricultural Research Institute, a herbal garden, *Dhanvantai vatika* has been maintained with 150 plant species. Organic cultivation practices, plant propagation and advanced crop production strategies are scientifically followed in this garden. It is a model herbal garden that can be replicated in an agro-ecotourism centre for the conservation of medicinal and aromatic genetic resources and traditional healing practices.

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References

Barbuddhe SB, Singh NP (2014) Agro-ecotourism: a new dimension to agriculture. Technical bulletin no. 46, ICAR-Central Coastal Agricultural Research Institute, Goa, India

Desai AR (2016) Basic components of agro-ecotourism: Future prospects as a potential agrienterprises. In: Training manual of short course on agro ecotourism: an emerging enterprise for agricultural diversification, ICAR-Central Coastal Agricultural Research Institute, Goa, India, 31 October–9 November 2016, pp 5–12

Korikanthimath VS, Desai AR, Barbuddhe SB (2005) Agro-ecotourism: prospects and potentialities. In: Proceedings of national seminar on agro ecotourism, ICAR-Central Coastal Agricultural Research Institute, Goa, India, 19–20 January 2005

Maneesha SR, Desai AR, Chakurkar EB (2020) Scope of spice gardens as agro-ecotourism centers in Konkan-Malabar coasts of India. In: Souvenir and abstracts of the national seminar on spices: emerging trends in production, processing and marketing, ICAR-Central Coastal Agricultural Research Institute, Goa, India, 21–22 January 2020

Maneesha SR, Devi SP, Singh NP (2019) *Kulagar*—a potential system to conserve crop diversity. Indian J Plant Genet Resour 32(2):135–140

Ramakrishnappa K (2002) Impact of cultivation and gathering of medicinal plants on biodiversity: case studies from India In: Biodiversity and the ecosystem approach in agriculture, forestry and fisheries. Satellite event on the occasion of the ninth regular session of the Commission on Genetic Resources for Food and Agriculture, Rome, 12–13 October 2002

Salvi BR, Sawant BN (2014) Agro-ecotourism: a new dimension to agriculture. Regional Fruit Research Station, Dr. B.S. Konkan Krishi Vidyapeeth, Vengurle, Maharashtra, India, p 52

Singh NP, Maneesha SR, Rajkumar RS et al (2016) Introduction and concept of agro eco tourism (AET) models. In: Training manual of short course on agro ecotourism: an emerging enterprise for agricultural diversification, ICAR-Central Coastal Agricultural Research Institute, Goa, India, 31 October–9 November 2016, pp 1–4

Chapter 16
Potentials of Teen (*Ficus carica*) as a Fruit Crop in Coastal Bangladesh

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Abstract Teen (*Ficus carica*) is a composite fruit called "syconium" belonging to the family Moraceae. It can be grown well in a wide range of soils like heavy clay, loams, sandy loam and light sand. Under an expansive environment, fig plants may be cultivated which requires subtropical and mild climate for its growth and development. Light rain with a dry climate is necessary to produce fruits and at least eight hours daylight period is required for its ripening. Almost all of these climatic conditions prevail in Bangladesh. Figs (*Ficus racemosa* and *Ficus hispida*) grow wild in Bangladesh and are tree-type plants. On the other hand, Teen (exotic fig, *Ficus carica*) is an ideal shrubby plant suitable for yard garden to replace the wild tree-type figs (*Ficus* sp.) growing spontaneously in Bangladesh. Teen is very rich in mineral resources, energy (317.78 kcal 100 g^{-1}), carbohydrate (73.50%), fat (0.56%), protein (4.67%), fiber (3.68%) and moisture (16.63%). Amateur gardeners in Khulna, the southwest coastal region of Bangladesh, gave a try to cultivate the Teen (*Ficus carica*) collected from Middle East countries which showed primarily the cultivation potentials of this crop. In this context, an attempt was made to evaluate the cultivation potentials of the Teen (*Ficus carica*) in coastal Bangladesh. A survey work using a pretested interview questionnaire has been conducted in this regard in selected areas of Khulna region. A morpho-anatomical study has also been conducted at Agrotechnology Discipline, Khulna University, Bangladesh. The majority of the

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farmers (67%) in the study area know about Teen. All the respondents expressed willingness to eat and cultivate Teen as fruit where 73% of the respondents are willing to cultivate it commercially. The morpho-anatomical study also justified the suitability of Teen as an adaptive fruit crop for cultivation in the southwest coastal region of Bangladesh.

Keywords Bangladesh · Morpho-anatomy · Nutrition · Potentials · Teen

16.1 Introduction

The history of figs dates back over 2000 years when the Greeks considered the fig to be "more precious than gold" (Washburn and Brennand 2010). The religious importance of fig is also significant. Though it is mainly grown in the temperate regions as fruit, it also grows in tropical and subtropical zones. It can be grown in coastal areas and is tolerant of most types of soil (Brien 2002). Fig is rich in both nutritional and medicinal values (Gani et al. 2018). As a developing country, malnutrition is common in Bangladesh (Uddin et al. 2016). To overcome this problem, production and the availability of fruits have to be improved. Teen (*Ficus carica*) is a type of edible fig that could be introduced in Bangladesh as a new fruit crop to boost up the production and the availability of fruits here. In Bangladesh, fig grows in the wild and its use as a vegetable is common somewhere in rural areas. In the world market, there is an increasing demand for fresh and dried figs for their high nutrient, mineral and polyphenol content (Salimpour et al. 2019).

Edible fig (Teen) is a new fruit in Bangladesh, mainly brought by expatriates. Bangladesh has an excellent climate and fertile land along with adequate water for irrigation and a wide variety of soils, as well as a dynamic human resource. The pre-monsoon season (March–May) in Bangladesh is suitable for fig production which is a lag period for fruit here (Banglapedia 2015; Pasha and Uddin 2019); however, fig plants bear fruit round the year. Mehraj et al. (2013) evaluated the growth and yield performances of two exotic fig cultivars and suggested that the soil and climatic conditions of Bangladesh are suitable for the cultivation of exotic figs. Though, expanding salinity is a severe impediment in southwest coastal region of Bangladesh where it ranges between 2 and 16 dS m^{-1} (Ahmed et al. 2017). Figs are tolerant to moderate salinity (Vangelisti et al. 2019) with acceptable yield and can sustain up to a salinity of 10 dS m^{-1} (Salimpour et al. 2019). This signifies its potentiality as a suitable fruit crop for the coastal regions of Bangladesh.

However, no attempt has been taken for mass and managed cultivation of fig in Bangladesh. In this regard, the current study has been designed to evaluate the potentials of Teen cultivation and its acceptability as a fruit crop among the farmers and inhabitants in the southwest coastal region which is a climate-resilient area in Bangladesh. Morpho-anatomical relationship between the local and exotic cultivars of figs was also explored from the study.

16.2 Materials and Methods

A search was made through Google providing the keywords "fruit, nutrition, medicinal value, pharmacology, Bangladesh," etc. Data were compiled on the nutritional status of figs and other traditional fruits of Bangladesh and made a comparison among these species based on collected facts.

To evaluate the acceptance of Teen (*Ficus carica*) as a fruit crop in southwest coastal Bangladesh, a survey was conducted with pretested interview questionnaire. The survey was conducted by following the purposive random sampling (300 respondents) technique (Tongco 2007).

Morphological characteristics of local and exotic (two local and one exotic) fig cultivars were compared on the basis of leaf, shoot and pomological characteristics (both qualitative and quantitative) in light of the fig descriptors (IPGRI and CIHEAM 2003). The software ImageJ (Broken Symmetry Software Company) (Schneider et al. 2012) was used to measure leaf area (cm^2). The shoot characters were studied as terminal bud length (cm), terminal bud width (cm), length of first and second internode (cm) and apical dormancy. Fruit weight (g), fruit length (cm), fruit diameter (cm), fruit shape index, fruit skin color, etc., were selected as pomological characters. Vernier scale and a digital balance were used to measure fruit width, fruit length of mature fruits and fruit weight, respectively. The ratio of fruit width to fruit length was considered as fruit shape index.

Pomological differences among cultivars were determined by analysis of variance (one-way ANOVA). A comparison of the mean values was made using Duncan's multiple range test ($P \leq 0.05$). Statistical data were analyzed using Statistical Tool for Agricultural Research (STAR) statistical software (IRRI 2013).

Anatomical studies were done with leaf and stem samples from three fig species. The samples were fixed with formalin-aceto-alcohol (FAA) solution (formalin: glacial acetic acid: alcohol at 5:5:90) after washing with distilled water and kept in a glass jar sealed with an airtight lid (Bercu and Popoviciu 2014). Cross section was done manually following the technique of Yeung (1998). Carl Zeiss compound microscope, equipped with a fitted camera, was used for anatomical observations.

16.3 Results and Discussion

16.3.1 Nutritive, Medicinal and Pharmacological Values of Fig

Figs are nutritionally rich with high protein, fiber, carbohydrate, energy and minerals. However, it contains low fat and sugar in comparison with some local fruits (Table 16.1). It also possesses a high level of medicinal values (Badgujar et al. 2014). Antioxidants like α-tocopherols, flavonoids and phenolic compounds are available in fig (Sibel et al. 2005). Fig removes kidney and urinary bladder stones, and releases

Table 16.1 Comparison of nutritive values of fig with some local fruits of Bangladesh

Nutritive value	Unit	Fruit						References
		Fig	Mango	Jackfruit	Banana	Litchi	Papaya	
Moisture	g 100 g^{-1} dry weight basis	16.63	78.9–82.8	72.0–94.0	6.70 + 02.22	81.76	9.82 ± 0.09	Al-Snafi (2017), Ranasinghe et al. (2019), Maldonado-Celis et al. (2019), Martial-Didier et al. (2017)
Ashes		4.65	0.34–0.52	nd	8.50 + 1.52		5.98 ± 0.03	Al-Snafi (2017), Maldonado-Celis et al. (2019), Martial-Didier et al. (2017), USDA (2019)
Total protein		4.67	0.36–0.40	1.2–1.9	0.90 + 0.25	0.83	11.67 ± 0.04	Al-Snafi (2017), Maldonado-Celis et al. (2019), Martial-Didier et al. (2017), USDA (2019)
Carbohydrate		73.50	16.20–17.18	16.0–25.4	59.00 + 1.36	16.53	47.33 ± 0.08	Al-Snafi (2017), Ranasinghe et al. (2019), Maldonado-Celis et al. (2019), Martial-Didier et al. (2017), USDA (2019)
Dietary fiber		3.68	0.85–1.06	1.0–1.5	31.70 + 0.25	1.3	32.51 ± 0.03	Al-Snafi (2017), Ranasinghe et al. (2019), Maldonado-Celis et al. (2019), Martial-Didier et al. (2017), USDA (2019)

(continued)

Table 16.1 (continued)

Nutritive value	Unit	Fruit						References
		Fig	Mango	Jackfruit	Banana	Litchi	Papaya	
Fat		0.56	0.30–0.53	0.1–0.4	1.70 + 0.10	0.44	2.51 ± 0.13	Al-Snafi (2017), Ranasinghe et al. (2019), Martial-Didier et al. (2017), USDA (2019)
Sugar		trace	nd	nd	nd	15.23	1.78 ± 0.63	Al-Snafi (2017), Martial-Didier et al. (2017)
Energy	Kcal	317.78	62.1–190	21–98	519	66	43	Al-Snafi (2017), Maldonado-Celis et al. (2019), Pinnamaneni (2017), USDA (2019)
Calcium	mg 100 g^{-1} dry weight basis	6.00 ± 0.61	7–16	20.0–37.0	19.20 + 0.00	5.00	18.61 ± 0.78	Al-Snafi (2017), Anhwange et al. (2009), Ranasinghe et al. (2019), Maldonado-Celis et al. (2019), Martial-Didier et al. (2017), USDA (2019)

(continued)

Table 16.1 (continued)

Nutritive value	Unit	Fruit						References
		Fig	Mango	Jackfruit	Banana	Litchi	Papaya	
Iron		0.042 ± 0.003	0.09–0.41	0.5–1.1	0.61 + 0.22	0.31	0.65 ± 0.37	Al-Snafi (2017), Anhwange et al. (2009), Ranasinghe et al. (2019), Maldonado-Celis et al. (2019), Martial-Didier et al. (2017), USDA (2019)
Magnesium		1.38 ± 0.19	8–19	27.0	nd	10.00	19.11 ± 0.44	Al-Snafi (2017), Ranasinghe et al. (2019), Maldonado-Celis et al. (2019), USDA (2019)
Phosphorus		1.054	10–18	38.0–41.0	nd	31.00	221.54 ± 0.85	Al-Snafi (2017), Ranasinghe et al. (2019), Maldonado-Celis et al. (2019), Martial-Didier et al. (2017), USDA (2019)
Potassium		13.89 ± 0.42	120–211	191–407	78.10 + 6.58	171	516.33 ± 0.82	Al-Snafi (2017), Anhwange et al. (2009), Ranasinghe et al. (2019), Maldonado-Celis et al. (2019), Martial-Didier et al. (2017), USDA (2019)

(continued)

Table 16.1 (continued)

Nutritive value	Unit	Fruit						References
		Fig	Mango	Jackfruit	Banana	Litchi	Papaya	
Sodium		0.089	0–3	2.0–41.0	24.30 + 0.12	1.00	9.61 ± 0.73	Al-Snafi (2017), Anhwange et al. (2009), Ranasinghe et al. (2019), Maldonado-Celis et al. (2019), Martial-Didier et al. (2017), USDA (2019)
Zinc		nd	0.06–0.15	nd	nd	0.07	1.97 ± 0.21	Al-Snafi (2017), Maldonado-Celis et al. (2019), Martial-Didier et al. (2017), USDA (2019)
Copper		0.006	0.04–0.32	nd	nd	0.15	0.045	Al-Snafi (2017), Maldonado-Celis et al. (2019), Pinnamaneni (2017), USDA (2019)
Manganese		0.008 ± 0.00	0.03–0.12	nd	76.20 + 0.00	0.055	0.04	Anhwange et al. (2009), Maldonado-Celis et al. (2019), Pinnamaneni (2017), USDA (2019)

* nd = not defined

intestinal pain, piles, dyspepsia and anorexia (Ahmad 2009). Besides these, fig can prevent, control or cure some human diseases like anemia, asthma, blood pressure, bronchitis, constipation, diabetes, insomnia, mouth disorder (inflammation, wounds, etc.), osteoporosis, sores, skin ulcers, sore throat, swollen gums, toothache, tumors, warts, etc., even cancer (Marwat et al. 2011; Gani et al. 2018; Amara et al. 2008; Shai et al. 2001; Gond and Khadabadi 2008). Beneficial effects of fig tree (*Ficus carica*) leaf extract have been found against hyperglycemia, helminth infection, hypercholesterolemia, hypertriglyceridemia and bovine papillomatosis. The latex is widely used as a purgative and vermifuge (Marwat et al. 2011).

*16.3.2 Acceptance of Teen (***Ficus carica***) to the Farmers*

In Bangladesh, wild species of figs (joggo—*Ficus racemosa* and wild—*Ficus hispida*) are grown naturally and used as a vegetable and medicinal fruit but their consumption as fruit has not yet been reported (Mehraj et al. 2013). However, it is a very popular dessert in many countries including our neighbor, India (Kumar 2007). People know about cultivable figs (67% of the respondents in the study area) as it is mentioned in the Holy Quran, Hadith and the Bible (Borhany 2005). Many of them tasted Teen during Hajj or by their relatives coming after Hajj or by the people working in the Middle East countries. Most of the respondents (96%) expressed their desire to eat edible fig (Teen) as fruit (Table 16.2) if it becomes available in their

Table 16.2 Acceptance of Teen/fig as a fruit crop in southwest coastal region of Bangladesh

Sl. no.	Questions	Answer			
		Yes		No	
		Number	Percent (%)	Number	Percent (%)
1	Do you eat fig as fruit grown in your locality?	00	00	300	100
2	Do you cultivate fig in your orchard?	00	00	300	100
3	Do you know about edible fig (Teen)?	201	67	99	33
4	Are you willing to eat Teen/fig as fruit?	276	92	24	8
5	Would you cultivate edible fig (Teen) if it is possible in your locality?	300	100	00	00
6	Would you cultivate edible fig (Teen) if you get seedlings of good variety?	300	100	00	00
7	Would you cultivate fig (Teen) commercially if it is possible in your locality?	219	73	81	27

locality and all of them want to cultivate it where about three-fourths of the respondents (73%) showed willingness to cultivate it commercially as it is a high-value fruit (Reddy et al. 2008).

16.3.3 Comparison Among the Fig Cultivars on the Basis of Morphological Characters

Teen leaves are lobed having basal and lateral sinus, longest petiole and largest leaf area, but wild fig has highest leaf diameter (Fig. 16.1). The two native species of fig are vigorous in growth with high branching, while Teen is intermediate in growth nature (Ali and Chaudhary 2010; Bhalerao et al. 2014). Apical dominance is high in Teen and wild in comparison with joggo. Terminal bud length, width and their ratio significantly differed in three species where Teen has largest terminal bud. Shortest and thinnest first and second internode was observed in joggo fig.

Table 16.3 reveals the superiority of Teen (*Ficus carica*) over wild type of fig available in Bangladesh in both qualitative and quantitative characters as shape, size, color, and obviously in terms of yield. Fruits of Teen (*Ficus carica*) and joggo (*Ficus racemosa*) are oblate, but wild figs (*Ficus hispida*) are globose in shape. All three fruits become light green before maturation, but after maturity the Teen and local fig become pink and wild fig turns to yellow at ripe (Fig. 16.1 p, q and r). Majumder et al. (2011) stated similar observations. In case of fruit apex, Teen and wild are flat, while joggo is rounded. Teen is a plant with short and thick stalk, single and medium size fruitlet in low number but largest in size among the three. Wild and joggo bear long and slender fruit stalk with a cluster of fruits which are of small size.

Gaaliche et al. (2012) also observed large variability among pomological characters within fig germplasms in Tunisia. Fruit weight (45.33 g), fruit length (5.10 cm) and fruit diameter of Teen are much more than those of wild and joggo fig.

16.3.4 Comparison in Respect of Anatomical Characters

16.3.4.1 Anatomical Characters of Leaf

Single-row palisade parenchyma is arranged in Teen and wild but its double row in joggo (Table 16.4; Figs. 16.2 and 16.3). All three species contain a large number of druses crystal in mesophyll tissue, cystolith and vascular bundle. Cystolith and vascular bundles are clear in joggo (Fig. 16.3), and in the other two species, these are not so clear. According to Bercu and Popoviciu (2014), increasing thickness of cuticle and presence of hypodermis are probably the features of adaptation to xerophytic environment. Leaves of wild and Teen are rough as they bear more both

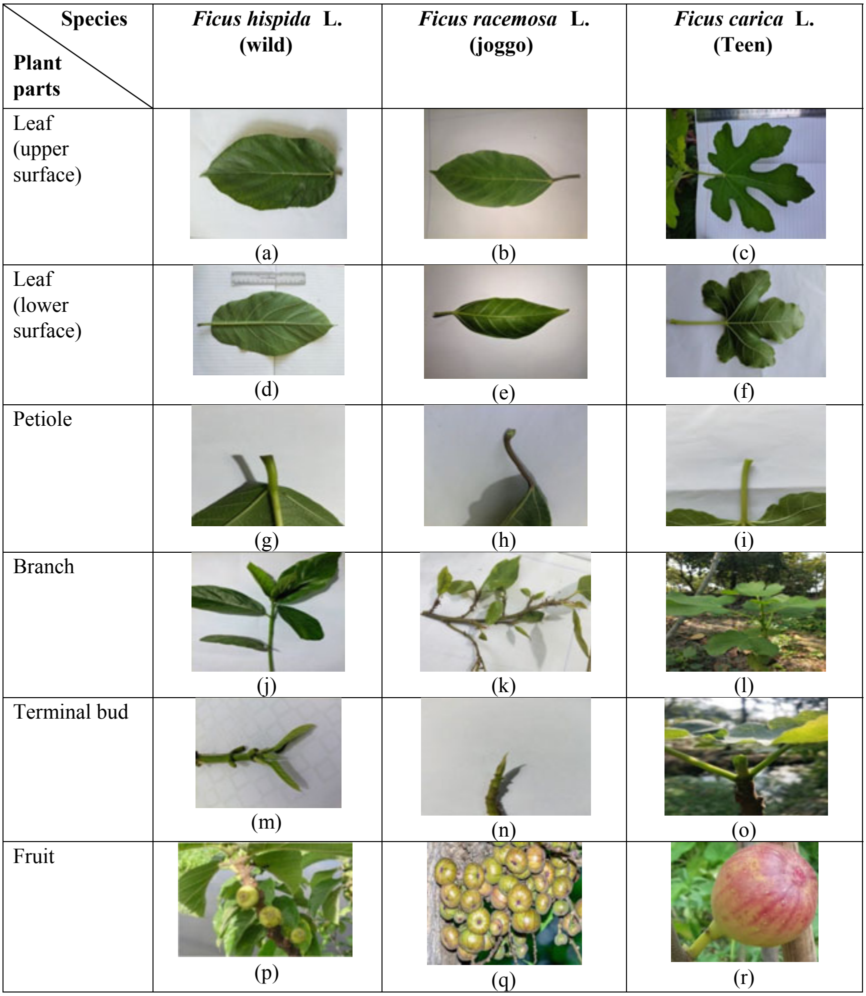

Fig. 16.1 Pictures of different morphological parts of wild, joggo and Teen fig

of the thick and thin trichomes compared to joggo fig (Fig. 16.2). This result supports the findings of Kim et al. (2011).

16.3.4.2 Anatomical Characters of Stem

Multiple epidermal layers were observed in the stem of all three species in the current study (Table 16.5). Similar observation was reported by Ali et al. (2013), and they emphasized that increasing thickness of stem epidermal layer could be an important factor against biotic and abiotic stresses. Thick and thin trichomes were found in the

Table 16.3 Qualitative and quantitative characters of fruit of different figs

Types	Fruit shape	External color (mature)	Size of fruitlets	Amount of fruitlets	Fruit weight (g)	Fruit length (cm)	Fruit diameter (cm)
Wild	Globose	Yellow	Small	High	21.9c	2.47c	1.73c
Joggo	Oblate	Pink	Small	High	32.11b	3.03b	1.27b
Teen	Oblate	Pink	Medium	Low	45.33a	5.10a	3.66a
Mean					33.12	3.53	2.25
CV (%)					5.37	6.87	3.78
SE					1.45	0.20	0.08
LSD (0.05%)					3.55	0.48	0.19

Table 16.4 Anatomical characters of leaf blade of three fig species

Sl. no.	Characters	Wild	Joggo	Teen
1	Palisade in one (+) or two (-) rows	+	-	+
2	Druses crystal in mesophyll present (+) or absent (-)	+	+	+
3	Vascular bundle present (+) or absent (-)	+	+	+
4	Trichomes both thick and thin (+) or thin (-)	+	-	+
5	Trichomes numerous (+) or few (-)	+	-	+

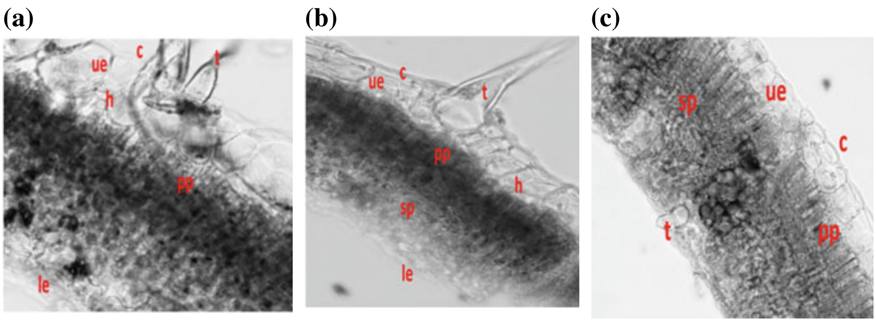

Fig. 16.2 Cross section of three fig leaves. **a** cross section of *Ficus hispida* L. leaf, **b** cross section of *Ficus carica* L. leaf and **c** cross section of *Ficus racemosa* L. leaf. t—trichome, c—cuticle, ue—upper epidermis, le—lower epidermis, h—hypodermis, sp—spongy parenchyma tissue and pp—palisade parenchyma tissue

stem samples where the trichomes were small and thin in Teen fig, and a random mixture of thick and thin trichomes were observed in joggo fig (Table 16.5 and Fig. 16.4 b, c). In wild fig, a large number of long and thick trichomes were found (Table 16.5 and Fig. 16.4a).

Sclerenchymatous cells were also present in stem medullary ray of all three fig species. Similarly, here xylem was present as both single and clusters (Table 16.5

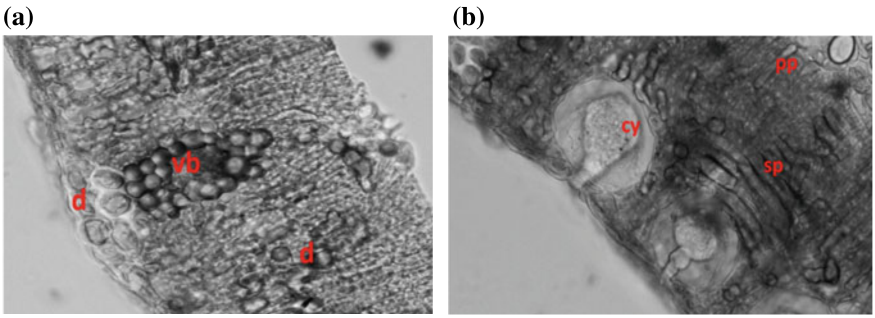

Fig. 16.3 Cross section of a leaf of *Ficus racemose.* **a**: Vascular bundle and druses crystal in leaf (*Ficus racemosa*) and **b** cystolith in leaf (*Ficus racemosa*). vb—vascular bundle, d—druses crystal, cy—cystolith, sp—spongy parenchyma tissue and pp—palisade parenchyma tissue

Table 16.5 Anatomical characters of stem of three fig species

Sl. no.	Characters	Wild	Joggo	Teen
1	Sclerenchymatous cells in medullary ray present (+) or absent (−)	+	+	+
2	Druses crystals in pith present (+) or absent (−)	+	+	+
3	Multiple epidermal layer present (+) or absent (−)	+	+	+
4	Trichomes both thick and thin (+) or thin (−)	+	+	_
5	Xylem present as single only (+) or single and clusters (−)	_	_	_
6	Leptocentric bundle present (+) or absent (−)	_	_	+
7	Druses crystal in ground tissue present (+) or absent (−)	+	+	_

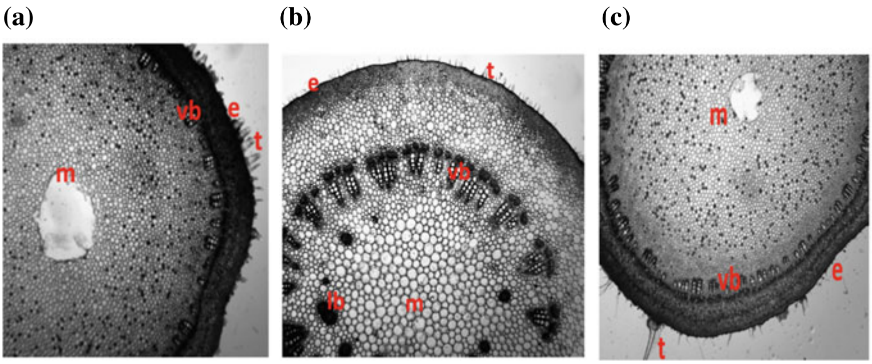

Fig. 16.4 Stem anatomical pictures of three fig species. **a** Stem anatomy of *Ficus hispida* L., **b** stem anatomy of *Ficus carica* L. and **c** stem anatomy of *Ficus racemosa* L. vb—vascular bundle, m—medulla, lb—leptocentric bundle, e—epidermis and t—trichome

and Fig. 16.4). Wild fig stem showed the highest number of clusters, and Teen fig stem showed the lowest. Ali et al. (2013) also reported variation in number of xylem clusters in several Teen fig cultivars. Prominent leptocentric bundles were only present in the stem of Teen fig where no druses crystals were observed in ground tissue (Table 16.5 and Fig. 16.4b). Though, Ali et al. (2013) reported the presence of druses crystals in the ground tissue in several cultivars of Teen fig.

In case of wild and joggo fig stem, druses crystals were also observed in their ground tissue but both lack leptocentric bundle (Table 16.5). Below the epidermal layer, several layers of collenchyma followed by parenchyma cells are present. This finding is also similar with the findings reported by Ali et al. (2013).

16.4 Conclusions

Teen (*Ficus carica*) is a very rich fruit in nutritive value in comparison with local fruits. As Bangladesh has the favorable climate for its production and Teen showed a lot of morpho-anatomical similarities with indigenous fig species, the Teen seems to be well adapted in Bangladesh conditions and has the potential for commercial cultivation. Farmers of southwest coastal region of Bangladesh are willing to cultivate Teen, and it represents the attitudes of farmers from other areas too. Teen may be a potential new fruit crop for this locality and Bangladesh as a whole.

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References

Ahmad M, Khan MA, Marwat SA et al (2009) Useful medicinal flora enlisted in Holy Quran and Ahadith. Ameri-Eurasian J Agric Environ Sci 5(1):126–140

Ahmed NU, Mahmud NU, Zaman MAU et al (2017) Effect of different salinity level on tomato (*Lycopersicon esculentum*) production under climate change condition in Bangladesh. Ann Res Rev Biol 13(3):1–9

Ali M, Chaudhary N (2010) *Ficus hispida*: A review of its pharmacognostic and ethnomedicinal properties. Pharmacognosy Rev 5(9):96–102

Ali ZA, Mustafa NS, Abdel-Roauf HS et al (2013) Characters of some fig cultivars by anatomical traits on both leaves and stems. World Appl Sci J 24(8):1065–1071. https://doi.org/10.5829/idosi.wasj.2013.24.08.13259

Al-Snafi AE (2017) Nutritional and pharmacological importance of *Ficus carica*—a review. J Pharmacy 7(3):33–48

Amara AA, El-Masry MH, Bogdady HH (2008) Plant crude extracts could be the solution: extracts showing in vivo antitumorigenic activity. Pak J Pharmaceutical Sci 21(2):159–171

Anhwange BA, Ugye TJ, Nyiaatagher TD (2009) Chemical composition of *Musa sapientum* (Banana) peels. Electronic J Environ Agric Food Chem 8(6):437–4442

Badgujar S, Patel VV, Atmaram H et al (2014) Traditional uses, phytochemistry and pharmacology of *Ficus carica*: a review. Pharmaceutical Biol 52(11):1487–1503. https://doi.org/10.3109/13880209.2014.892515

Banglapedia (2015) Fruits, the national encyclopedia of Bangladesh. Available from http://en.banglapedia.org. Accessed 15 Jul 2019

Bercu R, Popoviciu DR (2014) Anatomical study of *Ficus carica* L. leaf. Ann Romanian Soc Cell Boil 19(1):33–36. https://doi.org/10.ANN/RSCB-2014-0002

Bhalerao SA, Verma DR, Teli NC et al (2014) *Ficus racemosa* Linn: acomprehensive review. J Appl Chem 3(4):1423–1431

Borhany QSA (2005) Fig: the medicinal fruit of the Quraan. Yemen Times 883(14). http://www.yementimes.com. Accessed 23 Sept 2018

Brien J (2002) Fig growing in NSW. Agfact H3.1.19, first edition. NSW Agriculture. www.agric.nsw.gov.au. Accessed 12 Apr 2018

Gaaliche B, Saddoud O, Mars M (2012) Morphological and pomological diversity of fig (*Ficus carica* L.) cultivars in Northwest of Tunisia. Interna Schol Res Network ISRN Agron 2012:1–9. https://doi.org/10.5402/2012/326461

Gani G, Fatima T, Qadri T et al (2018) Phytochemistry and pharmacological activities of fig (*Ficus carica*): A review. Intern J Res Pharm Sci Res 3(2):80–82

Gond NY, Khadabadi SS (2008) Hepatoprotective activity of *Ficus carica* leaf extract on rifampicin-induced hepatic damage in rats. Indian J Pharm Sci 70:364–366

IPGRI and CIHEAM (2003) Descriptors for fig (*Ficus carica* L.). International Plant Genetic Resources Institute (IPGRRI), Rome, Italy and International Center for Advanced Mediterranean Agronomic Studies (CIHEAM), Paris. https://www.scirp.org. Accessed 4 Dec 2019

IRRI (2013) STAR—statistical tool for agricultural research, International Rice Research Institute, Philippines. www.bbi.irri.org. Accessed 1 Jan 2019

Kim KW, Cho D, Kim P (2011) Morphology of foliar trichomes of the Chinese cork oak *Quercus variabilis* by electron microscopy and three-dimensional surface profiling. Microsc Microanal 17(3):461–468

Kumar AR (2007) Studies on integrated nutrient and post-harvest management of fig (*Ficus carica* L.). Unpublished PhD Thesis, University of Agricultural Sciences, Dharwad, Karnataka, India. http://krishikosh.egranth.ac. Accessed 22 May 2018

Majumder DAN, Hassan L, Rahim MA et al (2011) Studies on physio-morphology, floral biology and fruit characteristics of mango. J Bangladesh Agric Univ 9(2):187–199. http://dx.doi.org/10.3329

Maldonado-Celis M, Yahia EM, Bedoya R et al (2019) Chemical composition of mango (*Mangifera indica* L) fruit: nutritional and phytochemical compounds. Front Plant Sci 10:1073. https://doi.org/10.3389/fpls.2019.01073

Martial-Didier AK, Hubert KK, Parfait KEJ et al (2017) Phytochemical properties and proximate composition of papaya (*Carica papaya* L. var solo 8) peels. Turkish J Agric Food Sci Tech 5(6):676–680. www.agrifoodscience.com, Accessed May 14, 2018

Marwat SK, Khan MA, Rehma FU et al (2011) Medicinal and pharmacological potentiality of the plant At-Tîn-Common fig (Ficus carica L.). Asian J Chem 23(1):1–10

Mehraj H, Sikder RK, Haider MN et al (2013) Fig (*Ficus carica* L.): a new fruit crop in Bangladesh. Int J Business Soc Sci Res 01(01):01–05. http://www.ijbssr.com. Accessed 10 May 2018

Pasha MK, Uddin SB (2019) Minor edible fruits of Bangladesh. Bangladesh J Plant Taxon 26(2):299–313

Pinnamaneni R (2017) Nutritional and medicinal value of Papaya (*Carica papaya* Linn.). World J Pharma Pharmaceutical Sci 6(8):2559–2578

Ranasinghe RASN, Maduwanthi SDT, Marapana RAUJ (2019) Nutritional and health benefits of jackfruit (*Artocarpus heterophyllus* Lam.): a review. Int J Food Sci. https://doi.org/10.1155/2019/4327183. Accessed on 12 Jan 2020

Reddy KVR, Reddy CP, Goud PV (2008) Effect of auxins on rooting of fig (*Ficus carica*) hardwood and semi hardwood cuttings. Indian J Agric Res 42(1):75–78

Salimpour A, Shamili M, Dadkhodaie A et al (2019) Evaluating the salt tolerance of seven fig cultivars (*Ficus carica* L.). Adv in Hort Sci 33(4):553565. https://doi.org/10.13128/ahsc8191

Schneider CA, Rasband WS, Eliceiri KW (2012) NIH Image to ImageJ: 25 years of image analysis. Nat Methods 9(7):671–675. https://doi.org/10.1038/nmeth.2089

Shai R, Kashman Y, Rabinowitz R et al (2001) Suppressors of cancer cell proliferation from fig (*Ficus carica*) resin: isolation and structure elucidation. J Nat Prod 64(7):993–996

Sibel K, Saglam H, Kivcak B (2005) ∞-tocopherol, flavonoid and phenol contents and antioxidant activity of *Ficus carica* leaves. Pharm Biol 43:683–686

Tongco MDC (2007) Purposive sampling as a tool for informant selection. Ethnobot Res Appl 5:147–158

Uddin MJ, Dey SR, Taslim T (2016) Trend and output growth analysis of major fruits in Chittagong region of Bangladesh. Bangladesh J Agric Res 41(1):137–150

USDA (2019) USDA National nutrient database for standard reference. https://ndb.nal.usda.gov/ndb. Accessed 10 Jan 2020

Vangelisti A, Zambrano LS, Caruso G et al (2019) How an ancient, salt-tolerant fruit crop, *Ficus carica* L., copes with salinity: a transcriptome analysis. Sci Rep 9:2561

Washburn C, Brennand C (2010) Preserve the harvest, FN/Harvest/2005–06pr, Utah State University, USA. https://extension.usu.edu. Accessed 23 Dec 2017

Yeung E (1998) A beginner's guide to the study of plant structure. In: Karcher SJ (ed) Tested studies for laboratory teaching, vol 19. Proceedings of the 19th workshop/conference of the Association for biology laboratory education (ABLE), pp 125–142

Chapter 17
Evaluation of Efficacy of Insecticides and Fungicides Combinations Targeting Dieback Disease of Cashew (*Anacardium occidentale* L.)

G. Raviraja Shetty, T. R. Ranganath, and Lakshmana

Abstract A field experiment was conducted at Agricultural and Horticultural Research Station, Ullal, Mangalore, during the period October 2018–May 2019 to evaluate the efficacy of selected insecticide, fungicides and their mix combinations against major pests and diseases of cashew. Among the tested chemical molecules and combinations, lambda-cyhalothrin in combination with copper oxychloride recorded a lower incidence of dieback (17.23%) with the highest per cent reduction in incidence over the control (71.89%) and produced the highest yield (26.21 kg tree^{-1}) followed by quinalphos in combination with mancozeb (20.58%, 66.42% and 23.50 kg tree^{-1}, respectively) and hexaconazole (22.42%, 63.43% and 22.41 kg tree^{-1}, respectively). No phytotoxicity symptoms were observed in the treated field. The tested combinations were found to be compatible with each other and can be safely used for the control of the simultaneous occurrence of tea mosquito bug and dieback disease of cashew.

Keywords Dieback · Cashew · Compatibility · Fungicide · Insecticide

17.1 Introduction

Cashew (*Anacardium occidentale* L.) is popularly known as the "Gold mine" of wasteland. Cashew was originally introduced into India from Brazil in the sixteenth century mainly for checking soil erosion on the coast. Initially, it was considered as

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a suitable crop for soil conservation, afforestation and also wasteland development but gradually gained commercial importance. In India, cashew is grown in an area of 10.27 lakh ha with a total production of 7.25 lakh million tonnes (MT) of raw nuts and unit area productivity of 706 kg ha^{-1} (Elakkiya et al. 2017), and in Karnataka, area under cashew is 129.065 thousand ha with a production of 89.447 MT. In India, it is mainly cultivated in Maharashtra, Goa, Karnataka and Kerala along the West coast and Tamil Nadu, Pondicherry, Andhra Pradesh, Orissa and West Bengal along the East coast. It is also grown to a limited extent in non-traditional areas such as Bidar, Kolar Chitradurga, Bagalkot and Gadag region of Karnataka.

Various factors are responsible for low yield of the crop, especially diseases play a vital role. There are more than 12 diseases that are reported to infect cashew trees worldwide. Anthracnose foliar blight, fruit rot, gummosis of twigs and trunk are often considered as the most relevant diseases causing severe damages across cashew growing areas. Among the diseases, anthracnose caused by *Colletotrichum gloeosporioides* Penz. and inflorescence and twig dieback is a common disease of cashew, causing huge loss in yield (Satapathy and Beura 2018). Inflorescence and twig dieback caused by *Lasiodiplodia theobromae* Pat. is a major factor limiting cashew nuts production in Nigeria. An average yield loss to *L. theobromae* infestation was estimated at 40–50%, and the disease is designated as a serious one which could cause a reduction of nut yield by 70% and more than 50% death of vegetative shoot (Adeniyi et al. 2019).

The fungus, *L. theobromae*, often invades twigs and branches from the tips of the trees, causing them to dry and the plant to wilt. Under favourable conditions, infections are characterized by dieback of twigs from the top, downwards, followed by discolouration and the death of leaves, particularly in older trees, which gives an appearance of fire scorch. Symptoms can also be observed in reproductive structures. In severe situations, the branches start drying one after another in a sequence, resulting in the death of the trees of the cashew plantation. Commonly, once the symptoms of decline or widespread dieback are evident, it is difficult to stop or reverse the progress of disease (Khanzada et al. 2015; Naqvi and Perveen 2015). In vivo studies demonstrated that *L. theobromae* becomes aggressive in colonizing host tissues when plants are under abiotic stress, such as heat, water stress or drought stresses. In general, dieback is one of the deadly diseases, which causes serious damage to the tree and its productivity. To manage dieback disease, traditional horticultural practices have been applied to confront the fungal attack. In general, avoidance of wounding of trees can limit disease incidence (Saeed et al. 2017). Cashew dieback disease is believed to be facilitated by damage caused by mired, tea mosquito bug (*Helopeltis spp.*) or coconut bug (*Pseudo theraptuswayii*) on cashew plant (Zhongrun and Masawe 2014). The symptoms of the disease include withering of the panicles, followed by progressive dieback of small flower stalks. This starts from the tips then advances downward to the main floral shoots (Intini and Sijaona 1983). The normal greenish colour of the health shoots progressively turns brown resulting in loss of flowers. Heavy infection appears similar to fire damage (Sijaona 2013). Damage caused by insect attack (*Helopeltis spp.* or *Pseudo theraptuswayii*) is considered as the predisposing factors to dieback infection.

The fungus attack young and tender shoots and flowers followed by dieback infection starting at tips and spreading downwards. The disease incidence may occur at any time of the year, but it is most conspicuous during October to November. Information of the status of diseases affecting cashew and their management strategies are vital for stakeholders in the cashew value chain in India. In this context, the present study was undertaken to evaluate the compatibility of selected insecticides and fungicides to manage the foliar pathogens associated with dieback disease of cashew.

17.2 Material and Methods

The experiment was conducted in Agricultural and Horticultural Research Station, Ullal, Mangalore, during the year 2019 in a randomized block design (RBD). There were seven treatments that were replicated thrice in an eight-year-old cashew plantation consisting of four cashew trees in each treatment. The treatments were T_1: quinalphos 25 EC @ 2 ml L^{-1} + mancozeb 75 WP @ 2 g L^{-1}; T_2: lambda-cyhalothrin 5 EC @ 1 ml L^{-1} + copper oxychloride @ 2 g L^{-1}; T_3: copper oxychloride 50 WP @ 3 g L^{-1}; T_4: carbendazim 12% + mancozeb 63% WP @ 2 g L^{-1}; T_5: quinolphos 25 EC @ 2 ml L^{-1}; T_6: hexaconazole 5 SC @ 2 ml L^{-1}: T_7: untreated control. Observation on disease incidence was recorded on 10 days after each spraying. Two sprays were imposed using a high volume knapsack sprayer (500 l ha^{-1}) at 21 days intervals. For assessing the disease incidence, the total number of plants and plants infected by dieback disease in each treatment were recorded separately. The per cent disease incidence (PDI) and per cent disease reduction (PDR) of dieback disease was calculated using the formula as follows:

PDI = Number of plants infected × 100/Total number of plants observed.
PDR = PDI (Control)−PDI (Treatment)/PDI (Control) × 100

The symptoms of phytotoxicity were also recorded at 5 and 10 days after the application of treatments. Finally, the yield was recorded on each tree basis and expressed in kg per average of four trees in each treatment. All data were statistically analysed using analysis of variance (ANOVA) to determine the differences between treatments and means were separated using Duncan Multiple Range Test (DMRT) at 5% probability level.

17.3 Results and Discussion

From the field observations and literature review, it was observed that the dieback disease was always associated with an insect attack. The injuries made by the insect predispose the plants for infection, and also, the dieback pathogen could easily enter the plant through the wounds made by the insect. In this experiment, insecticide like quinalphos and lambda-cyhalothrin was also included in combination with fungicides.

The result of the experiment depicts that the highest reduction in disease incidence was observed in plants sprayed with lambda-cyhalothrin + copper oxychloride (71.89%). It was followed by quinalphos + mancozeb (66.42%) and hexaconazole (63.43%). The insecticide quinalphos recorded 58.44% reduction in disease incidence over the control and was on par with the above treatments (Table 17.1). This revealed that the insecticide was equally efficient as fungicides in the management of dieback. The fungicidal property of quinalphos was earlier reported, and our results confirmed the earlier reports. The observation of per cent disease incidence revealed that all the treatments were superior over the control. The highest disease

Table 17.1 Effect of various treatments on per cent disease incidence (PDI) and per cent disease reduction (PDR) of dieback disease of cashew

Treatment details	PDI				Yield (kg per tree, Avg. of 4 trees)
	After 1st spray	After 2nd spray	Mean	PDR over the control	
T_1 = Quinalphos 25 EC (2 mL L^{-1}) + mancozeb 75 WP (2 g L^{-1})	22.17 (27.98)	19.04 (25.86)	20.58 $(26.95)^{de}$	66.42	23.50
T_2 = Lambda-cyhalotrin 5 EC (2 ml L^{-1}) + copper oxychloride (2 g L^{-1})	18.13 (25.19)	16.33 (23.70)	17.23 $(24.43)^{e}$	71.89	26.21
T_3 = Copper oxychloride 50WP (3 g L^{-1})	35.33 (36.44)	33.66 (35.41)	34.50 $(35.94)^{b}$	43.72	17.87
T_4 = Carbendazim 12% + mancozeb 63% WP (2 g L^{-1})	32.06 (34.46)	29.33 (32.75)	30.66 $(33.59)^{bc}$	49.99	19.85
T_5 = Quinolphos 25 EC (2 ml L^{-1})	26.13 (30.73)	24.83 (29.81)	25.48 $(30.22)^{cd}$	58.44	21.60
T_6 = Hexaconozole 5 SC (2 ml L^{-1})	24.17 (29.36)	20.67 (26.97)	22.42 $(28.21)^{de}$	63.43	22.41
T_7 = Untreated control	59.21 (50.32)	63.41 (52.79)	61.31 $(51.54)^{a}$	–	10.71
S. Em. (±)	1.38	1.51	1.43		
CV (%)	7.13	7.95	7.48		
CD% (p = 0.05)	4.25	4.57	4.39		

Note: Figures within parentheses are arcsine transformed values
Means with same letters in superscript within the column are not significantly different

incidence was in plants treated with copper oxychloride with the lowest record of yield 17.87 kg, and the lowest incidence was recorded in the treatment, lambda-cyhalothrin + copper oxychloride of 17.23% with the highest yield of 26.21 kg plant^{-1}. Our results were relatively in accordance with the findings of Lim and Singh (2000) who found that a mixture of fungicide (mancozeb) and insecticide (dicrotophos) application at blossom time resulted in a significant increase in yield and fruit set. The present results are also consistent with Seni et al. (2018), who reported there was less dead heart, white ear and lower per cent incidence of plant hopper and leafhopper when rynaxpyr was applied in combination with carbendazim and mancozeb in paddy.

17.4 Conclusions

In the present study, it was revealed that among the different treatments, significantly the highest reduction in disease incidence was observed in plants sprayed with lambda-cyhalothrin + copper oxychloride (71.89%), and it was followed by quinalphos + mancozeb (66.42%) and hexaconozole (63. 43%) disease reduction. All the tested insecticides and fungicides combinations are compatible with each other without adverse effect on the cashew tree.

References

Adeniyi DO, Adedayo DA, Abdulrahman AA et al (2019) Integrated system for cashew disease management and yield. Cameroon J Exp Biol 13(1):40–48

Elakkiya E, Sivaraj P, Prabhakar AV (2017) Growth and performance of cashew nut production in India—an analysis. Int J Curr Microbiol App Sci 6(6):1817–1823. https://doi.org/10.20546/ijcmas.2017.606.21

Intini M, Sijaona MER (1983) Little known disease of cashew (*Anacardium occidentale* L.) in Tanzania. Rivista Di Agricoltura Subtropicale e Tropicale 77(3):421–429

Khanzada MA, Lodhi AM, Rajput AQ et al (2015) Response of different mango cultivars to mango decline pathogen, *Lasiodiplodia theobromae* Pat. Int J Biol Biotechnol 12:643–647

Lim TM, Singh G (2000) Disease and pest problems of cashew in Malaysia. Int Cashew Symp 108:139–214

Naqvi SAH, Perveen R (2015) Mango quick decline manifestation on various cultivars at plants of particular age in the vicinity of district Multan. Pak J Phytopathol 27:31–39

Saeed EE, Sham A, Abuzarqa A et al (2017) Detection and management of mango dieback disease in the United Arab Emirates. Int J Mol Sci 18:2086

Satapathy RR, Beura SK (2018) Management of *Colletotrichum gloeosporioides* (Penz.) causing cashew anthracnose through botanicals. Int J Curr Microbiol and App Sci 7(9):3539–3543

Seni A, Pal R, Naik BS (2018) Compatibility of insecticide and fungicides targeting major insect pests and diseases. Int Bio-Resour Stress Manag 9(1):132–136

Sijaona MER (2013) Important diseases and insect-pest of cashew in Tanzania. Naliendele Agricultural Research Institute, Mtwara, Tanzania

Zhongrun Z, Masawe PAL (2014) Diseases and insect pests of cashew in Tanzania. Tropical Crops Genetic Resources Institute-CATAS, China and Naliendele Agricultural Research Institute, Mtwara, Tanzania

Chapter 18
Effect of Land Configuration on Yield and Nutrient Uptake by Wheat (*Triticum aestivum* L.) Under Partially Reclaimed Coastal Salt Affected Soil of South Gujarat

D. K. Borse, V. P. Usadadia, D. T. Tajane, and M. M. Patel

Abstract The field experiment was carried out during the Rabi seasons of 2016–17 and 2017–18 on wheat crop at Coastal Soil Salinity Research Station, Navsari Agricultural University, Danti, to evaluate the effect of different levels of land configuration on yield and nutrient uptake of wheat under partially reclaimed coastal salt-affected soil of South Gujarat. The land configuration methods comprised of flat bed, broad bed furrow, and ridge and furrow systems. Pooled data of two years revealed that yield attributes like effective tillers, spike length, spikelets spike^{-1}, grains spike^{-1}, etc., and yields of wheat crop were significantly influenced due to different land configurations. Among the land configuration methods, broad bed furrow treatment significantly influenced the yield and nutrient uptake by wheat crop, and in this method, significantly highest grain yield of wheat (3893 kg ha^{-1}) was recorded which was 14.77% higher than the flat bed method. The ridge and furrow treatment registered a significantly higher straw yield of 5274 kg ha^{-1}, but it was at par with the broad bed furrow method. In the case of nutrient uptake, the broad bed furrow method recorded significantly higher total N (105.53 kg ha^{-1}) and P (15.44 kg ha^{-1}) uptake, while potassium uptake (143.87 kg ha^{-1}) was higher in ridge and furrow method but at par with broad bed furrow treatment.

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Keywords Land configuration · Nutrient uptake · Saline soils · Wheat crop · Yield

18.1 Introduction

Wheat (*Tritium* spp.) is one of the most important cereal crops of India which is a main source of protein and calories in Indian diet. Worldwide, wheat production is about 730 million tons from near 290.10 million hectares area having 2717 kg ha^{-1} productivity (2016–2017). Wheat is grown on 30.06 million ha area with production of about 98.51 million tons with average productivity 3371 kg ha^{-1}. India contributes 14% of global area and 13.64% of world production of wheat crop. Uttar Pradesh, Punjab, Haryana, Madhya Pradesh, Rajasthan, Bihar, Maharashtra, Gujarat, Karnataka, and West Bengal are major states of wheat production. The appropriate agronomic management practices like suitable land configuration and regulated water usage are the most important factors for realizing desired yield potential with higher resource use efficiency (Deshmukh et al. 2016). Land configuration techniques reduced the process of land degradation by alleviating soil salinity and waterlogging problems as well as for the creation of irrigation resources in the coastal region. Raised bed method of sowing has been found helpful to minimize the effect of temporary waterlogging and salt injury to plants at the initial growth stage (Akbar et al. 2007). The bed-planted drill-seeded wheat performed better than the farmers' practice of conventional till broadcast wheat (IRRI 2009). Raised bed planting method provides better plant growth due to higher soil moisture, higher salt leaching, and reduction in evaporation from the soil surface (Zhang et al. 2007 and Li et al. 2010). Resource conservation technologies such as ridge and furrows and raised bed sowing have been found effective for saving water in crop production (Gupta and Zaidi 2004). Wheat is planted with different sowing methods depending upon the soil type, available soil moisture, time of planting, amount of residue, etc. Sowing of wheat on raised bed, a new technique is being widely practiced in Sonora State of Mexico for a long time (Hobbs et al. 1997). The bed planting in wheat crop prevents lodging, because of more silica content as compared to flat bed planting and prevent soil applied nitrogen losses by reducing leaching and gas emission (Sayre and Moreno 1997). Lodging and lodging score were reduced by 50–60% and 60–75% in bed planting as compared to flat bed planting, respectively (Tripathi et al. 1999). Wheat planting on raised beds could improve water and fertilizer use efficiencies. Bed and furrow method of planting provides ease in water and fertilizer application. Conventional sowing is commonly used for growing wheat, and the crop is irrigated by flood method of irrigation, but it leads to ineffective use of applied nitrogen owing to poor aeration and leaching and volatilization losses more (Abdul et al. 2015). Salt-affected soils have been adversely affected on the growth of most plants due to the presence of salts. Land configuration technologies like furrow-irrigated raised bed (FIRB) sowing could help to solve the salinity problem at some extent. Since variation in sowing pattern modifies macro- and micro-environment to which plants are exposed, FIRB sowing have the potential to improve the productivity of wheat (Sepat et al. 2010). The soil of coastal areas of South Gujarat is saline and saline-sodic in nature. Because of this, physical condition of these soils are poor and thereby adversely affect the productivity of Rabi crops. Since reliable information on land configuration in wheat crop under the salt-affected area in Gujarat is lacking; therefore, present study was taken to evaluate the effect of land configuration on wheat growth and yield under partially reclaimed coastal salt-affected soil of coastal Gujarat.

18.2 Materials and Methods

The experiment was carried out at Coastal Soil Salinity Research Station, Navsari Agricultural University, Danti, which is located about one km away from the Arabian Sea towards East and geographically at 20° 83‟N latitude and 72°52‟E longitude with an altitude of 2.5 m above mean sea level. The soil of the experimental field was clayey in texture, bulk density (1.65 Mg m^{-3}) slightly alkaline in pH (8.38–8.35), medium in salinity $EC_{2.5}$ (2.01–2.04 dS m^{-1}), low in organic carbon (OC, 0.42–0.43 6%), cation exchange capacity (CEC, 40.70–44.05 [cmol(p^{+}) kg^{-1}]), and exchangeable sodium percentage (ESP, 12.25–12.77%). The soil is partially reclaimed saline-sodic and had low available nitrogen (266–271 kg ha^{-1}), medium available phosphorus (39.15–40.35 kg ha^{-1}), and high available potassium (615–645 kg ha^{-1}) status in the surface layer.

Three land configuration systems, L_1: flat bed, L_2: broad bed furrow, and L_3: ridge and furrow, were evaluated with respect to the wheat growth and yield parameters and nutrient uptake. The experimental field was cultivated in the third and fourth week of November during 2016–2017 and 2017–2018, respectively, with the help of tractor drawn cultivator followed by harrowing and planking to achieve fine tilth. For sowing, flat bed, broad bed furrow, and ridge and furrow were prepared as per land configuration treatments. Standard agronomic practices were followed for raising the wheat crop. Observations on the growth, yield and yield attributes of wheat were recorded as per the standard methods. The total plant uptake of nitrogen, phosphorus, and potassium were calculated after determining their contents in the straw and grain sample following the standard methods of analysis (Ryan et al. 2001).

18.3 Results and Discussion

18.3.1 Growth Parameters

18.3.1.1 Plant Height

Plant height at 30 DAS, 60 DAS and at harvest were not influenced significantly due to land configuration treatments (Table 18.1). While, maximum plant height was recorded in ridge and furrow treatment. This could be attributed to maintenance of proper air moisture regimes under ridge and furrow method of sowing which might have improved the drainage resulting in good supply of available nutrients, soil aeration, and soil environment. This is in agreement with results obtained earlier by Jat et al. (2011) and Yadav et al. (2011).

18.3.1.2 Number of Tillers

The data pertaining to total number of tillers m^{-1} row length of wheat crop recorded at 60 DAS was significantly influenced due to land configuration methods. The broad bed furrow method recorded significantly higher number of tillers m^{-1} (111.2) over flat bed method and was at par with ridge and furrow method; the number of tillers m^{-1} registered in broad bed was 6.20% more over flat bed method (104.7) (Table 18.1). The increase in the number of tillers under the broad bed and ridge and furrow systems may be due to better aeration causing less penetration impedance and subsequent growth and development of the crop (Khan et al. 2010).

18.3.2 Yield Attributes

The data pertaining to yield attributes like effective tillers m^{-1}, spike length spikelets spike^{-1}, grains spike^{-1}, and test weight (1000 grain wt.) of wheat crop recorded at harvest is shown in Table 18.1.

18.3.2.1 Effective Tillers

The data indicated that significantly, the highest number of effective tillers m^{-1} row length (106.7) was recorded in the land configuration treatment of broad bed furrow. The lowest number of effective tillers (98.3) m^{-1} row length was observed in flat bed method. This might be due to enhancement early vegetative growth in terms of higher dry matter accumulation and consequently increased the effective tillers under raised bed method. Similar findings were reported by Bhat et al. (2006) and Idnani and Kumar (2012).

Table 18.1 Effect of land configuration on growth parameters and yield attributes of wheat crop (two years pooled data)

Treatments	Plant height (cm)			Total tillers m^{-1}	Effective tillers m^{-1}	Spike length (cm)	Spikelets $spike^{-1}$	Grains $spike^{-1}$	Test wt. (g)
	At 30 DAS	At 60 DAS	At harvest						
L_1—Flat bed	26.6	46.1	85.3	104.7	98.3	7.9	10.5	26.3	39.73
L_2—Broadbed furrow	27.1	47.3	86.9	111.2	106.7	8.8	13.0	29.6	41.99
L_3—Ridge and furrow	27.1	47.1	87.0	109.0	104.2	8.7	13.1	28.9	41.60
SEm ±	0.23	0.40	0.74	0.96	0.78	0.09	0.12	0.28	0.33
CD (P = 0.05)	NS	NS	NS	2.91	2.38	0.27	0.37	0.86	1.02
C.V.%	7.42	7.32	7.33	7.96	6.94	9.45	7.74	8.15	6.87

18.3.2.2 Spike Length

The broad bed furrow registered significantly higher spike length (8.8 cm), but it was statistically at par with ridge and furrow method (8.7 cm), while significantly, the lowest spike length (7.9 cm) was obtained in flat bed treatment.

18.3.2.3 Number of spikelet's spike^{-1}

The land configuration treatments significantly influenced the number of spikelet's spike^{-1}. Ridge and furrow treatment registered significantly higher number of spikelets spike^{-1} (13.1), but it was found at par with broad bed furrow method. This might be associated with development of plants with higher photosynthesis, translocation, and accumulation of photosynthates as compared to other methods. Similar findings were also reported by Idnani and Kumar (2012) and Sagar et al. (2017).

18.3.2.4 Number of Grains spike^{-1}

The treatment broad bed furrow registered significantly higher number of grains spike^{-1} (29.6) and was at par with ridge and furrow method and the lowest grains spike^{-1} (26.3) was noted under flat bed method.

18.3.2.5 Test Weight

The broad bed furrow treatment recorded significantly higher test weight (41.99 g) and was statistically at par with ridge and furrow method.

18.3.3 Yield and Harvest Index

Significantly, the highest grain yield of wheat (3893 kg ha^{-1}) was recorded under broad bed furrow, while straw yield (5274 kg ha^{-1}) was significantly highest in ridge and furrow. The lowest grain (3392 kg ha^{-1}) and straw (4884 kg ha^{-1}) yields were observed under flat bed method (Table 18.2). The increased in grain and straw yield of wheat under broad bed furrow and ridge and furrow method could be attributed to higher yield attributes and better environment and aeration causing less penetration impedance were responsible for better development and thereby producing higher yield. These results are in conformity with the findings of Jani et al. (2008), Ghane et al. (2009), and Mollaha et al. (2009).

The results revealed that broad bed furrow method recorded significantly the highest harvest index (42.94%) than rest of the treatments. This might be due to

Table 18.2 Effect of land configuration methods on yields and nutrient uptake by wheat crop (two years pooled data)

Treatments	Grain yield (kg ha^{-1})	Straw yield (kg ha^{-1})	Harvest Index	Nutrient uptake (kg ha^{-1})		
				N	P	K
L_1—Flat bed	3392	4884	40.64	88.69	11.80	127.13
L_2—Broad bed furrow	3893	5168	42.94	105.53	15.44	143.06
L_3—Ridge and furrow	3828	5274	41.99	100.98	14.54	143.87
SEm ±	42.03	62.26	0.28	1.21	0.17	1.70
CD (P = 0.05)	123.50	191.86	0.88	3.68	0.54	5.26
C.V.%	9.62	10.34	5.67	10.52	10.84	10.50

better soil environment in raised beds since prolonged ponding of water reduce the yield. Similar findings were also reported by Idnani and Kumar (2012).

18.3.4 Nutrient Uptake

The data on uptake of N, P, and K by the wheat crop under various land configuration systems are presented in Table 18.2. The broad bed furrow method recorded significantly higher uptake of N (105.53 kg ha^{-1}) and P (15.44), while ridge and furrow method recorded higher P uptake (143.87). The lowest uptake of N, P, and K were observed under flat bed method. This increase in nutrient uptake in wheat under broad bed furrow and ridge and furrow method of land configuration might be due to increased yields and enhanced fertilizer use efficiency, favorable microclimate within the root zone due to changed orientation of the wheat plants in rows on top of the beds and favorable soil conditions for mineralization of native as well as applied nutrients. Similar results have also been reported by Sepat et al. (2010), Abdul et al. (2015) and Sagar et al. (2017).

References

Abdul M, Atif M, Abid N et al (2015) Bed planting of wheat (*Triticum aestivum* L.) improves nitrogen use efficiency and grain yield compare to flat planting. The Crop J 3:118–124

Akbar G, Hamilton G, Hussain Z et al (2007) Problem and potential raised bed cropping systems in Pakistan. Pakistan J Water Resour 11(1):11–15

Bhat MA, Mahal SS, Vashaist KK et al (2006) Influence of genotype, planting methods and weed management on competitiveness on wheat (*Triticum aestivum* L.) and *Phalaris minor*. African J Agric Res 1(3):70–73

Deshmukh SP, Vasave JB, Patel AM (2016) A short review of land configuration of improve the plant growth, development and yields of cereals. Int J Interdiscip Res Innov 4(3):1–4

Ghane E, Feizi M, Mostafazadeh-fard B et al (2009) Water productivity of winter wheat (*Triticum aestivum* L.) in different irrigation/planting methods using saline irrigation water. International J Agric Biol 11:131–137

Gupta RK, Zaidi PH (2004) Potential of resource conservation technologies in enhancing use efficiency of groundwater resources in the Indo-Gangetic plains. In**:** Workshop papers, ground water use in northwest India, Centre for Advancement Of Sustainable Agriculture, New Delhi, p 202

Hobbs PR, Sayre KD, Ortiz-Monasterio JI (1997) Increasing wheat yields sustainably through agronomic means, Miscellaneous reports no 232958, CIMMYT: International Maize and Wheat Improvement Center, Mexico

Idnani LK, Kumar A (2012) Relative efficiency of different irrigation schedules for conventional, ridge and raised bed seedling of wheat. Indian J Agron 57(2):148–151

IRRI (2009) Revitalizing the rice-wheat cropping systems of the Indo-Gangetic plains: Adaptation and adoption of resource-conserving technologies in India, Bangladesh, and Nepal. International Rice Research Institute, Philippines

Jani PP, Tanwar SPS, Singhi SM (2008) Performance of durum wheat (*Triticum durum* Desf.) varieties under varying sowing methods and input levels. Indian J Fert 4(7):71–73

Jat ML, Gupta R, Saharawat YS, Khosla R (2011) Effect of precision land levelling and furrow irrigated raised bed planting techniques on productivity and input use efficiency in irrigated wheat on sandy loam soil of IGP. Am J Plant Sci 2:578–588

Khan MJ, Jan MT, Khan AU et al (2010) Management of saline sodic through cultural practices and gypsum. Pakistan J Bot 42(6):4143–4155

Li QQ, Zhou XB, Chen YH et al (2010) Grain yield and quality of winter wheat in different planting patterns under deficit irrigation regimes. Plant Soil Environ 56(10):482–487

Mollah MIU, Bhuiya MSU, Kabir MH (2009) Bed planting—a new crop establishment method for wheat in rice-wheat cropping system. J Agric Rural Develop 7(1&2):23–31

Ryan J, Estefan G, Rashid A (2001) Soil and plant analysis laboratory manual. 2nd edn. ICARDA, Aleppo, Syria

Sagar VK, Naresh RK, Sharma DK et al (2017) Furrow irrigated raised bed planting and irrigation schedules: Productivity, nutrient uptake and economics of irrigated wheat in Indo- Gangetic Plains. J Pharmacogn Phytochem 6(6):1014–1019

Sayre KD, Morneo Ramos OH (1997) Applications of raised beds planting systems to wheat (*Triticum aestivum* L.). Wheat special report no 31. CIMMYT: International Maize and Wheat Improvement Center, Mexico, pp 10–13

Sepat RN, Rai RK, Shiva (2010) Planting systems and integrated nutrient management for enhanced wheat (*Triticum aestivum* L.) productivity. Indian J Agron 55(2):114–118

Tripathi SC, Nagarajan S, Chauhan DS (1999) Evaluation of tillage in wheat (*Triticum aestivum* L.) under different method of rice (*Oryza sativa*) transplanting. Indian J Agron 44(4):219–222

Yadav SS, Kumar S, Singh H et al (2011) Effect of tillage practices and cultivars on growth and biomass production of wheat (*Triticum aestivum* L.). Progress Agric 11(2):386–389

Zhang J, Sun J, Duan A, Wang J, Shen X, Liu X (2007) Effects of different planting patterns on water use and yield performance of winter wheat in the Huang-Huai-Hai plain of China. Agric Water Manage 92(1–2):41–47

Chapter 19
Studies on Organic Farming in Coriander [*Coriandrum sativum* (L.)]-Radish [*Raphanus sativus* (L.)] Cropping Sequence in Coastal Region of Karaikal

V. Kanthaswamy and E. Venkadeswaran

Abstract A field experiment was conducted at Pandit Jawaharlal Nehru College of Agriculture and Research Institute, Karaikal, Puducherry, India during 2017–2020 under All India Coordinated Research Project on Vegetable Crops (AICRP-VC). The study was aimed to compare the sole organic and its combination with inorganic sources of nutrients management in coriander-radish cropping sequence. Variety Pusa Chetki of radish and CO4 of coriander were used in the experiment. The conventional practices (recommended FYM + fertilizer + plant protection with chemicals) + IIHR microbial consortium @ 12.5 kg ha^{-1}[T_4] registered the highest yield in the coriander-radish (130.93 q ha^{-1} of coriander leaves and 348.73 q ha^{-1} of radish roots, respectively) cropping sequence with maximum B:C ratio of 4.42. It will ensure the sustainability in production and soil health along with pollution-free environment.

Keywords Coriander · Cropping sequence · Organic farming · Radish

19.1 Introduction

Radish [*Raphanus sativus* (L.)] is consumed as raw or as a salad. It is rich in calcium, potash, phosphorus, and vitamin C, and the productivity of radish is influenced by several factors such as soil, varieties, fertilizer management, and various agro technique used for growing crops. The organic sources are directly or indirectly helpful in increasing the availability and uptake of nutrients from the soil and ultimately to boost up the yield and quality of radish without rendering the detrimental effects on physicochemical properties of the soil (Pathak et al. 2017). Coriander-radish

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cropping sequence is very popular in the vegetable-growing tract of the Central Plain Zone of India. Coriander [*Coriandrum sativum* (L.)] is an important major seed spice of India grown for both herbs as well as seed purposes. Application of organic manures is directly or indirectly helpful in increasing the availability and uptake of nutrients from the soil and ultimately improves the yield and quality of coriander without rendering the detrimental effects on physicochemical properties of the soil (Lal et al. 2017). Continuous use of chemical fertilizers has resulted in nutritional imbalance, depletion of soil organic matter, contamination of food and water, adverse effects on biodiversity as well as on human health. Supplying nutrients through organic sources can be opted for avoiding the hazardous effects of fertilizers and maintaining sustainability (Rajiv 2019). Organic amendments like farmyard manure (FYM), vermicompost, and microbial consortium may play a major role in supplementing the crop nutrients through their direct addition, improvement in soil condition, nitrogen fixation, and solubilization of fixed forms of phosphorus and zinc in soil. Arka microbial consortium is a carrier-based product that contains N fixing, P and Zn solubilizing and plant growth-promoting microbes as a single formulation. The novelty of this technology is that farmers need not apply N fixing, phosphorous solubilizing, and growth-promoting bacterial inoculants individually. This technology considerably reduces the cost of cultivation, besides the synergistic effects of the formulated microbes can help in sustainable vegetable production. Fertilizers cost is increasing day by day, therefore, the farmers are looking for alternate sources, which may lower down the cost of cultivation along with maintaining the fertility status of the soil. The responses of organic sources and biofertilizers with or without chemical fertilizer on a large number of crops have been reported by several workers. With this background, the study was aimed to compare the sole organic and its combination with inorganic sources of nutrient management in coriander-radish cropping sequence.

19.2 Materials and Methods

A field experiment was conducted at Pandit Jawaharlal Nehru College of Agriculture and Research Institute, Karaikal, Puducherry, India during 2017–2020 under All India Coordinated Research Project on Vegetable Crops (AICRP-VC). The soil was clay loam with pH of 6.36, EC of 0.02–0.08 dSm^{-1}, 9.85 g kg^{-1} of organic carbon, 19.45 kg ha^{-1}of available nitrogen, 26.85 kg ha^{-1} of available phosphorus, and 290.20 kg ha^{-1} of available potassium. Seven treatments comprising T_1, conventional practices (recommended FYM + fertilizer + plant protection with chemicals); T_2, vermicompost equivalent to 100% N recommended for each of the crop (plant protection with organic methods); T_3, FYM equivalent to 100% N recommended for each of the crop (plant protection with organic methods); T_4, conventional practices (recommended FYM + fertilizer + plant protection with chemicals) + IIHR microbial consortium @ 12.5 kg ha^{-1}; T_5, vermicompost equivalent to 100% N recommended for each of the crop + IIHR microbial consortium @ 12.5 kg ha^{-1}

(plant protection with organic methods); T_6, FYM equivalent to 100% N recommended for each of the crop + IIHR microbial consortium @ 12.5 kg ha^{-1} (plant protection with organic methods); and T_7, safe production practices (recommended FYM + fertilizer + plant protection with organic methods) + IIHR microbial consortium @ 12.5 kg ha^{-1} were evaluated in randomized block design with three replications. The size of the plot is 3.60 × 3.60 m^2. Coriander crop was grown for the purpose of fresh green leaves. Organic manures and IIHR microbial consortium were applied at the time of field preparation of coriander as per treatment. Microbial consortium contained nitrogen fixing, phosphorus and zinc solubilizing, and plant growth-promoting microbes in a single formation and is used to increase the nutrient-use efficiency as well as yield. Variety Pusa Chetki of radish and CO4 of coriander were used in the experiment. Sowing of coriander was done in *rabi* season, while radish in the *kharif* season during all three years. Coriander was sown in rows, spaced at 30 cm apart. In the case of radish, the crop was sown on ridges at 45 cm × 10 cm spacing. Both crops were raised with the recommended package of practices (coriander 60:40:30 kg NPK $ha^{-1}$and 15 t FYM ha^{-1} and radish 60:50:50 kg NPK and 20 t FYM ha^{-1}) except treatments. The observations on yield were recorded and they were analyzed by using standard statistical techniques. Based on the total variable cost and gross returns, net returns and returns $rupee^{-1}$ invested were calculated as per methods suggested by Devasenapathy et al. (2008).

19.3 Results and Discussion

The three years continuous study on sole organic and in combination with inorganic sources of nutrients management in coriander (CO4)-radish (Pusa Chetki) cropping sequence revealed that fresh green leaves yield of coriander and root yield of radish was influenced significantly by different treatments during all the three years (Table 19.1). Among the seven treatment combinations, the highest mean marketable leaf yield of CO4 coriander (130.93 q ha^{-1}) for all the three seasons was recorded in the treatment receiving recommended FYM + fertilizer + plant protection with chemicals) + IIHR microbial consortium @ 12.5 kg ha^{-1} [T_4] followed by the treatment receiving safe production practices (recommended FYM + fertilizer + plant protection with organic methods) + IIHR microbial consortium @ 12.5 kg ha^{-1} (122.39 q ha^{-1}) [T_7]. This might be due to the availability of more nutrients during the crop growth period. The addition of organic matter also might have created a favorable environment for better growth and development (Islam et al. 2010). This conforms with the findings reported by Rajiv (2019).

Among the seven treatment combinations, the pooled highest marketable root yield of Pusa Chetki radish (348.73 q ha^{-1}) for all the three seasons recorded in the treatment receiving the same recommended FYM + fertilizer + plant protection with chemicals) + IIHR microbial consortium @ 12.5 kg ha^{-1}[T_4] followed by the treatment receiving safe production practices (recommended FYM + fertilizer + plant protection with organic methods) + IIHR microbial consortium @

Table 19.1 Effect of organic inputs on yield and economics in coriander-radish cropping sequence

Treatments	Marketable leaf yield of CO4 coriander (q ha^{-1})				Marketable root yield of Pusa Chetki radish (q ha^{-1})				Cost of cultivation (Rs. ha^{-1})	Gross income (Rs. ha^{-1})	Net income	B.C ratio
	2017–18	2018–19	2019–20	Mean	2017–18	2018–19	2019–20	Mean				
T_1	81.01	88.73	86.50	85.14	282.40	263.88	290.40	278.89	62,750	2,41,402	1,78,652	2.84
T_2	83.56	90.66	88.40	87.54	300.15	278.54	284.00	287.55	68,300	2,64,750	1,96,450	2.87
T_3	87.50	95.67	92.00	91.72	309.41	300.15	298.80	302.78	67,450	2,78,400	2,10,950	3.12
T_4	112.42	141.97	138.40	130.93	357.94	326.38	362.00	348.73	78,130	4,23,500	3,45,370	4.42
T_5	99.22	125.38	118.55	114.38	322.53	302.85	310.00	311.79	89,230	3,94,700	3,05,470	3.43
T_6	99.76	123.45	112.40	111.87	327.54	311.72	318.00	319.08	76,520	3,25,400	2,48,880	3.25
T_7	103.85	135.03	128.30	122.39	329.86	320.98	358.00	336.28	69,450	2,97,500	2,28,050	3.28
CD (5%)	9.85	6.87	5.20	6.10	104.25	18.42	16.20	13.43				
CV (%)	6.84	4.90	2.11	4.22	6.74	4.20	3.51	5.12				

T_1 Conventional practices (recommended FYM + fertilizers + PP chemicals)
T_2 Vermicompost @ X (PP with organic methods)
T_3 FYM @ X (PP with organic methods)
T_4 Conventional practices (recommended FYM + fertilizer + PP chemicals) + IIHR microbial consortium @ 12.5 kg ha^{-1}
T_5 Vermicompost @ X + IIHR microbial consortium @ 12.5 kg ha^{-1} (PP with organic methods)
T_6 FYM @ X + IIHR microbial consortium @ 12.5 kg ha^{-1} (PP with organic methods)
T_7 Safe production practices (recommended FYM + fertilizer + PP with organic methods) + IIHR microbial consortium @ 12.5 kg ha^{-1}
* Where X is equivalent to 100% N recommended for each of the crop in the region

12.5 kg ha^{-1}(336.28 q ha^{-1})[T_7]. The progressive improvement in yield parameters of radish root with the use of adoption of safe production practices along with Arka microbial consortium @ 12.5 kg ha^{-1} might be due to an increase in growth parameters, which might have resulted in improved uptake of nutrients and photosynthetic activities. Similar results have also been obtained by Kumar et al. (2014) and Rajiv (2019).

Among the other treatments, application of conventional practices (recommended FYM + fertilizer + plant protection with chemicals) + fertilizers [T_1] registered the lowest cost of cultivation Rs. 62,750 ha^{-1} followed by FYM equivalent to 100% N recommended for each of the crops (plant protection with organic methods) [T_3] and vermicompost equivalent to 100% N recommended for each of the crop (plant protection with organic methods) [T_2] (Rs. 67,450 ha^{-1} and Rs. 68,300 ha^{-1}, respectively).

The gross income was significantly higher with recommended FYM + fertilizer + plant protection with chemicals) + IIHR microbial consortium @ 12.5 kg ha^{-1}[T_4] (Rs. 4,23,500 ha^{-1} followed by vermicompost equivalent to 100% N recommended for each of the crop + IIHR microbial consortium @ 12.5 kg ha^{-1} (plant protection with organic methods) [T_5] and FYM equivalent to 100% N recommended for each of the crop + IIHR microbial consortium @ 12.5 kg ha^{-1} (plant protection with organic methods) [T_6] (Rs. 3,94,700 ha^{-1} and 3,25,400, respectively). The treatment receiving recommended FYM + fertilizer + plant protection with chemicals) + IIHR microbial consortium @ 12.5 kg ha^{-1}[T_4] recorded the highest net income (Rs. 3,45,370 ha^{-1}) followed by vermicompost equivalent to 100% N recommended for each of the crop + IIHR microbial consortium @ 12.5 kg ha^{-1} (plant protection with organic methods) [T_5] and FYM equivalent to 100% N recommended for each of the crop + IIHR microbial consortium @ 12.5 kg ha^{-1} (plant protection with organic methods) [T_6] (Rs. 3,05,470 ha^{-1} and Rs. 2,48,880 ha^{-1}, respectively). The B:C ratio was significantly higher with recommended FYM + fertilizer + plant protection with chemicals) + IIHR microbial consortium @ 12.5 kg ha^{-1} [T_4] (4.42) followed by vermicompost equivalent to 100% N recommended for each of the crop + IIHR microbial consortium @ 12.5 kg ha^{-1} (plant protection with organic methods) [T_5] and safe production practices (recommended FYM + fertilizer + plant protection with organic methods) + IIHR microbial consortium @ 12.5 kg ha^{-1} [T_7] (3.43 and 3.28, respectively).

19.4 Conclusions

Based on three years of the investigation, it may be concluded that the conventional practices (recommended FYM + fertilizer + plant protection with chemicals) + IIHR microbial consortium @ 12.5 kg ha^{-1}[T_4] registered the highest yield in the coriander-radish (130.93 q ha^{-1} of coriander leaves and 348.73 q ha^{-1} of radish roots, respectively) crop sequence with maximum B:C ratio of 4.42. It will also ensure sustainability in production and soil health along with pollution-free environment.

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References

Devasenapathy P, Ramesh T, Gangwar B (2008) Efficiency indices for agriculture management research. New India Publishing Agency, New Delhi, India, p 136

Islam MM, Karim AJMS, Jahiruddin M, Majid MK, Miah GM, Ahmed MM (2010) Effect of organic manure and chemical fertilizer on crops in the radish-stem amaranthus—Indian spinach cropping pattern in homestead area. Aust J Crop Sci 5(11):1370–1378

Kumar S, Maji S, Kumar S et al (2014) Efficacy of organic manures on growth and yield of radish (*Raphanus sativus* L.) cv. Japanese White. Int J Plant Sci 9(1):57–60

Lal G, Harisha CB, Meena NK, Meena RD, Choudhary MK (2017) Performance of coriander varieties (*Coriandrum sativum* L.) under organic management system. Int J Seed Spices 7(1):8–11

Pathak M, Tripathy P, Dash SK et al (2017) Effect of source of nutrient on growth, yield and quality of radish (*Raphanus sativus* L.) in radish—coriander cropping sequence. Pharm Innov J 6(12):496–499

Rajiv (2019) Comparative performance of organic and conventional management practiceson productivity and profitability of coriander (*Coriandrum sativum*)-radish (*Raphanus sativus*) system. Indian J Agron 64(1):28–33

Chapter 20
Effect of NaCl Salinity on Various Parameters of Seed Germination of Cashew Nut (*Anacardium occidentale* L.)

Zakia Sultana, Mahmood Hossain, Md. Abdul Mannan, and Md. Monirul Islam

Abstract Cashew (*Anacardium occidentale* L.) is an economically important fruit crop. About 50 years ago, the tree species was introduced in the hilly areas of Bangladesh. But, its potentiality to grow in the southern saline prone coastal plains had never been explored. Assessment of salt stress tolerance is a vital observation to introduce any new crop in the salt-affected areas. Thus, an experiment was conducted under laboratory and shade house conditions to observe the effect of salinity on different germination parameters of cashew nut. Cashew seed nuts were subjected to five concentrations of NaCl solutions, viz., 0 (control), 5, 10, 15 and 20 ppt. The experiment was laid out in completely randomized design (CRD) with five replications. The germination parameters such as germination initiation time, last day of germination, germination duration, germination (%), mean germination time, mean germination ratio, uncertainty of germination process, synchronization index, germination index, coefficient of velocity of germination, time to 50% germination were studied. Results of the experiment revealed that most of the parameters were negatively influenced with the increase in NaCl salinity; germination (%) was higher in 0 ppt (91 $\pm$ 4%), followed by 5, 10, 15 ppt, and no seed germination was observed in 20 ppt salinity. Germination initiation time, germination duration, germination (%), mean germination ratio, uncertainty, germination index, coefficient of velocity of germination of cashew nut varied significantly with the increasing salinity. Germination (%), mean germination ratio, uncertainty, germination index, coefficient of velocity of germination of cashew nut had a significant negative correlation with

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NaCl salinity, whereas mean germination time and time to 50% germination had a positive significant correlation with NaCl salinity. In this study, only one genotype had been used, and in the future, studies with other genotypes are suggested for further extension of knowledge in this regard.

Keywords Cashew nut · Salinity · Seed germination

20.1 Introduction

Cashew (*Anacardium occidentale* L.) is a fast-growing evergreen tree, native to Northeast Brazil, grows wild in many places and is found from sea level up to an altitude of 1000 m with annual rainfall between 700 to 2000 mm and an annual temperature between 21 °C and 28 °C (FAO 1982; Duke 1983; Orwa et al. 2009). Cashew is not a soil-demanding plant and can be grown in almost all types of lands except wetlands; even it can be grown in saline and drought conditions. Cashew needs less care and can protect soil from water and wind erosion (Subasinghe 2004). The major cashew-growing countries are Brazil, Nigeria, India, Vietnam, Cambodia, etc. (Ferreira-Silva et al. 2009). In India, all the states along the coast of Bay of Bengal are famous for cashew growing. Cashew grows very well in the coastal plains of many Indian states like West Bengal, Tamil Nadu and Orissa (Rejani et al. 2013). Bangladesh is also situated in the same coastal belts as Indian cashew-growing states and has a favorable climate; however, there was a lack of initiatives to exploit the potentiality of cashew cultivation. Although about a half-century back, cashew was introduced in Bangladesh in its hilly areas of Chittagong Division (DAE 2020). Recently, Ministry of Agriculture has given priority to extend cashew cultivation in the hilly districts of Chittagong Division.

Bangladesh has a long coastal plain that accounts 1.689 million hectares, and most of the lands are salt affected (Islam 2006). High soil and water salinity along with suitable irrigation water scarcity are the major restrictions for agricultural growth in the area (Uddin and Nasrin 2013). There are huge lands that remain uncultivated due to increase in soil salinity during the dry season. Thus, many cultivable lands had been converted into shrimp or fish ponds (*gher*). The dykes of the *ghers* are being used for vegetable production in a limited scale. Still, there is an opportunity to use such dykes for salt- and drought-tolerant perennial fruit tree cultivation without hampering fish and vegetable crops (Mondal 2010; Uddin and Nasrin 2013). Rather than, that huge newly developed lands by river siltation processes are available for plantation. Fruit trees might be a good option to compensate the low-intensity fruit crop in this coastal region. The cashew nut tree is well known for being salt- and drought-tolerant; also, it has the capacity to bind soil that prevents soil erosion. Sometimes, fish ponds need wind-protecting tree species, and cashew is also suited for that purpose (Bhat 2010). Cashews are propagated by various methods; direct-seeded method is the most easiest and convenient one. Cashew nuts are harvested in April–May months, and seed viability lasts for a limited time (Makale et al. 2020).

For good plant establishment, it is better to sow in time as early as possible after harvesting the nuts. But at this time, soil salinity exists in higher peak in the coastal Khulna region.

For introducing a crop plant in saline-prone areas, its salinity-tolerance capacity should be examined. Saline stress is one of the most important factors that restricts the growth and yield of crop plants by a reduction in the germination rate and a delay in initiation of germination and subsequent seedling establishment. Smooth and speedy seed germination followed by vigorous seedling establishment is the prerequisite for ensuring healthy plants and ultimately good crop yield under salinity stress (Carneiro et al. 2004).

Salinity is a complex process and is caused by many salts although the major one is sodium chloride (Dubey 1997; Hasegawa et al. 2000 and Levitt 1980). That is why the determination of NaCl tolerance level for seed germination and seedling growth is very important. The present research work was, therefore, undertaken to evaluate the effect of NaCl salinity on seed germination of cashew seed nuts with a view to promote cashew cultivation in the coastal region of Southwestern Bangladesh.

20.2 Materials and Methods

The experiment was conducted in the shade house of Plant Breeding and Biotechnology Laboratory of Agrotechnology Discipline, Khulna University, from June to September 2018. The experimental site is situated between 22°12′ and 23°59′ north latitudes and between 89°14′ and 89°45′ east longitudes and elevation of 3 m /10 feet. The experimental material was mature cashew nuts which were collected from a five-year-old cashew tree from Khulna University campus during May 2018. The average weight, length and breadth of the seed were 3.69 g, 28.38 mm and 15.36 mm, respectively. Prior to the germination test, viability of seed nuts was determined by the tetrazolium method (Copeland and McDonald 2005).

Five levels of NaCl salt (0, 5, 10, 15 and 20 ppt) were used as experimental treatments. Each treatment was replicated five times. A plastic bowl (bottom radius 20 cm, upper radius 27 cm and height 22 cm) filled with 2.5 inches of coarse sand was used as a germination tray. Twenty seeds were taken for each replication. Thus, a total of 25 (5 × 5) such experimental units was prepared for a total of 500 (25 × 20) cashew seed nuts. A completely randomized design (CRD) was followed for this experiment. The required amount of unpurified NaCl salt was estimated using the following formula and added to distilled water to make the required solution of NaCl,

$$V_1 S_1 = V_2 S_2.$$

where V_1 = volume of the stock solution to be prepared, S_1 = NaCl concentration of the stock solution (100 ppt), V_2 = volume of the working solution to be prepared, S_2 = salt concentration of working solution to be prepared.

Initially, selected cashew nuts were presoaked with distilled water for 24 h and then they were placed on sand in germination bowl. The saline solutions were applied to the bowl containing plated seed nuts. Salinity in each bowl was checked at every 24 h interval and corrected as necessary. The emergence of epicotyl by rupturing of seed coat was considered as germination. The number of germinated seeds was counted and recorded at 24 h interval.

Seed germination parameters were calculated as follows:

Germination Initiation Time (GIT): Seed coat rupture and the emergence of epicotyl were considered as germination of seed. The number of germinated seeds was counted at 24 h intervals, and time was recorded for germination initiation time.

Last day of Germination (LDG): The day when no further germination occurred for four successive days was considered as LDG (Yulan et al. 2016).

Germination Duration (GD): It is the time in days between GIT and LDG.

Germination Percentage (GP) (Labouriau 1983a):

$$\mathrm{GP}(\%) = \frac{\text{Number of germinated seeds}}{\text{Total number of seeds placed}} \times 100$$

Germination percentage values were transformed to ArcSine using MS Excel and were analyzed using the analysis of variance (ANOVA) technique.

Mean Germination Time (MGT) (Orchard 1977):

$$\mathrm{MGT} = \frac{\sum n_i d_i}{\sum n_i}$$

where n_i = no. of germinated seeds in d_i; d_i = no. of days after seed sowing; $\sum n_i$ = total no. of germinated seeds in each replication at the end of the experiment. MGT values were analyzed using analysis of variance (ANOVA) technique and F-test.

Mean Germination Rate (MGR) (Labouriau 1983b): MGR is the reciprocal of the mean germination time and was calculated as,

MGR = 1/MGT

Uncertainty of germination process (U) (Labouriau and Valadares 1976): U is an adaptation of the Shannon index and measures the degree of uncertainty associated to the relative frequency of germination.

$$U = -\sum_{i=1}^{k} f_i \log_2 f_i, \quad \text{being } f_i = \frac{n_i}{\sum_{i=1}^{k} n_i}$$

where f_i: relative frequency of germination; n_i number of seeds germinated on the ith time; and k: last day of germination.

Synchronization Index (Z) [Ranal and Santana (2006) and Primack (1985)]:

$$Z = \frac{\sum C_{\mathrm{ni},2}}{N}$$

$$\text{Being, } C_{\mathrm{ni},2} = \frac{n_i(n_i - 1)}{2}, N = \frac{\sum n_i(n_i - 1)}{2}.$$

where $C_{ni,2}$: combination of germinated seeds in ith time, two together and n_i number of seeds germinated in the time i. Then, $Z = 1$ when the germination of all seeds occurs at the same time, and Z = 0 when at least two seeds could germinate, one at each time.

Germination Index (GI) (Karaguzel et al. 2004):

$$\mathrm{GI} = \sum \frac{n}{d}$$

where n = number of seedling emerging on day d; d = day after seed sowing.

Coefficient of velocity of germination (CVG) (Nichols & Heydecker 1968):

$$\mathrm{CVG} = \frac{\sum_{i=1}^{k} f_i}{\sum_{i=1}^{k} f_i x_i} \times 100$$

where f_i: number of seeds newly germinating on day i; x_i: number of days from sowing; and k: last day of germination. CVG percentage values were transformed to ArcSine using MS Excel and were analyzed using analysis of variance (ANOVA) technique.

Time to 50% germination (Ching 1959): It is the number of days required for 50% of the total seeds to germinate. It represents germination speed.

Data were calculated by simple and powerful Excel tool for seed germination measurements, and the calculated data were analyzed by Microsoft Excel 2010 and Statistical tool for Agricultural Research 2013 (STAR).

20.3 Results and Discussion

Cashew seed nuts were evaluated under five levels of NaCl salt, and different germination parameters were observed for their respond to salinity. The results of the experiment have been presented and discussed below.

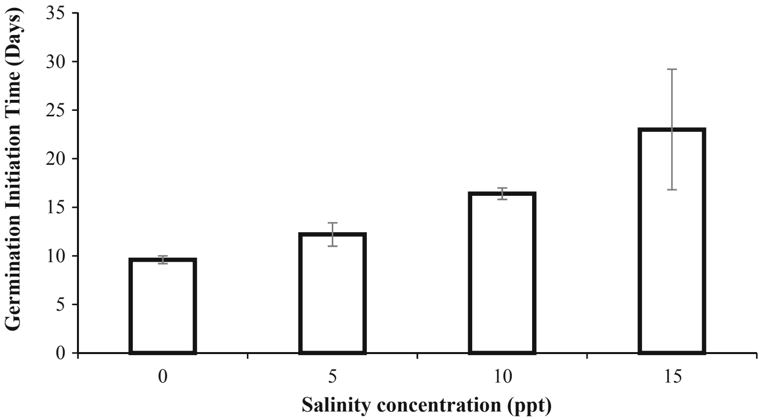

Fig. 20.1 Effect of salinity on germination initiation time of cashew nut

20.3.1 Effect of Salinity on Germination Initiation Time (GIT)

GIT of cashew nuts had significantly affected by the NaCl salt levels ($P \leq 0.01$). It was noticed that in controlled condition (0 salt), cashew nuts started germinating at 9.6 days, while in 5 ppt salinity, it required 12.2 days; in 10 ppt salinity, it required 16.4 days; in 15 ppt salinity, it took 23 days; and no germination was observed in 20 ppt salinity (Fig. 20.1). The above results revealed that an increase in salinity delayed germination initiation time. The results are in accordance with the findings of Babli Mog et al. (2017).

20.3.2 Last day of Germination (LDG)

This study showed that under control (no salt), cashew nut required 24.6 days to complete the germination process. Under NaCl saline condition at 5 ppt, last day of germination was observed 44.8 days, and at 10 ppt, it was 51.6 days, whereas at 15 ppt, germination was stopped after 41.8 days after sowing (Fig. 20.2). This result indicated that salinity prolongs the germination process. Similar observations were reported by Kayani et al. (1990), Franco et al. (1993), Katembe et al. (1998), Torres et al. (2000), Al-Karaki (2001) and Almansouri et al. (2001). This may be due to the reduction in water absorption during the imbibition phase or the excessive absorption of toxic ions, especially Na^+ and Cl^- as postulated by Prisco and O'Leary (1970).

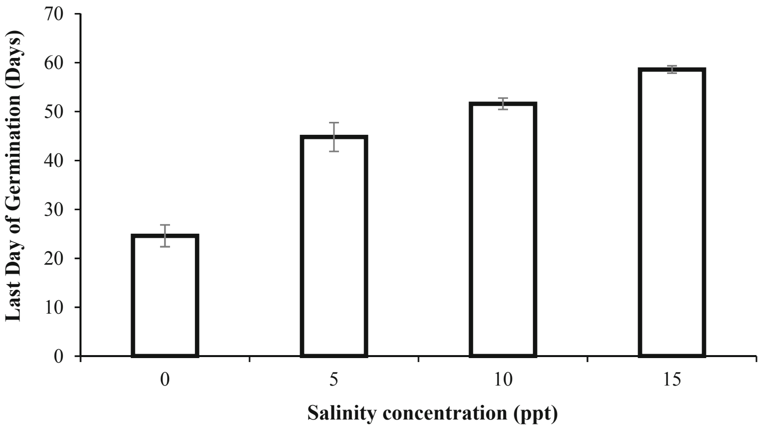

Fig. 20.2 Effect of salinity on last day of germination of cashew nut

20.3.3 Germination Duration (GD)

Under controlled condition (no salinity), germination duration was 15 days, whereas under NaCl saline condition at 5 ppt, 10 ppt and 15 ppt, germination duration was 32.6 days, 35.2 days and 35.6 days, respectively, (Fig. 20.3). This result indicated that NaCl salinity significantly ($P \leq 0.01$) prolonged cashew nut seed germination duration. Idelfonso et al. (2002) also found the same result. This may be caused by the increase of soluble salts in the substrate, resulting in a decrease in soil water availability and hampering the water absorption process by the seeds (Rhoades and Loveday 1990).

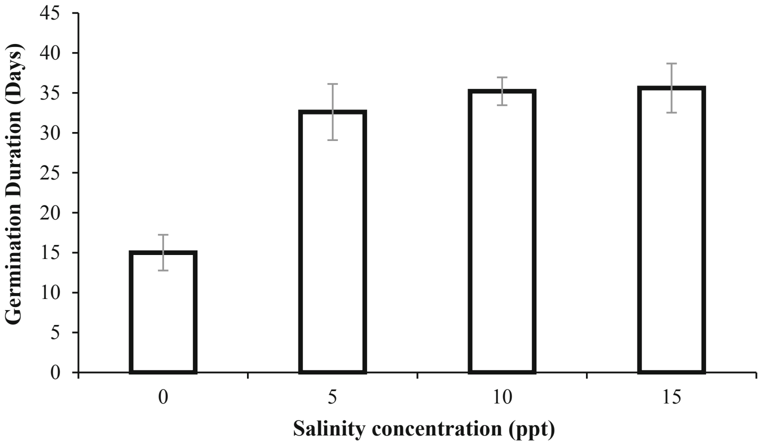

Fig. 20.3 Effect of salinity on germination duration of cashew nut

20.3.4 Germination Percentage (GP)

The germination percentage was higher (91%) in the control treatment followed by salinity concentration 5 ppt (58%), 10 ppt (34%) and 15 ppt (16%), respectively, and there was no germination observed under 20 ppt salinity (Fig. 20.4). This result indicated that salinity had a significant effect on the germination percentage of cashew nut seeds. Salinity stress mostly reduces the germination percentage and delays the onset of germination; its effects are modified by interactions with other environmental factors as temperature and light. Salinity can affect germination by affecting the osmotic component, i.e., Na and Cl accumulation (Živkovic et al. 2007).

When germination percentage data were plotted against the salinity levels, a straight linear regression line ($Y = -4.98x + 87.1$) was produced indicating a negative correlation between salinity and germination %. The regression equation also explains that for a single unit increase in NaCl salinity, germination % decreases by 4.9%. Regression coefficient $R^2 = 0.982$ indicates that 98% variation in germination % is caused by the variation in salinity levels (Figs. 20.4 and 20.5).

Johnson (1973) and Barros (1995) stated that salt stress influences the metabolic processes, such as the mobilization of the stored reserves for the growing embryonic axis; as a result, seed germination and seedling establishment are greatly influenced. Oliveira (2001) explained in a report that the main reserves of the cashew seeds are lipids, followed by carbohydrates, proteins and other constituents. Germination and seedling establishment of cashew under saline stresses led to the inhibition of mobilization of the cotyledons reserves, principally the lipids, resulting in a reduction of embryonic axis growth.

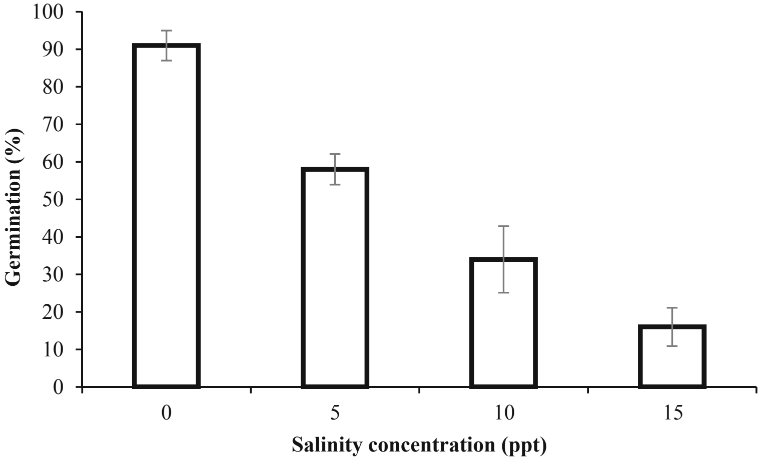

Fig. 20.4 Effect of salinity on germination percentage of cashew nut

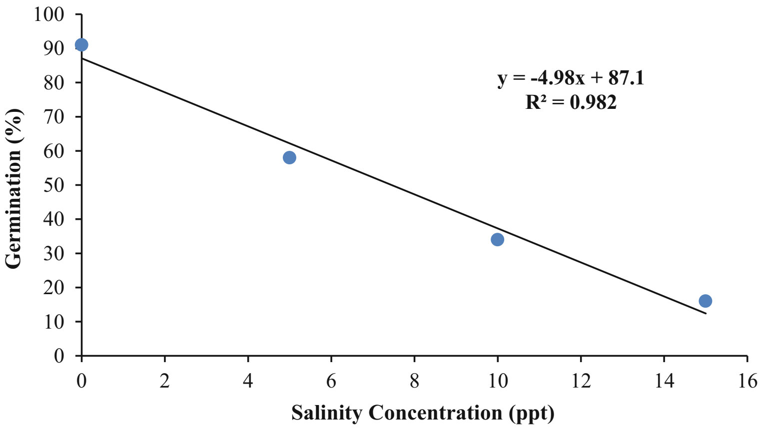

Fig. 20.5 Functional relationship between germination percentage and salinity in cashew nut

20.3.5 Mean Germination Time (MGT)

In this study, the mean germination time of cashew seed at control was less (18.55 days) than other salinity concentrations that were 5 ppt (25.56 days), 10 ppt (34.98 days) and 15 ppt (41.81 days) (Table 20.1). This result indicated that the mean germination time of cashew nut seeds was significantly ($P \leq 0.01$) increased with the increase of NaCl salinity. Dehnavi et al. (2020) also found salinity increased MGT of all sorghum genotypes.

20.3.6 Mean Germination Rate (MGR)

The mean germination rate is reciprocal of the mean germination time, and in this experiment, the mean germination rate of cashew seed was maximum (0.06), and at 15 ppt salinity concentration, the rate was minimum (0.02). This result indicated that NaCl salinity concentration had a significant inverse effect ($P \leq 0.01$) on the mean germination rate of cashew seed (Table 20.1). Since the higher salt concentration limited the water absorption, it slows down the germination rate (Tsegay and Gebreslassie 2014). Ungar (1995) observed that germination rate was a more sensitive parameter than germination percentage in *Atriplex platula.*

Table 20.1 Effect of different NaCl salinity concentrations on germination parameters of cashew

Salinity	Germination parameters (mean ± SE)						
	MGT	MGR	U	Z	GI	CVG	T50
0 ppt	18.55 ± 1.37	0.06 ± 0.004	2.21 ± 0.21	0.2 ± 0.039	1.0 ± 0.08	13.53 ± 0.49	17.26 ± 1.74
5 ppt	25.56 ± 2.23	0.04 ± 0.003	2.76 ± 0.16	0.09 ± 0.026	0.56 ± 0.08	11.54 ± 0.49	22.49 ± 3.53
10 ppt	34.98 ± 3.43	0.03 ± 0.004	1.9 ± 0.35	0.16 ± 0.048	0.23 ± 0.06	9.92 ± 0.59	36.75 ± 5.80
15 ppt	41.81 ± 1.54	0.02 ± 0.001	1.30 ± 0.10	0.21 ± 0.065	0.10 ± 0.02	8.92 ± 0.17	43.06 ± 2.30
CV(%)	18.94	21.28	25.22	59.98	25.19	10.59	29.91

20.3.7 Uncertainty of Germination (U)

The uncertainty index is associated with the distribution of the relative frequency of germination. In this experiment, it was found that salinity had a significant negative effect on the uncertainty of germination (Table 20.1). Here, the highest value (2.76 bit) was observed in 5 ppt, and the values decreased with the increase of salinity. High values of uncertainty indicate high diversity, and low values indicate more synchronized germination.

20.3.8 Synchronization Index (Z)

Synchronization means the degree of germination overlapping. Salinity had no significant effect on the synchronization index. Here, the highest value was observed (0.21) at 15 ppt in the control treatment (Table 20.1).

20.3.9 Germination Index (GI)

Germination index indicates the percentage of germination per day, so the higher the percentage and the shorter the duration, the higher the GI. Here, germination index was high (1.0) at the control and low (0.01) at 15 ppt (Table 20.1). This result indicated that salinity had a highly significant negative effect on the germination index of cashew nut. Dehnavi et al. (2020) also had reported a similar result.

20.3.9.1 Coefficient of Velocity of Germination (CVG)

The coefficient of velocity of germination gives an indication of the rapidity of germination. It increases when the number of germinated seeds increases and the time required for germination decreases. Here, CVG % was higher (13.53) in control and lower at 15 ppt (8.92) salinity concentration (Table 20.1). This result indicated that salinity had a highly significant negative effect on the coefficient of velocity of germination of cashew nut seed. Chakma et al. (2019) observed that the germination coefficient was significantly influenced different levels of NaCl salt concentration.

20.3.9.2 Time to 50% Germination (T50)

Time to 50% germination indicates time to reach 50% germination. The lowest value (17.26 days) was observed in control, and the highest value (43.06 days) was observed at 15 ppt salinity. Salinity had a significant ($P \leq 0.01$) effect on the time taken to reach 50% germination (Table 20.1).

A correlation analysis was performed among the germination parameters as well as with the salinity levels studied. Salinity had a highly significant negative correlation with germination %, mean germination rate, germination index and coefficient of velocity of germination of cashew nut seed. This result indicated that germination %, mean germination rate, germination index and coefficient of the velocity of germination of cashew nut seed were decreased with the increase of salinity. Uncertainty of the germination process had a significant negative correlation with salinity. The results indicated that with the increase of salinity, the uncertainty of germination process decreased. Mean germination time and time to 50% germination had a positive significant correlation with salinity. With the increase of salinity, mean germination time and time to 50% germination increased. Synchronization index and coefficient of variation of germination time were found to be negatively correlated with salinity (Table 20.2).

20.4 Conclusions

Cashew nut seed germinated up to 15 ppt salinity (germination -16%), but no seed germinated at 20 ppt salinity. Salinity had a highly significant negative effect on seed germination % of cashew nut along with mean germination rate, germination index and coefficient of velocity of germination. Germination initiation time, germination duration, germination(%), mean germination ratio, uncertainty, germination index, coefficient of velocity of germination of cashew nut varied significantly with the increasing salinity. Germination (%), mean germination ratio, uncertainty, germination index, coefficient of velocity of germination of cashew nut had a significant negative correlation with salinity, whereas mean germination time and time to 50% germination had a positive significant correlation with salinity. So, cashew can be suggested for the southwestern region of Bangladesh as it completed germination at moderately saline stress. In this study, we had selected only one genotype for evaluation; however, it is necessary to screen other genotypes of cashew to generate further information which will be useful for the selection of salinity tolerant cashew genotypes.

Table 20.2 Correlation of different germination parameters with salinity

Parameters	Salinity	G %	MGT	MGR	U(bit)	Z	GI	CVG%	T50
G %	-0.8860**								
MGT	0.5221*	-0.3218							
MGR	-0.8524**	0.8497**	-0.3763						
U(bit)	-0.5588*	0.5860**	0.0796	0.4555*					
Z	-0.2380	0.3244	0.0628	0.3839*	-0.2437				
GI	-0.9197**	0.9410**	-0.5440*	0.8974**	0.4381*	0.3348			
CVG%	-0.7542**	0.8029**	-0.0710	0.9446**	0.5787**	0.3752	0.7667**		
T50	0.5278*	-0.3623	0.9692**	-0.4395*	-0.0514	0.1493	-0.5698**	-0.1596	

Pearson's product—moment correlation, NS—non-significant,* —correlation is significant at the 0.05 level, and **—correlation is significant at the 0.01 level.

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References

Al-Karaki GN (2001) Germination, sodium, and potassium concentrations of barley seeds as influenced by salinity. J Plant Nutr 24:511–522

Almansouri M, Kinet JM, Lutts S et al (2001) Effect of salt and osmotic stresses on germination in durum wheat (Triticum durum Desf.). Plant Soil 231:243–254

Babli Mog J, Adiga D, Nayak MG et al (2017) Germination and seedling establishment in cashew (*Anacardium occidentale* L.): an interaction between seed size, relative growth rate and seedling biomass. J Plantation Crops 45(2):110–120. https://doi.org/10.19071/jpc.2017.v45.i2.3305

Barros LM (1995) Botânica, origem e distribuição geográfica. In: Araújo JPP, Silva VV (eds) Cajucultura: modernas técnicas de produção. EMBRAPA/CNPAT, Fortaleza, pp 55–72

Bezerra MA, de Lacerda CF, Filho EG et al (2007) Physiology of cashew plants grown under adverse conditions. Brazil J Plant Physiol 19(4):449–461

Bhat MG, Nagaraja KV, Rupa JTR et al (2010) Cashew research in India. Hort Sci 5(1):1–16

Carneiro PT, Fernandes PD, Gheyi HR et al (2004) Salt tolerance of precocious-dwarf cashew rootstocks-physiological and growth indexes. Sci Agric (Piracicaba, Braz) 61(1): https://doi.org/10.1590/S0103-90162004000100002

Copeland OL, McDonald MB (2005) Seed science and technology. Chapman & Hall, New York

Ching TM (1959) Activation of germination in Douglas fir seed by hydrogen peroxide. Plant Physiol 34:557–563

Chakma P, Hossain MM, Rabbani MG (2019) Effects of salinity stress on seed germination and seedling growth of tomato. J Bangladesh Agric Univ 17(4):490–499. https://www.banglajol.info/index.php/JBAU/article/view/44617

DAE (2020) Problems and prospects of cashew and coffee cultivation in hill areas. Department of Agricultural Extension (DAE), Khamarbari, Dhaka, Bangladesh

Dehnavi AR, Zahedi M, Ludwiczak A et al (2020) Effect of salinity on seed germination and seedling development of sorghum (*Sorghum bicolor* (L.) moench genotypes. Agron 10(6):859. https://doi.org/10.3390/agronomy1006085

Dubey RS (1997) Photosynthesis in plants under stressful conditions. In: Pessarakli M (ed) Handbook of photosynthesis. Marcel Dekker, New York, pp 859–975

Duke JA (1983) Handbook of energy crops. NewCROPS web site, Purdue University. http://www.hort.purdue.edu/newcrop/duke_energy/dukeindex.html

FAO (1982) Espèces fruitières forestières: fiches techniques. FAO, Forêts 34:5–11

Ferreira-Silva SL, Voigt EL, Viégas RA et al (2009) Influência de porta-enxertos na resistência de mudas de cajueiro ao estresse salino. Pesq Agropec Bras 44:361–367

Franco JA, Esteban C, Rodriguez CE et al (1993) Effects of salinity on various growth stages of muskmelon cv. Revigal. J Hort Sci 68:899–904

Idelfonso L, Bezerra Hans RG, Pedro DF et al (2002) Germination, formation. of rootstocks and grafting of early dwarf cashew under saline stress. Brazilian J Agric Environ Eng 6(3):420–424

Islam SKA, Miah MAQ, Habib MA, et al (2013) Diversity of fruit and timber tree species in the coastal homesteads of southern Bangladesh. J Asiat Soc Bangladesh Sci 39(1):83–94

Johnson DV (1973) The botany, origin and spread of the cahew (*Anacardium occidentale* L.) J Plant Crops 1:1–7

Karaguzel O, Cakmakci S, Ortacesme V et al (2004) Influence of seed coat treatments on germination and early seedling growth of *Lupinus varius* L. Pak J Bot 36(1):65–74

Katembe WJ, Ungar IA, Mitchell JP et al (1998) Effect of salinity on germination and seedling growth of two *Atriplex* species (Chenopodiaceae). Ann Bot 82:167–175

Kayani SA, Naqvi HH, Ting IP et al (1990) Salinity effects on germination and mobilization of reserves in jojoba seed. Crop Sci 30:704–708

Labouriau LG, Valadares MEB (1976) On the germination of seeds of *Calotropis procera* (Ait.) Ait. f. An Acad Bras Ciênc 48:263–284

Labouriau LG (1983a) A germinação das sementes. Organização dos Estados Americanos. Programa Regional de Desenvolvimento Científico e Tecnológico. Série de Biologia. Monografia 24

Labouriau LG (1983b) Uma nova linha de pesquisa na fisiologia da germinação das sementes. In Anais do XXXIV Congresso Nacional de Botânica. SBB, Porto Alegre, p.11–50

Levitt J (1980) Responses of plants to environmental stresses: water, radiation, salt and other stresses. Academic Press, New York, pp 365–488

Makale AR, Nene WA, Kapinga FA et al (2020) Effects of cashew seeds storage duration on germination and performance of seedlings in Tanzania. Am J Plant Sci 11:1784–1796. https://doi.org/10.4236/ajps.2020.1111128

Mondal M (2010) Crop agriculture of Bangladesh: challenges and opportunities. Bangladesh J Agric Res 35(2):235–245. https://doi.org/10.3329/bjar.v35i2.5886

Nichols MA, Heydecker W (1968) Two approaches to the study of germination data. Proceedings of the International Seed Testing Association 33:531–540

Oliveira MSC (2001) Estudo da composição lipídica e efeito do estresse hídrico em membranas foliares de cajueiro anão precoce (*Anacardium occidentale* L.). M.Sc. dissertation, Universidade Federal do Ceará, Fortaleza

Orchard T (1977) Estimating the parameters of plant seedling emergence. Seed Sci Tech 5:61–69

Orwa C, Mutua A, Kindt R et al (2009) Agroforestry database: a tree reference and selection guide version 4.0. World Agroforestry Centre, Kenya

Primack RB (1985) Longevity of individual flowers. Annu Rev Ecol Evol Syst 16(1):15–37

Prisco JT, Eneas Filho J, Gomes Filho E et al (1981) Effect of NaCl salinity on cotyledon starch mobilization during germination of *Vigna unguiculata* (L.) Walp seeds. Rev Brasil Bot 4:63–71

Prisco JT, O' Leary JW (1970) Osmotic and "toxic" effects of salinity on germination of *Phaseolus vulgaris* L. seeds. Turrialba 20:177–184

Ranal MA, de Santana DG (2006) How and why to measure the germination process? Brazilian J Bot 29(1):1–11

Rejani R, Rupa TR, Nayak MG et al (2013) Suitability of cashew growing areas in India – an appraisal using GIS. J Agrometeorol 15(Special Issue-II):123–128

Rhoades JD, Loveday J (1990) Salinity in irrigated agriculture. In: Stewart DR, Nielsen DR (ed) Irrigation of agricultural crops. Agron 30. Madison: ASA, CASSA and SSSA, p 1089–1142

Subsainghe S (2004) Development of salt affected loads in southern Sri Lanka with special reference to Humbantola district, Proceedings of the second academic sessions: 1–7

Torres SB, Vieira EL, Marcos-Filho J et al (2000) Efeitos da salinidade na germinação e no desenvolvimento de plântulas de pepino. Rev Bras Sem 22:39–44

Tsegay BA, Gebreslassie B (2014) The effect of salinity (NaCl) on germination and early seedling growth of *Lathyrus sativus* and *Pisum sativum var.abyssinicum.* African J Plant Sci 8(5):225–231

Uddin MT, Nasrin M (2013) Farming practices and livelihood of the coastal people of Bangladesh. Progress Agric 24(1–2):251–262. https://doi.org/10.3329/pa.v24i1-2.19177

Ungar IA (1995) Seed germination and seed-bank ecology of halophytes Marcel Dekker, New York, p 599–627. https://doi.org/10.1201/9780203740071-23

Yulan X, Nianhui C, He B, Ruili Z, Zhao W, Mao J, Duan A, Li Y, Woeste K et al (2016) Germination and early seedling growth of *Pinus densata* Mast provenances. J for Res 27(2):283–294

Živković S, Dević M, Filipović B, Giba Z, Grubišić D et al (2007) Effect of NaCl on seed germination in some *Centaurium* Hill. species (Gentianaceae). Arch Biol Sci 59(3):227–231

Chapter 21
Exploring the Growth and Yield Performance of Intercrops in Cashew (*Anacardium occidentale* L.) Orchard Under Coastal Climate of Karnataka

G. Raviraja Shetty, Lakshmana, and T. R. Ranganath

Abstract A field trial aimed at investigating the influence of intercrops on yield, growth, seed weight, plant girth, plant spread, and growth performance of the cashew varieties with intercrops like elephant foot yam, turmeric, banana, tapioca, bush pepper, ginger, and mango ginger during the established phase was carried out at Agricultural and Horticultural Research Station, Ullal, in the coastal zone of Karnataka. From the two years study, it was observed that the intercrop performance was found to be good and produced acceptable economic yield. The cashew varieties Ullal-1, Ullal-2, Ullal-3, Ullal-4, Madakathara-2, and Bhaskara showed good performance without much effect of the intercrops on its normal yield. The yield of various intercrops like elephant foot yam, tapioca, turmeric vars. Salem and Cadapa, ginger, mango ginger, banana, and bush pepper recorded were 4.00, 6.5, 1.47 and 0.14, 0.11, 0.21, 17.60, and 0.25 kg plant^{-1}, respectively. The average cashew yield of 17.80, 17.8, 13.55, 16.67, 21.82, and 15.08 kg plant^{-1} were obtained from the varieties Ullal-1, Ullal-2, Ullal-3, Ullal-4, Madakathara-2, and Bhaskara, respectively.

Keywords Cashew · Coastal climate · Growth and yield · Intercropping

21.1 Introduction

Cashew (*Anacardium occidentale* L.) is an evergreen tree. It was introduced in India during the latter half of the sixteenth century for the purpose of afforestation and soil

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conservation. From its humble beginning as a crop intended to check soil erosion, now cashew has emerged as a major foreign exchange earner next only to tea and coffee. Cashew is a seasonal crop, and the farmer can get the farm return in the same land if he goes for the other cash crops. It bears yield from third year onwards being a long duration and widely spaced crops. It offers great scope for intercropping (Bedi 1964).

Intercropping is one of the potential cropping systems to use natural resources more efficiently than by growing a single crop. Intercropping is claimed to be one of the most significant cropping techniques in sustainable agriculture; reduces weed competition; and helps to maintain the fertility of the orchards. The growing of leguminous tree crops helps to improve the soil fertility in cashew orchards (DAP 1996). The intercropping is practiced in the first 6 years of cashew plantation due to short canopy spread and provide more juvenile phase; hence, there is sufficient space between crop rows with the main objective of deriving some income until the cashew starts giving economic returns. The benefits of such a practice may include food security for the household, income generation to partially offset the cost of establishment, weed control, and better use of growth resources (Rodrigo et al. 2001; Opoku-Ameyaw et al. 2003). However, the success of the intercropping system will depend on whether the intercrops compete with the cashew trees for growth resources. Usually, grasses, leafy and rooty vegetables, small fruit crops and flower crops are common in coastal Karnataka. During the initial years of plant growth pineapple, papaya, tapioca, and vegetable are suggested in cashew plantations of Dakshina Kannada district (Rao and Yadukumar 1991).

Considering the above facts, this paper reports the findings of a study aimed at developing sustainable cashew intercropping systems that improve cashew growth and yield and at the same time can provide economic returns to the farmers during the establishment phase of cashew plantation.

21.2 Materials and Methods

The experiment was carried out during 2019 and 2020 at the Agricultural and Horticultural Research Station of the University of Agricultural and Horticultural Sciences located at Ullal, Mangalore, in the coastal zone of Karnataka. The soils are mainly typical laterite soils of the west coast with patches of red sandy loam. The soil is acidic in nature with a pH range of 5.4–5.8. The crop response to manuring and irrigation is very good in this type of soil. A ten-year-old cashew farm (8 m $\times$ 8 m spacing) was selected for the experiment. The experiment was laid out in a randomized block design with five replications.

The elephant foot yam was planted in three rows between two rows of cashew variety Ullal-1. The banana (Variety G9) in a single row was planted between Ullal-3 cashew rows, one row of tapioca was planted in between Ullal-3 cashew rows, the mango ginger was planted in 3 rows between two rows of cashew variety Ullal-1 and Ullal-2, 3 rows of ginger was planted between Ullal-2 and Ullal-3 cashew rows, 3 rows of turmeric (var. Salem) were planted between Ullal-3 and Ullal-4 cashew rows, 3 rows of turmeric (var. Cadapa) was planted between Ullal-4 and Madakathara-2 cashew rows, and three rows of bush pepper was planted between the rows of Madakathara-2 and Bhaskara. Manuring, plant protection, and interculture operations were done as per the recommended package of practices. The observations on yield, plant height, stem girth, canopy spread, leaf area, and vegetative shoot were recorded. The experiment data of each observation were subjected to ANOVA separately in a randomized complete block design (RCBD), and the test of significance was done at $P = 0.05$. Critical difference values were calculated wherever 'F' tests were significant (Panse and Sukhatme 1985).

21.3 Results and Discussion

The data on the growth parameters and yield of the intercrops have been presented in Table 21.1. From the pooled data, its evident the plant height of the various crops, namely tapioca, banana, elephant foot yam, turmeric var. Salem, turmeric, var. Cadapa, bush pepper, ginger, and mango ginger recorded was 64.9, 85.75, 93.85, 102.65, 99.2, 56.5, and 123.4 cm, respectively. The stem girth of the intercrops varied from a maximum of 13.8 cm in banana and the least was in case of bush pepper (1.25 cm) as they have different growth habits. Similarly, the canopy spread varied from a maximum of 154.75 cm in elephant foot yam to the lowest of 23.66 cm in ginger. The canopy spread was 27.20, 106.75, 86.35, 83.70, 120.00, and 65.60 in tapioca, banana, turmeric var. Salem, turmeric, var. Cadapa, bush pepper and mango ginger. The leaf area was recorded in the intercrops tapioca, banana, elephant foot yam, turmeric var. Salem, turmeric, var. Cadapa, bush pepper, ginger, and mango ginger was 32.94, 1545.84, 125.90, 700.61, 693.00, 194.50, 105.95, and 690.85 cm^2, respectively.

Among the intercrops, the highest yield of 35.2 kg $plant^{-1}$ was recorded in banana while the yield of tapioca obtained was 6.5 kg $plant^{-1}$. The yield of other intercrops like elephant foot yam, turmeric var. Salem, turmeric var. Cadapa, bush pepper, ginger, and mango ginger obtained was 4, 1.48, 0.14, 0.25, 0.11 and 0.21 kg $plant^{-1}$, respectively.

Adiga and Kalaivanan (2017) had obtained a maximum yield of tapioca (18.71 t ha^{-1}), when grown as an intercrop with cashew. In elephant foot yam Opoku-Ameyaw et al. (2011) recorded yield of 5 kg $plant^{-1}$ along with 40.1 mm stem girth, 122.5 cm height, 194.2 cm canopy spread. Similar to this study, Vikram and Hegde (2014a, b) reported that the growth of ginger and turmeric as intercrop in cashew plantation was significantly higher for plant height, pseudostem diameter, number of tillers, and leaf area index.

A perusal of the data presented in Table 21.2 revealed that during both the years of study the yield of cashew variety Madakathara-2 was significantly the highest (pooled mean of 21.83 kg $plant^{-1}$). The yield of cashew varieties Ullal-1, Ullal-2, and Ullal-4 was statistically at par and ranked second. The cashew variety Bhaskar yielded

Table 21.1 Growth and yield performance of intercrops cultivated in cashew orchard

Inter crop	Plant height (cm)			Stem girth (cm)			Canopy spread (cm)			Leaf area (cm^2)			Vegetative shoot/branch (Nos.)			Yield of inter crops (kg $plant^{-1}$)		
	2019	2020	Pooled	2019	2020	Pooled	2019	2020	Pooled	2019	2020	Pooled	2019	2020	Pooled	2019	2020	Pooled
Tapioca	64.40	65.40	64.90	3.20	3.80	3.50	28.00	26.40	27.20	32.40	33.48	32.94	3.01	4.00	3.50	–	6.50	6.50
Banana (G9)	85.30	86.20	85.75	13.40	14.20	13.8	107.10	106.40	106.75	1543.50	1548.18	1545.84	6.00	9.20	7.61	–	35.20	35.20
Elephant foot yam	94.60	93.10	93.85	9.42	9.86	9.64	153.40	156.10	154.75	123.40	128.40	125.90	5.00	5.00	5.03	3.81	4.20	4.00
Turmeric (var. Salem)	102.10	103.20	102.65	6.50	6.02	6.26	84.60	88.10	86.35	701.20	700.02	700.61	5.05	6.00	5.53	1.45	1.50	1.48
Turmeric (var. Cadapa)	100.00	98.40	99.20	5.60	5.90	5.75	79.40	88.00	83.70	700.00	686.00	693.00	5.00	5.00	5.00	0.14	0.14	0.14
Bush pepper	45.00	68.00	56.5	1.00	1.50	1.25	90.00	150.00	120.00	194.00	195.00	194.50	15.00	24.00	19.50	0.22	0.28	0.25
Ginger	85.30	86.20	85.75	4.10	4.30	4.20	24.10	23.22	23.66	105.10	106.80	105.95	3.02	4.00	3.50	0.11	0.11	0.11
Mango ginger	121.60	123.40	122.5	7.60	8.60	8.10	64.10	67.10	65.6	699.60	682.10	690.85	2.00	2.00	2.02	0.21	0.21	0.21

Table 21.2 Growth and yield performance of cashew varieties

Cashew varieties	Yield (kg plant^{-1})			Seed weight (g)			Apple weight (g)			Plant girth (m)			Plant spread (m)		
	2019	2020	Pooled	2019	2020	Pooled	2019	2020	Pooled	2019	2020	Pooled	2019	2020	Pooled
Ullal-1	17.50	18.10	17.80	6.72	6.75	6.74	33.57	35.64	34.61	0.88	0.89	0.89	8.56	8.86	8.71
Ullal-2	17.80	17.81	17.81	6.51	6.56	6.54	57.76	57.89	57.83	0.72	0.76	0.74	7.76	7.70	7.73
Ullal-3	13.50	13.60	13.55	10.40	10.48	10.44	77.87	77.93	77.90	0.85	0.89	0.87	9.63	9.69	9.66
Ullal-4	16.10	17.25	16.68	8.35	8.65	8.50	44.68	45.54	45.11	0.85	0.91	0.88	8.89	8.98	8.94
Madakathara-2	20.40	23.25	21.83	10.20	9.99	10.10	65.69	65.13	65.41	0.89	0.91	0.90	8.99	9.17	9.08
Bhaskar	14.60	15.56	15.08	8.94	8.80	8.87	43.62	45.54	44.58	0.85	0.91	0.88	8.67	8.98	8.83
F-Test	*	*	*	**	**	*	**	**	*	*	*	**	*	**	*
SEm(±)	0.398	0.131	0.401	0.023	0.026	0.313	0.178	0.049	0.054	0.005	0.006	0.005	0.046	0.172	0.185
CD @5%	1.273	0.381	1.198	0.076	0.089	0.938	6.524	0.154	0.160	0.017	0.020	0.002	0.145	0.511	0.542

* significant at 5%
** signifcant at 1%

15.08 kg cashew per tree while the lowest yield was recorded in the variety Bhaskar (15.08 kg plant^{-1}) and Ullal-3 (13.55 kg plant^{-1}). However, the seed was highest in Ullal-3 and Madakathara-2 (10.44 and 10.10 g), followed by Ullal-4 (8.50 g) and Bhaskar (8.87 g), while it was lowest in the varieties Ullal-1 (6.74 g) and Ullal-2 6.54 g). On the other hand, the weight of cashew apple was significantly highest in Ullal-3 followed by Madakathara-2, Ullal-2, Ullal-4, Bhaskar, and the least in Ullal-1 (Table 21.2). The highest plant girth was observed in Madakathara-2, followed by Ullal-1, Ullal-4, Bhaskar, Ullal-3, and the lowest in Ullal-2. The canopy spread was highest in Ullal-3, followed by Madakathara-2, Ullal-4, Bhaskar, Ullal-1, and Ullal-1.

Based on the results obtained above, it was observed that the cashew is well-adapted to existing climate and the crops can be well grown in coastal zone. The intercrops were also found to perform better in the cashew orchard. Similar findings were reported by Opoku-Ameyaw et al. (2011), who observed that the cashew yields were not significantly affected by the inter-cropping systems. Also, the height and girth of cashew seedling were found to increase under intercropping. Improvement in the growth of cashew due to intercropping may be ascribed to the tillage and other agronomic practices like fertilizer application and weeding (Abeysinghe 2009).

21.4 Conclusions

On a final note, the findings of this study indicate that even with intercropping in cashew during the established phase, in general the cashew varieties have maintained good and normal yield during the study period. There is no competition between the intercrops for water and nutrient for the cashew crop and their cultivation reduced the weed menace in orchard. The performance of all the intercrops planted with cashew was found to be better and inclusion of such crops in the established cashew plantations, improve resource use efficiency, and help to generate extra income to partially offset the cost of establishment.

References

Abeysinghe DC (2009) Effect of intercropping of young cashew (*Anacardium occidentale* L.) on land productivity. In: Proceedings of the cashew research workshop, Wayamba University, Sri Lanka, 20 November 2009, p 23

Adiga JD, Kalaivanan D (2017) Cashew based cropping systems. In: Saroj PL (ed) Cashew: improvement, production and processing. Astral International Pvt. Ltd., New Delhi, India, pp 277–293

Bedi R (1964) The Glory lily. Indian Hort 8:9–10

DAP (1996) Information bulletin on Myanmar. Department of Agriculture Planning, Ministry of Agriculture and Irrigation, The Union of Myanmar, Myanmar

Opoku-Ameyaw K, Oppong FK, Amoah FMS et al (2011) Growth and early yield of cashew intercropped with food crops in northern Ghana. J Tropical Agric 49(1–2):53–57
Opoku-Ameyaw K, Oppong FK, Ofori-Frimpong K et al (2003) Intercropping robusta coffee with some edible crops in Ghana: agronomic performance and economic returns. Ghana J Agric Sci 36:13–21
Panse VS, Sukhatme PV (1985) Statistical methods for agricultural workers. Indian Council of Agricultural Research, New Delhi, India, p 152–155
Rao EVVB, Yadukumar N (1991) Directions of cashew research in India with specific reference to Dakshina Kannadda district. In: Proceedings of seminar on cashew development in Karnataka, Mangalore, vol 1, pp 8–9
Rodrigo VHL, Stirling CM, Teklehaimanot Z (2001) Intercropping with banana to improve fractional interception and radiation use efficiency of immature rubber plantations. Field Crops Res 69(3):237–249
Vikram HC, Hegde NK (2014a) Performance of ginger in cashew plantation (as intercrop) compared to sole cropping. Asian J Hort 9(1):187–189
Vikram HC, Hegde NK (2014b) Performance of turmeric in cashew plantation as intercrop compared to sole cropping. Asian J Hort 9(2):496–499

Chapter 22
Development in Rice-Fish-Livestock Farming for Higher Production and Income in Coastal Areas

Dhurjati P. Sinhababu and Annie Poonam

Abstract In Asia, around 80% of world rice is grown covering about 80 million (m) hectares (ha) in irrigated and 60 m ha in rainfed lowland conditions, including deepwater and coastal areas. These areas offer a suitable environment for growing fish, prawn, ducks and other aquatic organisms. Rice-fish culture, a 'Globally Important Agricultural Heritage System', was widely practised in total 28 countries on six continents during mid-1900s. This culture system got a setback during mid-1960s for a period of more than a decade due to the introduction of high-yielding cultivars in rice associated with high amount of chemical use. During 1980s, rice-fish culture revived with renewed global interest after the emergence of relatively safe chemicals and introduction of integrated pest management (IPM) in rice production. Subsequently, this culture system was diversified with the integration of other compatible components like vegetable and fruit crops, duck and other animals. Specifically, rice-fish-/duck farming evolved as an effective and beneficial tool for IPM in rice production in terms of controlling rice pests as well as for quality food production and higher income. In the coastal areas of India, Bangladesh and Vietnam, rice-fish production remained an age-old practice in the form of capture fisheries with the popular indigenous systems, viz., *Bheri/Bhasabadha*, *Pokkali* and *Khazan* in India and *Bheri/Gher* in Bangladesh. The productivity in the traditional systems was less ranging from 0.5 to 3.0 t of rice and 50–600 kg of fish and prawn/shrimp ha^{-1} yr^{-1}. These production systems were improved during 1980s with the introduction of salt-tolerant improved rice cultivars and selective stocking and management of freshwater and brackish water fish and prawn/shrimp attaining higher productivity of 2.4–5.7 t ha^{-1}of rice and about 200–2100 kg of fish and prawn/shrimp ha^{-1} yr^{-1}, with a net income up to US$ 2263 in one crop cycle. Research at ICAR-National Rice Research Institute, Cuttack, India, during 1990s and thereafter led to the development and dissemination of two rice–fish–horticulture–livestock-based diversified farming system models in rainfed waterlogged lowland and deepwater situations, including coastal areas. These

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farming system models have the potential of increasing production by around ten folds and net income by fifteen times (US$ 1500–4000 ha^{-1} yr^{-1}) over traditional rice farming. Rice-fish system is an ecologically sound and climate smart technology as it: (i) restricts chemical use, (ii) reduces greenhouse gas emission, (iii) facilitates multiple use of water, including harvested water for crops production, (iv) promotes recycling of farm wastes perse and (vi) helps conservation of the ecosystem. Adoption of rice–fish–horticulture–livestock-based farming systems with policy and institutional supports can greatly contribute to food, nutritional and economic security for coastal farmers.

Keywords Coastal areas · Duck · Income · Integrated farming system · Prawn · Rice-fish

22.1 Introduction

Global agriculture faces multiple challenges for achieving around 60–70% higher production required for about 9.2 billion population by 2050, from the fast-diminishing natural resources, increasing cost of farming and rising threat of climate change. The scenario is more alarming, especially for the fragile coastal ecosystem from where about 40% of the world population derives their livelihood. A change in farming approach like integrated farming system (IFS), involving agriculture, aquaculture and livestock rearing will be a viable option for sustainable and risk-absorbing production systems in coastal areas. About 134 million (m) hectares (ha), more than 80% of the world rice area, in the form of irrigated, rainfed lowland, including deepwater and coastal wetlands are suitable for rice, fish, horticulture crops and livestock integration, and such farming system can significantly contribute to food, nutrition and income security.

We briefly describe in this paper, the global research and developments in rice-fish-livestock farming, especially in coastal ecosystem, its impact on improvement of livelihood of coastal farmers, and the future strategies.

22.2 Rice-Fish Culture: History

According to archaeological and written records, rice-fish culture started in China over 1700 years ago due to the release of excess fish fry in rice fields (Li 1992; Cai et al. 1995); though some author suggested introduction of this practice in Southeast Asia from India 1500 years back (Tamura 1961; Coche 1967; Ali 1992). Rice-fish farming remained in practice 200 years ago in Thailand (Fedoruk and Leelapatra 1992), while in Japan and Indonesia, it was developed in mid-1800s (Kuronoma 1980; Ardiwinata 1957). In coastal ecosystem, fish production from rice fields is an age-old practice in the form of capture fisheries in India and Bangladesh (Ghosh

1992; Yousuf Haroon et al.1992). In Vietnam, wild fish capture from transplanted rice zones of Mekong Delta was in practice 200 years ago (Kien et al. 2020).

22.3 Rice-Fish Culture: Developments

22.3.1 1940s–1950s

The FAO Rice Committee recognized the importance of rice-fish culture back in 1948 (FAO 1957). Subsequently, the Indo-Pacific Fisheries Council (IPFC) and the International Rice Commission (IRC) made a joint program for promoting this culture. Thereafter, it was included in discussion in the IPFC, the General Fisheries Council of the Mediterranean (GFCM), the FAO Rice Meeting and the IRC. IPFC and the IRC formulated a joint program for promoting research on utility of fish culture in rice fields. By the mid-1900s, rice-fish culture was being practised in 28 countries on six continents, Africa, Asia, Australia, Europe, North America and South America (FAO 1957). Among fish, common carp (*Cyprinus carpio*) was the most popular species, followed by tilapia (*Oreochromis mossambicus*). Other species were gouramy (*Trichogaster pectoralis*), buffalo fish (*Ictiobus cyprinellus*), carassius (*Carassius auratus)*, murrels or snakeheads (*Channa* spp.), catfish (*Clarias batrachus*), etc. In brackish water, milkfish (*Chanos chanos*), mullets (*Mugil* spp.) and penaeid shrimps (*Penaeus* spp.) were used (Halwart and Gupta 2004).

The rice (traditional cultivars/land races) yield in rice-fish co-culture ranged from 0.5 to 2.97 tonnes (t) ha^{-1} and the fish yield largely varied depending on various factors and was as low as 1.5–40 kg ha^{-1} in extensive method of culture to 100–200 kg ha^{-1} yr^{-1} with an average rate of 120–150 kg ha^{-1} yr^{-1}. The fish yield was recorded much higher (1100–1800 kg ha^{-1} yr^{-1}) in Japan with supplementary feeding (Coche 1967; Vincke 1979).

In coastal ecosystem, the traditional practice of fish production in rice field was popularly known as *Bhasabadha/Bheri* in the form of wild aqua-cropping in West Bengal, prawn filtration technique in *Pokkali* rice field of Kerala (locally called '*Chemmeen Kulter*'), *Khazan* system in Goa of India, and *Bheri/Gher* in Bangladesh. The productivity in these traditional practices was 0.5–1.5 t of rice ha^{-1} and 100–600 kg^{-1} ha^{-1} yr^{-1} of fish and prawn in India, and 0.60–1.30 t of rice ha^{-1} and 290 kg of shrimp and fish ha^{-1} in Bangladesh, respectively. In Vietnam, 2–3 t of rice and 50 kg shrimp and 150–200 kg ha^{-1} fish yield was reported in coastal areas (Jhingran and Ghosh 1987; Lightfoot et al. 1992; Xuan and Matsui 1998).

22.3.2 1960s–1970s

Development of 'Taichung (Native) 1' using the semidwarf mutant gene followed by evolvement and introduction of other high-yielding rice varieties like IR 8 and others in mid-1960s drastically reduced rice-fish culture around the world for more than a decade due to high amount of chemical use and intensification of rice production programmes (Halwart and Gupta 2004).

22.3.3 1980s–1990s

During 1980s, global interest in rice-fish farming was renewed. A collaborative project of the International Rice Research Institute's (IRRI) Asian Rice Farming Systems Network (ARFSN) led by the International Center for Living Aquatic Resources Management (ICLARM), presently World Fish Center, was implemented involving many institutions throughout Asia. The International Development and Research Center (IDRC) of Canada co-sponsored National Rice-Fish Farming Systems Symposium in Wuxi, China (Halwart and Gupta 2004). Subsequently, Integrated Pest Management (IPM) was introduced in rice farming. Relatively safe chemicals (pesticides, herbicides, molluscicides) and their doses for use in rice-fish culture were also reported (Cagauan and Arce 1992). Integration of other components was taken up in rice-fish field like azolla/chicken/crops, fruits (grape, banana), sugarcane/frog in China (Ying 1986) and duck, banana in Indonesia (Syamsiah et al.1992).

In rice-fish culture, high-yielding varieties (HYVs) of rice with dwarf to tall height, preferably stiff-culm types, were preferred depending on the water level in the field. Among fish species besides, worldwide accepted common carp and tilapia, other cultured species were grass carp (*Ctenopharyngodon idella*) and silver carp (*Hypophthalmichthys molitrix*) particularly in China, silver barb (*Barbodesgonionotus*) in Bangladesh, Indonesia and Thailand, and the Indian major carps, viz. catla (*Catla catla*), mrigal (*Cirrhinus mrigala*) and rohu (*Labeo rohita*) in Bangladesh and India, and also freshwater giant prawn (*Macrobrachium rosenbergii*). Nile tilapia (*Oreochromis niloticus*) were preferred over the Mozambique tilapia (*O. mossambicus*) in many places. In brackish water rice fields, mullets (*Mugil* spp.), *Lates calcarifer*, *Eutroplus suratensis*, tilapia, penaeid shrimps (*Penaeus* spp.), *Metapenaeus* spp., were reared.

Rice yield under rice-fish farming ranged between 0.5 and 7.7 t ha^{-1} depending on the rice ecology, cultivars and management levels. The fish and prawn combined yield was in the range of 27–2720 kg ha^{-1} depending on the culture environment, species and management practices (Lightfoot el al. 1992).

In coastal areas, the traditional rice-fish farming practices like *Bhasabadha* in West Bengal and *Pokkali* fields of Kerala, India, were modified/improved with proper field design, introduction of improved salt-tolerant rice cultivars, soil salinity management, selective stocking of brackish water fish and prawn/shrimp species and their management. This farming practice increased productivity of both rice (2.5–3.0 t ha^{-1}) and fish and prawn/shrimp (600–3750 kg ha^{-1} yr^{-1}) with an annual net profit of US$ 1209 ha^{-1} in *Bhasabadha* system. In shallow coastal saline rice fields of West Bengal, 2.4–2.7 t ha^{-1} of rice and 826–3300 kg of fish and shrimp ha^{-1} yr^{-1}were reported in multi-locational trials. Improved practices in *Pokkali* rice fields also enhanced the productivity of both rice (0.7–2.7 t ha^{-1}), shrimp and fish (785–2135 kg ha^{-1} yr^{-1}) (Ghosh 1992).

In Bangladesh, the improved practice, including in *Gher*, comprises either shrimp and fish culture with 280–450 kg ha^{-1}yield depending on the water exchange, followed by *aman* rice or *boro* rice followed by shrimp and fish culture with a yield of 200–250 kg shrimp and 150–175 kg of fish ha^{-1}. The yield of *aman* and *boro* rice ranged from 0.50–1.40 t ha^{-1} and 3.2–7.7 t ha^{-1}, respectively, (Yousuf Haroon et al. 1992).

In Vietnam under brackish water fish/shrimp-rice + fish/shrimp system, improved rice yield of 2.4 t ha$-^{1}$ and fish and shrimp yields of 15 kg day^{-1} and 2–3 kg day^{-1}, respectively, were reported (Mai et al. 1992). In five coastal provinces of Mekong Delta, there was about 5000 ha area of rice-brackish water shrimp farming in1984 with average shrimp yield of 640 kg $ha^{-1}$and rice yield in the range of 3.5–4.0 t ha^{-1} (Xuan and Matsui 1998).

22.3.4 1990s–2010s

The ecology-wise suitable HYVs of rice, including hybrids, were grown in rice-fish farming. In fish culture, there was a change from monoculture or simple species combination such as carps, to multiple species combination (polyculture), and also towards high valued species. Besides finfish species, crustaceans, amphibians, molluscs and reptiles were reared in rice field. The rice-fish area fast expanded during 1990s. China was the maximum producer of fish (1.2 mt) from rice-fish farming with about 15% coverage (1.3 m ha) under this system out of the suitable rice areas during 2010. In India, the rice-fish area was reported 2.0 m ha in the 1990s across different ecosystems from terraced rice fields in the hilly terrain to coastal lands and deepwater rice fields (FAO 2012). The rice and rice-fish areas in different countries are given in Table 22.1.

The rice yield under rice-fish culture was reported in the wide range of 1.60–8.25 t ha^{-1} yr^{-1} depending on the rice ecology, type of cultivars and management levels. The fish yield also widely varied from a minimum of 116–3100 kg ha^{-1} yr^{-1} based on the culture methods, water level, refuge area, species and management levels (Halwart and Gupta 2004). In China, rice yield of 7.5 t ha^{-1} and fish yield of 750 kg ha^{-1} without feeding, and average increase of 225 kg rice yield in rice-fish farming were reported. An average annual net profit of US$ 1813 could be obtained in this farming with intensive management and culture of high valued fish and prawn (Xiuzhen 2003). Dwiyana and Mendoza (2006) reported high land use efficiency

Table 22.1 World rice and rice-fish area, by environment

Country	Rice ('000 ha)					Rice-fish ('000 ha)
	Total	Irrigated	Rainfed lowland	Flood prone	Upland	
		(% of total rice area)				
Bangladesh	11,670	22	47	23	8	–
Cambodia	1910	8	48	42	2	–
P.R. China	30,670	93	5	–	2	1300
Egypt	462	100	–	–	–	
India	43,500	55	27	5	13	2000
Indonesia	13,690	72	7	10	11	138.3
Korea, Rep	1208	91	8	–	1	0.1
Lao PDR	557	2	61	–	37	–
Madagascar	1140	10	74	2	14	13.4 (highlands)
Malaysia	691	66	21	1	12	–
Sri Lanka	791	37	53	3	7	
Thailand	11,490	7	86	7	1	25.5 (culture) 2966.7 (capture)
Vietnam	6303	53	28	11	8	153 (Mekong delta)

Compiled from the reports of Halwart (1999), FAO (2012), USAID (2016), Pathak et al (2018)

(Rp 9,010,239 ha^{-1}) over rice alone (Rp 5274403 ha^{-1}; 1 US$ = Rp 14,306.40) or increase of farmers' income by 1.74 times in Indonesia.

A case study on rice, fish, azolla, duck integrated farming in Philippines, revealed significant rice yield increases in rice-fish culture combined with either azolla or duck or both over rice monoculture (2.7 t ha^{-1}). Fish (Nile tilapia) yield was highest (618 kg ha^{-1}) in rice-fish-azolla-duck farming, while net income was highest (US$ 3779) in rice-fish-duck system (Cagauan et al. 2000). Yield of fish was higher under rice-fish-duck farming (1.23 t ha^{-1}) than rice-fish (0.91 t ha^{-1}) due to better growth rates, and with 61% egg production in duck in Bangladesh (Islam et al. 2004). A study by Channabasavanna and Biradar (2007) in India indicated higher system productivity (15,555 kg ha^{-1} yr^{-1}) and net returns (Rs. 48603 ha^{-1} yr^{-1}) in rice-fish-poultry integrated farming system over conventional rice-fish system (6667 kg ha^{-1} yr^{-1} and Rs. 21599 ha^{-1} yr^{-1}, respectively; 1 US$ = 72.39 Indian Rupee). The IFS also recorded the highest water productivity (43.2 kg ha^{-1} cm^{-1}) and labour use efficiency (25.17 kg ha^{-1} labour^{-1}).

The rice-fish farming system was listed one of the 'Globally Important Agricultural Heritage System' (GIAHS) by the FAO, United Nations Development Programme (UNDP) and Global Environment Facility (GEF) in 2005 owing to its long history and diversified patterns and techniques (http://www.fao.org/nr/giahs/giahs-home/en/).

In coastal wet lands/flood plains of Kerala, India, under sequential rice-fish farming comprising culture of fish during wet season and improved rice in dry season, the productivity ranged from 3.3–7.0 t ha^{-1} in the case of rice and 350–1600 kg ha^{-1} yr^{-1} in the case of fish with net income of Rs. 25,000–62,000 ha^{-1} yr^{-1}. The rotational rice-fish system enhanced farm income by about 72% over the traditional farming (Padmanabhan et al. 2001; Padmakumar 2006). In *Pokkali* fields, Sasidharan et al. (2012) recorded 2.4–4.4 t ha^{-1} yield of salt-tolerant HYVs of rice along with 229 kg ha^{-1} fish under rice-fish farming. Inclusion of shrimp with yield of 425 kg ha^{-1}, as a rotational crop increased benefit–cost ratio (2.03). Rahman and Burman (2012) reported that *Gher* farming, a unique system of integrated HYV rice-fish-prawn culture, was expanding rapidly over the two decades in the coastal regions of Bangladesh because of its proven high economic potential. They concluded that this system will be sustainable in future based on their analysis on energy use (net energy balance 18,510 MJ ha^{-1} and energy use efficiency of 1.72), provided sustained high productivity from rice component. Berg (2002) based on a survey in Mekong Delta of Vietnam found the highest net income (19,500,000 VND ha^{-1} yr^{-1}) in IPM rice-fish farmers, due to comparatively low costs and high yields of both rice and fish and lowest net income (15,800,000 VND ha^{-1} yr^{-1}; 1 US$ = 23,046 VND) in non-IPM rice-fish farmers due to their high costs and low yields, and advocated adoption of IPM strategies as a necessary complement to fish farming practices. Nguyen (2014) reported net return from one rice-freshwater shrimp cycle in 2006 was US$ 2263, 85% of which was from the shrimp activity in Mekong Delta, which was much higher compared to double-and triple-cropping of rice. Rice-brackish water shrimp farming area in the Delta increased to 153,000 ha in 2014 with yields ranging from 300 to 500 kg ha^{-1}. These semi-intensive rice-shrimp systems include one crop of wet season rice and one or two crops of tiger shrimp or white-leg shrimp (USAID 2016). Preston and Clayton (2003) found that farmers' incomes improved significantly by adopting this system. In coastal areas of Philippines, 4.6–7.4 t ha^{-1} of rice and 0.1–0.45 million of tilapia fingerlings with net income of US$ 600–3200 were reported under rice-fish farming. In rice-prawn farming, the prawn yield was 257 kg ha^{-1} with net income of US$ 1292 during EL NINO and 120 kg $ha^{-1}$with net income of US$ 858 during LA NINA (Lopez and Mendoza 2004).

During this period, the ICAR-National Rice Research Institute, Cuttack, India, developed two rice-fish-horticulture-livestock-based integrated farming systems (IFS) technologies / models for rainfed waterlogged lowlands, including coastal areas, especially for the eastern India, viz., (1) Rice-fish diversified farming system for rainfed lowland (up to 50 cm water depth) and (2) Multitier rice–fish–horticulture–livestock based farming system for deepwater (50–100 cm water depth) conditions. Components such as HYVs of rice, fish, prawn, ducks and other crops (pulses, oilseeds, vegetables, watermelon) are grown after wet season rice, and also dry season rice in the main field while vegetables, tuber crops, fruit and plantation crops, flowers, beekeeping, mushroom, agroforestry, poultry, goatery, etc. are taken on wide dykes/uplands in tiers, in these models.

Table 22.2 On-farm performance of rice-fish-horticultural crops-duck farming system in coastal areas of Odisha (Districts Kendrapara and Puri)

Farm No.	Farm area (ha)	Operational cost (Rs)	Gross income (Rs.)	Net income (Rs.)	Net income (Rs. ha^{-1})
1	0.44	35,240	96,800	61,560	139,909
2	0.30	30,200	75,800	45,600	152,000
3	0.80	64,300	178,960	114,660	143,325
4	0.32	25,760	79,670	53,910	168,469
5	0.80	61,900	165,560	103,660	129,575
6	0.52	42,940	154,300	111,360	214,154
7	0.36	29,120	66,300	37,180	103,278

The annual productivity in the two IFS models ranges from 14 to 18 t of food crops, 600–1000 kg of fish and prawn, 500–800 kg of meat and 8000–12,000 eggs, 150 kg mushrooms, 16–21 kg honey in addition to flowers, fuel and fibre wood and 3–6 t of rice straw and other crop residues as feeds for livestock from one hectare of farm area. These systems annually generate a net income of about US $1500–4000 based on the components and level of their management. These farming systems can increase farm productivity by 10–12 folds and average annual net income up to 15 times over mono-cropping of traditional rice (Sinhababu 1996; Sinhababu et al. 2009, 2012). These IFS models were adopted in many locations in coastal areas of Odisha and West Bengal (Poonam et al. 2019) including super-cyclone (1999)-affected coastal areas of Odisha, realizing higher net farm income by about 15 times over traditional rice farming (Sinhababu et al. 2006).

The rice-fish-horticultural crops (vegetables, tuber and fruit crops)-duck farming was taken up in small farms in coastal areas of two districts (Kedrapara and Puri) of Odisha and in one district (South 24-Parganas) of West Bengal during the year 2011–13. The net income in 14 such farms ranged from Rs. 98,571 to 214,154 ha^{-1} yr^{-1} (Tables 22.2 and 22.3). AMMI Stability Index (ASI) analysis based on pooled data of five parameters of these 14 farms indicates usually better stability in income generation in the case of comparatively small farm area. Lower operational costs also contribute to income stability in rice-fish-crops-duck farming (Table 22.4).

22.4 Rice-Fish-Livestock Interactions and Benefits

In integrated farming system, components like rice, fish, prawn and duck are strongly interrelated and create various useful interactions and synergistic effects in the rice field resulting dynamic wastes (nutrients) recycling within the farm. Other components when added, like other crops and livestock (chicken), are also positively interrelated (Fig. 22.1). These activities promote optimum resources utilization and in

Table 22.3 On-farm performance of rice-fish-horticultural crops-duck farming system in coastal areas of West Bengal (District South 24-Parganas)

Farm No	Farm area (ha)	Operational cost (Rs.)	Gross income (Rs.)	Net income (Rs.)	Net income (Rs. ha^{-1})
1	0.27	19,350	47,300	27,950	103,519
2	0.40	28,840	79,400	50,560	126,400
3	0.27	22,000	57,700	35,700	132,222
4	0.40	29,160	98,800	69,640	174,100
5	0.67	50,685	171,600	120,915	180,470
6	0.27	19,200	47,700	28,500	105,556
7	0.14	11,100	24,900	13,800	98,571

One US$ = 72.39 Indian Rupee

turn, help develop an ecologically sound cost-effective production system due to the following benefits.

22.4.1 Reduction in Chemicals Use

Fish and ducks feed on rice weeds and insect pests in the field. Stocking fish in rice fields reduces pest infestation and thus reduces (if not eliminates), the need for application of herbicides and insecticides and particularly molluscicides, where snail predatory fish are cultivated (Waibel 1992; Cagauan 1995; Halwart 2001; Sinhababu et al. 2013). The practical and economic advantages of using fish instead of chemicals are often obvious.

Ducks are effective in controlling other rice pests like molluscs and crabs. Prawn also feeds on algae, insect larvae and worms. The movement of these animals creates tillage effects in the field.

Berg (2001) reported 65% decrease in pesticides use in rice-fish farms against 40% increase in rice alone in Mekong Delta, Vietnam. According to Xie et al.(2011), 68% less pesticides and 24% less chemicals fertilizers are required in rice-fish farming than rice monoculture, without affecting the rice yield. In Bangladesh, 20% higher rice yield and 50% more net return besides, weed and insect control, improvement in soil health and reduction of inputs cost were reported with integration of ducks in rice field (Hossain et al.2005). Zhang et al. (2009) found that duck can replace pesticide use in terms of controlling pest damage without reducing rice yield in a rice-duck system. Fish and ducks can be used as IPM tools for sustainable rice production, monetary benefits and/or nutritional value (Little et al. 1996; Yousuf Haroon and Pittman 1997; Berg 2001).

Table 22.4 AMMI Stability Index (ASI) and rank of ASI for the five parameters of on-farm rice-fish-horticultural crops-duck farming system in coastal areas of Odisha and West Bengal

Farm No.	Farm area			Operational cost			Gross income			Net income			Net income		
	Farm area (ha)	ASI	Rank	Operational cost (Rs.)	ASI	Rank	Gross income (Rs.)	ASI	Rank	Net income (Rs.)	ASI	Rank	Net income (Rs. ha^{-1})	ASI	Rank
1	0.355	0.116	1	27,295	13	1	72,050	183.7	2	44,755	203	2	121,714	435	4
2	0.35	3.020	6	29,520	622	5	77,600	1024.8	3	48,080	806	3	139,200	172	1
3	0.535	4.297	7	43,150	1168	7	118,330	1817.0	7	75,180	1390	6	137,774	182	2
4	0.36	2.787	5	27,460	830	6	89,235	1378.3	5	61,775	1087	4	171,285	590	5
5	0.735	0.348	2	56,293	191	3	168,580	1080.3	4	112,288	1127	5	155,023	1694	6
6	0.395	1.045	4	31,070	356	4	101,000	1483.3	6	69,930	1492	7	159,855	2196	7
7	0.25	0.697	3	20,110	106	2	45,600	0.6	1	25,490	64	1	100,925	338	3

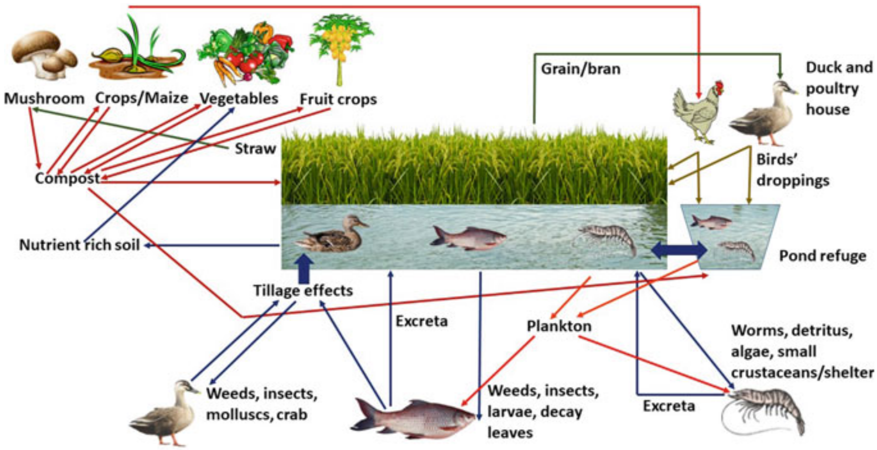

Fig. 22.1 Rice, fish, prawn, duck, crops interactions in integrated farming

22.4.2 Reduction in Greenhouse Gas Emission

Rice-fish farming reduced the emission of CH_4 by nearly 30% compared to rice monoculture in study in China (Lu and Li 2006). Later Yuan et al. (2009) reported that rice-duck and rice-fish complex ecosystems can effectively decrease and control CH_4 and N_2O emission in rice fields. Though Frei et al. (2007) in irrigated fields of Bangladesh and Datta et al. (2009) and Bhattacharyya et al. (2013) in rainfed lowland paddies in India, observed increase in CH_4 emission under rice-fish farming, not to the levels reported in intensive rice farming. However, Datta et al. (2009) and Bhattacharyya et al. (2013) found significant reduction (9–29%) in N_2O emission under rice-fish farming.

22.4.3 Multiple Use of Water

Sinhababu and Mahata (2007) from India reported the amount of rainwater harvest and its utilization in rice-fish diversified farming system under rainfed lowland. The water harvested in the pond refuge of 1300 m^2 area was 1820 m^3 equivalent to 140 cm average depth of water. The irrigation water requirement for dry season crops in the field was 21.4% and that for other components on dykes was 10% of the stored water. The water loss due to evaporation and percolation was 40%. Thus, saving of excess water to the extent of 28.6% was possible in rainfed rice-fish system under shallow groundwater table and lowland condition in Mahanadi delta areas of Odisha. The net water productivity of the system was Rs. 13.8 m^{-3}. Sinhababu et al. (2008) observed about 50% reduction in water salinity in fish refuge pond after five years under on-farm rice-fish farming in coastal saline areas of Odisha.

22.5 Way Forward

Rice-fish-livestock integrated farming is a dynamic production system; that often calls for refinement/changes depending on the target domain, available resources, socio-economic profile of the stakeholders and also the climate change. Some of the important research and adoption strategies in this respect are as follows.

22.5.1 Research Strategies

(i) Development of location-specific cost-effective field designs, (ii) standardization of efficient water management/water-saving options, (iii) improvement of culture system, viz., suitable genotypes (plants, fish, animals) and efficient management of nutrients, pests, disease, (iv) improvement of ecology in terms of nutrients/energy flow and feeding ecology, (v) creating more synergism between the components for ensuring maximum resources use perse, (vi) value addition, (vii) market intelligence and (viii) women empowerment.

22.5.2 Strategies for Popularization

(i) Survey of resources, (ii) identification and characterization of potential areas by RRA/PRA, GIS techniques, (iii) prioritization of areas, (iv) multi-locational on-farm trials and refinement of technologies, (v) development of location-specific IFS models, (vi) awareness development and capacity building of all stakeholders through training, Farmers Field Schools (FFSc) and ICT, and (vii) provision of credit facilities, quality inputs, market and other infrastructural facilities.

22.6 Conclusions

The importance of rice–fish–horticulture–livestock farming in ensuring food and economic security in coastal ecosystem needs to be properly realized, and accordingly, suitable policy and other support systems are to be developed. Concerted team efforts involving all stakeholders, including researchers, extension personnel, bankers, NGOs, farmers production groups (FPOs) and farmers, are necessary for successful adoption of this farming system. Location-specific need-based IFS clusters supported with timely and quality input delivery mechanism and marketing network need to be developed. The multi-ecological functions of rice-fish-livestock farming and its role in buffering climate change adversities and helping stability should be fully secured for sustained improvement of livelihood in coastal areas.

References

Ali AB (1992) Rice-fish farming in Malaysia: past, present and future. In: Dela Cruz CR, Lightfoot C, Costa-Pierce BA, Carangal VR, Bimbao MP (eds) Rice-fish research and development in Asia. ICLARM conference proceedings, vol 24, pp 69–76

Ardiwinata RO (1957) Fish culture in the rice fields in Indonesia. Proc Indo-Pacific Fisheries Council 7:119–154

Berg H (2001) Pesticide use among rice farmers in the Mekong Delta, Vietnam. Crop Protect 20:897–905

Berg (2002) Rice monoculture and integrated rice-fish farming in the Mekong Delta Vietnam—economic and ecological considerations. Ecological Econ 41:95–107

Bhattacharyya P, Sinhababu DP, Roy KS et al (2013) Effect of fish species on methane and nitrous oxide emission in relation to soil C, N pools and enzymatic activities in rainfed shallow lowland rice-fish farming system. Agric Ecosyst Environ 176:53–62

Cagauan AG, Arce RG (1992) Overview of pesticide use in rice-fish farming in Southeast Asia. In: Dela Cruz CR, Lightfoot C, Costa-Pierce BA et al (eds) Rice-fish research and development in Asia. ICLARM conference proceedings, vol 24, pp 217–234

Cagauan AG, Branckaert RD, Van Hove C (2000) Integrating fish and azolla into rice-duck farming in Asia. Naga: The ICLARM Quarterly, January–March, pp. 4–10

Cagauan AG (1995) Overview of the potential roles of pisciculture on pest and disease control and nutrient management in rice fields. In: Symoens JJ, Micha JC (eds) Proceedings of the Seminar on "The management of integrated agro-piscicultural ecosystems in tropical areas", 16–19 May 1994, Brussels. Tech Centre for Agric and Rural Coop (CTA) Royal Academy of Overseas Sciences. Brussels, pp 203–244

Cai R, Ni D, Wang J (1995) Rice-fish culture in China: the past, present and future. In: MacKay KT (ed) Rice-fish culture in China. International Development Research Centre (IDRC) Ottawa, Canada, pp 3–14

Channabasavanna AS, Biradar DP (2007) Relative performance of different rice-fish-poultry integrated farming system models with respect to system productivity and economics. Karnataka J Agric Sci 20:706–709

Coche AG (1967) Fish culture in rice fields. A worldwide synthesis. Hydrobiologia 30:11–44

Datta A, Nayak DR, Sinhababu DP et al (2009) Methane and nitrous oxide emissions from an integrated rainfed rice-fish farming system of Eastern India. Agric Ecosyst Environ 129:228–237

Dwiyana E, Mendoza TC (2006) Comparative productivity, profitability and efficiency of rice monoculture and rice-fish culture systems. J Sustainable Agric 29:145–166. https://doi.org/10.1300/J064&29n01_11

FAO (1957) Fish culture in rice fields. In: A preliminary review and annotated bibliography from Section II and III of Proc. Indo-Pacific Fisheries Council, vol 7. FAO, Rome, pp 193–206

FAO (2012) Fish culture in rice fields. In: World Review of Fisheries and Aquaculture Part 1 under The State of World Fisheries and Aquaculture, FAO Report, Rome, pp 30–33

Fedoruk K, Leelapatra W (1992) Rice field fisheries in Thailand. In: Dela Cruz CR, Lightfoot C, Costa-Pierce BA et al (eds) Rice-fish research and development in Asia. ICLARM conference proceedings, vol 24, pp 91–104

Frei M, Razzak MA, Hossain MM et al (2007) Methane emissions and related physicochemical soil and water parameters in rice–fish systems in Bangladesh. Agric Ecosyst Environ 120:391–398

Ghosh A (1992) Rice-fish farming development in India: Past, present and future. In: Dela Cruz CR, Lightfoot C, Costa-Pierce BA, Carangal VR, Bimbao MP (eds) Rice-fish research and development in Asia. ICLARM conference proceedings, vol 24, pp 27–43

Halwart M, Gupta MV (eds) (2004) Culture of fish in rice fields. FAO, Rome. Italy and The World Fish Center, Penang. Malaysia, p 83

Halwart M (1999) Fish in rice-based farming systems–trends and prospects. In: Dat van Tran (ed.) International Rice Commission—assessment and orientation towards the 21st Century. Proceedings of the 19th session of the International Rice Commission, 7–9 Sept 1998, Cairo, Egypt, pp 130–141

Halwart M (2001) Fish as a component of integrated pest management in rice production. In: FAO/ICLARM/IIRR Integrated agriculture-aquaculture-a primer. FAO Fisheries Technical Paper 407, pp 115–117

Hossain STH, Sugimoto G, Ahmed U et al (2005) Effect of integrated rice-duck farming on rice yield, farm productivity, and rice-provisioning ability of farmers. Asian J Agric Develop 2:79–86

Islam SS, Azam MG, Adikhary SK et al (2004) Efficiency of integrated rice, fish and duck polyculture as compared to rice and fish culture in a selective area of Khulna District, Bangladesh. Pakistan J Biol Sci 7:468–471

Jhingran AG, Ghosh A (1987) Aquafarming in coastal India. J Indian Soc Coast Agric Res 5:1–9

Kien NV, Hoang Han N, Cramb R (2020) Trends in rice-based farming systems in the Mekong Delta. In: Cramb R (eds) White gold: the commercialisation of rice farming in the Lower Mekong Basin, pp 347–373. https://doi.org/10.1007/978-981-15-0998-8_17

Kuronoma K (1980) Carp culture in Japanese rice fields. (Edited and condensed by R.S.V. Pullin from the author's original work published in 1954). In: Pullin RSV, Shehadeh ZH (eds) Proceedings of the ICLARM-SEARCA conference on integrated agriculture-aquaculture farming systems. Manila, Philippines, pp 167–174

Li K (1992) Rice-fish farming system in China: past, present and future. In: Dela Cruz CR, Lightfoot C, Costa-Pierce BA et al (eds) Rice-fish research and development in Asia. ICLARM conference proceedings, vol 24, pp 17–26

Lightfoot C, Costa-Pierce BA, Bimbao MP et al (1992) Introduction to rice-fish research and development in Asia. In: Dela Cruz CR, Lightfoot C, Costa-Pierce BA et al (eds) Rice-fish research and development in Asia. ICLARM conference proceedings, vol 24, pp 1–10

Little DC, Surintaraseree P, Innes-Taylor N (1996) Fish culture in rainfed rice fields of northeast Thailand. Aquaculture 140:295–321

Lopez MV, Mendoza TC (2004) Management options for salt-affected rice-based farming systems during the El Niño and La Niña Phenomena. J Sustain Agric 23:19–37. https://doi.org/10.1300/J064v23n04_04

Lu J, Li X (2006) Review of rice-fish-farming systems in China-one of the Globally Important Ingenious Agricultural Heritage Systems (GIAHS). Aquaculture 260:106–113

Mai VQ, Le TD, Dang KS et al (1992) Rice field aquaculture systems in the Mekong Delta, Vietnam: potential and reality. In: Dela Cruz CR, Lightfoot C, Costa-Pierce BA et al (eds) Rice-fish research and development in Asia. ICLARM conference proceedings, vol 24, pp 105–115

Nguyen VK (2014) An economic evaluation of flood dike construction in the Mekong Delta: cost-benefit analysis of flood protection dike construction in an Giang Province. Lambert Academic Publishing

Padmakumar KG (2006) Rice-fish rotation in Kuttanadu-the flood plain rice lands of Kerala: sustainability issues. In: Abstract. 26th international rice research conference and 2nd international rice congress, October 9–13, New Delhi, India

Padmanabhan PG, Narayanan NC, Padmakumar KG (2001) Economic viability of an integrated and sustainable resource use model for Kuttanad. Kerala Research Programme on Local Level Development Centre for Development Studies. Thiruvananthapuram. Discussion Paper No. 33, pp 42

Pathak H, Samal P, Shahid M (2018) Revitalizing rice systems for enhancing, productivity and climate resilience. In: Pathak H, Nayak AK, Jena M et al (eds) Rice research for enhancing productivity, profitability, and climate resilience. ICAR-National Rice Research Institute, Cuttack, Odisha, India, pp 1–17

Poonam A, Sanjoy S, Nayak PK et al (2019) Rice-fish integrated farming systems for eastern India. NRRI Research Bulletin No.17, ICAR- National Rice Research Institute, Cuttack. Odisha. India, p 33+iii

Preston N, Clayton H (eds) (2003) Rice-shrimp farming in the Mekong Delta: biophysical and socioeconomic issues. Australian Centre for International Agricultural Research (ACIAR) Technical Report No 52e. Canberra. Australia, p 170

Rahman S, Barmon BK (2012) Energy productivity and efficiency of the 'gher' (prawn-fish-rice) farming system in Bangladesh. Energy XXX:1–8. https://doi.org/10.1016/j.energy.2012.04.027

Sasidharan NK, Abraham CT, Rajendran CG (2012) Spatial and temporal integration of rice, fish, and prawn in the coastal wetlands of central Kerala, India. J Tropical Agric 50:15–23

Sinhababu DP (1996) Rice-fish system-an excellent choice for higher productivity and sustainability in rainfed lowlands. J Indian Soc Coast Agric Res 14:225–228

Sinhababu DP, Singh BN, Maity BK et al (2006) Crop rehabilitation and management for supercyclone hit coastal areas of Orissa. J Indian Soc Coast Agric Res 24:351–355

Sinhababu DP, Mahata KR, Saha S (2008) Participatory approach to rice-fish farming in coastal ecosystem: prospects and value addition. J Indian Soc Coast Agric Res 26(1):44–47

Sinhababu DP, Saha S, Sahu PK (2013) Performance of different fish species for controlling weeds in rainfed lowland rice field. Biocontrol Sci Technol 23:1362–1372. https://doi.org/10.1080/09583157.2013.838622

Sinhababu DP, Mahata KR (2007) Rice-fish diversified farming-a rainwater recycling based highly profitable system in rainfed lowlands in eastern India. In: Water management in Fisheries and Aquaculture. Vass KK, Sarangi N, Mitra K et al (eds) Proceedings of the national consultations on water management in fisheries and aquaculture, New Delhi, India, pp 83–89

Sinhababu DP, Nayak PK, Sahu PK (2009) Rice-fish diversified farming system for rainfed lowland areas. NRRI Technology Bulletin-8 (2nd Revision). ICAR-National Rice Research Institute, Cuttack, Odisha, India

Sinhababu DP, Pandey V, Nedunchezhiyan M et al (2012) Multitier rice-fish-horticulture based farming system for deepwater areas. NRRI Technology Bulletin-80. ICAR-National Rice Research Institute, Cuttack, Odisha, India, p 12

Syamsiah I, Suriapermana S, Fagi AM (1992) Research on rice-fish culture: past experiences and future research program. In: Dela Cruz CR, Lightfoot C, Costa-Pierce BA et al (eds) Rice-fish research and development in Asia. ICLARM conference proceedings, vol 24, pp 287–293

Tamura (1961) Carp cultivation in Japan. In: Borgstrom G (ed) Fish as food, vol 1, pp 103–120. Academic Press, New York

USAID (2016) Development of rice-shrimp farming in Mekong River Delta, Vietnam. United States Agency for International Development, Washington DC. USAID. Mekong Adaptation and Resilience to Climate Change (ARCC). Asian Management and Development Institute (AMDI), p 60

Vincke MMJ (1979) Fish culture in rice fields: its status and future role. In: Pilley TVR, Dill WA (eds) Advance in Aquaculture. Fishing Needs Ltd., Farnham, Surrey, England, pp 208–223

Waibel H (1992) Comparative economics of pesticide use in rice and rice-fish farming. In: Dela Cruz CR, Lightfoot C, Costa-Pierce BA et al (eds) Rice-fish research and development in Asia. ICLARM conference proceedings, vol 24, pp 245–254

Xie J, Liangliang H, Jianjun T et al (2011) Ecological mechanisms underlying the sustainability of the agricultural heritage rice–fish coculture system. In: PNAS—Proceedings of the National Academy of Sciences of the United States of America, November 1–7. https://doi.org/10.1073/pnas.1111043108/-/DCSupplemental

Xiuzhen F (2003) Rice-fish culture in China. Aquaculture Asia, October–December 200:44–46

Xuan VT, Matsui S (eds) (1998) Development of farming systems in the Mekong Delta of Vietnam. Ho Chi Minh City Publishing House, Ho Chi Minh City

Ying P (1986) Rice pest and disease control by fish and frogs-probing a pesticide-free stereo agricultural system. Selected Paper on Fishery Economics 3(4):40–42

Yousuf Haroon AK, Dewan S, Karim SMR (1992) Rice-fish production systems in Bangladesh. In: Dela Cruz CR, Lightfoot C, Costa-Pierce BA et al (eds) Rice-fish research and development in Asia. ICLARM conference proceedings, vol 24, pp 165–171

Yousuf Haroon AK, Pittman KA (1997) Rice–fish culture: feeding, growth and yield of two size classes of *Puntius gonionotus* Bleeker and *Oreochromis* spp. in Bangladesh. Aquaculture 154:261–281

Yuan W, Cao C, Li C et al (2009) Methane and nitrous oxide emissions from rice-duck and rice-fish complex ecosystems and the evaluation of their economic significance. Agric Sci China 8:1246–1255

Zhang J, Benliang Z, Xin C et al (2009) Insect damage reduction while maintaining rice yield in duck-rice farming compared with mono rice farming. J Sustain Agric 33:801–809. https://doi.org/10.1080/10440040903303389

Chapter 23
Coastal Homestead Farming Systems for Enhancing Income and Nutritional Security of Smallholder Farmers

Sukanta Kumar Sarangi

Abstract Homestead farming (HSF) is a production system adjacent to the dwelling house of the farmer. It encompasses diverse crops cultivation, fishery in pond, small-scale livestock rearing and sometimes allied activities such as mushroom cultivation and apiculture. By-product of one component often used as input for other, making it a perfect farming system. Crops include vegetables, fruits, ornamental plants, betel vine, medicinal, spices and condiments depending upon the location. Vegetables are generally seasonal/annual crops such as brinjal, chilli, green leafy vegetables, beans and cole crops, and ornamental plants are marigold, jasmine, dahlia, etc. Unlike in past, the HSF needs to be transformed from subsistence to a sustainable, remunerative enterprise with generation of market-driven products. To achieve this, new models of HSF are to be developed, validated and popularized. This paper aims to highlight some of the modern HSF suitable for coastal agro-ecosystem and how these systems enhance the income and nutritional security of resource-poor farmers inhabiting the coastal region. Women participation is an integral component of HSF, owing to which the diversity of crops is higher, and there is round the year production. Inclusion of enterprises such as pisciculture, animal husbandry reduces the risk. In some of the coastal HSF, betel vine cultivation can result in income of Rs. 1.5 lakh yr^{-1}. Agroforestry-based HSF, involving spices (ginger and turmeric), tuber crops (yam, sweet potato, tapioca and colocasia) grown as intercrops with fruit plants like papaya and pineapple may result a net benefit of US $ 1052 yr^{-1} after meeting the household needs. As per Indian Council of Medical Research, for normal male adult, the need of energy, protein, fat, calcium and iron per day is 170 cal, 17 g, 3.5 g, 750 mg and 25 mg, respectively. Therefore, to meet this, HSF should focus on the nutritional aspects of selected crops to address malnutrition and anaemia. For healthy crop production, compost pit should find a place in the design. Cultivation of some of the crops in gunny bags also saves space and increase per plant production. Millets such as ragi, sorghum, bajra and high protein maize may be included in hill HSF. Pond-based HSF in salt-affected Sundarbans meet the household fish needs and provide scope for growing of aquatic leafy vegetables such as *kalmi sag* (*Ipomoea aquatica*)

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in floating beds. This system integrated with duckery further increase the income and nutritional security. Multi-storey HSFs are also profitable such as coconut + black pepper in first storey, banana + papaya + guava in second storey and cowpea + turmeric + elephant foot yam in ground storey. Coconut-based HSF may also be used for production of fodder crops such as guinea grass (*Panicum maximum*) for dairy cattle. To make HSF as a self-reliant and profitable system, structural and policy support are needed.

Keywords Agroforestry · Farming system · Household income · Intercrops · Models · Nutrition · Salinity

23.1 Introduction

The burgeoning world population not only need sufficient food, but also balanced diet rich in nutrients and energy to be fit and competent to cope with rising stress due to various obvious constraints the world is going to face. This is particularly important for developing countries and low-income provinces, islands, coastal regions, etc., where due to population pressure and climate change-related risks, there will be severe stress on natural resource base. Homestead farming or home gardening or family farming is one such avenue, which may come to rescue under these circumstances provided adequate scientific interventions and investments are made in this sector or size of farming. Homestead farming system (HFS) in perpetuity is a small household production system adjacent to the dwelling house of the farmer, generally in an elevated position in contrast to the large field scale farming. HFS is well known in India for centuries, our father of Nation, Mahatma Gandhiji's visions of Gram Swaraj (i.e. self-sufficient but interlinked village) gave a call for 'production by the masses' instead of 'mass production'.

The United Nations General Assembly has declared the year 2014 as International Year of Family Farming, recognizing the importance of this system of farming in conserving biodiversity, household nutritional security, and in maximizing production. HFS in general is diverse in nature (Sarangi 2009) as a large variety of crops are grown along with other enterprises such as aquaculture, poultry rearing, mushroom cultivation, dairy, goatery and piggery depending upon the location and food habit of the people. There are more than 570 million farms in the world, and more than 500 million (>90%) can be considered family farms (Lowder et al. 2016). In India, the farm holding size continuously declined (from 2.28 ha in 1970–71 to 1.08 ha in 2015–16), and at the same time, the number of holdings increased from 71 million in 1970–71 to 146.5 million in 2015–16 (Fig. 23.1). In many developing countries, particularly in South Asian countries, majority of the holdings are small in size and practise homestead farming. In Bangladesh, out of 14.7 million agriculture holdings, over 80% occupy less than a quarter of a hectare of cultivated area (Ferdous et al. 2016).

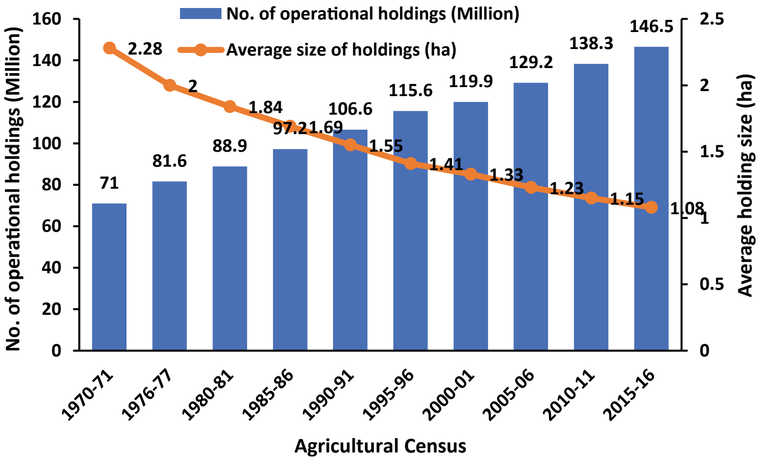

Fig. 23.1 Number of operational holdings and average holding size in India. *Source* DACFW (2020). All India Report on Agriculture Census 2015–16, Department of Agriculture, Cooperation & Farmers Welfare Ministry of Agriculture & Farmers Welfare Government of India 2020

The sustainable development goal no. 2 of the United Nations, targets to end hunger, achieve food security and improve nutrition and sustainable agriculture during the period 2015–2030. To achieve this goal, homestead farming may be the entry point in the South Asia. To address, food security, it is essential to conserve natural resources (water, soil), conserve biodiversity (cereals, beans, vegetables, pseudo-cereals, small millets, indigenous pulses, oilseeds and many more forest plants form important component of food source) and integrate livestock in the farming system (Fig. 23.2), which are integral component of homestead farming (Singh et al. 2005).

Fig. 23.2 Strategy to achieve food security in the most vulnerable regions

Table 23.1 Diverse homestead farming system models suitable for coastal region

S. No.	HFS model	Location	References
1	Pond/aquaculture-based	Bangladesh and West Bengal, India	Kabir et al. (2015) Sundaray et al. (2014) Mandal et al. (2016)
2	Agroforestry-based (*Pekarangan)*	Indonesia	Arifin et al. (2012)
3	Plantation crop-based	Goa, India	Singh et al. (2014)
4	Mixed vegetable/nutrition garden—*Mo Upakari Bagicha* Rooftop nutrition garden	Odisha, India Tamil Nadu, India	http://olm.nic.in https://www.dtnext.in
5	Coconut and fodder intercropping	Kerala, India	John (2014) Lakshmi et al. (2007)
6	Animal/forage-based smallholder farming	Mekong region, Cambodia, Lao PDR, India	Philp et al. (2019)
7	HFS for year-round production	Bangladesh	Ferdous et al. (2016)

23.2 Relevance of Homestead Farming in Coastal Region

The coastal areas are more vulnerable under the climate change scenario due to the proximity to sea coast, where the natural calamities such as floods, cyclones, droughts and seawater intrusion happen frequently. To meet the food and nutritional security of these vulnerable community, various homestead farming models (Table 23.1) may be adopted depending upon the location, household needs and local market demand.

Homestead farming encourages different subsidiary components such as (1) pisciculture (2) duckery (3) backyard poultry (4) goat rearing (5) rabbit rearing (6) dairy (7) piggery (8) mushroom cultivation (9) vermicompost production (10) honeybee keeping and (11) plant nursery; as a result, this system conserves biodiversity, increases income, preserves indigenous technical knowledge and ensures food as well as nutritional security (Fig. 23.3).

23.3 Homestead Farming Systems

23.3.1 Homestead Farming Systems of Sundarbans Region

Small and marginal farmers inhabiting in the Sundarbans region of Bangladesh and West Bengal, India, practise pond-based homestead farming systems (Table 23.2). However, there are differences in HFS between Bangladesh and West Bengal. Significant difference in homestead land size between regions are observed. Landholdings at Kakdwip, a low salinity area, were the largest with median 0.14 ha and also had the highest income. Landholding is the smallest in Polder 3 (Bangladesh), a high

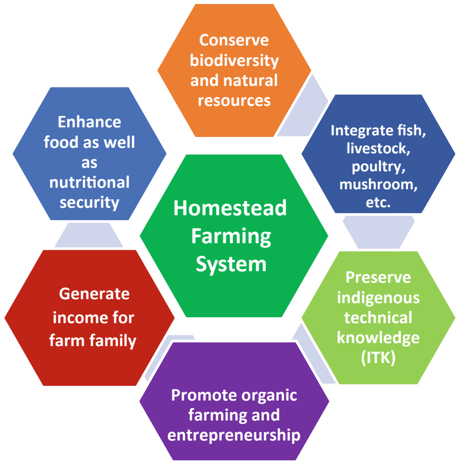

Fig. 23.3 Multifaceted role of homestead farming system in coastal region

Table 23.2 Different components and area allocation in HFS of Sundarbans region

Components	Land area (%) allocation in HFS	
	Bangladesh	West Bengal
Aquaculture pond	45	50
Vegetable garden	15	29
Livestock shade	3	8
Poultry shade	1	6
Fruit trees	36	7

Source Kabir et al. (2015)

salinity area, with a median of just 0.03 ha per household (Kabir et al. 2015). HFS yield value from low salinity areas was much higher (US$ 324) than from high salinity areas (US$ 164) of West Bengal. This was also the case in Bangladesh. Home gardening activities are centered around women, and it can also increase the income of women, which may result in the better use of household resources and improved caring practices and empowerment (Sundaray et al. 2014).

In South 24 Parganas district of West Bengal, the majority (94%) of households in rural areas practise pond-based HFS, with allocation of about 50% land for pond, which is used for culture of fish species such as *Labeo rohita* (Rohu), *Catla catla* (Catla), *Cirrhinus mrigala* (Mrigal), *Hypophthalmichthys molitrix* (Silver carp), *Ctenopharyngodon idella* (Grass carp), and *Puntius japonicus* (Japanipunti) (Bhattacharya et al. 2012). However, production from homestead aquaculture (68.2 kg yr^{-1} $household^{-1}$, i.e., 1400 kg ha^{-1}) is below the national average (2700 kg ha^{-1} yr^{-1}) (Bhattacharya et al. 2013). The gross income from HFS is higher from aquaculture activities than non-aquaculture activities (horticulture and animal husbandry) except for betel vine cultivation. Betel vine cultivation is practised by 22% households with the highest gross income of more than Rs. 60,000 per

Table 23.3 Consumption and marketing pattern of homestead production in Sundarbans

Items	Contribution (%)			Average production (kg per household)
	Home consumption	Fulfilling the total requirement	Marketed	
Vegetables	70–75	30–40	25–30	340
Fish	30–35	50–60	60–65	143
Fruits	85–90	–	5–10	–
Livestock	80–85	50	10–15	–

Source Mandal et al. (2016)

year (CIBA, 2012–13). The betel vine-based HFS combined with homestead aquaculture, animal husbandry can ensure a sustainable income of Rs. 1.5 lakh (~ US$ 2500) a year (Sundaray et al. 2014). Among crops, vegetables such as Indian spinach (*Basella alba*), brinjal (*Solanum melongena*), arum (*Colocasia esculenta*), elephant foot yam (*Amorphophallus paeoniifolius*), chilli (*Capsicum annuum*), bitter gourd (*Momordica charantia*), pumpkin (*Cucurbita maxima*), okra (*Abelmoschus esculentus*), potato (*Solanum tuberosum*) and onion (*Allium cepa*) are cultivated. Among trees, drum stick (*Moringa oleifera*), mango (*Mangifera indica*), coconut (*Cocos nucifera*), find place in the pond dykes. Animals such as cows, goats, poultry birds and duck are reared. In the ponds, some farmers grow water spinach locally called *kalmi sag* (*Ipomoea aquatica*) belonging to Convolvulaceae (Morning glory) family, as floating beds. For meeting the nutritional security of poor small and marginal farmers, this crop has a promise and should find place in the farming system to supply at least 120 g of green leafy vegetable per person per day (Sarangi et al. 2010). However, in spite of this diverse system, the present system does not fulfil the needs of all households due to poor economic status, poor water and seed quality, soil salinity and disease infection. Almost 23% households are unable to get proper nutrition (Bhattacharya et al. 2013).

It was estimated, on an average 70–75% of vegetables produced in the HFS of Sundarbans were consumed by the family members that accounted for nearly 30–40% of their total requirement (Table 23.3). Some part of the harvest (25–30%) was being marketed almost daily or at alternate day. Similarly, around 30–35% of fish produced in the HPS was consumed by the farm family that accounted for 50–60% of their total households' requirement of fish (Mandal et al. 2016).

23.3.2 Coconut-Based HFS

Coconut-based HFS is found in Kerala State of India with other perennial crops such as areca nut, black pepper, cocoa, cashew and various tree species such as teak (*Tectona grandis*), jackfruit (*Artocarpus heterophyllus*), wild jack (*Artocarpus hirsutus*), casuarina (*Casuarina equisetifolia*), portia (*Thespesia populnea*), silver oak (*Grevillea robusta*) and erythrina (*Erythrina variegata*). Cattle and poultry form the animal component of this system (John 2014). In this four-tier structured system, trees of >25 m height form the upper canopy, medium-sized fruit trees, spice, timber/fuel trees (10–20 m height) form the second layer, pepper, tree spices and fruit trees (3–10 m height) form the third layer and the fourth layer (1–3 m in height) includes banana, cassava and other tuber crops (Jacob 1997). Coconut-based fodder production systems enable rearing of dairy cattle in homesteads of Kerala. Guinea grass (*Panicum maximum*) is highly suitable fodder crop for cultivation as an inter-crop with coconut. Guinea grass is shade tolerant, nutritious and palatable fodder for dairy cattle. Coconut plants are planted at a spacing of 7.5 m × 7.5 m, and fodder crops are grown in the interspace leaving 2 m area around the coconut plant. Application of 200–150–200 kg N–P_2O_5–K_2O ha^{-1} plus 100 kg magnesium ha^{-1} and 1 kg boron ha^{-1} to guinea grass along with 88–57–112 kg N–P_2O_5–K_2O ha^{-1} to coconut recorded the highest yields of 94.5 t ha^{-1} green fodder and 107 nuts $palm^{-1}$ yr^{-1} (Lakshmi et al. 2007).

23.3.3 Mixed Vegetable-Based Homestead Nutrition Gardens

Promotion of improved homestead gardens in rural areas is the most important strategy to tackle malnutrition by supplying different dietary needs (Table 23.4). To attain a malnutrition-free India by 2022, the Government of India launched the National Nutrition Mission or *Poshan Abhiyaan*. The National Rural Livelihood Mission is promoting kitchen gardens as part of farm livelihood intervention strategy for National Nutrition Mission to combat malnutrition by promoting healthy eating and improving agro-ecological practices (Suri 2020).

There is growing evidence that food-based strategies, including homestead food production, have an impact on vitamin A deficiency and other micronutrient deficiencies. Micronutrient deficiency disorders are serious problems in South Asian countries with long-term consequences. Globally, more than 250 million children in developing countries are at risk of vitamin A deficiency and more than half of these children live in South Asia. Iron deficiency affects more than 2000 million women and children and more than 1500 million people in the world are at risk of iodine deficiency. Homestead farming in these regions play very important role to increase availability and consumption of varieties of vegetables, fruits, and some animal foods by keeping small animals, poultry and/or fish. Keeping in view, the size of homestead, it is important to utilize the space very effectively. Plants of different habits of growing such as creepers, climbers, shade-tolerant plants and multipurpose trees/plants are grown to gain the maximum land-use efficiency. Similarly, plants are also grown on the rooftop, in soil-filled bags, in the bunds, boundaries of fields, fences, etc. Climbers such as cucumber (*Cucumis sativus*), bitter gourd (*Momordica charantia*), ridge gourd (*Luffa acutangula*), snake gourd (*Trichosanthes cucumerina*), country bean (*Dolichos lablab*), Indian spinach (*Basella alba*) can be grown vertically by the use of bamboo sticks/wooden platform (Fig. 23.4), vegetables such

Table 23.4 Vegetables and fruits suitable for homestead nutrition gardens

S. No.	Dietary requirement	Crops
1	Calories	Potato (*Solanum tuberosum*), tapioca (*Manihot esculenta*), sweet potato (*Ipomoea batatas*), yam (*Dioscorea* spp.), colocasia (*Colocasia esculenta*), onion (*Allium cepa*), plantain (*Musa paradisiaca*), breadfruit (*Artocarpus altilis*), jack fruit (*Artocarpus heterophyllus*), pumpkin (*Cucurbita maxima*), onion (*Allium cepa*), banana (*Musa acuminata*), peas (*Pisum sativum*), etc.
2	Proteins	Peas (*Pisum sativum*), cowpea (*Vigna unguiculata*), grams (*Cicer arietinum*), soybean (*Glycine max*), fish, eggs, meat, etc.
3	Vitamin A	Carrots (*Daucus carota*), spinach (*Spinacia oleracea*), amaranthus (*Amaranthus viridis*), colocasia (*Colocasia esculenta*), capsicum (*Capsicum annuum*), methi (*Trigonella foenum-graecum*) leaves, drumstick (*Moringa oleifera*) leaves, pumpkin (*Cucurbita maxima*), mango (*Mangifera indica*), papaya (*Carica papaya*), passion fruit (*Passiflora edulis*), tomato (*Solanum lycopersicum*), orange flesh sweet potato, etc.
4	B-Complex	Peas (*Pisum sativum*), broad beans (*Vicia faba*), tomato (*Solanum lycopersicum*), banana (*Musa acuminata*), grapes fruits (*Citrus paradisi*), okra (*Abelmoschus esculentus*), capsicum (*Capsicum annuum*) and other vegetables
5	Vitamin C	Aonla (*Emblica officinalis*), leafy vegetables, tomato (*Solanum lycopersicum*), orange (*Citrus sinensis*), lemon (*Citrus lemon*), guava (*Psidium guajava*), mango (*Mangifera indica*), etc.
6	Calcium	Curry leaves (*Murraya koenigii*), drumstick (*Moringa oleifera*), spinach (*Spinacia oleracea*), vegetables, custard apple (*Annona reticulata*), fish, etc.
7	Iron	Green leafy vegetables, beans, pulses, dates, raisins, guava, etc.

Fig. 23.4 Growing climbing type of vegetables over bamboo/wooden platform/rooftop

as ridge gourd, bitter gourd (Fig. 23.5), spice crop ginger (*Zingiber officinale*) can be grown in soil-filled bags in the homestead (Fig. 23.6).

As per Indian Council of Medical Research (ICMR), for normal male adult, the need of energy, protein, fat, calcium and iron per day is 170 cal, 17 g, 3.5 g, 750 mg

Fig. 23.5 Vegetable growing in soil-filled bags

Fig. 23.6 Ginger cultivation in soil-filled bags

and 25 mg, respectively. ICMR recommended that every individual should consume at least 300 g of vegetables in a day consisting of at least 50 g of green leafy vegetables (GLV), 200 g of other vegetables and 50 g of roots and tubers. A person should also consume at least 100 g of fresh fruits in a day. Pregnant women should consume 100 g of GLV to meet the higher requirement of iron and folic acid. Therefore, to make the vegetables and fruits easily available, nutrition gardens play an important role.

The Ministry of Human Resource Development, Government of India has developed guidelines for school nutrition gardens in government and aided schools under the mid-day meal scheme. Several states of India are now emphasizing on nutrition gardens through government schemes, e.g. Odisha Livelihood Mission (OLM) under the Panchayati Raj and Drinking Water department is promoting nutrition sensitive agriculture by promoting kitchen gardens (http://olm.nic.in).

To create awareness about the importance of vegetables and fruits, the Tamil Nadu (TN) government emphasizing on roof gardens in more than 1500 state-run schools. The produce from these gardens would be used in school kitchens serving nutritious noon meal scheme. Horticulture department of TN has tied up with the School Education Department to establish such gardens. Government schools that have terrace with enough space to plant at least 20 vegetable varieties, tomatoes, ladies' finger, coriander, chillies, beans, pumpkin, beans and spinach would be in the list. Members of Self-Help Groups (SHG) that are engaged with Horticulture Department would train students, who are members of Eco Clubs and National

Green Corps. This initiative will create interest among the students in gardening activities and to educate children about nutrition (https://www.dtnext.in/News/TamilNadu/2019).

23.3.4 Homestead Agroforestry Systems

In Indonesia intensively cultivated homestead agro-forestry systems (*pekarangan*) contribute an average 56% to the household dietary needs and contribute 20.9% of household income (Arifin et al. 2012). Banana, papaya, guava, mango, orange, coconut, coffee and cacao form the tree component, whereas cassava, sweet potato, tomato, chilli, etc., form crop component of this system. *Pekarangan* is a traditional homestead garden, which is an optimal and sustainable land-use type of agroforestry system in the tropical region of Indonesia (Arifin et al. 2014). Salient features of this system are (1) sustainable and abundant bioresources, (2) uses local wisdom and local knowledge of the community, (3) practices as agro-forestry, agro-silvo-pasture and agro-silvo-fishery systems, (4) agricultural biodiversity and sustainable material circulation are maintained, (5) potential land for ecosystem services such as carbon sequestration, water resource management, agrobiodiversity conservation and landscape beautification.

Agro-forestry-based HFS (Table 23.5) plays a significant role in improving food and nutritional security of the smallholder farmers in developing countries like India, Bangladesh, Sri Lanka and other Asian countries (Singh et al. 2016). Papaya, banana, pineapple, etc., are grown as fruit crops besides vegetables, spices, tubers, mushroom, poultry and goatery components. This system ensured a year-round supply of a wide spectrum of food materials as well as contributed to income security by selling in nearby market with a net profit of US$ 1052 from 0.15 ha area in a year.

Sri Lankan home gardens in Kandy and adjacent districts, such as Badulla, Kegalle, Kurunegala, Matale, Nuwara Eliya and Rathnapura, are popularly known as Kandyan home gardens (KHGs) or Kandyan forest gardens (Pushpakumara et al. 2016). KHGs are a common traditional agroforestry system with valuable perennial and semi-perennial fruit crops as well as animal component (Galhena et al. 2013). In KHGs, the most common fruit trees are jackfruit, mango, cashew, citrus, guava, sweet orange, rambutan and avocado. In the understorey layer below 3 m, pineapple is the most common species, whereas in the lower stratum (3–10 m) banana, cacao, passion fruit, lime and lemon are common. In the middle stratum (10–15 m), papaya, avocado, mangosteen, breadfruit and some citrus species commonly occur. In the upper-middle stratum, over 15 m, jackfruit, mango, durian, wild breadfruit and breadfruit are the dominant fruit crop species (Pushpakumara et al. 2016).

Table 23.5 Agro-forestry-based homestead farming system for economic and livelihood security

Production System	Yield	Average home consumption (%)	Net profit from market sale (US $ yr^{-1})
Vegetables[a]	1443 kg from 0.08 ha	45	415
Spices and tuber crops[b]	280 kg from 0.03 ha	26	175
Fruits[c]	1050 kg from 0.04 ha	34	150
Mushroom	42 kg from 50 cubes	31	65
Poultry	15 nos.	-	-
Eggs Meat	980 nos. 27 kg	22 30	85 51
Goatery			
Female Kids	2 nos. 4 nos.	- -	- 111
Vermicompost Poultry manure Goat manure	5500 kg yr^{-1} 290 kg yr^{-1} 800 kg yr^{-1}	100 100 100	- - -
Total			1052

[a] Okra, bitter gourd, cucumber, cowpea, chilli, brinjal, tomato, cauliflower, carrot, [b] Local spices crop (ginger, turmeric), tuber crops (yam, dioscoria, tapioca, colocasia) and pineapple were grown as inter-crop in the fruit plantation area. [c] Papaya, banana and pineapple. *Source* Singh et al. (2016)

23.3.5 Animal/Forage Crop-Based Homestead Farming

In some of the HFS, animals contribute significantly to household income, particularly by selling dairy productions such as milk. In such system to reduce the high-cost requirement of animal feed, fodder crops may be cultivated in the homestead area to supplement the feed requirement. Para grass (*Brachiaria mutica*) also known as buffalo grass or water grass is suitable fodder crop for high rainfall areas, as it is a semi-aquatic plant. It can be propagated from seeds as well as from stolons (stem cuttings). Napier grass (*Pennisetum purpureum*) also known as elephant grass is a C4 plant suitable for coastal region as it requires warm and moist climate and heavy soils for good growth. The first fodder yield can be obtained in 90 days and subsequent cuts in every 50–60 days. Hybrid Napier Bajra (HNB) is an inter-specific hybrid between bajra (*Pennisetum glaucum*/*typhoides*) and napier grass and combines high quality and faster growth of bajra with the deep root system and multicut habit of napier grass. It is suitable for round the year green fodder production purpose. It contains 8–12% crude protein and 26–28% crude fibre. The total digestible nutrient ranges from 55–58%. First cutting about 50–60 days after its planting and thereafter each subsequent cutting may be taken at about 20–25 days interval. It is a perennial grass, which can be retained for 4–5 years.

23.3.6 HFS for Year-Round Production

This system utilizes the homestead resources in scientific ways for producing fresh vegetables and fruits over space (open sunny place, rooftop, trellis, fence, boundary, marshy land and partially shady place) and time and to enhance the nutritional supplies for the family throughout the year (Ferdous et al. 2016). This model supplied 55–79 kg head^{-1} yr^{-1} vegetables compared to bench mark level of 21–30 kg head^{-1} yr^{-1}; as a result, there was an increase in food security and reduction in malnutrition of farm families of Rangpur region in Bangladesh. Vegetables such as radish (*Raphanus sativus*), cabbage (*Brassica oleracea* var. capitata), tomato (*Solanum lycopersicum*), brinjal (*Solanum melongena*), spinach (*Spinacia oleracea*), garlic (*Allium sativum*), coriander (*Coriandrum sativum*), Chinese mallow (*Malva verticillate*), Joseph's coat (*Amaranthus tricolor*), okra (*Abelmoschus esculentus*), Indian spinach (*Basella alba*), water spinach (*Ipomoea aquatica*), stem amaranth (*Amaranthus lividus*) and tossa jute (*Corchorus olitorius*) were selected for year-round vegetable production in beds (5 m × 6 m size) under the open sunny space. In the rooftop, creepers such as bottle gourd (*Lagenaria siceraria*) and ash gourd (*Benincasa hispida*) were grown. French bean (*Phaseolus vulgaris*) and snake gourd (*Trichosanthes anguina*) were grown in trellis. Bitter gourd (*Momordica charantia*) and ribbed gourd (*Luffa acutangula*) were grown in fences. In the boundary, six to nine papaya (*Carica papaya*) plants were planted. Marshy land was utilized by growing tannia (*Xanthosoma sagittifolium*). Shade-tolerant crops such as ginger (*Zingiber officinale*) and turmeric (*Curcuma longa*) were grown in partially shady place. In this system, organic manures such as cow dung, poultry manure, compost, kitchen ash, vegetable refuse, crop residues and tree litters were used to supply the nutrient requirement of the crops.

23.4 Epilogue

Mostly the present form of homestead farming systems is household consumption-oriented, and there is need to make this system market-oriented. There are constraints such as lack of access to quality seeds, lack of capital, high cost of production and low productivity. To address these, there is need to create awareness, imparting training, creating linkages with credit organizations and government schemes. State-of-the-art technology needs to be promoted for making the system profitable with the production of market-driven products. Emphasis may be given on protected cultivation of high value crops, vertical, rooftop farming, intensification of pond banks, intercropping, integration of fodder crops. Initiatives need to be developed for organic production as well as certification, post-harvest processing and value addition, linking of farmers, formation of farmers producer organizations, forward and backward linkages.

References

Arifin HS, Munandar A, Schultin KG et al (2012) The role and impacts of small-scale, homestead agro-forestry systems ("*pekarangan*") on household prosperity: an analysis of agro-ecological zones of Java, Indonesia. Int J Agri Sci 2(10):896–914

Arifin HS, Kaswanto RL, Nakagoshi N (2014) Low carbon society through Pekarangan, traditional agroforestry practices in Java, Indonesia. In: Nakagoshi N, Mabuhay JA (eds) Designing low carbon societies in landscapes. Ecological Research Monographs, Springer, Tokyo, pp 129–143. https://doi.org/10.1007/978-4-431-54819-5_8

Bhattacharya A, Sundaray JK, Deo AD et al (2012) Homestead production-strategy for nutrition and food security: an assessment in the coastal villages of Ganges Delta. In: Global symposium on aquatic resources for eradicating hunger and malnutrition-opportunities and challenges, Mangalore, 4–6 Dec 2012, p 154

Bhattacharya A, Deo AD, Sundaray JK et al (2013) Impact of homestead farming system on rural economy: A study in South 24 Pargana district of West Bengal. Abstract no. T09OP02. Presented in Second International Conference on Ecosystem Conservation and Sustainable Development, University of Kerala, Kerala, India, 3–5 Oct 2013, p 405

CIBA (2012–13). Annual report. Central Institute of Brackish water Aquaculture, Chennai, India, p 85. https://krishi.icar.gov.in/jspui/bitstream/123456789/1135/1/CIBA%20Annual%20Report%202013.pdf

DACFW (2020) All India report on agriculture census 2015–16. Department of Agriculture, Cooperation & Farmers Welfare, Ministry of Agriculture & Farmers Welfare, Government of India, p 390

Ferdous Z, Datta A, Anal AK et al (2016) Development of home garden model for year-round production and consumption for improving resource-poor household food security in Bangladesh. NJIS-Wageningen J Life Sci 78:103–110. https://doi.org/10.1016/j.njas.2016.05.006

Galhena DH, Freed R, Maredia KM (2013) Home gardens: a promising approach to enhance household food security and wellbeing. AgricFood Secur 2:8. http://www.agricultureandfoodsecurity.com/content/2/1/8

John J (2014) Homestead farming in Kerala: a multi-faceted land-use system. Rev Agrar Studies 4(1):1. http://ras.org.in/homestead_farming_in_kerala

Jacob J (1997) Structure analysis and system dynamics of agroforestry home gardens of Southern Kerala. Unpublished PhD thesis, College of Agriculture, Kerala Agricultural University

Kabir KA, Sundaray JK, Mandal S et al (2015) Homestead farming system: comparative characterization and role in resource poor farmers' livelihood in Bangladesh and West Bengal. In: Humphreys E, Tuong TP, Buisson MC, Pukinskis I, Phillips M (eds) Revitalizing the Ganges costal zone: turning science into policy and practices conference proceedings. CGIAR Challenge Program on Water and Food (CPWF), Colombo, Sri Lanka, pp 251–264

Lakshmi S, George A, Pillai GR et al (2007) Nutrient needs of coconut-based fodder production systems in homesteads of Kerala. Better Crops 91(4):28–29

Lowder SK, Skoet J, Raney T (2016) The number, size and distribution of farms, smallholder farms, and family farms worldwide. World Dev 87:16–29. https://doi.org/10.1016/j.worlddev.2015.10.041

Mandal S, Burman D, Sarangi SK et al (2016) Homestead production systems in coastal salt-affected areas of Sundarbans: status and way forward strategies, In: Dagar JC, Sharma PC, Sharma DK, Singh AK (eds) Innovative saline agriculture. Springer, India. https://doi.org/10.1007/978-81-322-2770-0

Philp JN, Vance W, Bell RW et al (2019) Forage options to sustainably intensify smallholder farming systems on tropical sandy soils—a review. Agron Sustain Dev 39:30. https://doi.org/10.1007/s13593-019-0576-0

Pushpakumara DKNG, Heenkenda HMS, Marambe B et al (2016) Kandyan home gardens—a time tested good practice from Sri Lanka for conserving tropical fruit tree diversity. In: Sthapit B, Lamers HAH, Rao VR, Bailey A (eds) Tropical fruit tree diversity—good practices for in situ

and on-farm conservation. Routledge Taylor & Francis Group, New York, pp 127–146. https://www.bioversityinternational.org/fileadmin/user_upload/Tropical_Fruit_Tree_Diversity.pdf
Sarangi SK (2009) Indigenous farming system of Adi tribes: source of food, nutrition and medicine. LEISA INDIA 11(1):22–23
Sarangi SK, Bandyopadhyay BK, Mandal S (2010) Kalmisag (*Ipomoea aquatica*)—a green leafy vegetable having promise in the coastal salt affected soils. In: Sarangi SK, Mahanta KK, Gokhale NB, Mandal S, Burman D, Bandyopadhyay BK (eds) Abstracts, 9th national symposium of Indian Society of Coastal Agricultural Research on recent outlook on sustainable agriculture, livelihood security and ecology of coastal region, 27–30 Oct 2010. Goa, India, p 149
Singh AK, Gohain I, Datta M (2016) Upscaling of agroforestry homestead gardens for economic and livelihood security in mid-tropical plain zone of India. Agrofor Syst 90:1103–1112. https://doi.org/10.1007/s10457-015-9886-7
Singh K, Sharma HC, Singh Yashwant et al (2005) Strategies for sustainable crop production. In: Pratap S, Maliwal PL (eds) Technologies for food security and sustainable agriculture. Agrotech Publishing Academy, Udaipur, Rajasthan, India, pp 204–222
Singh NP, Manjunath BL, Desai AR et al (2014) Technology package for nutritional and livelihood security through homestead farming. Technical Bulletin 37, ICAR Research Complex for Goa (Indian Council of Agricultural Research), Goa, India
Sundaray JK, Bhattacharya A, Deo AD et al (2014) Women in homestead vegetable farming. Empowering Women in Agriculture, pp 78–89. https://www.livelihoods-india.org/uploads-livelihoodsasia/subsection_data/women-in-homestead-vegetable-farming-by-j-k-sundaray-a-bhattacharya-a-d-deo-j-p-sharma-a-g-ponniah-and-t-k-ghoshal.pdf
Suri S (2020) Nutrition gardens: a sustainable model for food security and diversity. ORF Issue Brief No. 369. Observer Research Foundation, New Delhi, India, pp 1–18. https://www.orfonline.org/research/nutrition-gardens-a-sustainable-model-for-food-security-and-diversity-67933/

Chapter 24
Water Budgeting and Enhancing Water Productivity in Lowland Rice-Fish Farming System

S. K. Rautaray and A. Mishra

Abstract Two important problems in lowland rice field include low agricultural productivity and underutilization of excess water. The low productivity is due to excess and deficit water stress in wet and dry season, respectively. Taking advantage of good quality water and heavy textured soil, rice-fish-based farming system is often suggested. Experience with a vertisol in coastal waterlogged area revealed that seepage percolation rate was low (0.47 mm d^{-1}) in November and increased to 1.93 mm d^{-1} in April. Wet and dry season rice cultivation is feasible with rice-fish system in waterlogged areas by water harvesting and with irrigation from supplementary farm pond. For this, one-hectare rice-fish system requires supplementary farm pond of 0.18 ha. Similarly, for intermediate lowland in Brahmaputra river valley, supplementary farm pond of 0.18 ha was required for two rice crops in rice-fish system. Six years of study at Brahmaputra river valley revealed that the water productivity of the integrated rice-fish system (1.04 kg rice equivalent yield m^{-3}) was 2.88 times higher as compared to rice fallow system (0.36 kg m^{-3}). For the shallow lowland system, water productivity (0.9 kg rice equivalent yield m^{-3}) with rice-fish system was 2.1 times higher compared to traditional practice of sole rice.

Keywords Rainwater harvest · Rice-fish system · Waterlogging · Water productivity

24.1 Introduction

Globally, area under lowland rice accounts 91% of the area under rice cultivation (163 M ha). In India, such lowland rice area is 86.5%, being distributed in irrigated (22 M ha), rainfed (14.6 M ha) and flood-prone (2 M ha) areas. Out of the lowland

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area in India, 11.6 M ha faces the problem of waterlogging. Two important problems in lowland rice field include low agricultural productivity and underutilization of excess water. The low productivity is due to excess water stress during July to December and deficit water stress in dry season (January to June). However, the water quality is mostly suitable for agriculture unlike grey water (containing pathogens, toxic chemicals and heavy metals), and some ground water with geogenic problems (arsenic, fluoride, iron and salinity). Out of 11.6 M ha area with waterlogging problem, 2.2 M ha comes under canal command and the remaining 9.4 M ha is in low-lying topography (Planning Commission 2011).Often, rice field is waterlogged due to flash floods in river valleys due to high rainfall in upper catchment.

The area and intensity of waterlogging may increase in future as 10–15% more rainfall is expected in tropical areas with lesser number of rainy days in climate change scenario. An increase in number of dry days, a decrease in frequency of light to medium precipitation events and increased frequency of high rainfall events (Giorgi et al. 2019) may result in increased deficit or excess water stress. North-west coast to the south-east coast of India is generally waterlogged, and the problem may aggravate due to higher rainfall than the average (World Bank 2013). Bindoffet al. (2007) reported that the projected sea-level rise of 50 cm by the year 2100 may create more waterlogged area. Further, construction of new highways, buildings and industries is likely to add the area under waterlogging.

Demand for water has already increased manifold over the years due to urbanization, agriculture expansion, increasing population, rapid industrialization and economic development. At present, changes in cropping pattern and land-use pattern, over-exploitation of water storage and changes in irrigation and drainage are modifying the hydrological cycle in many climate regions and river basins. Several studies around the globe show that climatic change is likely to impact significantly upon freshwater resources availability. So, it is important to harvest a part of the excess water in rainy season for pisciculture and field crop production in dry season.

For lowland areas, different land shaping options are suggested. These include farm ponds, raised and sunken beds, and rice-fish integrated system. Out of these, rice-fish system is a better option as it involves low volume of earth work and low investment. Also, the popular rice crop is important part of the system. Adoption of fish rearing in lowland rice ecology is a low cost and sustainable practice to harvest high-value animal protein and minerals. The system allows fish entry into rice field and promotes synergistic interaction between the rice and fish. Growing of fruits and vegetables on the dykes may provide additional source of income, employment, minerals, vitamins and antioxidants. Also, the volume of harvested water can be enhanced by increasing area and depth of pond refuge and trenches.

The hydrological processes, water budget, and environmental benefits and consequences of farm ponds are not quantified fully (Ouyang et al. 2017). There are few studies, highlighting the water budgeting for aquaculture, agriculture and on-dyke horticulture at micro-level. This is mainly due to a limited volume of the harvested water and huge loss out of it. However, efficient use of harvested water is warranted adopting the improved water conservation approaches. This is very important in the context of the increased demand of fresh water for agriculture, aquaculture, industrial needs and ecosystem sustenance. Efficient use of limited volume of harvested water is very important for the small holder farms in Asia and Africa. The region is disadvantageous regarding erratic rainfall distribution and high evaporative demand.

The rice-fish system harvests water by collecting rainfall, runoff and subsurface flow, storing flood water and conserving water from streams at peak flows. These processes take place mainly in rainy season (June to October) and to little extent in winter and summer season in tropical India. Water requirement of rice during the dry spell in rainy season is met using the harvested water in the system. The used water is refilled within the season from subsequent rainfall events and/or stream flows. Harvested water at the end of rainy season is useful for growing post-rainy crops and dyke crops. The volume of harvested water being limited and the practice being costly, economic water productivity of the used water must be high. Adoption of water use efficient crops and varieties is known to enhance water productivity. Growing the crop during the low evaporative demand period (November to March) is useful in water economy, and hence, winter crops are water use efficient. Similarly, micro-irrigation, pipe conveyance, proper irrigation scheduling and water use near the pond are useful in enhancing water productivity. However, information on water budgeting at micro-level for enhanced water productivity is meagre. An attempt is made to compile the information on water budgeting and productivity for rice-fish system under different lowlands.

24.2 Method

24.2.1 Study Site and Soil

Available information on water budgeting and productivity for different lowlands, viz. deep lowlands (water depth > 100 cm), intermediate lowlands (water depth 30–60 cm) and shallow lowlands (water depth < 30 cm), was collected. For the deep lowland, the study site was coastal waterlogged ecosystem in Puri district, Odisha (Rautaray 2020). It comes under the South Eastern Coastal Plain Zone of Odisha. The soil was moderately acidic (pH 5.6–6.3) and low salinity (EC 1.4–1.6 mS cm^{-1}). Soil texture was clayey (52–55% clay, 30–34% silt and 10–14% sand). The soil was under the order vertisol. Bulk density varied from 1.5 to 1.6 Mg m^{-3} while porosity from 27 to 30%. Saturated hydraulic conductivity was very low (1.1–1.4 cm d^{-1}). The soil was low in organic carbon (0.5%) and available N (210 kg ha^{-1}) and medium in available P (19.7 kg ha^{-1}) and K (147.4 kg ha^{-1}). For the intermediate lowland, the study site was Regional Rainfed Lowland Rice Research Station, Gerua, Assam. The soil texture at the experimental site was silty clay loam with mild acidic pH 5.8 to 6.1 and high organic carbon 10 to 12 g kg^{-1} (Walkley and Black, 1934). The soil was medium in available N (280–290 kg ha^{-1}) and P (18–21 kg ha^{-1}) while high in K (295–303 kg ha^{-1}). The bulk density varied from 1.2 to 1.3 Mg m^{-3} and saturated water content from 0.40 to 0.42 $m^3\ m^{-3}$. The site for the shallow lowland was at the research farm of Indian Institute of Water Management at Mendhasal. The soil texture was sandy clay loam. The field capacity and wilting point were 0.27 and 0.10 $m^3\ m^{-3}$, respectively.

24.2.2 Water Balance Analysis

Pan evaporation and rainfall data were collected from Agrometeorological Observatory using open pan evaporimeter and rain gauge, respectively. Water level of the farm pond was noted from graduated scale. By using the water balance equation, seepage (S) in mm day^{-1} was estimated from the observed values of rainfall, irrigation, evaporation and change in water depth of the pond. In post-rainy season, surface and subsurface inflow were negligible.

$$\Delta h = R - I - S - E$$

where Δh = change in water height in a week, R = rainfall, I = volume of irrigation water used for crops, E = evaporation and S = estimated seepage rate.

24.2.3 Estimation of Consumptive Use

Reference evapotranspiration (ET_o) was estimated as follows:

$$ET_o = K_p \times E_{pan}$$

where ET_o is reference evapotranspiration (mm d^{-1}), K_p is pan coefficient and E_{pan} is pan evaporation (mm d^{-1}). Mean monthly FAO-56 ET_o (mm d^{-1}) was used (Nag et al. 2014). Consumptive use or crop ET or crop water requirements (ET_c) were determined by multiplying the ET_o with the crop coefficient (K_c).

$$ET_c = K_c \times ET_o$$

The K_c value for initial, crop development, mid-season and the late season stage for rice crop were taken as 1.15, 1.15, 1.23 and 1.06, respectively, as per Tyagi et al. (2000). ET_c in a month was estimated by multiplying ET_o with the stage-specific K_c and number of days the crop was in that growth stage. When two growth stages fall in a month, then ET_c for the two stages was summed up.

24.3 Results and Discussion

Water budgeting and productivity for different standing water depths in lowlands and soil conditions are presented in this section.

24.3.1 Deep Lowland Area with Clayey Soil

For the deep lowland area with high clay content, the problem is plenty of water in rainy season. This should be converted to opportunity by harvesting as much water as feasible. Estimated seepage percolation rate (mm d^{-1}) from the recorded value of change in water height (Δh), rainfall and evaporation amount for November 2017 to April 2018 is presented (Rautaray 2020). Highest water level of 2.80 m was noted on 1 November 2017, while the lowest level of 2.28 m was on 30 April 2018 (Table 24.1). Water balance analysis of the water harvesting farm pond shows that seepage rate varied from 0.47 to 1.93 mm d^{-1} during the study period. Low percolation rate (0.5 mm d^{-1}) in November–December months may be due to low hydraulic gradient with the surrounding soil and high ground water level. The rate increased to 1.93 mm d^{-1} in April month which might be due to increase in hydraulic gradient in dry period. Bouman et al. (2007) reported that typical percolation rates varied from 1 to 5 mm d^{-1} for rice fields in heavy clay soils. Rao and Dhruvnarayana (1979) reported percolation loss of 2 mm d^{-1} based on measured data in puddled rice field by ponded basin method. The lower seepage percolation rate noted for the present study site was due to low seepage percolation from pond situation because of low topography. Also, high clay content (52–55%) and swelling property of clay in wet period were responsible.

Water harvesting up to potential level in wet season and growing of water-loving crops (water chestnut and deep water rice) was suggested (Rautaray 2020). Emphasis was given for high yielding dry season rice crop. Estimated crop consumptive use for

Table 24.1 Water balance components in different months for the year 2017–18

Months	Change in water height (Δh in mm)	Rainfall (mm)	Evaporation (mm)	Estimated seepage percolation (mm d^{-1})
November	−13.5	55.0	54.5	0.47
December	−38.2	26.0	48.7	0.50
January	−88.5	0	56.5	1.03
February	−112.5	0	83.5	1.04
March	−150.1	0	103.1	1.52
April	−116.5	50.7	109.2	1.93

Source Rautaray (2020)

dry season rice under proposed rice-fish system was 628.9 mm. A low seepage percolation amount of 143.5 mm was worked out. Water requirement of rice crop includes consumptive use and unavoidable application losses. Also, special crop need like puddling need is required for transplanted rice. This special need could be avoided in the proposed system by transplanting seedlings into the soft mud maintained with constant waterlogging. The consumptive use and seepage percolation need were worked out as 772.4 mm. Residual harvested water could provide 200 mm. So, the irrigation requirement was worked out as 572.4 mm. This requirement may come down in years of good dry season rainfall.

Dry season rice occupies 6000 m^2 area in 1 ha rice-fish system. So, the water requirement for dry season rice was 3434 m^3 considering residual harvested water of 0.2 m. A supporting farm pond (45 m $\times$ 40 m $\times$ 3 m) in addition to the area with rice-fish system is required to meet this demand and the water need for pisciculture and dyke crops. So, for an improved rice-fish farming system, the refuge pond should occupy 700 m^2 area considering optimal depth of 2 m. The rice-fish system should have two side trenches occupying 1000 m^2 area with tapering depth of 0.75–1.5 m. In addition, the supporting pond should occupy an area of 1800 m^2 pond (3 m deep) for the purpose of dual rice cultivation in main field. Higher amount of water harvesting for two rice crops in the proposed rice-fish system of deep lowland area and round the year water availability provides favourable condition for fish growth and yield.

24.3.2 Intermediate Lowland with Silty Clay Loam Soil

Ponded water level on rice field measured using a graduated scale for the year 2002–03 is shown in Fig. 24.1. Harvested water in wet season resulted in continuous ponded water on rice field. On 15 August, highest water level of 51 cm was noted (Rautaray 2011). Water level was contained below the canopy of rice plant by drainage through PVC outlet. A higher ponded water depth maintained in the rice-fish field was primarily intended for the benefit of fish. It facilitated the fish to enter into rice field and collect plankton and insects from a large forage area (60% rice area + 17% pond refuge and trench area). Also, it is beneficial in harvesting more rainwater. The wet season rice was harvested at a ponded water level of 24 cm on rice field in November end. After one month, seedlings of dry season rice were transplanted when the residual ponded water on field was 16 cm. This ponded water met the crop requirement till mid-February. Rice field was dry and hair cracks developed at few points indicating critical irrigation need on 18 February. First irrigation amounting 12 cm was provided on 19 February from supplementary pond. The second irrigation amounting 13 cm was provided on 9 March. Thus, the water requirement of the dry season rice was met from the harvested water from wet season rice (16 cm), irrigation water (25 cm) and dry season effective rainfall (47.04 cm). For the year 2003–04, 50 cm water was provided through irrigation (Table 24.2). For irrigating 6000 m^2 rice area, about 3000 m^3 water supplying resource is required. Supplementary farm pond (45 m $\times$ 40 m $\times$ 2.5 m) is required to meet this demand. Water used for the

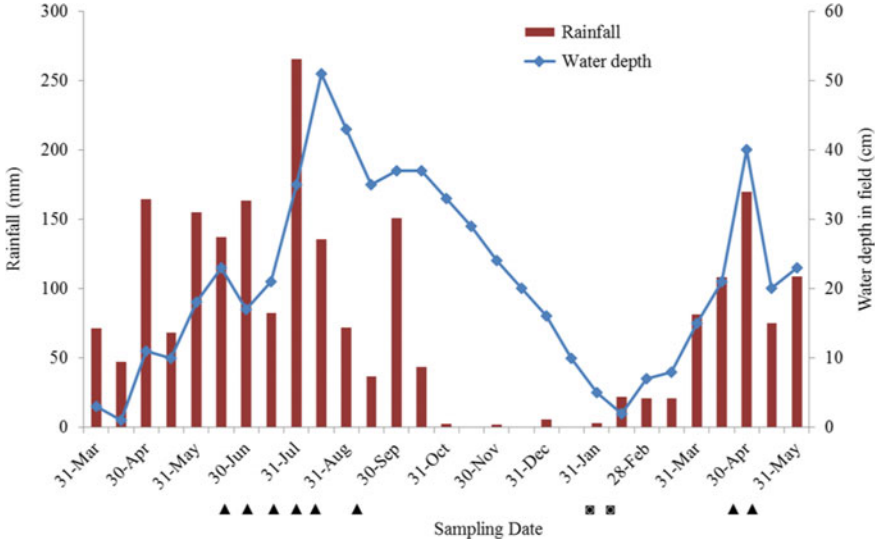

Fig. 24.1 Rainfall and water depth on the rice field of the rice-fish system from March 2002 to May 2003 (▲—water drained from field, ◙—irrigation given)

Table 24.2 Water used for dry season rice with the rice-fish system and the control in different years

Water used (cm)	Rice-fish system				Control			
	2002–03	2003–04	2004–05	Mean	2002–03	2003–04	2004–05	Mean
Land preparation	–	–	–	–	25	25	25	25
Residual water	16	7	5	9.33	–	–	–	–
Irrigation	25	50	39	38	51.5	61.0	50.5	54.33
Effective rainfall	47.04	34.26	45.65	42.32	45.31	33.19	43.63	40.71
Total	88.04	91.26	89.65	89.65	121.81	119.19	119.13	120.04

rice-fish system was 88.04 cm as compared to 121.81 cm with the control. For the control, intentionally, continuous ponding water (5 ± 2 cm) was allowed to keep down the weed population and to maintain mud softness for root proliferation. Also, ponding water was beneficial in reducing cold stress in rice plant.

Yield, economics and water productivity of the rice-fish system are presented in Table 24.3. The results revealed that for wet season rice, the rice-fish system was superior as compared to the control for grain yield (10.6%) and net return (25.7%). Regarding dry season rice, the rice-fish system was inferior as compared to the control for grain yield (17.3%) and net return (41.7%). The superior performance

Table 24.3 Yield, economics and water productivity of rice cultivation in wet and dry seasons with the rice-fish system and control (mean of 3 years 2002–03 to 2004–05)

Farming system	Grain yield (t ha^{-1})	Straw yield (t ha^{-1})	Net return (INR)	B:C ratio	Water productivity	
					[a]($kg\ m^{-3}$)	[b](INR m^{-3})
Rice-fish system						
Wet season rice	3.96	5.16	12,296	1.99	0.49	1.51
Dry season rice	4.36	5.51	8046	1.50	0.49	0.91
Rice–rice system	8.32	10.67	20,342	1.71	0.49	1.19
Control						
Wet season rice	3.58	5.02	9780	1.82	0.36	0.97
Dry season rice	5.27	5.98	13,803	1.73	0.44	1.15
Rice–rice system	8.85	11.0	23,583	1.76	0.40	1.07

[a] Grain yield (kg) per m^3 water used, [b] net return (INR) per m^3 water used

of the dry season rice with the control was due to higher fertilizer application rate (80 kg vs. 40 kg N ha^{-1}). Also, the puddling was done for the control only. Physical and economic water productivity for the wet season rice with the rice-fish system was more as compared to control. This was due to high yield and net return in wet season rice with the rice-fish system which in turn was due to better on-farm water management. In spite of higher yield (5.27 t ha^{-1}) of dry season rice with the control, physical water productivity was higher with rice-fish system. This was due to the lower amount of water used for the rice-fish system (89.65 cm) versus control (120.04 cm). However, economic water productivity of the dry season rice was less with the rice-fish system. This was due to low grain yield and net return due to low fertilizer use and no puddling. Combining the results for both the seasons, physical and net water productivity of rice–rice cropping system with the rice-fish system was 0.49 kg m^{-3} and INR 1.19 m^{-3}, respectively, compared to 0.40 kg m^{-3} and INR 1.07 m^{-3} with the control. Thus, the physical water productivity and net water productivity for the rice-fish system were higher by 23% and 11%, respectively. For the 6-year study, the water productivity of the integrated rice-fish system was 1.04 kg m^{-3}. This was 2.88 times higher as compared to rice fallow (0.36 kg m^{-3}).

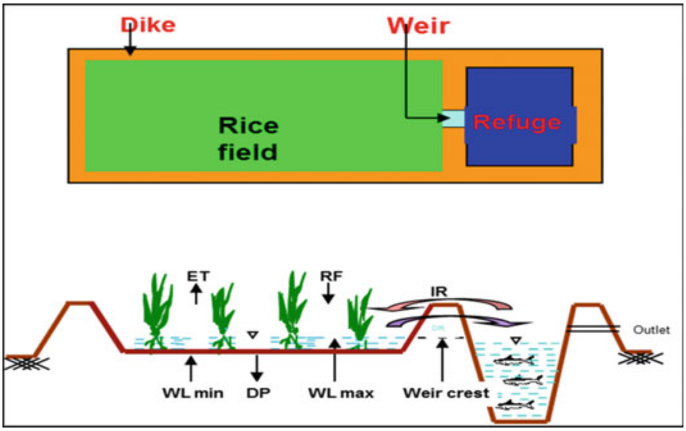

Fig. 24.2 Schematic view of 'two-stage rainwater harvest' (Mishra et al. 2014)

24.3.3 Shallow Lowland with Sandy Clay Loam Soil Texture

Mishra et al. (2014) suggested for 'two-stage rainwater harvest' in rainfed shallow lowlands of plateau areas. The first stage allowed ponding water up to 20 cm on rice field using field bund with the provision of a weir. In second stage, the surplus water flowing over the weir was collected in a refuge pond for fish rearing (5–8% of field area). The system helped increasing cropping intensity, productivity, profitability and employment generation due to water harvesting. However, in such system, volume of harvested water was low to meet the water requirement of dry season crops and fish. Importantly, fish yield is expected to be low due to their confinement in refuges only and lack of interaction with rice field for forage due to obstruction by field bunds (Fig. 24.2).

The concept of 'two-stage rainwater harvest' was replicated with a self-reliant farming system (Rautaray et al. 2016). In this system, 24.6% area was allocated for water harvesting farm pond and 12.3% for dyke around pond. In wet season, rice was grown in 63% area (1 ha). In rainy season, rainfall was sufficient for wet season rice. Rainwater was managed using 20 cm high dykes around the rice fields. The runoff water from the rice fields was collected in the farm pond using an 'inlet structure' after sedimentation in a lowland rice plot. The excess water from the farm pond was drained through a 'surplus structure'. In wet season, the pond was always full with water (2.6 to 2.8 m deep). Volume of water harvested after wet season rice for the first, second and the third year was 9932, 10,300 and 10,085 m^3, respectively (water depth of 2.55 m, 2.65 m and 2.59 m, respectively), with a mean of 10,106 m^3. The farm pond could meet irrigation requirement of 1 ha light-duty *rabi* crops provided by flexi pipes and also the dyke crops provided by drip irrigation. The system generated 18.05 t ha^{-1} rice equivalent yield with water productivity of 0.9 kg m^{-3}. This is 2.1 times higher as compared to sole rice system of 0.43 kg m^{-3}.

References

Bindoff NL, Willebrand J, Artale V et al (2007) Observations: oceanic climate change and sea level. In: Solomon S, Qin D, Manning M et al (eds) Climate change: the physical science basis, Contribution of working group 1 to the fourth assessment report of the Intergovernmental Panel on Climate Change. Cambridge University Press, UK and NY, USA, pp 385–432

Bouman BAM, Lampayan RM, Tuong TP (2007) Water management in irrigated rice: coping with water scarcity. International Rice Research Institute, Los Baños, Philippines, p 54

Giorgi F, Raffaele F, Coppola E (2019) The response of precipitation characteristics to global warming from climate projections. Earth Syst Dyn 10:73–89. https://www.earth-syst-dynam.net/10/73/2019/esd-10-73-2019.pdf

Mishra A, James BK, Mohanty RK et al (2014) Conservation and efficient utilization of rainwater in the rainfed shallow lowland paddy fields of Eastern India. Paddy Water Environ 12:25–34

Nag A, Adamala S, Raghuwansi S et al (2014) Estimation and ranking of reference evapotranspiration for different spatial scales in India. J Indian Water Resour Soc 34(3) http://iwrs.org.in/journal/july2014/6jul.pdf

Ouyang Y, Paz JO, Feng G et al (2017) A model to estimate hydrological processes and water budget in an irrigation farm pond. Water Resour Manage 31:2225–2241. https://doi.org/10.1007/s11269-017-1639-0

Planning Commission (2011) Mid-term appraisal of eleventh five year plan 2007–2012. Oxford University Press, New Delhi, p 500

Rao KVGK, Dhruvnarayana VV (1979) Analysis of drainage coefficients for surface drainage design in rainfed lowland rice fields. Ind J Soil Conserv 7(2):12–20

Rautaray SK (2020) Field design for enhancing water productivity in waterlogged areas with efficient water harvesting and farming system. Agric Res 10:255–261. https://doi.org/10.1007/s40003-020-00493-0

Rautaray SK (2011) Rice-fish farming system as micro-water resource and income generation under rainfed lowland situations. J Water Manag 19(1):52–57

Rautaray SK, Srivastava RC, Mohanty S, Raychaudhuri S (2016) Designing of a self-reliant farming system for small holder farm in high rainfall areas. J Indian Soc Coastal Agric Res 34:33–39

Tyagi NK, Sharma DK, Luthra SK (2000) Evapotranspiration and crop coefficients: measurement and computation for crop water requirements, Bulletin no. 1/2000, Central Soil Salinity Research Institute, Karnal, India

Walkley A, Black IA (1934) An examination of Degtjareff method for determining soil organic matter and a proposed modification of the chromic acid titration method. Soil Sci 37:29–37

World Bank (2013) India: climate change impacts. http://www.worldbank.org/en/news/feature/2013/06/19/india-climate-change-impacts

Chapter 25
Multilevel Integrated Farming Model in *Pokkali* Lands of Kerala

A. K. Sreelatha, P. V. Diya, and Nisha Paul

Abstract The marshy *Pokkali* tracts typify a unique ecosystem having a rich biodiversity, where salinity, acidity and submergence are the major hindrances for crop production. The present study was conducted to evaluate the multilevel integrated farming system with rice–prawn/crab–duck–goat in *Pokkali* lands in a farmer's field at Thathappilly, Ernakulam district, Kerala. The farming system involved integration of aquaculture, livestock and poultry along with *Pokkali* rice cultivation for maximizing productivity. The rice cultivation was in low saline phase, exclusively organic without any external inputs. In the month of May, rice fields were allowed to dry and mounds were prepared, where sprouted *Pokkali* seeds were sown. The mounds were dismantled after 30 days of sowing and seedlings were transplanted in the field at spacing of 20 cm x 15 cm. By mid-October, the rice was harvested by cutting only the panicle at a height of 30–35 cm from the top and the remaining biomass was left in the field. The grain yield was 2 t ha^{-1}. Ducks (35 no.) were released into these harvested fields, in which paddy wastes were the feed for them. They were also released as pest control in standing crop fields too. From November, salinity builds up and prawn/crab cultivation was practised. Prawn seeds (*Penaeus monodon*) were stocked in the field @ 30,000 per ha along with small crab seeds. They subsisted on the organic matter from decayed stubbles and drying water weeds. The harvest was after 100 days of culture, and the recorded yield was 300 kg ha^{-1} and 250 kg ha^{-1} for prawn and crab, respectively. Along with this, goat farming (12 goats) supported the farmer by providing a steady income. The study revealed that multilevel integrated farming model is suitable for acid saline soils of *Pokkali* lands with paddy–prawn–crab in lowlands and other crops in the uplands with duck and goat farming with a benefit–cost ratio of 2.06.

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Keywords Integrated farming · Pokkali · Rice · Prawn · Duck · Goat · Soil properties

25.1 Introduction

Wetlands were often referred as the ‘kidneys’ of the earth, which support a wide array of flora and fauna and deliver many ecological, climatic and social functions. Kerala is endowed with largest proportion of land area under wetlands (one-fifth of total land area) in comparison with other states of India. Kerala with its long coastal line of about 580 km has sixteen lagoons or backwaters covering an area of 650 km^2 linked to the sea. Most of the coastal lands are deltaic areas at river mouths or reclaimed backwaters which are situated either at sea level or 1.0–1.5 m below mean sea level. This leads to intrusion of sea water up to a distance of 10–20 km upstream during high tides.

The coastal zone of Kerala is characterized by a unique system of paddy cultivation, locally known as *Pokkali* cultivation. It is an age-old, eco-friendly, traditional and naturally organic method of paddy cultivation followed in the coastal regions of Ernakulam, Alappuzha and Thrissur districts bordering the Arabian Sea extending a total area of 5500 ha and being cultivated for the past 900 years. The *Pokkali* fields are cultivated once in a year during the low saline phase/monsoon season (June to October) followed by prawn farming during the high saline phase (November to April). *Pokkali* is the most saline-tolerant rice variety of the world and the donor of *Saltol* gene for the international saline-tolerant rice breeding programme. It is a variety blessed with tolerance to three abiotic stresses, *viz.* salinity, submergence and acidity. In view of the uniqueness of the farming practices, *Pokkali* farmers have received Geographical Indication Certificate in 2009 and the central government’s Plant Genome Saviour Community Award in 2011.

Rise in farm production is the most efficient way of alleviating poverty, protecting environment and bringing about socio-economic transformation in rural areas to sustain livelihoods. Diversified agriculture including rice cultivation in combination with livestock, poultry farming and aquaculture has been recognized as a revolutionary concept to increase production. The *Pokkali* rice–shrimp sequential farming is a classic example of sustainable agri-aqua integration providing a means of rural livelihood. By integrating shrimp with rice, pond sediments were used to fertilize rice crops that results in reducing the use of chemical fertilizers in rice production, whereas rice crop stubbles act as feed for shrimps. It is a smart practice to enhance resilience of aquaculture communities to climate change especially sea-level rise that results in severe salinity intrusion and also improve the efficiency of land use.

This integrated, intensive and eco-friendly farming alternative increases production and profitability. Such a regenerative farming strategy that blends different farming practices through biological diversification and nutrient recycling is most relevant to the wetlands of Kerala, where escalation in cost of production and environmental degradation have become a matter of major concern. In this context, the

Rice Research Station, Vyttila, came up with a study on multilevel integrated farming system in *Pokkali* fields with rice–prawn–crab–duck–goat farming. The study aims at an in-depth analysis of integrated farming for maximizing the productivity and to compare the performance with the existing traditional farming systems.

25.2 Materials and Methods

25.2.1 Location and Season of Study

The experiment was conducted in the Thathapilly, Padasekharam (10°12′ N latitude and 76°26′ E longitude) of Kottuvally panchayath in Ernakulam district of Kerala. For the study, rice crop was raised from June to October 2017, followed by prawn/crab farming from December 2017 to April 2018.

25.2.2 Rice Cultivation

The land preparation for rice cultivation was started by the month of April. Bunds were strengthened, and sluices were repaired for regulating water level. Fields were then drained during low tides and allowed to dry. Mounds were prepared along the field, which facilitated washing down of salts during rains. By 4 May 2017 with the onset of monsoon, sprouted seeds were sown at the rate of 100 kg per hectare on the mounds and the mounds were dismantled after 30 days of sowing. The seedlings were the transplanted in the field uniformly with a spacing of 20 × 15 cm. Being inherently fertile, chemical fertilizers or pesticides are not used in *Pokkali* lands making it unique from other farming systems. The crop was harvested on 19 October 2017.

25.2.3 Prawn/Crab Culture

The field was prepared by strengthening bunds and sluices, removing floating weeds and vegetation and fixing net in order to prevent the entry of non-insect pest. Stocking of tiger prawn (*Penaeus monodon*) seeds was carried out on 28 December 2017, in the same field after two months of rice harvest. Prawn seeds @ 30,000 ha^{-1} were released along with small crab seeds. For first month, feeding was done with company feed named 'Higashi'. Thereafter, they were fed with 1 kg of wheat, twice in a day. Mud crabs were provided with sardine fish as feed from two months before harvest. Prawns and crabs were harvested after 100 days of culture by pumping out the water from entire field and by using cast netting and ring nets, respectively. The total catch is composed of tiger prawns, other species of prawns, crabs, pearl spot and many other fishes.

25.2.4 Duck and Goat Farming

The study involved integration of ducks (35 no.) and goats (12 no.) along with *Pokkali* rice cultivation. Normally, ducks were released after the harvest of paddy cultivation in *Pokkali* fields. Remaining paddy waste contributes the feed for them. Ducks were also released in the standing crop fields, so that the pest population can be controlled. Goat farming supports farmers by providing a steady income. Fodders and other local feeds like jack leaves were available in plenty and free of cost.

25.2.5 Collection of Soil Samples

Soil samples were collected from field during three stages. First set was collected in June 2017 (before the rice cultivation) from a depth of 0–15 cm. The next two soil samplings were carried out in October 2017, at the time of rice harvest, and in April 2018, at the time of prawn/crab harvest, respectively.

25.2.6 Chemical Characterization of Soil Samples

The chemical parameters like pH, electrical conductivity, organic carbon (OC), available phosphorous (P), potassium (K), calcium (Ca), magnesium (Mg), sulphur (S), iron (Fe), manganese (Mn), zinc (Zn), copper (Cu), boron (B) and sodium (Na) were determined for the collected soil samples. Soil pH and electrical conductivity (EC) were measured in 1:2.5 soil water suspension, using pH meter and conductivity meter, respectively (Jackson 1958). Organic carbon of the soil was estimated by wet digestion method (Walkley and Black 1934). Available P in the soil samples was extracted using Bray No. 1 reagent (Bray and Kurtz 1945) and determined colorimetrically using spectrophotometer by reduced ascorbic acid blue colour method (Watanabe and Olsen 1965). Available K, Ca, Mg and exchangeable Na in the soil samples were extracted using neutral normal ammonium acetate and were estimated by flame photometer and atomic absorption spectrophotometer (Jackson 1958). Available S in soil samples was extracted using 0.15% $CaCl_2$ solution and estimated using spectrophotometer through turbidimetry (Tabatabai 1982). Available micronutrients in soil samples were extracted with 0.1 M HCl in 1:10 ratio, and the contents in filtrate were analysed using atomic absorption spectrophotometer (Sims and Johnson 1991). Available B in soil samples was estimated with hot water soluble method, followed by the colorimetric estimation using azomethine-H in spectrophotometer (Watson 1988).

25.3 Results and Discussion

25.3.1 Soil Characterization Before Rice Cultivation

A detailed account of different soil chemical parameters before rice cultivation is depicted in Table 25.1. Before the rice cultivation, the pH of the soil was 6.74 which comes under neutral range. Initial soil sampling was done in June, and occurrence of heavy rain created changes in soil acidity due to leaching effects. According to Sreelatha and Joseph (2019), soil pH in different *Pokkali* land use systems ranged from 5.69 to 7.26. Electrical conductivity of soil was 1.51 dS m^{-1}, and the OC content was 2.16%. Salinity of *Pokkali* lands is influenced by periodic sea water inundations, and *Pokkali* lands do not have any protection from direct entry of saline water. Heavy rain dilutes the salts, and water present in fields becomes non-saline.

Among major nutrients, available P and K contents were high and recorded the values as 71.32 kg ha^{-1} and 281.11 kg ha^{-1}, respectively. Sasidharan (2004) also observed the same and stated that it was due to tidal influence. Regarding secondary nutrients, available Ca content in the soil was recorded as low (218.61 mg kg^{-1}), as observed by Diya and Sreelatha (2018). The available Mg content was found to be 10.69 mg kg^{-1} in the soil and was below the sufficiency level. Available S content

Table 25.1 Initial chemical characterization of the experimental soil

Soil properties	Unit	Initial	Remarks
pH		6.74	Neutral
EC	dSm^{-1}	1.51	Non-saline
Organic carbon	%	2.16	High
Available P	kg ha^{-1}	71.32	
Available K		281.11	
Available Ca	mg kg^{-1}	218.61	Deficient
Available Mg		10.69	
Available S		232.21	Sufficient
Available Fe		122.48	
Available Mn		5.66	
Available Zn		12.76	
Available Cu		0.19	Deficient
Available B		0.60	Sufficient
Available Na		164.28	High

was high and recorded a value, 232.21 mg kg^{-1}, and was in accordance with studies of Santhosh (2013).

With respect to micronutrients, available Fe, Mn, Zn and B were recorded above sufficiency level and the values were 122.48 mg kg^{-1}, 5.66 mg kg^{-1}, 12.76 mg kg^{-1} and 0.60 mg kg^{-1}, respectively. On contrast, available Cu content was found to be deficient (0.19 mg kg^{-1}). The exchangeable Na content in the soil was 164.28 mg kg^{-1}. Mohan and Sreelatha (2016) found that availability of Fe and Mn was high in *Pokkali* soils, even to the range of toxicity and reported significant variations in exchangeable Na content. Direct marine influences along with high organic matter content contributed to high content of available boron in organically complexed form in *Pokkali* tracts. Chelation of Cu by organic colloids resulted in unavailability of Cu (Santhosh 2013).

25.3.2 Soil Characterization After Rice and Prawn/Crab Cultivation

Soil chemical properties after rice and prawn/crab cultivation are given in Table 25.2. Soil pH was neutral before the rice cultivation. It changed to very strongly acidic range after rice harvest (4.14) and moderately acidic range after prawn harvest (5.94). Presence of heavy rain caused changes in soil acidity due to its leaching effects. Wide variations were observed in case of EC. Soil was non-saline before and after rice cultivation, but became slightly saline after prawn harvest (8.15 dS m^{-1}). This

Table 25.2 Changes in soil chemical properties after rice and prawn/crab cultivation

Soil properties	Unit	After rice cultivation	After prawn/crab cultivation
pH		4.14	5.94
EC	dS m^{-1}	1.60	8.15
Organic carbon	%	2.32	2.37
Available P	kg ha^{-1}	61.02	82.75
Available K		375.61	988.90
Available Ca	mg kg^{-1}	169.99	401.70
Available Mg		14.15	22.98
Available S		1156.00	1594.00
Available Fe		306.50	582.95
Available Mn		4.19	11.15
Available Zn		8.27	20.41
Available Cu		1.07	0.31
Available B		0.91	1.13
Available Na		95.15	201.65

specifies the importance of low and high saline phases in *Pokkali* cultivation. Tidal action has significant effect on soil EC (Sasidharan 2004). No significant change was observed in OC content after rice and prawn cultivation.

With respect to major nutrients, available P content was high before and after (61.02 kg ha^{-1}) rice cultivation and increased to a value of 82.72 kg ha^{-1} even after prawn cultivation. An increment in available K content was observed after rice and prawn cultivation and rated as high. In *Pokkali* soil, available K content varied between 13 and 1777 kg ha^{-1} (Sreelatha and Shylaraj 2017). High content of available K in paddy–shrimp land use system among different *Pokkali* land use systems was noticed by Sreelatha and Joseph (2019).

Available Ca status fluctuated from sufficient to deficient (169.99 mg kg^{-1}) level after rice harvest, but got doubled after harvest of prawn (401.70 mg kg^{-1}). This may be due to deposition of Ca-rich exuvia of prawns and crabs (Tacon, 1987). In *Pokkali* lands, Ca is found in water soluble form and organic complexed Ca, so that its availability got directly influenced by tidal action and organic matter content. It was also found that chelation of Ca by organic colloids in soils with organic matter (Bhindu 2017). Available Mg content was found to be low after rice and prawn harvest. It might be due to high solubility of Mg minerals in soils with pH below 7.5 (Lindsay 1979). Sulphur content was extremely high after rice as well as prawn harvest. Yoshida (1981) found that organic acids and sulphides cause S toxicity in lowland rice. Santhosh (2013) also reported high S content in *Pokkali* lands due to acid sulphate nature.

Regarding micronutrients, an increment was noticed in case of available Fe, Mn, Zn and B after prawn/crab harvest and remained in high status. The result was comparable with the studies of Mohan and Sreelatha (2016), and Sreelatha and Joseph (2019). Available Cu showed high value at rice harvest stage and got reduced at the time of prawn harvest. This might be due to chelation of Cu by organic colloids. Available Na content in soil fluctuated and remained high. Bhindhu (2017) stated that periodic inundation of marine water rich in Na^+ and Al^{3+} cations greatly influence *Pokkali* lands.

25.3.3 Rice and Prawn Yield

The rice harvest was carried out in the third week of October. Only panicles were harvested at a height of 30 to 35 cm from the top, and the remaining plant part is left in the water column. Harvested bundles of panicles were brought to the bund using small boat by the farmer. The rice registered a yield of 2 t ha^{-1}. Prawns were of medium growth and attained a final size of 15–18 cm in 100 days of culture. Crabs were also harvested along with prawns. Total catch was composed of tiger prawns, other prawn species, crabs, pearl spot (*Etroplus suratensis*) and many other fishes. They were harvested by pumping out the water from entire field. Prawns were harvested by cast netting and hand picking and crabs by using ring nets. The prawn and crab yield was 300 kg ha^{-1} and 250 kg ha^{-1}, respectively.

25.3.4 Returns from Duck and Goat Farming

Farming system involved integration of poultry and goat along with *Pokkali* cultivation. This supports farmers by providing a steady income. Returns from duck farming were sale of eggs and ducks for meat purpose. For one-year period of study, about 3000 eggs and 35 ducks were sold, which was highly profitable for the farmer. Along with this, sale of goat milk, kids and manures from the goat farming provided an additional return. About twenty kids were sold at Rs. 2500/- per kid.

25.3.5 Benefit–Cost Ratio of Multilevel Integrated Farming System

The results of the present study suggest that growing rice, prawn + crab, goat and duck together is a potentially better alternative which can yield significantly higher production compared to the traditional *Pokkali* farming alone. Analysis of benefit–cost ratio approved the same. Cost and returns from rice cultivation, prawn/crab cultivation, duck and goat farming are given individually in Tables 25.3, 25.4, 25.5 and 25.6, respectively. The BC ratio obtained for this multilevel integrated farming system was 2.06 (Table 25.7). This is mainly because of the fact that the leftovers of prawn/crab cultivation become manure for rice cultivation and stubbles of rice cultivation become feed for both duck and prawn. This reduces external means of fertilizers, thus found to be cost effective.

Table 25.3 Costs and benefits of rice cultivation

S. No.	Components	Charges (Rs.)
Cost of cultivation of rice per ha		
1	Seed cost	6500
2	Land preparation and sowing	18,000
3	Weeding (8 women)	4000
4	Transplanting (19 women)	12,000
5	Harvesting (17 women + 4 men)	8750
6	Threshing (3 women + 3 men)	2800
7	Drying (2 men + 2 women)	3000
Total		55,050
Returns		
Yield 2.00 t ha^{-1} @ Rs 60 kg^{-1}		1,20,000

Table 25.4 Costs and benefits of prawn/crab cultivation

S. No.	Components	Charges (Rs.)
Costs		
1	Field preparation, sluice maintenance, fixing nets	10,000
2	Prawn seedlings	40,000
3	Prawn feed	20,000
4	Crab seedlings	1,00,000
	Crab feed	15,000
5	Harvest (labour charge, pump set, etc.)	20,000
	Total	2,05,000
Returns		
1	Prawn yield 300 kg ha^{-1} @ Rs 600 kg^{-1}	1,80,000
2	Crab yield 250 kg ha^{-1} @ Rs 1000 kg^{-1}	2,50,000
	Total	4,30,000

Table 25.5 Costs and benefits of duck farming

S. No.	Components	Charges (Rs.)
Costs		
1	Ducks (35 nos.)	10,500
2	Feed	2500
	Total	13,000
Returns		
1	Eggs (Rs. 10 egg^{-1})	30,000
2	Ducks (Rs. 300 kg^{-1})	10,500
	Total	40,500

Table 25.6 Costs and benefits of goat farming

S. No.	Components	Charges (Rs.)
Costs		
1	Goat (12 nos.)	48,000
2	Construction of shed	8000
3	Feed	2000
	Total	58,000
Returns		
1	Goat milk	36,720
2	Sale of kids (2500 kid^{-1})	50,000
3	Sale of manure (300 g day^{-1} for 1 year @ 5 kg^{-1})	6570
	Total	93,290

Table 25.7 BC ratio of multilevel integrated farming system

Gross expenditure	Rs. 3,31,050
Gross returns	Rs. 6,83,790
BC ratio	2.06

25.4 Conclusions

The overall result in this study indicated that integrated rice–prawn–crab–goat–duck system in *Pokkali* fields is a good example for a sustainable model of development, which has the potential to regain the glory of *Pokkali* fields. Integration of aquaculture with rice farming is the safest strategy for sustaining rice production, increasing profit and maintaining ecological balance of the region. This system is completely organic and environment-friendly as no external elements were used for cultivation. In addition, integrated farming is found to enhance the nutrient status of the soil. It is a smart practice to enhance resilience of aquaculture communities to climate change and also improve the efficiency of land use.

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References

Bhindu PS (2017) Chemistry and transformations of calcium and magnesium in tropical acid soils of Kerala. M.Sc.(Ag) thesis, Kerala Agricultural University, Trissur

Bray RH, Kurtz LT (1945) Determining total, organic and available forms of phosphate in soils. Soil Sci 59:39–45

Diya PV, Sreelatha AK (2018) Effect of calcium salts application on soil properties of *Pokkali* soils. J Tropic Agric 56(2):183–186

Jackson ML (1958) Soil chemical analysis. Prentice Hall of India Private Ltd., New Delhi, p 498

Lindsay WL (1979) Chemical equilibria in soils. Wiley-Interscience, New York, p 449

Mohan A, Sreelatha AK (2016) Nutrient dynamics in Pokkali soils. Int J Appl Pure Sci Agric 2(9):119–123

Santhosh C (2013) Chemistry and transformation of boron soils of Kerala. PhD thesis, Kerala Agricultural University, Trissur

Sasidharan NK (2004) Enhancing the productivity of the rice-fish/prawn farming system in *Pokkali* lands. Ph.D. thesis, Kerala Agricultural University, Trissur

Sims JR, Johnson GV (1991) Micronutrient soil tests. In: Mortvedt JJ (ed) Micronutrients in agriculture, 2nd edn. SSSA Book series 4, USA, p 427–476

Sreelatha AK, Joseph C (2019) Soil quality assessment under different land uses in Pokkali lands of Kerala. J Indian Soc Coastal Agric Res 37(1):1–6

Sreelatha AK, Shylaraj KS (2017) *Pokkali* rice cultivation in India: a technique for multi-stress management. In: Gupta SK, Goyal MR (eds) Soil salinity management in agriculture: technological advances and applications. Apple Academic Press Inc., Waretown, NJ, pp 317–335

Tabatabai MA (1982) Sulphur. In: Page AL, Miller RH, Keene DR (eds) Methods of soil analysis part 2. Chemical and microbiological properties, 2nd edn. American Society of Agronomy and Soil Science Society of America, Madison, USA, pp 501–534

Tacon AGJ (1987) The nutrition and feeding of farmed fish and shrimp—a training manual. Food and Agriculture Organization of the United Nations, Rome. http://www.fao.org/docrep/field/003/ab470e/AB470E00.html.TOC. Accessed 16 Dec 2016

Walkley AJ, Black IA (1934) Estimation of soil organic carbon by chromic acid titration method. Soil Sci 31:29–38

Watanabe FS, Olsen SR (1965) Test of ascorbic acid method for determining phosphorous in water and sodium bicarbonate extracts from soil. Soil Sci Soc Am Proc 29:39–45

Watson ME (1988) Recommended soil boron test. In: Dahnke WC (ed) Recommended chemical soil test procedures for North Central Region. North Dakota Agric Expt Stn Bull No. 499

Yoshida S (1981) Fundamentals of rice crop science. International Rice Research Institute, Los Banos, Philippines, p 267

Chapter 26
Sustainable Nutritional and Income Security Through Integrated Farming in the Coastal Saline *Pokkali* Ecosystem of Kerala

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Abstract *Pokkali* system of cultivation, unique in the world, produces naturally organic rice in the coastal saline soils of Kerala. Rice-fish/prawn is the traditional system followed in this system. Over a decade, less attention is given to rice cultivation making the system less sustainable and leaving many fields barren. Ensuring more income per unit area from *Pokkali* fields is the only way to attract farmers back to *Pokkali* cultivation and to bring back the glory of the traditional farming system. To develop and demonstrate profitable new enterprises in the *Pokkali* ecosystem, a project was taken up including various integrating components. Different farming systems compared were rice alone (low saline phase), rice-fish rotational system and rice-fish + poultry system. A new model-floating duck cage (2 numbers) that can carry 50 ducks each was developed and installed over a field of one acre (0.4 ha), the average size holding of a marginal farmer. Duck droppings favoured the fish culture of Tilapia (*Oreochromis niloticus*) and the average size of fish increased by 476.5 g without any external feed. Production of eggs and meat by poultry increased farm income and contributed to the nutritional security of the neighbourhood. Duck released to paddy fields after harvest of rice reduced duck feed to a great extent (5 kg day^{-1} for 100 ducks). Increasing the income from rice fields by year-round utilization of the farm land by judiciously mixing fish + poultry with rice reduced the negative trend in the rice production front. The study proved that duck rearing is a viable component for integration in the rice-fish *Pokkali* ecosystem. Besides, rice-fish + duck farming system formed an important strategy for climate moderation by an additional transfer of C (average load of 3 kg organic matter per day by100 ducks) to the soil and enhancing other ecosystem services.

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26.1 Introduction

Pokkali is a peculiar and sustainable 'rice farming' system in the coastal saline soils of Kerala. *Pokkali* rice is the naturally produced organic rice of Kerala having a high amount of antioxidants and a low glycemic index. *Pokkali* ecosystem has two phases, one a low saline phase (June–October) during which salinity is partially washed out and salinity tolerant rice is cultivated and secondly, a high saline phase (November to May) during which prawns and other brackish water fishes are grown. *Pokkali* system is unique in the world and has received geographic indication certificate for *Pokkali* brand and Plant Genome Saviour Community Award. *Pokkali*, the most saline tolerant rice variety of the world has proved its dominance as an international donor of *Saltol* QTL as recognized by the International Rice Research Institute, Manila, Philippines. *Pokkali* rice varieties are blessed with tolerance to three abiotic stresses viz., salinity, submergence and acidity all in one variety (KAU 2013).

Fish culture forms an integral part of *Pokkali* cultivation. The live feed generation by the disintegrating paddy stubbles intentionally left during the harvest of rice forms the basis of bio-energic resources for the alternative production of rice and prawn in these wetlands. With the cessation of the monsoon, the seawater inundates the *Pokkali* fields resulting in a gradual change in the salinity of the water. The brackish water will also carry the shrimp seeds and other fingerlings of brackish water fishes into the *Pokkali* fields, which forms the base for sequential culture (Sasidharan and Padmakumar 2012). But now, less attention is given to rice cultivation and this makes the system less sustainable. *Pokkali* farming which was acclaimed as a sustainable model has turned into a loss-making venture due to the widespread incidence of white spot disease (WSD) on shrimps for many years. Labour shortage, high wages, lack of proper machinery and lack of branding of *Pokkali* products aggravated the crisis. Most of the *Pokkali* fields that produced lots of organic paddy and shrimp in the past are left barren now. Ensuring more income per unit area from *Pokkali* fields is the only way to attract farmers back to *Pokkali* cultivation and to bring back the glory of the traditional farming system.

Increasing the income from rice fields by year-round utilization of the farmland by a judicious mix of one or more compatible enterprises with rice can halt the negative trend in the rice production front. Livestock, fishery and duckery are some of the enterprises that are compatible with rice in increasing farm income. Besides integrated farming systems (IFS), which can maintain and enhance both carbon storage and other ecosystem services, are an important strategy for climate moderation.

26.2 Materials and Method

26.2.1 Location

With an aim to develop and demonstrate sustainable and profitable new enterprises in the Pokkali ecosystem, a project was taken up during 2018–19 and 2019–20 at Rice Research Station, Vyttila, the only salinity research centre of Kerala Agricultural University. Rice Research Station, Vyttila, is situated in a representative site in the middle of the *Pokkali* tract of Kerala state, India. It is the only institute that investigates the various aspects of the rice-based farming system of the salinity prone coastal tracts in Kerala. The study site is located at 9°58′ N latitude, 76°15′ E longitude and an altitude of 1.2 m above mean sea level.

26.2.2 Soil Properties

Pokkali soils comprise low lying marshes and swamps situated near the mouths of streams and rivers not far from the sea. They are rich in organic matter with tidal ingression playing a major role in maintaining the nutrient status of the soil. These soils are inherently acidic with an average pH range of 3.0–5.5 and become acid saline due to seawater ingression. They have a clay loam texture. The high salinity in the soil resulting from tidal actions of the sea distinguishes *Pokkali* soils from other soil types of Kerala. Water-soluble salts like sulphates and chlorides of sodium and manganese are present in high proportion. In dry conditions, white incrustations of aluminium hydroxide also develop on the soil surface. The electrical conductivity (EC) of soils during the high saline phase (November–May) varies from 12 to 24 dS m^{-1} and average salt content reaches up to 20 mg kg^{-1}. During the low saline phase (June–October) water becomes almost fresh, salt content reduces to traces and later, EC ranges between 6 and 8 dS m^{-1}. The physicochemical characteristics of soil in the experimental site are detailed in Table 26.1.

26.2.3 Climate and Season

The region experiences a warm humid climate. The mean annual rainfall of the area was 2900 mm, the major part of which was received during the South-west monsoon. The mean evaporation rate during the cropping season was 2.7 mm day^{-1}. The maximum day temperature varied from 27 to 34 °C and minimum temperature from 21 to 27 °C. The relative humidity was very high, exceeding 90% during the cropping season. Heavy rains occurring continuously for 10–15 days result in flash flooding during the monsoon season.

Table 26.1 Initial physicochemical properties of the experimental soil

Particulars	Content	Method used
Coarse sand (%)	4.67	Robinson international pipette method (Piper 1966)
Fine sand (%)	21.76	
Silt (%)	19.63	
Clay (%)	50.76	
pH	4.22	Soil water suspension 1:2.5 and read in a pH meter (Jackson 1967)
EC	0.96	Soil water suspension 1:2.5 read in a conductivity meter and (Jackson 1967)
Organic carbon (%)	2.33	Wet digestion method (Walkley and Black 1934)
Available N (kg ha^{-1})	353.3	Alkaline permanganate method (Subbiah and Asija 1956)
Available P (kg ha^{-1})	26.5	Bray-I extractant ascorbic acid reductant method (Watanabe and Olsen 1965)
Available K (kg ha^{-1})	368.8	Neutral normal ammonium acetate extractant, flame photometry (Jackson 1967)
Available Ca (mg kg^{-1})	263.0	Neutral normal ammonium acetate extractant, flame photometry (Jackson 1967)
Available Mg (mg kg^{-1})	44.0	Neutral normal ammonium acetate extract method with atomic absorption spectrophotometer (Jackson 1967)
Available S (mg kg^{-1})	38.5	Extraction using 0.15% $CaCl_2$ solution and estimated using spectrophotometer (Tabatabai 1982)

For the study, rice crop was raised from June to October 2018 and 2019, followed by fish and fish + duck farming from November to April 2018–19 and 2019–20, respectively.

26.2.4 Establishment of Different Farming Systems

Different farming systems compared for sustainability under *Pokkali* ecosystem were.

- Rice alone (low saline phase)
- Rice- fish/prawn rotational system
- Rice-fish + poultry.

26.2.4.1 Rice Alone System

Special cultivation practices were adopted in *Pokkali* ecosystem to tolerate three abiotic stresses viz., acidity, salinity and submergence. Land preparation was started in April before the onset of the monsoon. Bunds were strengthened, channels were made all around the plot, and sluices were repaired for regulating the water level in the field. Water in the field was drained during low tide, and shutters were placed preventing further entry of water. Mounds of 1 m^2 base and 0.5 m height were made to facilitate the washing down of salts during rains. With the onset of monsoon, dissolved salts from the surface of mounds were flushed out from the field. Mounds act as an elevated in-situ nursery that protects the rice seedlings from flash floods. Pre-germinated seeds of high yielding rice variety Vyttila-8 were broadcasted on these mounds and were then plastered with soil to prevent predation by birds. Mounds were dismantled 21 days after sowing, and seedlings were uniformly planted in the field at a spacing of 20 × 15 cm. Management of the water level was the major operation done after transplanting. Since the organic matter content was high, no additional nutrients were supplemented to the soil. Harvesting was done in October by cutting the panicles alone leaving the stubbles behind to form fish feed. Observations on growth, yield and yield parameters were recorded following standard procedures.

26.2.4.2 Rice-Fish Rotational System

In rice-fish system, rice crop was grown as in the case of rice alone system. After rice, during November, the bunds were strengthened, weeds were removed and channels were deepened all around the field and diagonally across the field, to a depth of 1 m. Fish *Oreochromis niloticus* (Tilapia) was stocked at a density of 7500 nos ha^{-1}. Artificial feeding was provided partially to maintain the growth of fish. Growth of fish was observed at different intervals and depending upon the weight of fish, the quantity of feed was determined. Fish was harvested in April. Length and weight of the fish were recorded and Fulton's condition factor (K) for fish was calculated as per formula (Froese 2006) given below:

$$K = \frac{W}{L^3} \times 100$$

where W = weight of fish (g), L = Length of fish (cm).

26.2.4.3 Rice-Fish + Poultry System

In the rice-fish + poultry system also, tilapia was introduced first during the high saline phase as in the case of rice-fish system. When fish seed attained a reasonable size (not to be consumed by ducks), ducks were introduced at the rate of 250 ducks ha^{-1} (100 ducks in 0.4 ha). Since the construction of duck cages over ponds and fields was very expensive, a new model of floating duck cage that can carry 50 ducks was developed with the dimensions of 4 m × 2 m × 1.3 m (Fig. 26.1). Four sides were covered using GI weld mesh. The floor was given by plastic slat of size 60 cm × 60 cm, and roofing was provided with roofing sheets. The float was made using

Fig. 26.1 Floating duck cage

Table 26.2 Nutrient content of duck feed (broken rice and pellets)

Parameters	Feed (broken rice)	Pellet feed
Total N (%)	1.42	2.71
P (%)	0.31	0.69
K (%)	0.16	0.27
Ca (%)	0.10	2.34
Mg (%)	0.12	0.43
S (%)	0.03	0.14

4 drums of 200 L capacity. Two cages were used in one acre (0.4 ha). Layer ducks were released to the field during the daytime. Feed was provided twice a day as broken rice and as pellets depending upon the growth stage of the duck. The average nutrient content of the feed (broken rice and pellets) is given in Table 26.2. Every month, total droppings in a day were collected, dried and analyzed for nutrient status as per FAO (2000).

26.2.5 Economic Analysis

Gross returns from rice and subsidiary components in terms of grain yield, duck eggs and fish weight were recorded. Being naturally organic, *Pokkali* rice fetched a higher price in the market (65 kg^{-1}). Tilapia was marketed @ Rs 160 kg^{-1} and duck egg @ Rs. 10. The cost of cultivation of rice and subsidiary components based on the

Table 26.3 Growth and yield parameters of rice in different farming systems during 2019

Treatment	Plant height (cm)	No. of tillers m^{-2}	No. of panicles m^{-2}	Filled grains per panicle (No.)	Grain yield (t ha^{-1})
Rice alone	113	442	351	113	3.52
Rice-fish + duck	117	454	378	112	3.77
Rice-fish + duck	115	455	388	123	4.14
CD (0.05)	3.08	11.2	18.35	5.48	0.212

cost of inputs purchased was calculated based on prevailing labour charges and the market price of different inputs. The benefit–cost ratio was worked out by dividing the gross return by total expenditure per hectare.

26.3 Results and Discussion

26.3.1 Growth and Yield of Rice

The growth and yield of rice in all the three farming systems followed a uniform pattern in 2018, as there was no treatment difference in soil and crop production conditions, resulting in an average yield of 3.08 t ha^{-1}. In the second year (2019), a significant increase in crop yield due to the addition of the fish /fish + duck system was observed (Table 26.3). Rice followed by fish and duck registered a yield increase of 17.4% over the rice alone system. The addition of duck and fish droppings and food waste of poultry improved the organic matter status of the soil, part of which provided the feed for fish. Part of the dissolved carbon was lost as water in the field ingressed and egressed regularly at the desired level during high and low tides respectively. However, the continuous addition of droppings and feed remnants having high N, Ca and Mg (Table 26.4) and the tidal ingression could improve the nutrient status of the soil, favouring yield improvement in the succeeding year.

26.3.2 Growth of Fish

Rice-fish system improved the biological potential of rice fields since the stubbles left after harvest decomposed and provided shelter and feed for the growth and development of live feed, which formed ideal food for fish (Sasidharan and Padmakumar 2012). However, the present study proved that duck rearing is a viable component for integration in the rice-fish *Pokkali* ecosystem. Average loading of 3 kg organic

Table 26.4 Composition of duck manure and its mean loading rate by100 ducks

Proximate composition of manure	Partial feeding with broken rice and pellet
Mean loading rate	3–4 kg dry wt day^{-1}
Nitrogen	1.75–3.88%
Phosphorus	0.77–0.98%
Potassium	0.38–0.93%
Calcium	3.2–3.66%
Magnesium	0.51–0.63%
Sulphur	0.15–0.21%

Table 26.5 Effect of fish-duck integration on the growth of fish

Treatments	2018–19			2019–20		
	Average length (cm)	Average weight (g)	Condition factor (K)	Average length (cm)	Average weight (g)	Condition factor (K)
Fish alone	31	693	2.3	30.6	716	2.49
Fish + duck	35.3	1106	2.5	37.6	1256	2.78

matter day^{-1} by 100 ducks to the pond/field favoured fish culture. It was observed that the bodyweight of Tilapia in the integrated farming system increased by 476.5 g on an average for two years without any additional feed when compared to the body weight of fish not integrated with duck (Table 26.5). It was also observed that by integrating duck and fish in floating duck cages, wastes resulting from livestock feeding (i.e. uneaten feed residues) were directly consumed by the cultured fish reducing the operating costs of fish production. The nutritional value of the manure and feed remnants was preserved because losses of nitrogen and energy due to natural wastage, fermentation, evaporation and non-reversible coagulation were eliminated (FAO 1988).

The condition factor (*K*) of a fish reflected physical and biological circumstances and fluctuations by interaction amongst feeding conditions, parasitic infections and physiological factors (Le Cren 1951). This also indicated the changes in food reserves and therefore was considered as an indicator of the general fish condition. Moreover, body condition provided an alternative to the expensive in vitro proximate analyzes of tissues (Sutton et al. 2000). Therefore, information on condition factors was vital to culture system management because they provided the producer with information on the specific condition under which organisms are developing (Araneda et al. 2008). The average values of condition factor '*K*' recorded in the present study from monoculture and IFS fields were 2.4 and 2.6, respectively. Higher *K* value denotes a positive correlation with gonadal development, a reliable measure of lipids such as short-chain PUFA, EPA, DHA and negative linkage with body water content contributing to higher fish quality.

Table 26.6 Feed consumption pattern of ducks (100 nos) with and without foraging

	Feed consumption (kg day^{-1})	Cost of feed (Rs. day^{-1})	Egg production (No day^{-1})	Total egg production in 6 months (No)
Without foraging	15	365	56	6,720
With foraging	10	250	74	8,880

26.3.3 Growth and Egg Production of Ducks

Release of ducks to paddy fields (foraging) after harvest of rice reduced duck feed consumption to a great extent (Table 26.6). Straw, unharvested and fallen grains, chaff and other residues of rice crop served as part of the feed for fish and duck. Ducks also fed on the weeds, unwanted small fishes and pests like snails in the field. This reduced the artificial feeding of ducks, but enhanced the growth and favoured higher egg production. Besides, duck feed costs could be saved due to the natural food (i.e. phytoplankton and aquatic plants) developing in the pond/field. Ducks benefitted directly from eating aquatic plants and consequently helped to keep the water surface clean of algal blooms and floating aquatic macrophytes, which has also been reported by Wohlfarth and Schroeder (1979) and Plavnik et al. (1983). Besides, elimination of costs of manure collection, storage and transportation, and consequent improvement in land/water productivity, providing an alternative solution to manure waste disposal on land or at sea and thereby reducing environmental pollution could also be considered as advantages of duck-fish integration (FAO 1988).

26.3.4 Economics

The inclusion of new enterprises in the farming system ensured stability in farm income. Integration of duck reduced the cost of fish feed @ Rs 166 day^{-1} and releasing them to paddy fields reduced the cost of duck feed @ Rs 115 day^{-1} for 100 ducks. This also enhanced employment generation (515 man-days $year^{-1}$) and provided additional income. It further helped in enhancing the benefit-cost (B:C) ratio (Table 26.7) and maintaining soil health as sequencing rice, duck and fish

Table 26.7 Economics of various enterprises in *Pokkali* ecosystem (0.4 ha)

S. No.	Treatments	Cost of cultivation (Rs.)	Returns (Rs.)	B:C ratio
1	Rice alone (6 months)	50,872	91,572	1.80
2	Fish (6 months)	92,410	207,000	2.24
3	Rice-fish (one year)	143,828	304,916	2.12
4	Rice-fish + duck (1 year)	178,948	429,475	2.39

culture over time and space, complimented each other through effective recycling of wastes/residues. A similar study conducted in the wetlands of Tamil Nadu revealed that integration of rice-fish-poultry-pigeon resulted in higher productivity, economic returns and employment opportunities (Jayanthi et al. 2001).

26.3.5 Additional Transfer of Organic Carbon to Soil

Soil organic carbon management is the key to achieving soil resilience to climate change. Therefore, soil-carbon sequestration is an important strategy to cope with climate change. This holds true only if it causes an additional transfer of carbon from the atmosphere to the land. Rice-fish + duck farming system formed a workable solution for climate mitigation by an average addition of 3 kg organic matter day^{-1} having an organic carbon content of 25.7% by 100 ducks acre^{-1} to the soil and enhancing other ecosystem services.

26.4 Conclusions

Integrated fish + duck farming system proved to be more efficient than independent fish or livestock farms in terms of the utilization of primary resources such as feed, water, labour, land and transportation facilities. Sources of possible income to the farmer got diversified, through additional fish, meat or egg sales. The study proved that rearing of 100 ducks is a viable component for integration in the rice-fish *Pokkali* farm of size 0.4 ha, the average size holding of a marginal farmer, providing a B:C ratio of 2.4 to the farmer. Besides, rice-fish + duck farming system formed an important strategy for climate moderation by an additional transfer of C (average load of 3 kg organic matter per day by 100 ducks) to the soil and enhancing other ecosystem services.

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References

Araneda M, Perez EP, Gasca LE (2008) White shrimp *Penaeus vannamei* culture in fresh water at three densities: condition state based on length and weight. Aquaculture 283:13–18

FAO (1988) The nutrition and feeding of farmed fish and shrimp—a training manual 3. Feeding methods. A report prepared for the FAO Trust Fund GCP/RLA/075/ITA project support to the regional aquaculture activities for Latin America and the Caribbean. Food and Agriculture Organization of The United Nations, Brasilia, Brazil

FAO (2000) Simple soil plant and water testing techniques for soil resource management. Document AGL/MISC/2000, Rome, Italy, p 158

Froese R (2006) Cube law, condition factor and weight—length relationships: history, meta-analysis and recommendations. J Appl Ichthyol 22(4):241–253

Jackson ML (1967) Soil chemical analysis. Prentice Hall of India, New Delhi, p 498

Jayanthi C, Rangasamy A, Mythili S et al (2001) Sustainable productivity and profitability to integrated farming systems in low land farms. In: Extended summaries of national symposium on farming systems research in new millennium, ICAR-Indian Institute of Farming Systems Research, Modipuram, Uttar Pradesh, India, 15–17 Oct 2001, pp 79–81

KAU (2013) Five decades of glorious research at rice research station, Vyttila (1958–2013). Directorate of Extension, Kerala Agricultural University, Kerala, India

Le Cren ED (1951) The length-weight relationships and seasonal cycle in gonad weight and condition in the perch (*Perca fluviatilis*). J Anim Ecol 20:201–219

Piper CS (1966) Soil and plant analysis. Hans Publishers, Bombay, India, p 348

Plavnik I, Barash H, Schroeder GL (1983) Utilization of ducks droppings in fish farming. Nutr Rep Int 28(3):635–641

Sasidharan NK, Padmakumar KG (2012) Rice based farming systems in Kerala. In: Proceedings Kerala environmental congress, Centre for Environment and Development, Thirunanathapuram, Kerala, 16–18 Aug 2012

Subbiah BV, Asija GL (1956) A rapid procedure for the estimation of available nitrogen in soils. Curr Sci 25:259–260

Sutton SG, Bult TP, Haedrich RL (2000) Relationships among fat weight, body weight, water weight and condition factors in wild Atlantic salmon parr. Trans Am Fish Soc 129:527–538

Tabatabai MA (1982) Sulphur. In: Page AL, Miller RH, Keene DR (eds) Methods of soil analysis part 2, chemical and microbiological properties, 2nd edn. American Society of Agronomy and Soil Science Society of America, Madison, USA, pp 501–534

Walkley AJ, Black IA (1934) Estimation of soil organic carbon by chromic acid titration method. Soil Sci 31:29–38

Watanabe FS, Olsen SR (1965) Test of an ascorbic acid method for determining phosphorus in water and $NaHCO_3$ extracts from soil. Soil Sci Soc Am J 29(6):677–678

Wohlfarth GW, Schroeder GL (1979) Use of manure in fish farming—a review. Agric Wastes 1:279–299

Chapter 27
Integrated Farming System Model for Sustainable Production, Livelihood Security, Income and Employment Generation to Farmers Under North Konkan Coastal Zone of Maharashtra

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Abstract Food security, employment, income generation, resource conservation and environment protection have emerged as major world concerns. The integrated farming systems (IFSs) are vulnerable to climate change and must adapt to maintain and improve productivity and its stability. IFS is a powerful tool; it holds the key for ensuring income, employment, livelihood and nutritional security in a sustainable mode for small and marginal farmers. IFS approach is a judicious mix of two or more components, while minimizing competition and maximizing complementarities with advance agronomic management tools aimed at sustainable and environment-friendly improvement of farm income and family nutrition. Konkan region of Maharashtra comes under high rainfall zone receiving on an average 3000–3500 mm rainfall in 95–110 rainy days during *kharif* season. Considering the agro-climatic conditions, natural resources, land holding of farmers and farmer's needs of Konkan region, an ideal integrated farming system model for small and marginal farmers has been developed on an area of 1.00 ha for family having 3 males and 3 females (6 persons)

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at Regional Agricultural Research Station, Karjat, Dist. Raigad under All India Co-ordinated Research Project on Integrated Farming Systems. The objectives of this study are to assess the impact of integrated farming system model in respect of employment generation, recycling of farm produce and increasing profit per unit area per unit time and to demonstrate efficient use of available farm resources. The IFS model comprised of different enterprises, viz., crops and cropping systems on an area of 0.50 ha, horticulture component (fruit crops + nursery) 0.40 ha, livestock components namely, dairy, goatery and poultry on area of 35.75 m^2 each (107.25 m^2), vermicompost unit on 18.00 m^2, and rest of the land (874.75 m^2) was used for operational and other purposes. This region is dominated by rice-based cropping systems due to high rainfall. Therefore, the total production of the model was converted in terms of rice equivalent yield (REY). The average of six years data revealed that the total production of 47.09 t REY was obtained from 1.00 ha area. In terms of economic returns, the gross and net returns were Rs. 715,957 and Rs. 210,553, respectively. IFS has created more number of working days in the system due to involvement of more enterprises than cropping systems alone. Six years average employment generation through present IFS model was found to be 1085 man days, and its value was Rs. 204,819 which contributed 40.53% in the total cost of production. This has provided employment opportunity almost throughout the year. The average total cost of production of the IFS model was Rs. 505,404 ha^{-1}, which included outside purchase for Rs. 193,250 ha^{-1} (38.24%), value of recycled material within the system of Rs. 107,336 ha^{-1} (21.24%) and for farm labours costing Rs. 2,04,819 ha^{-1} (40.53%). On an average of six-year study, the benefit: cost ratio was 1.42 by inclusion of different modules in the model. Farmers can increase their net returns by saving the expenditure on farm labours through employment of family labours. The six years compiled data of IFS model showed that as far as the demand of essential foods for a family of 6 members per annum is considered, the annual production in this model was surplus for cereals, oilseeds, milk, fruits and vegetables commodities.

Keywords Employment generation · Integrated farming systems · Rice equivalent yield · Sustainable production · Livelihood security

27.1 Introduction

Today's concerns regarding environmental safety and sustainability of land productivity are increasing among scientists, administrators and environmentalists. Food security, employment, income generation, resource conservation and environment protection have emerged as major world concerns. Due to ever-increasing population and decline in per capita availability of land in the country, practically, there is no scope for horizontal expansion of land for agriculture. Only vertical expansion is possible by integrating farming components requiring lesser space and time and ensuring reasonable returns to farm families (Lal et al. 2018). The integrated farming systems (IFSs) are vulnerable to climate change and must adapt to maintain and improve productivity and its stability. IFS is a powerful tool; it holds the key for ensuring income, employment, livelihood and nutritional security in a sustainable mode for small and marginal farmers. The current scenario in the country indicates that area under cultivation may further dwindle, and more than 20% of current cultivable area will be converted for non-agricultural purposes by 2030 (Gill et al. 2005). The integrated farming systems approach is considered to be the most powerful tool to enhance the profitability of farming systems, especially for small and marginal farmhouse holders. Farming systems integrate natural resources and regulate into farming activities to achieve maximum replacement of off-farm inputs and to secure sustainable production of high-quality food and other products through ecologically preferred technologies and therefore sustain farm income, reduce environment pollution and stabilize multiple function of agriculture.

27.1.1 Integrated Farming System Approach

IFS approach is defined as "a judicious mix of two or more components, while minimizing competition and maximizing complementarities with advance agronomic management tools aimed at sustainable and environment-friendly improvement of farm income and family nutrition" (Singh and Ravisankar 2017). Preservation of bio-diversity, diversification of cropping or farming system and maximum recycling of residues ensure the success of this farming system approach. In general, farming system approach is based on several objectives that include sustainable improvement of farmhouse hold systems involving rural communities, enhanced input efficiency in farm production, satisfy the basic needs of farm families, improve the nutrition and raise family income through optimum use of resources and proper recycling of residue within the system.

The future agricultural system should be reoriented from the single commodity system to food diversification approach for sustaining food production and income. Integrated farming systems, therefore, assume greater importance for sound management of farm resources to enhance farm productivity, which will reduce environmental degradation and improve the quality of life of resource poor farmers and to maintain agricultural sustainability.

27.1.2 Aims of Integrated Farming System

1. Efficient recycling of farm and animal wastes
2. Minimizing the nutritional losses and maximizing the nutrient use efficiency
3. Following efficient cropping systems and crop rotations
4. Complementary combinations of farm enterprises.

27.1.3 Goals of Integrated Farming System

1. Maximization of yield of all modules to provide steady and stable income at higher levels.
2. Rejuvenation/amelioration of system's productivity and sustainability.
3. Satisfy the basic needs, improve nutrition, provide employment opportunity and raise family income
4. Reducing the use of chemical fertilizers and other harmful agro-chemicals by recycling waste material from different modules and through natural cropping system management to provide pollution-free, healthy produce and environment to the society at large (Lal et al. 2018).

27.1.4 About Konkan Region

Konkan region is a western coastal part of the Maharashtra state. The total geographical area of the *Konkan* region is 29.37 lakh ha out of which, 8.20 lakh ha is under cultivation. Agriculture in the *Konkan* region is characterized by the preponderance of extremely small size and scattered land holdings. The present cropping intensity is very low, i.e. 114% only (Pawar et al. 2011). This region comes under high rainfall zone receiving on an average 3000–3500 mm rainfall in 95–110 rainy days during *kharif* season. The soils of South *Konkan* coastal zone are lateritic and North *Konkan* coastal zone are medium black in nature having slightly acidic in reaction and medium to high in organic carbon content. However, low in available nitrogen, medium to moderately high in available phosphorus and moderately high to high in potash. Due to high rainfall, rice is main crop grown during rainy season on part of uplands, midlands and lowlands. On sloppy lands finger millet, proso millet, groundnut, pulses and vegetables are grown, whereas on hillocks and hill side mango, cashew and other rainfed fruit crops are grown. On alluvial well-drained soils, coconut and arecanut are grown under irrigation in which spices are grown as intercrops. After harvest of *kharif* rice, different crops are grown on residual soil moisture with life-saving irrigations and under fully irrigated conditions. The objective of the study was to develop an ideal and profitable model of integrated farming system for marginal and small farmhouse holds of *Konkan* region of Maharashtra state by efficient use of available farm resources and to assess the impact in respect of employment generation, recycling of farm produce and increasing profit per unit area per unit time.

27.2 Materials and Methods

Considering the agro-climatic conditions, natural resources, land holding of farmers and farmer's needs of the region, an ideal integrated farming system model was studied on an area of 1.00 ha at Regional Agricultural Research Station, Karjat, Dist. Raigad under All India Co-ordinated Research Project on Integrated Farming System for six consecutive years from 2013–14 to 2018–19. Geographically, Karjat is situated at 18.92° N latitude, 73.33° E longitude, 52.00 m above mean sea level (MSL). This region comes under coastal hot and humid agro-ecosystem in North Konkan coastal zone (MH-2). The agro-climatic zone is 12 westcoast plains and Ghat zone with average rainfall 3000–3500 mm per year. The climate is characterized hot and humid. The experimental site has even topography with a gentle slope having good drainage. The soil is medium black in nature under *Typic Haplustepts* soil type. The soil texture is clay loam with 75–100 cm depth. The soil pH was 6.5, EC 0.25 dS m^{-1}, organic carbon 1.07% (high), available N 111.50 kg ha^{-1} (very low), available P_2O_5 23.04 kg ha^{-1} (moderately high) and available K_2O 217.28 kg ha^{-1} (moderately high) before start of experiment. The integrated farming systems was started with different modules comprising of 6 different crops and cropping systems on 0.50 ha area, horticulture module consisting fruit crops and nursery on 0.40 ha area, livestock modules comprising of dairy animals 3 cows (2 cross breed Jersey + 1 local breed), goatery 12 number unit (10 female + 2 male) and poultry having 2 to 3 batches per year (150 to 200 birds per batch) each module on 35. 75 m^2 area (total 107.25 m^2), the complimentary enterprises, i.e., vermicomposting on 18 m^2 area and remaining 874.75 m^2 area was utilized for bund and boundary plantation, kitchen gardening, roads, operational areas, etc. Components of 1.00 ha IFS model is given in Table 27.1. All the recommended package of practices were done for each crop in the cropping systems. The daily goat and poultry feeding and routine work in the livestock module was done regularly as per recommended by the university. Data on different aspects of various modules were recorded as per the standard procedures. As there were different enterprises, the production from each enterprise was different in forms. All the production was converted in to rice equivalent yield for easy calculation. The formula of equivalent yield is given by Reddy and Reddy (2003). The study of IFS model was taken by considering the six members of farm family. Before start of experiment, the base line study was conducted for average size of land holding of small and marginal farmers of this region, and it was 1.44 ha and 0.36 ha, respectively. The prevailing major farming system in *Konkan* region consists field crops + horticulture + livestock + composting, comprising an area of 73%, whereas second ranking farming system adopted by farmers is field crops + dairy/draught animals on an area of 18%.

27.3 Results and Discussion

This region is dominated by rice-based cropping systems due to high rainfall. Therefore, the total production of the model from each modules/enterprises was converted in terms of rice grain equivalent yield (REY). The modulewise production in terms of REY and its economic analysis are depicted in the Table 27.2. The average of six years data showed total production of 47.09 t REY obtained from 1.00 ha area. In terms of economic returns, the gross and net returns were Rs. 715,957 and Rs.

Table 27.1 Area and composition of IFS model (Area—1.00 ha)

I. Cropping systems				
Kharif season			Rabi season	
Crop		Area (ha)	Crop	Area (ha)
Rice		0.20	Brinjal	0.10
			Water melon	0.10
Finger millet		0.05	Cowpea	0.05
Ground nut		0.10	Field bean	0.10
Cucumber		0.10	Sweet corn	0.10
Fodder crop-Napier bajra hybrid (perennial)		0.05	Fodder crop-Napier bajra hybrid (perennial)	0.05
Total I		0.50	Total I	0.50
II. Horticulture				
1	Mango	Alphonso, Keshar and Ratna		0.20
2	Aonla	Krishna, Kanchan and Chakayya		0.05
3	Sapota	Kali patti		0.05
4	Coconut + intercrops i. Black pepper ii. Cinnamon iii. Nutmeg	Pratap i. Panniyur-1 ii. Konkan Tej iii. Konkan Sugandha		0.05
5	Nursery Mango grafts Sapota grafts	Ratna, Keshar and Alphonso Kali patti		0.05
	Total II			0.40
III. Livestock				
A	Dairy animals 3 cows	2 crossbred jersey + 1 local		35.75 m^2
B	Goat unit (10 F + 2 M)	Konkan Kanyal		35.75 m^2
C	Poultry 3 to 4 batches/year (150 to 200 birds/batch)	Giriraj and Kadaknath		35.75 m^2
	Total III			107.25 m^2
IV. Complementary enterprise				
	Vermicompost unit	Eiseniafoetida		18.00 m^2
	Total IV			18.00 m^2
V. Land for other uses				
	Stores, threshing yard, operational area, roads, bunds, etc.			874.75 m^2
	Total V			874.75 m^2
	Grand total (I + II + III + IV + V)			1.00 ha

Table 27.2 Production and economic analysis of different components of integrated farming systems (av. of 6 years)

Components	REY (t)	Gross return (Rs.)	Net return (Rs.)	Cost of cultivation (Rs.)	B:C ratio
Cropping systems	11.34	169,375	66,595	102,780	1.65
Horticulture	10.31	160,805	45,429	115,375	1.39
Dairy	8.67	129,312	25,637	103,675	1.25
Poultry	7.97	122,877	41,240	81,636	1.51
Goatary	5.53	84,689	27,047	57,643	1.47
Vermicompost	3.37	48,900	4605	44,295	1.10
Total	47.09	715,957	210,553	505,404	1.42

210,553, respectively, with B:C ratio 1.42. Under crops and cropping systems, rice–brinjal, rice–watermelon, finger millet–cowpea, groundnut–field bean, cucumber–sweet corn and fodder crop (perennial–Napier bajra hybrid) systems were grown on 0.50 ha area. This component produced 11.34 t REY (28.04%) with gross and net returns for Rs. 169,375 (24.98%) and 66,595 (35.52%), respectively. The horticulture component included fruit crops, namely mango, aonla, sapota and coconut grown on area of 0.35 ha apart from nursery (0.05 ha). In nursery, mango and sapota grafts were prepared and sold. The contribution of horticulture component in terms of REY was 10.31 tonnes (21.90% of total production). This component contributed Rs. 160,805 (20.69%) and Rs. 45,429 (17.62%) gross and net monetary returns, respectively. Livestock component comprised dairy, poultry and goatery. Initially in the year 2012–13, two cross-bred Jersey and 1 local cow were purchased. Dairy component contributed 8.67 tonnes REY which was 18.40% of the total REY. Dairy component gave average gross and net returns of Rs. 1,29,312 and Rs. 25,637, respectively. The per cent share of gross and net returns to total was 19.12 and 16.28, respectively. In 2013–14, 2014–15, 2015–16, 2016–17, 2017–18 and 2018–19, one-day-old 190, 330, 471, 500, 600 and 500 number of chicks were purchased and reared. Out of which, 173, 314, 439, 485, 583 and 427 survived birds were sold. The *Giriraj* and *Kadaknath* breeds were reared in the model. *Kadaknath* breed is fetching good prize with minimum cost of production. The monetary returns from poultry were converted into REY. The average production of 7.97 tonnes REY was obtained from poultry component which was 16.92% in total IFS model production. This realized Rs. 122,877 and Rs. 41,240 gross and net returns, respectively. In terms of percentage, it was of 16.09% and 16.96% of total gross and net returns, respectively. At the initiation of model, goat unit of 6 females and 1 male was purchased. Every year, the saleable male and female goats were sold. Average of 6 years showed that the goat unit contributed 5.53 tonnes REY, and its per cent share was 11.75. This component realized Rs. 84,689 (11.82%) gross and Rs. 27,047 (11.53%) net returns. The edible by-produce of crops and cropping systems and main produce of forage crop were fed as a dry and green fodder to dairy animals. Crop residues, livestock manures/droppings and shed

Table 27.3 Total cost of inputs purchased, generated and recycled within the model, expenditure on wages and their per cent share

Year	Total input cost (Rs.) (TIC)	Value of inputs purchased from market (Rs.) and its per cent share in TIC	Value of inputs (Rs.) generated and recycled within the model and its per cent share in TIC	Expenditure on wages (Rs.) and its per cent share in TIC
2013–14	365,152	131,847 (36.11%)	97,873 (26.80%)	135,432 (37.09%)
2014–15	372,288	135,134 (36.30%)	71,284 (19.15%)	165,870 (44.55%)
2015–16	476,605	170,925 (35.86%)	101,470 (21.29%)	204,210 (42.85%)
2016–17	539,598	202,236 (37.48%)	111,162 (20.60%)	226,200 (41.92%)
2017–18	623,948	260,947 (41.82%)	116,601 (18.69%)	246,400 (39.49%)
2018–19	654,834	258,408 (39.46%)	145,626 (22.24%)	250,800 (38.30%)
Average of 6 years	505,404	193,250 (37.84%)	107,336 (21.46%)	204,819 (40.70)

wastes were used for preparation of vermicompost. The vermicompost unit produced 3.37 t REY (6.95%) giving Rs. 48,900 (7.30%) and Rs. 4605 (2.10%) average gross and net returns, respectively. These results are in conformity with the Ramrao et al. (2005), Sharma et al. (2008) and Channabasavanna et al. (2009). IFS components comprising field crops, vegetables, floriculture, poultry fishery and cattle of the low lying valley areas gave higher net returns (Rs. 2.11 lakh ha^{-1}) and B:C ratio of 2.5 besides ensuring additional employment of 221 man days (Ravisankar et al. 2006).

The yearwise as well as average of 6 years total cost of production of the IFS model was shown in Table 27.3. The total cost of production was Rs. 505,404 ha^{-1}, which included outside purchase for Rs. 1,93,250 ha^{-1} (37.84%), value of recycled material within the system of Rs. 107,336 ha^{-1} (21.46%) and for farm labours costing Rs. 204,819 ha^{-1} (40.70%). Farmers can increase their net returns by saving the expenditure on farm labours through employment of family labours. From the table, it was clear that the per cent share on labour cost continuously declined from the year 2014–15 (44.55%) to last year 2018–19 (38.30%), whereas the value of recycling in terms of cost was increased from year 2014–15 (Rs. 71,284) to 2018–19 (Rs. 145,626).

Employment generation for farm family throughout the year is one of the important objectives of the IFS model. IFS has created more number of working days in the system due to involvement of more enterprises than cropping system alone. This has provided employment opportunities round the year. Due to high rainfall zone, rice is the base crop in this region. Rice crop required higher labour for the major operation, viz., uprooting of seedlings, transplanting, and harvesting operations. In the present IFS model, the average employment generation was found to be 1085 man days, and its value was Rs. 204,819 which contributed 40.70% in the total cost of production (Table 27.4). All the enterprises required higher labour except poultry (25 man days) and vermicompost preparation (33 man days). In this model, goatery

Table 27.4 Yearwise employment generation in IFS model

Years	Enterprise-wise employment generated (man days)						Total man days	Total value (Rs.)	% share in COC
	Crops	Horticulture (fruit crops + nursery)	Dairy	Poultry	Goatary	Other (VC)			
2013–14	301	131 (11 + 120)	175	14	155	60	836	135,432	37.09
2014–15	292.5	86 (11 + 75)	185	21	304	33	921.5	165,870	44.55
2015–16	312.5	316 (17 + 299)	154	24	295	33	1134.5	204,210	42.85
2016–17	297	334 (17 + 317)	158	28	289	25	1131	226,200	41.92
2017–18	326	393 (34 + 359)	166	30	293	24	1232	246,400	39.49
2018–19	339	392 (35 + 357)	165	30	303	25	1254	250,800	38.30
Av. of 6 years	311	275 (21 + 254)	167	25	273	33	1085	204,819	40.70

Table 27.5 Enterprise-wise value of recycled products and by-products (Rs.) and total value of recycled farm products (av. of 6 years)

Enterprise	Value of recycled products and by-products (Rs.)
Crops	11,396
Horticulture (fruit crops + nursery)	35,247 (9617 + 25,630)
Dairy	22,465
Vermicompost	38,228
Total value of recycled	107,336

unit is reared as semi-intensive system. For grazing purpose, it required more labour unit. Ultimately, it was converted into higher expenditure on wages of labour. It reflects on less net returns by goatery unit. A field study on rainfed farming systems in Odisha revealed that integrated faming system approach was found superior to farmers practice in terms of higher net returns, B:C ratio, sustainability index and employment generation (Barik et al. 2010). These results are in line with Patel et al. 2018 and Mukhopadhyay et al. (2018).

Recycling is the soul of integrated farming systems. The end product of the one enterprise is the major input of the other enterprise. The average value of intermittent use of recycled farm produces and by-produces from crop unit, horticulture (fruit crops + nursery unit), dairy unit and vermicompost unit was in the tune of Rs. 11,396, Rs. 35,247, Rs. 22,465 and Rs. 38,228, respectively, (Table 27.5). The total quantity of recycled products in IFS model developed at Himachal Pradesh KrishiVishvavidyalaya, Palampur was 211.30 q, and their monetary value was Rs. 66,858 (Negi et al. 2018). The component-wise production of recycled material and their intermittent use with their market values were also estimated. Total quantity of 53,295.60 kg/L/no. of farm produce and by-produce for worth of Rs. 145,626.08 (22.24%) to be purchased from the market were utilized and recycled within different components of the model during 2018–19 (Table 27.6). Every farm enterprises and related products used for recycling within the system. The total product recycled (kg/L/no.) with their market values of cropping systems, dairy unit, goat unit, poultry unit, horticulture unit and vermicompost unit was 10,917.60 (Rs. 27,913.58), 23,773 (Rs. 37,359.50), 3852 (Rs. 3852.00), 747 (Rs. 1494.00), 4956 (9912.00) and 9050 (65,095.00), respectively, in the year 2018–19.

As per the standards given by Indian Council of Medical Research the demand of essential foods for a family of 6 members per annum, the annual production in this model is surplus for cereals, oilseeds, milk, fruits and vegetables commodities (Table 27.7). Only demand of pulses was not fulfilled by this present model.

Table 27.6 Recycled products in IFS model—total quantity and its market value calculated as per guidelines given separately (year 2018–19)

Farm enterprises and related products used for recycling within the system	Quantity produced (kg/L/no.)	Intermittent use of recycled farm produces and by-produces (kg/L/nos.)					Total products recycled (kg/L/no.) with their market value in parenthesis (Rs.)
		Crop unit	Nursery (hort.)	Dairy unit	Vermicompost unit	Hort. (fruit crops)	
A. Cropping systems							
Grains (kg) (used as animal feed)							
Crops straw (kg)	2228.10			2228.10	–		2228.10 (Rs. 4456.20)
Green fodder (kg)	7740			7740			7740 (Rs. 23,220)
Green manure (kg) (N%—0.42)							
Crop residue (kg) (N%—0.65)	949.50				949.50		949.50 (Rs. 237.38)
Litter fall (kg) (N%—1.29)							
Total (A)	10,917.60			9968.10	949.50		10,917.60 (Rs. 27,913.58)
B. Dairy unit							
Cow dung	18,413				18,413		18,413 (Rs. 27,619.50)
Urine	4380		3000		1380		4380 (Rs. 8760)

(continued)

Table 27.6 (continued)

Farm enterprises and related products used for recycling within the system	Quantity produced (kg/L/no.)	Intermittent use of recycled farm produces and by-produces (kg/L/nos.)					Total products recycled (kg/L/no.) with their market value in parenthesis (Rs.)
		Crop unit	Nursery (hort.)	Dairy unit	Vermicompost unit	Hort. (fruit crops)	
Shed waste	980				980		980 (Rs. 980)
Total (B)	23,773		3000		20,773		23,773 (Rs. 37359.50)
C. Goat							
Dung (shed waste)	3852				3852		3852 (Rs. 3852)
Total (C)	3852				3852		3852 (Rs. 3852)
D. Poultry							
Poultry litter	747				747		747 (Rs. 1494)
Total (D)	747				747		747 (Rs. 1494)
E. Horticulture (fruit crops)							
Mango and sapota scion sticks	4956		4956				4956 (Rs. 9912)
Total (E)	4956		4956				4956 (Rs. 9912)

(continued)

Table 27.6 (continued)

Farm enterprises and related products used for recycling within the system	Quantity produced (kg/L/no.)	Intermittent use of recycled farm produces and by-produces (kg/L/nos.)					Total products recycled (kg/L/no.) with their market value in parenthesis (Rs.)
		Crop unit	Nursery (hort.)	Dairy unit	Vermicompost unit	Hort. (fruit crops)	
F. Vermicompost							
Vermicompost	8945	1875	4870			2200	8945 (Rs. 53670)
Vermiwash	95		95				95 (Rs. 1425)
Vermiculture	10				10		10 (Rs. 10,000)
Total (F)	9050	1875	4965		10	2200	9050 (Rs. 65,095)
Grand total (A + B + C + D + E + F)	53,295.60	1875	12,921	9968.10	26,331.50	2200	53,295.60 (Rs. 145,626.08)

Table 27.7 Demand and production of farm commodities from IFS model (demand as per ICMR standards)

Particulars	Demand as per ICMR standards (6 family members)	Actual annual production
Cereals (kg)	876	905.33
Pulses (kg)	150	108
Oilseeds (kg)	144	232
Milk (L)	480	1910.42
Fruits (kg)	144	2712.17
Vegetables (kg)	360	3811.67
Green fodder (kg)	–	7063.37
Dry fodder (kg)	–	1821.17
Other (vermicompost)	–	6116.67

27.4 Conclusions

It can be concluded that diversification of existing farming systems with change in crop(s), cropping systems, inclusion of horticultural crops with nursery, addition and improvement of livestock components, kitchen garden, bunds and boundary plantation is essential to improve the income and better recycling in small and marginal households. Farmers can sustain and economical viable by adopting the different modules in IFS. Farmers can increase their net returns by saving the expenditure on farm labours through employment of family labours. The annual production in this model was fulfilling of the family demand with balance food and livelihood security.

References

Barik KC, Mohanty D, Nath SK et al (2010) Assessment of integrated farming system for rainfed ecosystem in Deogarh district of Odisha. In: Extended summaries, 2010. XIX national symposium on resource management approaches towards livelihood security, 2–4 Dec 2010, Bangalore, p 172

Channabasavanna AS, Biradar DP, Prabhudev KN et al (2009) Development of profitable integrated farming system model for small and marginal farmers of Tungabhadra project area of Karnataka. Karnataka J Agric Sci 22(1):25–27

Gill MS, Samra JS, Singh G (2005) Integrated farming system for realizing high productivity under shallow water-table conditions. Research bulletins. Department of Agronomy, PAU, Ludhiana, pp 1–29

Lal M, Patidar J, Kumar S, Patidar A (2018) Different integrated farming system model for irrigated condition of India on basis of economic assessment: a case study—a review. Int J Chem Studies 6(4):166–175

Mukhopadhyay SK, Ray M, Chatterjee S et al (2018) Integrated farming system models for lower Gangatic Plains. In: National symposium on integrated farming systems for 3Es. University of Agricultural Sciences, Bengaluru, pp 33–36

Negi S, Sharma SK, Pathania P et al (2018) Integrated farming system model/modules for enhancing productivity and profitability in North Western Himalaya region. In: National symposium on integrated farming systems for 3Es. University of Agricultural Sciences, Bengaluru, pp 27–32
Patel AM, Patel KM, Saini AK (2018) IFS models for Gujarat plains and hills. In: National symposium on integrated farming systems for 3Es. University of Agricultural Sciences, Bengaluru, pp 23–26
Pawar LG, Chavan AP, Dalvi AS et al (2011) Efficient alternative cropping system. Published by Project Directorate of Farming System Research, Modipuram, U.P. (ICAR), pp 262–272
Ramrao WY, Tiwari SP, Singh P (2005) Crop-livestock integrated farming system for augmenting socio-economic status of small holder tribal of Chhattisgarh in central India. Livestock Resfor Rural Develop 17:90
Ravisankar N, Pramanink SC, Rai RB et al (2006) Study on integrated farming system for low lying valley areas of Bay Islands. Indian J Fert 2(7):49–51
Reddy TY, Reddi GHS (2003) Cropping systems. Principle of Agronomy. Kalyani Publication, pp 468–489
Sharma YK, Bangarva GS, Sharma SK (2008) Farming system based constraints faced by farmers. Indian Res J Ext Edu 8(1):57–59
Singh JP, Ravisankar N (2017) Integrated farming systems for sustainable agricultural growth: strategy and experience from research. National seminar on integrated farming systems for sustainable agriculture and enhancement for rural livelihoods. Retired ICAR Employee's Association, and ICAR–NAARM, Hyderabad, Telangana, pp 18–31

Chapter 28
A Critical Appraisal on the Present Status of Coconut Cultivation in Lakshadweep Islands and Strategies for Enhancing Sustainability

P. P. Shameena Beegum, C. Thamban, and K. Samsudeen

Abstract Coconut evolved in coastal ecosystem and Lakshadweep Islands is one of the original homes. The 10 inhabited islands of Lakshadweep are blessed with suitable coconut cultivars. Fishes and coconuts are the major livelihood option of localite. Though natural home, coconut farming in Lakshadweep islands faces many constraints in its cultivation and processing for value addition. It is essential to know the ground realities to formulate strategies to improve income from farming and farm-based industries. With the objective of exploring the scope of horticultural crops with emphasis on coconut in the island ecosystem, a survey was made in six major islands of Lakshadweep including Kavaratti, Androth, Agatti, Kadmat, Amini and Kiltan. The investigation describes coconut farming scenario in the Lakshadweep islands and suggests strategies for conservation and sustainable utilization of coconut genetic resources, quality planting material production, agro-techniques for sustainable coconut production and coconut-based multiple cropping and integrated farming, product diversification, besides capacity building programmes for youth, farmers and extension personnel. Role of farmer producer organizations (FPOs) and coordination between various agencies in improving the situation for sustainable coconut-based industry are also flagged by the authors.

Keywords Lakshadweep · Islands · Coconut farming · Coconut value addition · Strategies

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28.1 Introduction

Lakshadweep is India's smallest union territory located in Arabian Sea. Though there are 36 tiny coral islands, only 10 islands are inhabited with population of 64,429 (2011 census) (Fig. 28.1). Coconut and Lakshadweep Islands are in co-existence for centuries. Coconut evolved in coastal ecosystem and Lakshadweep Islands is one of the original home. Coconut cultivation and copra making is a part of the day to day activities of islanders. The socioeconomic fabric in the Lakshadweep Islands is mainly supported by coconut. Though coconuts are abundant, it is not systematically cultivated on a commercial scale. Value addition in coconut is primarily seen in the form of copra. Of late, some private firms are engaged in the manufacturing of coconut oil, virgin coconut oil, etc. Tremendous opportunities exist in the islands for enhancing income through product diversification and marketing of value-added coconut products. Improvement in the farm sector of islands should primarily focus on coconut-based income-generating activities. It is essential to know the realities on the ground, to formulate strategies to improve income from farming and farm-based industries. This chapter is based on the survey conducted at various islands of Lakshadweep. The status and suggested strategies mentioned are based on the stakeholder interaction sessions and field visits conducted to assess the coconut farming scenario in the islands. Fragmented holdings, overcrowding of palms, senile and unproductive palms, lack of adoption of multiple cropping and integrated farming, lack of availability of skilled palm climbers and high wage rate,

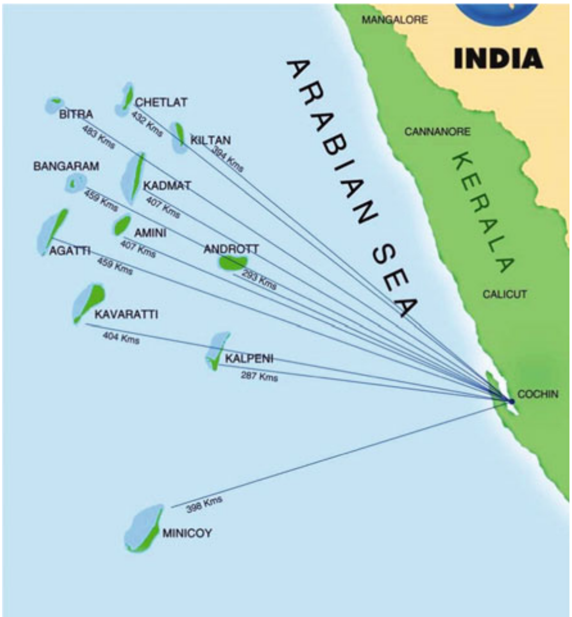

Fig. 28.1 Lakshadweep Islands

crop loss due to rodents, the incidence of pests like rhinoceros beetle, eriophyid mite, spiralling whitefly, diseases like bud rot, widespread deficiency of micronutrients like boron, low level of product diversification, lack of transport facilities, lack of storage and marketing facilities, inadequate extension support, etc. are the major constraints underlying in the coconut sector. Detailed insight each problem, the potential for improvement and future strategies are described in the chapter.

28.2 Coconut Farming in Lakshadweep Islands: Scenario and Strategies

As the farming activities in these islands are coconut based, any effort to enhance income from farming should necessarily focus on coconut cultivation and value addition. Area, production and productivity under coconut cultivation with total number of palms across the islands are listed in Table 28.1.

28.2.1 Maintenance of Optimum Palm Density

Coconut gardens in the islands are densely planted/grow coconut palms of different age groups which adversely affect productivity. Every farmer demarcates the boundaries of his landed property with closely planted coconut. As per the statistics made available by Department of Agriculture for the year 2017–18, average number of coconut palms per ha in Lakshadweep is 408 compared to the palm density of 175

Table 28.1 Coconut cultivation in Lakshadweep Islands (2018–19)

Name of island	Area (in ha)	Total no. of palms	Productivity (nuts per ha)	Production (no. of nuts)
Kavaratti	392.4	164,808	35,587	13,964,339
Agatti	338.12	142,010	35,880	12,131,746
Amini	243.5	102,270	35,630	8,675,905
Kadmat	306.10	128,562	33,650	10,300,265
Kiltan	149.6	62,832	33,880	5,068,448
Chetlat	100.1	42,042	33,760	3,379,376
Bitra	7.7	3234	6670	51,359
Androth	452.75	190,155	36,650	16,593,288
Kalpeni	258.5	108,570	34,550	8,931,175
Minicoy	426.1	146,962	19,980	8,513,478
Total	2674.87	1,091,445	30,623.7	87,609,378

Source Thamban et al. (2019)

palms per ha recommended for main land. Crop loss due to rodent damage is mainly due to the overlapping of leaves in the crown because of the overcrowded coconut palms which facilitate easy movement of rodents from palm to palm without climbing down to ground.

Strategies

- Considering the island ecosystem and socioeconomic condition, optimum coconut density needs to be worked out experimenting with various spacing of palms that can optimally harvest available sunlight.
- Coconut farmers need to be made aware about the significance of thinning the density of palm and the need of maintenance of optimum palm density for higher productivity. Model coconut gardens highlighting the benefits of maintenance of optimum palm density should be developed in all islands.
- Interventions for cutting and removing old and senile palms and scientific replanting should be given emphasis while formulating strategies for improving the efficiency of coconut cultivation these islands. Besides, farmers should be provided with adequate incentives for the same.

28.2.2 Conservation and Utilization of Coconut-Genetic Resources and Production of Quality Planting Material

Laccadive ordinary tall and Laccadive microtall are the predominantly grown cultivars (Fig. 28.2). Laccadive microtall has the highest oil content (72%). In addition to these prominent ones, there are a few other types like Laccadive orange dwarf, Laccadive yellow dwarf, Laccadive green dwarf and Laccadive mini-microtall. Treasure of variability in coconuts are enormous and this helped breeders from outside to develop new varieties and hybrids. In addition, planting material production can be enhanced by utilizing mother palms in the Lakshadweep Islands (Krishnakumar et al. 2014). Many institutions and entrepreneurs from Kerala are keen to procure coconut

Fig. 28.2 Diversities in coconut cultivars

seed nuts from Lakshadweep Islands and as such the potential for production and distribution of planting material through FPOs can be utilized as a source of income to the coconut farmers in islands. The coconut variety 'Chandrakalpa' released by ICAR-CPCRI during 1985 was a selection from Lakshadweep Ordinary Tall (LCT) and hybrid 'Chandralaksha' is a cross between LCT and Chowghat Orange Dwarf (COD) with an annual yield of 100-110 nuts.

Strategies

- Coconut-genetic resources endemic to Lakshadweep Islands need to be thoroughly explored and documented in the biodiversity register at village panchayat level.
- Mother palms of released varieties of coconut available in the islands should be identified and geo-tagged for production quality planting material.
- Farmer producer organizations need to be formed and facilitated to take up production and distribution of quality planting material in all islands.

28.2.3 Organic Farming and Soil Health Management

Coconut farming in the islands is natural farming without doing any cultivation practices except planting and harvesting. There is restriction in the use of chemicals in Lakshadweep. Symptoms of micronutrient deficiency especially boron are observed widely in coconut palms in all the islands (Fig. 28.3). Vegetable and fruit plants, which are grown in limited scale in the islands, are also affected by nutrient deficiencies. Soil erosion is also observed in the sea shore. Systematic efforts to assess the soil health status of islands for formulating suitable interventions for nutrient management are yet to be made. Availability of organic manure is limited here. Dried coconut leaves, spathe, rachis, spikelet, etc. are available in plenty in the islands, and these can be

Fig. 28.3 Boron deficiency symptoms in coconut

utilized effectively to make available quality organic manure required for coconut and subsidiary crops.

Strategies

- Efforts should be made for the comprehensive assessment of soil health status and formulation of package of practices recommendations for soil health and crop health management taking into cognizance the local availability of inputs and policy on organic farming in the islands.
- Interventions to popularize vermicomposting of coconut leaves and raising green manure crops in coconut gardens are to be implemented to enhance the availability of quality organic manure and for improving soil fertility status.
- Farmer Producer Organizations (FPOs) are to be facilitated to take up production and marketing of organic products and incubation support provided to them through appropriate entrepreneurship development programmes.
- Common brand 'Lakshadweep organic' to be developed for exploiting the potential of organic market.

28.2.4 Coconut-Based Multiple Cropping and Integrated Farming

The adoption of cropping systems is limited due to lack of spacing between palms. Interventions to promote coconut-based farming systems as part of enhancing agro-biodiversity in Lakshadweep islands are highly relevant and significant. The potential for inter-/mixed cropping of vegetables and fruits in coconut gardens if properly utilized can considerably reduce the dependence of the islands on import of such items from the mainland.

Strategies

- Preference of farmers in the islands about the component crops and subsidiary enterprises to be integrated with coconut cultivation needs to be analysed and performance of such combinations to be assessed in farmers' field.
- Establish demonstration plots on coconut-based inter-/mixed cropping and integrated farming in all islands.
- Link the interventions to promote coconut-based farming systems with interventions for cutting and removing old and senile coconut palms and scientific replanting.
- Maintenance of optimum palm density.

28.2.5 Enhancing Food and Nutritional Security Through Cultivation of Vegetable and Fruit Crops

To meet the vegetables and fruits demand, people depend on the mainland. Of late, many people have started growing these crops in rooftop gardens in the terraces of their houses, mostly in grow bags with the support of the Department of Agriculture. Vegetable crops like brinjal, bhindi, tomato, amaranthus, chilli, cabbage, cauliflower are grown in grow bags in terraces of houses. Vegetable and fruit plants are affected by various pests (aphids, mites, white fly, mealy bug, etc.) and diseases (bacterial wilt, mosaic, etc.).

Strategies

- Facilitate formation of FPOs and provide incubation support to take up enterprises on poly-house/hi-tech farms for production and marketing of vegetables in suitable localities in islands where open space is available.
- Facilitate formation of women SHGs to take up production and marketing of quality seeds and planting material of vegetables, fruit plants and tuber crops in farms under the Department of Agriculture. Besides, potting mixture for grow bags also can be prepared and sold by these SHGs for the islanders.
- Implement interventions to support farmers for the cultivation of vegetables, fruit plants and tuber crops in the low-lying areas (‘thottam’) and in the homesteads.
- Schemes to support farmers for effectively utilizing potential for marketing of organic vegetables should also be implemented.

28.2.6 Management of Pest and Diseases

Thirty to forty-four percentage of damage in coconuts is due to rodents. Overcrowding of coconut palms, lack of crown cleaning, improper harvest, residual waste management in the garden, absence of predators and lack of adoption of proper crop management practices are some of the reasons for rat infestation. Many farmers perceived that restriction to use rodenticides for controlling rats as per the organic farming policy has resulted in increased loss due to rat menace. Bud rot and stem bleeding diseases have been observed in few coconut gardens in some of the islands. Damage due to rhinoceros beetle and eriophyid mite is noticed in all the islands. Recently, infestation of coconut palms by rugose spiralling white fly is observed in Kavaratti Island. Vegetable and fruit plants also are affected by various pests and diseases. Due to various reasons such as lack of awareness about crop protection technologies, lack of availability of inputs for plant protection measures, inadequate extension support, farmers are unable to effectively adopt any pest/disease management measures in coconut and subsidiary crops.

Strategies

- As has been already mentioned, evolve package of practices recommendations for crop health management in coconut and subsidiary crops taking into account the organic farming policy for the islands.
- Organize capacity building programmes on crop protection technologies for coconut and subsidiary crops to benefit extension personnel, farmers, palm climbers and agricultural labourers.
- Implement farmer participatory extension interventions to enhance adoption of crop protection technologies in coconut and subsidiary crops.

28.2.7 Capacity Building Initiatives to Benefit Youth

Unavailability of skilled climbers is a major setback faced by farmers of all islands which adversely affect timely harvest and plant protection operations, especially rodent control, in coconut. Even though the present wage rate is quite attractive for the climbers (as high as 50 rupees per palm), climbing coconut trees is considered as an inferior job by the upper elite sections of the population. Mechanical device for climbing coconut palms is used by climbers of some islands.

Strategies

- Conduct sensitization programmes to develop favourable attitude towards the job of coconut climbing among all sections of island population.
- Organize capacity building programmes in all islands on coconut tree climbing using mechanical tools in line with the 'Friends of Coconut Trees' scheme implemented by the Coconut Development Board.
- Topics related to crown cleaning, hybridization technique for production of coconut hybrids, control measures for bud rot disease, control of rodents, etc. should also be included in the capacity development programme for youth besides coconut harvesting.

28.2.8 Capacity Building Programmes to Benefit Farmers and Extension Personnel

Coconut farmers in the islands can be provided exposure to sustainable coconut production technologies (enhance productivity and income) as part of the department schemes to enhance their knowledge and skill. Besides, they need to be trained on formation and management of Farmer Producer Organizations (FPOs) to reduce cost of cultivation and to enhance income from coconut farming. Similarly, extension personnel under the Department of Agriculture in Lakshadweep Islands also needs to be kept abreast with the advances in coconut production technologies through appropriate capacity building programmes.

28.2.9 *Value Addition and Marketing*

28.2.9.1 Harvesting

There is a traditional way of harvesting and undertaking post-harvests operations among the people of Lakshadweep. Palm climbing is done in traditional manner with rope by skilled workers belonging to certain sections. Apart from them, service of the skilled workers from main land is also utilized by the farmers. The present wage rate is attractive; however, shortage of skilled climbers is faced in all the islands as climbing coconut trees is considered as an inferior job by the upper elite sections of the population. In some of the islands, the frequency of harvesting in coconut has come down to four times per year against six times as in earlier days. Mechanical device for climbing coconut palms is used by climbers of some islands. Conducting sensitization programmes to develop favourable attitude towards coconut climbing among all sections of island population is the need of the hour as a strategy for solving the problem of shortage of skilled climbers. Besides, more capacity-building programmes are needed to be organized in all islands for youth on coconut palm climbing using mechanical device in line with the 'Friends of Coconut Trees' scheme implemented by Coconut Development Board.

28.2.9.2 Storage/Seasoning

Harvested nuts are generally heaped under shade for few months before processing. This type of storing is also known as seasoning and has many advantages such as easier husking and shelling. As a result, the yields of copra and oil and the quality of oil increase. In some places, harvested nuts are heaped in open areas till dehusking is done which may affect the seasoning of the stored nut, and further leads to deterioration of quality.

28.2.9.3 Dehusking

Traditionally, husking is done manually by skilled workers with the help of an iron spike driven to the ground. A skilled worker can dehusk around 2000–2500 nuts per day. A worker gets Rs. 0.5–1.0 per nut. Adoption of handy and popular coconut husking tool, called 'keramitra', developed by Kerala Agricultural University may be made available for domestic use which is comparatively easier to operate especially for women workers. There is no practise of the mechanical dehusking which in fact is not needed at present. However, mechanical dehusking may be useful in future days. ICAR-CPCRI has attempted to modify the existing commercially available power operated coconut dehusker with a capacity of 350 coconuts h^{-1} and a power requirement of 2 HP.

28.2.9.4 Processing

Copra, coconut oil, coir and coir products, neera (coconut inflorescence sap) and coconut jaggery are the major traditional coconut-based enterprises that exist in the islands. Limited transportation options, poor mechanization, high cost of transportation, poor marketing facilities, etc. are some of the reasons for poor performance of value addition sector.

Coconut Consumption Pattern

One-fourth of the total nuts production is consumed domestically. Nearly, 5% of the total production is used for tender nut purpose. Limited quantity of nuts were used to process into desiccated coconut powder in the desiccated coconut powder units run by Lakshadweep Development Corporation Limited (LDCL) which was recently stopped functioning. There is enormous potential for coconut-based product diversification in Lakshadweep.

Marketing of Coconut

Coconut marketed mainly in two ways. It is sold either as fresh nuts after dehusking or as copra to the mainland (Kozhikode in Kerala and Manglore in Karnataka). The estimated figure obtained from Androth Island revealed that presently 90% of the harvested nuts is sold as nuts and 10% is converted to copra.

Production and Marketing of Copra

Copra making using traditional drying yards and its marketing are the foremost economic activity in the agrarian sector (Fig. 28.4). Modern copra dryers are used by some entrepreneurs. Due to the inefficiency of traditional sun drying, it is difficult to meet the minimum standards specified by the procuring agencies.

Copra prepared is sold either to private local traders or to co-operative society in the island. There are motor sailing vessels (MSV) locally called ‘Manchu’ through that copra is transported to the markets in mainland. Co-operative Supply and Marketing Society in the islands functioning under the Department of Co-operation procures copra from farmers during the season from January to May.

While procuring copra, the societies ensure good quality of the copra as per the specification; ensuring that copra procured conform to the standards for the maximum limits of tolerance for fungal infected copra (5% by count), wrinkled kernels rubbery copra (5% by count), smoky kernels (5% by count), moisture (5%) and insect infestation (nil). Island farmers often experience difficulties due to the delay in payment for the copra sold and insistence for the quality standards by the co-operative societies. Societies will send the copra to the apex body, viz., the Lakshadweep Co-operative

Fig. 28.4 Copra drying yards

Marketing Federation at Beypore, Kozhikode. The federation in turn sells the copra from Kozhikode to NAFED or big private enterprises like MARICO or other big private traders in the mainland; usually within two days. Farmers in the islands will be paid the balance amount by the society in the next day after the copra is sold in the mainland market by the federation. Though societies most of the times offer higher market rate for copra compared to the private traders, delay in payment is a problem experienced by farmers, and hence, many of the farmers transact with private traders.

Coconut Oil

There are some modern small-scale copra milling units running in the islands in private sector to meet the demand for coconut oil. One or two firms export oil to the Middle East countries (Fig. 28.5). There are certain drawbacks including marketing issues, shortage of funds for nuts procurement, labour shortage, transportation costs and lack of continuous transportation options throughout the year.

Virgin Coconut Oil (VCO)

Conventional processing of VCO is practised in islands (Fig. 28.6). Small self-help groups (Dweepasree) used to prepare and market VCO. The pricing for the produced

Fig. 28.5 Coconut oil

Fig. 28.6 Conventional hot processing of virgin coconut oil

VCO is improper and cheap as we could visualize from the visits made to two units in Amini (Rs. 380/- and 260/- per litre), respectively. Village Dweep panchayat supports VCO production through interventions under which coconuts are supplied to women, and VCO produced by them is collected back and sold @ Rs 100/- per 100 ml. The women enrolled in this scheme gets about Rs 360/- as wages per day. Options for by-product utilization can be explored. Though VCO is attracting attention worldwide as a value-added coconut product having a number of medicinal and nutraceutical properties, there are no commercial VCO production units in the islands employing modern methods and machineries except one unit owned by a private entrepreneur, in Andrott Island. He is manufacturing VCO through Direct Micro Expelling (DME) technology in his enterprise ‘Dweep Fibres and Traders’.

Fig. 28.7 Neera (coconut inflorescence sap) tapping

Fig. 28.8 Processing of *katti* (neera concentrate)

At this juncture, people should be made aware about the functional and nutraceutical values of VCO for fetching better market. There is vast potential for commercial production and marketing of under the 'Lakshadweep organic brand'. Technological interventions are needed in VCO processing and marketing.

Neera or Coconut Inflorescence Sap

Traditional neera tapping is followed in islands. It is consumed as fresh neera or converted to coconut vinegar, neera spread/*katti* (Figs. 28.7 and 28.8). The conventional method of neera (locally known as 'meera') tapping involves cutting the unopened spadix for about 15 cm from the tip of spathe. After a week, the entire spathe will be removed. The inflorescence sap oozing out is collected twice in a day in plastic can/bottle kept close to the cut end of the spadix. Tapping is done for about

Fig. 28.9 Desiccated coconut powder unit at Kadmat Island

45 days. The Department of Agriculture has been implementing a major scheme for promoting neera tapping and jaggery preparation in the islands. Though 'neera' is used as a health drink, majority of it is converted into natural vinegar as it has tremendous usage in household as a preservative in fish curries and pickles. CPCRI technologies for neera tapping based on coco sap chiller and further value addition to natural coconut sugar can be adopted in Lakshadweep as through this method, neera with zero alcoholic content could be well ensured. Lakshadweep halwa is very famous in mainland as many bakery shops in Kozhikode and Ernakulam sell the product in the name of Lakshadweep halwa. It is made with coconut gratings and neera spread (semi solid concentrated neera).

Desiccated Coconut Powder

There are some desiccated coconut powder (DCP) units at Kadmat, Amini, Androth, Kalpeni and Agatti Islands (Fig. 28.9) under Lakshadweep Development Corporation Limited (LDCL). It is sold in the islands and also in the outlet of LDCL at Kochi. DC powder has a great demand throughout the tourist season (October to March). However, efforts should be made to popularize the product all over the country along with speciality as processed from organically grown coconuts. There is a huge scope for improving the functioning of the coconut processing units under LDCL. Units

Fig. 28.10 Coir fibre factory

including building and infrastructure need to be renovated with improved machineries such as desheller, testa remover, pulverizer and a better packaging system. Further, setting up of a quality control laboratory also can be thought of.

Coir and Coir Products

Under the Department of Industries, U.T of Lakshadweep, fibre factories, fibre production demonstration centres and curling units functioning in various islands. These units produce coir fibre, curled fibre, coir yarn and coir mats (Fig. 28.10). In the coir fibre factory of Kadmat Island, about 1200 coconut husks are processed per day for coir fibre using the retting method. The yield of fibre obtained is about 70–75 kg. Coir pith, the by-product, is unutilized. Women labourers (10 women workers) are engaged for coir spinning. The conveyer belt is not in working condition. Sales of the mat produced is confined only to the factory outlet.

Strategies are to be initiated to replace with improved machineries so as to reduce the drudgery and increase efficiency. Efforts are also needed to collaborate with different agencies working on coir-based products. In addition, coir pith, the by-product, is presently underutilized which needs to be converted into usable form.

There is coir jewellery unit at Androth (Fig. 28.11). There exists an ample scope in popularizing coir jewelleries. An incubation centre can be set up with financial support from the government. In addition to coir fibre based jewellery, shell based handicrafts are of great potential and need to be strengthened.

Scope for Production and Marketing of Value Added Coconut Products

In addition to the value-added products discussed above, there is a potential for facilitating enterprises such as coconut ice cream, coconut chips.

Fig. 28.11 Coir jewellery

28.2.9.5 Farmer Producer Organizations (FPOs)

Lakshadweep's land holding size is about 0.27 ha. Group approach is the best way to conquer the resource limitations and to adoption of technologies for higher productivity and income from coconut farming. The Department of Agriculture has made effort in formation of coconut farmers' societies in connection with organic certification programme. However, these societies are almost non-operational. Also, support is to be given to the self-help groups of women to pursue entrepreneurship in coconut-based microenterprises.

28.3 Conclusions

Coconut cultivation is the major livelihood of the people of Lakshadweep Islands, and hence, any effort to improve farm sector in the islands needs to primarily focus on coconut-based income-generating activities. Interventions on conservation and utilization of coconut-genetic resources and production of quality planting material, organic farming and soil health management, coconut-based multiple cropping and integrated farming, management of pest and diseases, capacity-building initiatives to benefit youth, farmers and extension personnel are to be formulated and implemented for the sustainable development of coconut sector in Lakshadweep Islands. Co-ordinated efforts of various agencies are also indispensable for effectively implementing the interventions for sustainable development of farm sector in Lakshadweep Islands. Besides, inadequacy of entrepreneurship for exploring the prospects for income generation through coconut-based value-added enterprises is quite evident from the present scenario. Besides, the potential of marketing coconut products from Lakshadweep as 'organic' is yet to be explored. Few entrepreneurs who have ventured to market organic coconut oil are encountered with many problems especially those related to transportation and marketing. Problems due to limited transportation and marketing facilities, lack of difficulty in repair and maintenance of the existing old machinery in the coconut processing units functioning under government agencies, lack of efforts for facilitating farmer collectives to take up value addition enterprises, lack of proper guidance for individual private entrepreneurs in the islands for the production and marketing of coconut value-added products, lack of labour and high wage rate, etc. adversely affect the sector. Active involvement of Govt. institutions/agencies, coconut growers and other stakeholders is to be ensured in the planning and implementation of interventions.

References

Krishnakumar V, Jerad BA, Joseph Rajkumar A et al (2014) Four decades of CPCRI interventions on coconut-based island ecosystem at Minicoy, Lakshadweep. CPCRI Tech Bull 86:32

Thamban C, Shameena Beegum SK, Ramesh SK (2019) Strengthening coconut sector in Lakshadweep Islands. Indian Coconut J 60(1):6–16

Part II
Resource Management and Technological Innovations in Fisheries and Animal Husbandry

Chapter 29
New Paradigms in Freshwater Aquaculture in Coastal Ecosystems in India: Happiness and Hope

J. K. Jena and P. C. Das

Abstract The 19-fold increase in fish production in the last seven decades in India, i.e., from 0.75 million metric tonnes (MMT) in 1950–51 to the present level of 14.2 MMT amply justifies the importance of the fisheries sector not only providing the protein and nutritional security of the masses but also its increasing contribution to the national economy. When the production from capture fisheries was stagnating, aquaculture has become a saviour for enhancing the targeted growth in fish production. From the meagre 0.37 MMT in 1980 to over 9.0 MMT at present, a 25-fold increase in aquaculture production in just four decades has placed the country as a forerunner on the global front. The freshwater sector that shares over 90% of total aquaculture production is largely contributed by carps and meeting the demand of the domestic front. The coastal ecosystem is contributing a significant share of the 8.2 MMT of freshwater aquaculture production with Andhra Pradesh, West Bengal, and Odisha being the major producers. Increasing production of diversified freshwater species including those of exotic striped catfish, pacu, and tilapia again is largely contributed by Andhra Pradesh. While carp polyculture and monoculture of exotic striped catfish have been steering the freshwater aquaculture production, a range of other non-conventional culture systems, viz., sewage-fed fish culture, integrated farming systems, cage and pen culture, and the new technologies like RAS and biofloc systems has made freshwater aquaculture an increasingly growing activity across the country. As a backyard avenue, ornamental fish breeding and rearing have been proved to be highly viable activity especially for the areas adjoining cities/towns due to their assured market. The self-sufficiency in quality carp seed production through large-scale adoption of the technologies of controlled breeding, hatchery production, and seed rearing has been ensuring guaranteed seed supply and practically guiding the aquaculture development in the country. Success in the development of breeding

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and seed production technologies of over 40 cultivable freshwater finfish and prawn species is leading farmers to adopt new species for culture diversification. In this endeavour, it is the coastal ecosystem led by the state of West Bengal contributing the bulk of the seed production in the country. Availability of a host of farmers'-friendly technologies with varied production potential, execution of different technology transfer programmes through the institutional frameworks, increasing private investments, good temperature regimes, productive soil, good water availability, and above all, increasing demand for fish have been instrumental for the accelerated growth of freshwater aquaculture in the coastal eco-regions. The fisheries sector in India has been able to demonstrate a phenomenal average annual growth rate of 10.88% to the national GVA in the last five years. Freshwater aquaculture has been the principal contributor to this growth, and it is expected that the sector would continue to take the lead in meeting the projected production target of 22.0 million tonnes of fish by 2025 and also contributing to increased employment generation.

Keywords Aquaculture diversification · Carp polyculture · Coastal ecosystem · Freshwater aquaculture · Integrated farming · Prawn culture

29.1 Introduction

Fish production in India has shown phenomenal growth in the post-independent period with the present production level at 14.2 MMT, a whopping 19-fold increase as compared to the 0.75 MMT in 1950–51(DoF 2020a). With marine fish catch hovering around 3.5 MMT since the last decade, aquaculture has been the main source of increase in fish production in the country. From a meagre 0.37 MMT in 1980 to over 9.0 MMT at present, aquaculture has shown a 25-fold increase in production in just four decades placing the country as a forerunner on the global front. The coastal ecosystem has provided significant support to increase fish production over these years. It consists of the nine maritime states and four union territories (UT) stretching to a total coastline of 8118 km producing 3.72 MMT of fish in 2019–20. Only, about 15% of the available 1.2 million hectares (m ha) of brackish water area all along the coasts have been put to use for the land-based aquaculture activity, mostly for the shrimp farming that produces about 0.8 MMT of cultured shrimp per year. Shrimp export from aquaculture contributed to about two-thirds of US$ 7.0 billion of seafood export from the country in 2019–20. These coastal states also possess 59.1% (1.438 m ha) of the country's 2.433 m ha pond and tank resources which form the basis of freshwater aquaculture (Fig. 29.1). Also, 72.4% of the 2.93 m ha reservoir and 62% of the 7.98 m ha wetland resources of the country are present in these coastal states (DAHD&F 2018). About 65% of the total inland production in 2019–20 came from these coastal states, and further, a significant share of this (5.89 MMT) was contributed by the states of Andhra Pradesh, West Bengal, and Odisha (DoF 2020a).

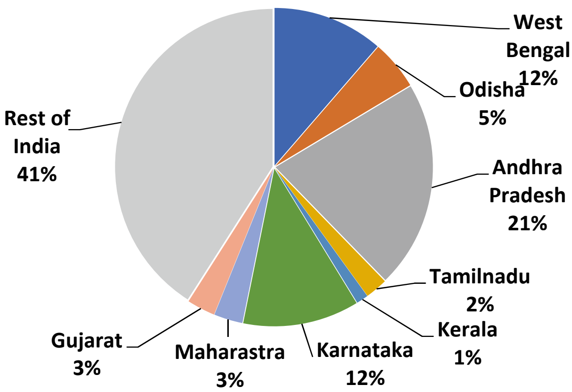

Fig. 29.1 Tanks and ponds in coastal states (Country total—2.433 m ha)

The coastal ecosystem of the country is spread on both east and west coasts and falls under a varied agroclimatic zone. It supports the livelihood of about 30% of the inland fisherman population of the country apart from the entire marine fisherman population. While the states on the east coast possess 40% of the freshwater pond resources of the country, 19.2% are available on the west coast. The diverse resource base provides wide scope for the culture of diversified fish species. Most of the freshwater aquaculture activity incidentally is concentrated on the east coast, especially in the states of Andhra Pradesh, West Bengal, and Odisha.

The breakthrough in the induced breeding of carps in 1957 and subsequent technological developments in various aspects of aquaculture including mass-scale hatchery seed production, nursery rearing, and fingerling production, and grow-out carp polyculture principally steered the freshwater aquaculture development in India (Ayyappan et al. 2011). Implementation of the 'All India Coordinated Research Project on composite carp culture and fish seed production' by the Indian Council of Agricultural Research (ICAR) in 1970s, which helped in the refinement of the packages of practices of carp culture further, was instrumental in the dissemination of scientific carp farming (Ayyappan and Jena 2005). In recent years, the sector has seen significant progress on all fronts, be it technology upgradation in seed production and grow-out culture of diversified species, system diversification, breed improvement, production of balanced feed, or improved health care; all contributing to the increase in production and productivity. The increased realization of fish farming as a potential full-time activity, substantial investment flow and strong government support in terms of numerous developmental schemes have also catalysed the aquaculture development in the country.

29.2 Aquaculture Diversification

Freshwater aquaculture in the country has remained mostly carp-centric, especially the culture of the three Indian major carp species (catla *Catla catla*, rohu *Labeo rohita,* and mrigal *Cirrhinus mrigala*) under the polyculture system. Apart from these, the three exotic carps, viz., silver carp *Hypophthalmichthys molitrix*, grass carp *Ctenopharyngodon idella,* and common carp *Cyprinus carpio* also formed an important component of composite carp farming in several places. Taking the advantage of the rich fish biodiversity of the country, the freshwater aquaculture during the last 3–4 decades has been able to expand its species spectrum to over 40 indigenous fish and prawn species, and several of which are regionally important ones with very high consumer preference and market price (Raizada et al 2019). The availability of the breeding and mass-scale seed production technologies and further access to the hatchery-produced seed also provide ample opportunity to the farmers to diversify culture practices. The important species include minor carps and barbs (kalbasu *Labeo calbasu*, fringed-lipped carp *Labeo fimbriatus*, Kuria labeo *Labeo gonius*, bata *Labeo bata,* reba *Cirrhinus reba,* Olive barb *Puntius sarana*), catfishes (magur *Clarius magur*, singhi *Heteropneustes fossilis,* butter catfish *Ompok pabda,* and *O. bimaculatus*), murrels (*Channa striata* and *C. marulius*), other finfishes of importance (climbing perch *Anabas testudineus*, chital *Chitala chitala*), and freshwater prawn (giant freshwater prawn *Macrobrachium rosenbergii* and Indian river prawn *M. malcolmsonii*). In recent years, the sector further has witnessed increasing adoption of diversified freshwater species including those of exotic striped catfish (*Pangasianodon hypophthalmus*), pacu (*Piractus brachypomus*), and tilapia (*Oreochromis niloticus*). Freshwater aquaculture production of the country is estimated to be about 8.2 MMT, out of the total inland fish production of 10.44 MMT (DoF 2020a) and the important groups being major carps, exotic carps, minor carps, catfishes, and others (Fig. 29.2).

Andhra Pradesh, the major freshwater aquaculture producing state today initiated pond culture in the Kolleru lake region only in 1976. Initially, the state government constructed only 133 fish ponds covering an area of 2040 ha (Ramakrishna et al. 2013). During the last four decades, aquaculture in the state has turned to be a typical commercial activity, involving major carps, striped catfish, and pacu as the major species. The states of West Bengal and Odisha have been utilizing the resources mostly as a homestead activity comprising a wide range of species in the culture system. Fish being a preferred food item for over 95% population of these two states, more than two dozens of species including the indigenous major carps, minor carps, and barbs, catfishes, murrels, climbing perch, chital, and freshwater prawn are cultured in the pond systems of these states to meet the diverse options of the consumers. Compared to the east coast, the coastal states on the west coast have less freshwater aquaculture activity. Although most of these states, barring Gujarat, have a considerable fish-eating population, marine fishes have greater consumer preference over freshwater fishes. However, in recent years, freshwater aquaculture activity has received increased attention. The Deccan Plateau being the potential hub for several

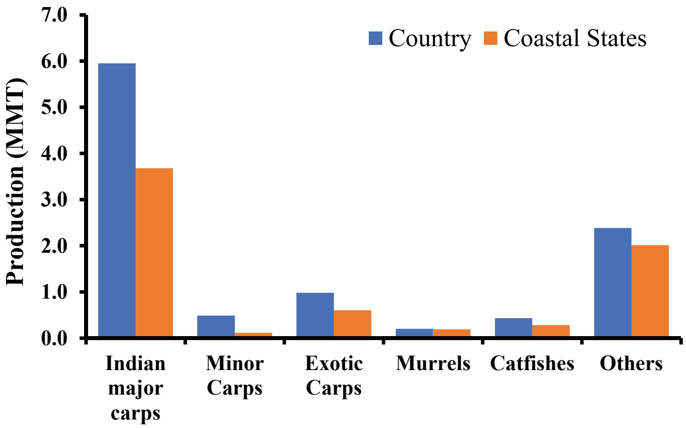

Fig. 29.2 Inland fish production of major species groups in coastal states in 2019–20

potential cultivable endemic fish fauna, particularly the medium-sized carps and barbs, there has been a greater focus on technology development of breeding and seed production of several species, viz., *Labeo dussumeri*, *Hipselobarbus pulchelus*, *Puntius karnaticus,* and *P. kolus*. While these diversified species have proved to be potential components in the major carp-based polyculture system, it is expected that their large-scale adoption would largely depend on their assured seed availability.

The exotic striped catfish has become the next important cultured species after carps in the pond culture system, specifically in Andhra Pradesh. Over these years, the species has also achieved its strong presence in several land-locked states, viz., Chhattisgarh, Jharkhand, Bihar, and Uttar Pradesh. The other important catfishes being adopted in the culture systems are magur, singhi, and butter catfish. While monoculture of these species has seen increased adoption in the northeastern states, in the coastal states, they are mostly cultured in West Bengal and to a limited extent in Odisha. These fishes are also cultured as the component species in carp polyculture and have been contributing to increased farm income due to their higher market price. Of late, the singhi has received increased preference as a promising species in the biofloc-based aquaculture system.

The high market value of murrels (striped snakehead *Channa striata* and great snakehead *Channa marulius*) especially in West Bengal and the South Indian states like Tamil Nadu, Andhra Pradesh, Telengana, and Karnataka although has created increased interest for culture of these species, inadequacy in seed availability has been the major bottleneck for their large-scale farming. However, the recent success in mass-scale seed production of these species has opened scope for their adoption in the culture system.

Besides the finfishes and freshwater prawns, the culture of freshwater mussel *Lamelliden marginalis* is increasingly becoming popular as a cash crop for freshwater pearl production in the coastal region. As a backyard avenue, ornamental fish breeding and rearing have also been proved to be highly viable activity especially for the areas adjoining cities/towns due to their assured market. Although the country possesses rich biodiversity of indigenous freshwater ornamental fish, efforts during the years have mainly focussed to develop breeding and seed production protocol of a few low-valued indigenous and exotic species. Greater focus, however, is given at present to breed high-valued indigenous ornamental species. With the areas around Kolkata, Chennai, and Mumbai have become major hubs of breeding and culture of ornamentals over these years, several new units are coming up in the states of Kerala, Andhra Pradesh, and Odisha (Silas et al. 2011; Ayyappan et al. 2016). Being highly flexible in the scale of operation, ornamental fish farming is being adopted as a backyard activity by the small and marginal women farmers and also as large-scale commercial activity.

Andhra Pradesh is continued to be the major producer of inland fish production among the coastal states, followed by West Bengal and Odisha (Fig. 29.3). The bulk of the present culture production comes from about 70% of the available ponds and tanks resource in the country. The burgeoning demand for freshwater fish not only has necessitated 100% utilization of available resources but also advocated for increased intensification and expansion of aquaculture in new resources. Over the years, though carp polyculture and monoculture of exotic striped catfish have been steering the freshwater aquaculture production, a range of other non-conventional culture systems, viz., sewage-fed fish culture, integrated farming systems, cage and pen culture, and the new technologies like RAS and biofloc systems have made freshwater aquaculture an increasingly growing activity across the country. Further, within the carp production system, several modifications have been made in the

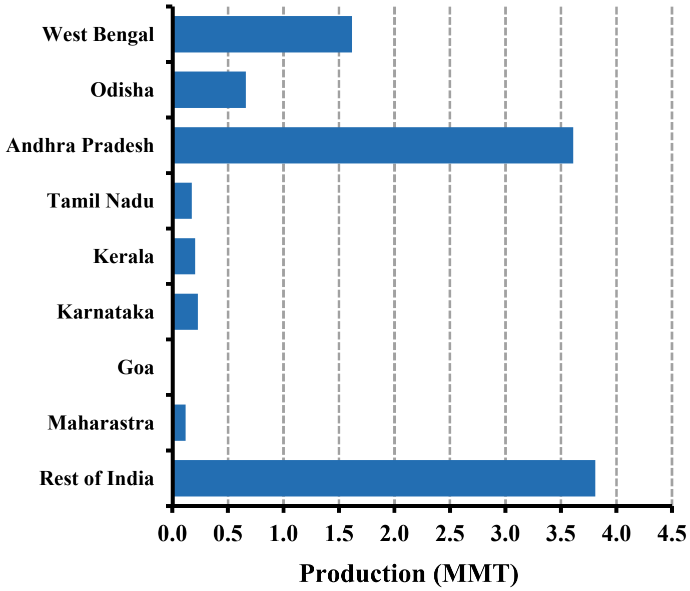

Fig. 29.3 Inland fish production in the coastal states in 2019–20

cropping patterns to ensure higher yield, low feed requirement, shortening of crop period, low investment, increased investment capacity, and lower risk factors. Some of the important farming practices in vogue in freshwater aquaculture systems in the coastal states are discussed.

29.2.1 Carp Polyculture

The technology of carp polyculture developed during 1970s brought the aquaculture to the level of industrial enterprise at present. The farming practices, however, have undergone several need-based modifications which were largely influenced by the market demand and investment capacity of the farmers in different parts of the country. But, the technology of carp polyculture yet has been the core of all developments with over 60% of the freshwater aquaculture production coming from three Indian major carp species. Carp farming further has also seen a marked shift from stocking fingerlings to adopting the concept of fattening with the use of a larger seed stocking size of 200–300 g to shorten the crop period, as adopted largely by the farmers of Andhra Pradesh. The average productivity in carp farming has been varying between 3–4 tonnes ha^{-1} yr^{-1}, while higher production levels of 8–10 tonnes ha^{-1} yr^{-1} are realized by several enterprising farmers in Andhra Pradesh and other states (Jena et al. 2020; Ayyappan 2021). Studies have also shown 15–20% increase in fish production with the introduction of minor carp and barb species in major carp-based polyculture systems. These species, because of their smaller marketable size, also have shown potential for better utilization of the seasonal ponds (Jena and Das 2011). Besides the conventional system of single stocking and single harvesting, the promotion of newer approaches, viz., single stocking at higher density and multiple harvesting, multiple stocking—multiple harvesting, and multiple cropping are also increasingly being adopted (Das et al. 2019). Such cropping systems also help in the reduction of FCR and assuring the periodical money flow besides reduction of investment and disease risk.

29.2.2 Monoculture of Striped Catfish and Other Exotic Species

The higher growth rate of the striped catfish *P. hypophthalmus* compared to other cultivable indigenous catfishes and feasibility of its farming at a very high density with higher yield realization were the principal factors for its increased adoption in the culture system of the country. The absence of intra-muscular bone further is a boon for its popularity in the North Indian states as well as for the hotel industry. Andhra Pradesh has been at the forefront to adopt striped catfish in the aquaculture system. The state has shown a steady increase in the culture area of the species since the early 2000s to reach a maximum of about 32,000 ha in 2010 with an average yield of 17–20 tonnes ha^{-1}under monoculture (Belton et al. 2017). Further, with the use of balanced floating feed under intensive monoculture setup, the yield level often reached 40-50 tonnes ha^{-1}. However, due to the reduced market price of the species in the later period and its increased adoption in several other states, viz., Chhatisgarh, Bihar, Jharkhand, Uttar Pradesh, Punjab under both pond-based and cage culture systems, the coverage area in Andhra Pradesh has seen a marked decline in recent years. In terms of production volume, the contribution of striped catfish is next to the three Indian major carp species.

Apart from the striped catfish, the pacu and tilapia have made their way into the culture system in recent years. Although pacu is yet to be an officially approved species for farming in the country, its culture area has increased to over 2500 ha during the last 10 years, which, however, is largely confined to the state of Andhra Pradesh. Farming of tilapia was officially banned in the country over the decades due to its prolific breeding and threat to the environment. However, the relaxation given recently for farming of the improved variety of monosex tilapia and red tilapia, with certain restrictions, has led to a growing interest in their large-scale adoption in several coastal states. While pacu is being cultured as a component species in the carp polyculture system and also under monoculture, the farming of tilapia has been adopted under monoculture in ponds and also as a species of choice in the biofloc system. At present, a few farms in Kerala and West Bengal are producing tilapia on a very large scale and catering to the domestic and export market.

29.2.3 Culture of Freshwater Prawn and Marine Shrimp in Freshwater

The availability of hatchery-produced seed, a surge in demand due to the decline in marine shrimp production caused by white spot syndrome virus (WSSV) and the higher market price of freshwater prawn led to increased adoption of giant freshwater prawn farming in the country during the early 2000s, especially in Andhra Pradesh followed by West Bengal. Freshwater prawn culture took off in a big way in different districts of Andhra Pradesh, especially Nellore District during 2000–2003. With average annual productivity of about 1.0 tonne ha^{-1} under monoculture, the production of freshwater prawn had reached 41,870 ha during 2003–04, with Andhra Pradesh contributed about 90% of the total. The farming intensity, however, declined subsequently due to several reasons most important being the outbreak of White Tail Disease and reduced export price and less profit margin in farming. Further since 2012, successful cropping of the Pacific white shrimp *Litopenaeus vannamei* is taken up in freshwater ponds (Muralidharan 2016). Large areas of ponds have been converted considering the high returns of its farming. The culture of freshwater prawn, however, is showing the sign of revival with production reaching about

9500 tonnes during 2019–20, and it is expected that with the availability of genetically improved seed having 30% higher growth, farming of this species would expand in the coastal regions in coming days.

The feasibility of farming black tiger shrimp at low salinity due to its euryhaline nature also helped for its farming in low-salinity waters in some of the districts of Andhra Pradesh during the initial years. However, it was subsequently replaced after the introduction of the Pacific white shrimp in the late 2000s. In the last decade, a vast expansion of shrimp production has further taken place in the state through the construction of new ponds or the use of ponds previously used for fish farming.

29.2.4 Integrated Farming System

Based on the concept of waste recycling, the integrated farming system is an effective system for judicious and effective utilization of resources. Integrated farming system models such as pig-cum-fish culture, duck-cum-fish culture, and paddy-cum-fish culture are highly popular in the northeastern region. Fish-cum-duck farming and fish-cum-poultry farming are among the popular integration models which have been adopted by many farmers in the eastern coastal states. With demonstrated production levels of 3–5 tonnes of fish ha^{-1} water area, mainly through fertilization of water with the generated wastes from the quantified numbers of livestock or birds, integrated fish farming has proved to be highly economically viable and environmentally friendly technology (Gopakumar et al. 2000; Ayyappan and Jena 2003). Integration of high-valued horticulture crops such as strawberries and other seasonal fruits on pond dyke with indigenous fish species in the pond has become a popular model in West Bengal. Similarly, the rice-fish system with integration of seasonal vegetables and fruit crops, apiary and mushroom on dyke, and pulses/watermelon in the main field during rice fallow season is a popular model in lowland rice ecosystem of coastal Odisha.

29.2.5 Sewage-Fed Fish Farming

Sewage-fed fish farming forms an important aquaculture activity in certain parts of West Bengal, especially in the freshwater *bheries*. In such a system, the organic wastes/sewage after a certain degree of treatment is used as a nutrient source in extensive fish farming. The traditional technology of sewage-fed farming which was in vogue over decades, however, has undergone substantial modification over the years incorporating an aspect of primary treatment before the water is fed to the culture ponds. Polyculture of Indian major carp along with silver carp and common carp in large ponds with treated sewage water has been yielding production levels of 3.0–4.0 tonnes ha^{-1} yr^{-1}. Multiple stocking and multiple harvesting are common practices adopted (Ayyappan and Jena 2001; Jena et al. 2020). Further, the water released from such culture ponds also meets the water quality criteria specified for irrigation water. High-density farming with the incorporation of minor carps, viz., *C. reba* and *L. bata* and tilapia along with major carps is quite a common practice.

29.2.6 Aquaculture in Inland Open-Waters

The nine coastal states together possess 72.4% of the 2.93 m ha reservoir and 62% of the 7.98 m ha wetland resources of the country (DAHD&F 2018), and the greater part of the fish production from these resources comes from the capture fisheries and culture-based fisheries. The governmental intervention on stock enhancement during the last two decades, especially through *in situ* carp seed rearing in pens (enclosure) and ranching of pond-reared seed, along with other participatory management measures has helped to improve the fisheries of several reservoirs and wetlands in the country. Such interventions have led to increased productivity of many of the small and medium reservoirs from a level of 20–25 kg ha^{-1} to 150 kg ha^{-1}.

The developmental need to increase fish production from the reservoirs has led to increased cage- and pen-farming activities in recent years. The striped catfish has been the species of choice for cage culture due to its higher growth and production. In most common rectangular cages of 6 m × 4 m × 4 m, production levels of 2.5–3.0 tonnes are achieved in 6–8 months culture period. During the last decade, the technology although has seen greater adoption especially in the land-locked states of Jharkhand, Chhattisgarh, Madhya Pradesh, and Telangana, the coastal states also resorting to greater adoption of the technology these years.

29.2.7 New Generation Aquaculture Systems and Practices

During recent years, different new aquaculture systems, viz., biofloc system (BFS), re-circulatory aquaculture system (RAS), and aquaponics have been adopted in different parts of the country including the coastal states. Based on the principle of high-density fish production, these systems can be futuristic options, especially for peri-urban fish farming, when scarcities of land and water resources are going to be critical determinants for the expansion of aquaculture in coming years. Among these, the biofloc system has generated huge interest among fish farmers and particularly among the youths in recent years. Despite being energy and capital-intensive production system, it has proved to be an economically viable alternative system of fish production in many countries. However, at present, a limited number of farms are operating across these states where cultured species mainly include singhi, tilapia, striped catfish, and climbing perch. Research efforts are on to bring more high-valued species under the ambit of culture in the biofloc system. Impetus is being given through different governmental schemes for large-scale establishment of the *peri-urban* system such as biofloc and RAS, which are likely to increase fish production in the coming days.

Production of organic fish has now become an important intervention in aquaculture as the choice of consumers to opt for safe and quality food is increasing, even if it taxes higher price on them. Though lower stocking density and stringent farming protocol have been characteristics of organic farming, the higher price compensates for the production loss. Successful attempts have been made to produce organic fish and prawn species, and farmers are adopting this technology day by day.

With the availability of hatchery-produced seeds of important brackishwater species, it is also feasible to take some of these species like seabass (*Lates calcarifer*), grey mullets (*Mugil cephalus*), milkfish (*Chanos chanos*), and pearl spot (*Etroplus suratensis*) into the freshwater aquaculture system.

29.3 Fish Seed Production

Over the years, induced breeding and seed production protocols have been standardized for more than 40 freshwater species. Carps being the major cultivable species, in order to meet the seed demand, over 3000 eco-hatcheries including small-scale FRP hatcheries are engaged in carp breeding and seed production in the country. West Bengal has been at the forefront of freshwater fish seed production with more than half of these carp hatcheries are operating in the state. The state is also operating several specialized hatcheries for striped catfish, magur, pabda, murrels, and other cultivable finfish species. Among the other coastal states, Odisha and Andhra Pradesh have also been able to boost seed production of different species including freshwater prawn over these years through the establishment of new hatcheries in the private sector. Availability of synthetic inducing agents and hatchery technologies for different species together with the experience gained over the last six decades has been instrumental for bringing self-sufficiency in seed production of 52 billion fry in the country in 2019–20 (DoF 2020a). West Bengal is playing a pivotal role in the seed supply chain in the country. Besides, the entire production of the freshwater prawn and shrimp seed comes from over 550 hatcheries in the coastal states, the bulk of which, however, is again contributed by Andhra Pradesh.

The development of aquaculture or propagation of any cultivable species largely depends on the timely availability of quality seeds of the desired species and size. Small and seasonal earthen ponds, which otherwise are not apt for grow-out production are effectively used for nursery rearing. It has been possible for the farmers to harvest one to two crops fry in such ponds within a breeding season of 3–4 months. High-density nursery rearing is now advocated in large concrete tank systems for more seed production per unit area as compared to the earthen ponds. Six to eight times higher fry production per unit area are being realized in such tanks through the harvest of 3–4 crops during a season. Despite assured availability of required carp fry in most of the states, there has been always a deficiency in the supply of fingerling which is a prerequisite for the success of any commercial culture. Fingerling rearing has so far been a less popular activity in the sector, largely due to possession of only one or two ponds by most of the farmers which they use for nursery or grow-out production. This is the case in almost all coastal states except that of Andhra Pradesh where there have been several seed rearing hubs, which ensure the seed demand of the commercial farming hub of about 100,000 ha in Krishna-West Godavari Delta. The mega-programme 'Mission fingerling' launched by the government recently is expected to promote such activity and strengthen the seed chain of the cultivable species not only in the coastal states but also all over the country.

In grow-out carp culture ponds in many parts of India, especially in Andhra Pradesh, stunted juveniles of 200–300 g are commonly used for stocking (Belton et al. 2017). The increased demand for stunted fingerlings/juveniles has created an opportunity for a separate tier of seed rearing for the farmers who are engaged in full-time seed rearing activity around the year. Protocols are available for the production of stunted fingerlings and yearlings which have enabled the farmers to practise fish fattening with reduced culture duration.

29.4 Stock Improvement

Improving the seed quality has been of prime importance in the aquaculture sector to harness the production potential of different species. Over the years, several techniques have been applied that include hybridization, ploidy manipulation, selective breeding. Though more than 40 intra-generic, inter-specific, and intra-specific carp hybrids had been produced but had limited success in achieving hybrid vigour. The revolutionary success came through selective breeding in rohu, popularly known as '*Jayanti*', which after its 9th generation of selection has demonstrated over 50% higher growth than that of commonly farmed rohu at farmers' fields. With the demonstrated encouraging result in rohu, the ICAR-Central Institute of Freshwater Aquaculture (CIFA), Bhubaneswar, an institute located in the state of Odisha has also expanded its selective breeding programme to other important species, viz., catla and giant freshwater prawn. While in the case of freshwater prawn 30% higher growth has been demonstrated after 10th generation of selection, catla has shown 30% higher growth even after 2nd generation (Jena et al. 2020). The institute over these years has been able to promote the spread of these improved fish through 'Multiplier Units' in several states. The National Freshwater Fish Brood Bank (NFFBB), established under the aegis of the National Fisheries Development Board (NFDB), Government of India in 2013 on the campus of Odisha State Govt. Fish Farm at Kausayaganaga, Bhubaneswar, has also been disseminating the genetically improved seed to different hatcheries in Odisha and neighbouring states. Besides, several hatcheries across the country have also been employing the milt cryopreservation technique for stock improvement. The technique is not only helping to overcome the issue of inbreeding in the hatcheries but also ensures stock improvement through male gamete exchange and reduction in the cost and maintenance of brood fish (Ayyappan et al. 2016). There has been improvement in the protocols for the broodstock maintenance and induced breeding of the major carps. The use of specialized broodstock diets like CIFABROOD™ is not only bringing early maturity in carps but also significantly increasing the spawn yield. Protocols have been developed for multiple breeding in carps where the same broodfish could be bred 2–3 times through stretching the breeding season. Early breeding has been made in carps during the pre-monsoon period with environmental manipulations.

29.5 Nutrition and Feed

Feeding of cultured fish in aquaculture systems in the country was restricted to certain commercial aquaculture farms in different regions till recent years, which, however, has been increasingly accepted by the farmers across India. The coastal states being the hubs of aquaculture activity, both for freshwater species and shrimps, the farmers in these regions have been the early adopters to the feeding practice. In carp polyculture, the feeding practices are largely confined to bran-oilcake mixture through ‘pole or rope feeding’ (Ramakrishna et al. 2013), although some commercial farmers are shifting to floating pellet feeds at present. With the increased area and greater adoption of intensive farming practices in this region, there has been a significant upsurge in feed demand over these years. Although the country has been able to meet the growing feed demand for shrimp farming in the last two decades with the establishment of several feed plants by the private sector, significant development in the commercial floating feed supply for the freshwater species happened only in the last decade. Over 30 feed plants are operating for the production of shrimp feed, mostly in the coastal region, with an installed capacity of about 1.6 MMT (Ambasankar et al. 2017). Recently, a few factories are also established in Odisha, West Bengal, and other land-locked states with varied production capacities.

Floating, sinking, and slow sinking forms of commercial feeds in varied pellet sizes are now available in the market. Specialized feeds for striped catfish, Indian major carps, and freshwater prawn are also available for the different life stages. Farm-made feeds produced from the identified non-conventional ingredients are increasingly used in several farms. There have been attempts to increase the efficiency of these feeds through effective feeding management to curb the FCR. While the demand for feed for fish and shrimp farming is increasing gradually, the non-availability of raw materials has been a concern at a time the aquaculture industry has to compete with the dairy and poultry industries. Efforts have been made to identify alternate feed ingredients from the locally available feed materials. The fishmeal, which is the most expensive and inevitable ingredient in the commercial feed of shrimp, freshwater prawn and carnivorous fishes, has to be replaced by ingredients of plant origin.

29.6 Disease Management

Increased intensity of farming over the years has also increased the vulnerability of the crops to disease emergence. Periodical occurrences of different diseases in shrimp and freshwater prawn farming, in particular, have led to setbacks in the growth of their farming, thereby requiring a greater focus on proper diagnosis, surveillance, and effective disease management. On the contrary, the health management in the freshwater fish farming sector has been at low key due to the lower occurrence of fatal diseases. Epizootic ulcerative syndrome (EUS) and parasitic infestation by *Argulus* have been the two common disease issues in freshwater aquaculture, which are being effectively managed by the application of CIFAX-a chemical formulation of ICAR-CIFA, and certain anti-parasitic drugs, respectively. Issues of poor growth and unexpected mortality in several cases are largely found to be due to the poor management and deterioration of water quality, especially during the latter part of the culture period. However, there has been a growing awareness among the farmers during these years to minimize their crop loss which may arise due to diseases, improper nutrition, and water quality deterioration. Implementation of the National Surveillance Programme on Aquatic Animal Diseases (NSPAAD) in 20 selected states and 2 union territories, including all the coastal states of the country during the last seven years has been a significant step forward to have a close vigil on the endemic and new disease outbreak in the aquaculture sector (Sood et al. 2020). The programme funded by the Department of Fisheries, Government of India, with the active participation of 29 partner organizations under the leadership of ICAR-National Bureau of Fish Genetic Resources (NBFGR), Lucknow, is tracing and tracking the emerging disease problems in different aquaculture systems through specialized laboratories and providing necessary guidelines for prevention and cure of the diseases. Under the programme, an 'emergency response system' is in place to tackle any new outbreak. Several diagnostic laboratories have been established by the entrepreneurs too, especially in the state of Andhra Pradesh. Refinement of environment management protocol, development of diagnostic tools, formulations of therapeutics, use of immuno-stimulants, etc. are some of the key tools being used at present to trace and control the diseases in the sector.

29.7 Fish Marketing

Almost total fish produced from aquaculture in India goes for domestic consumption, while cultured shrimps are mostly exported to other countries. The state of Andhra Pradesh produces bulk of the inland fish (3.6 MMT in 2019–20) and possesses an organized cold chain in fish marketing. It has been able to supply the fishes to several states of the country. Although the states like West Bengal and Odisha also produce a good quantity of fish from freshwater aquaculture, possessing about 95% of the fish-eating population, these states are also forced to source fish from Andhra

Pradesh. Recent years further witnessed live fish transportation to the short-distance local markets and holding facilities in most of the states, which have become a new marketing strategy to fetch a higher value. With the increasing consumers' preference for fresh fillets, ready-to-cook and ready-to-eat fish in recent years, there has been an increasing reach of freshwater fish in the domestic supermarkets too.

29.8 Perspectives

The fisheries sector in India has been able to demonstrate a phenomenal average annual growth rate of 10.88% to the national GVA in the last five years. Towards this, the share of freshwater aquaculture has been quite substantial through a consistent increase in fish production of the country. As stated, the coastal region has taken the lead to supply a lion's share of the produce, both for the domestic and export markets. It is expected that when the country is targeting to produce 22 MMT fish by 2025 (DoF 2020b) with a contribution of 15.5 MMT from aquaculture and again 14 MMT from freshwater aquaculture, the coastal states must continue to contribute significantly in the coming days. The task although seems to be quite challenging with all odds, viz., reducing freshwater resources, water shortage, high input cost, labour scarcity; apart from the environmental concern and climate change, it needs to be accomplished. The present R&D focus on frontier areas such as breed improvement, culture diversification, vertical increase in productivity, feed development for diversified species, disease surveillance and management, water budgeting, development of climate resilience systems and practices, post-harvest value addition, and market creation is expected to continue its significant role towards keeping the growth pace of aquaculture as earlier years. It is required that Indian aquaculture is further supported by innovative developmental programmes like the ongoing PMMSY, increased investment, and greater efforts on technology dissemination.

References

Ambasankar K, Vasagam KPK, Vijayan KK (2017) India, Nutrition and feeding status of aquaculture feed and feed ingredient production and utilisation in India. Network of Aquaculture in Asia-Pacific, Bangkok, Thailand. https://enaca.org/?id=891

Ayyappan S, Jena JK (2001). Sustainable freshwater aquaculture in India. In: Pandian TJ (ed) Sustainable Indian fisheries. National Academy of Agricultural Sciences, New Delhi, India, pp 88–133

Ayyappan S, Jena JK (2003) Grow-out production of carps in India. J Appl Aqua 13(3/4):251–282

Ayyappan S, Jena JK (2005) Inland aquaculture. In: Chadha KL, Swaminathan MS (eds) Aquaculture and environment. Malhotra Publishing House, New Delhi, India, pp 547–572

Ayyappan S, Jena JK, Lakra WS et al (2016). Fisheries science. In: Singh RB (ed) 100 Years of agricultural sciences in India. National Academy of Agricultural Sciences, New Delhi, India, pp 259–304

Ayyappan S, Sugunan VV, Jena JK et al (2011) Indian fisheries. In: Ayyappan S, Moza U, Gopalakrishnan A, Meenakumari B, Jena JK, Pandey AK (Tech Coordination) Handbook of fisheries and aquaculture, 2nd edn. Indian Council of Agricultural Research, New Delhi, India, pp 1–31

Ayyappan S (2021). National aquaculture sector overview, India. National aquaculture sector overview fact sheets. In: FAO Fisheries Division [online], Rome. Updated. Assessed 6 June 2021

Belton B, Padiyar A, Ravibabu G et al (2017) Boom and bust in Andhra Pradesh: development and transformation in India's domestic aquaculture value chain. Aqua 470:196–206

DAHD&F (2018) Annual report 2017–18. Department of Animal Husbandry, Dairying & Fisheries, Ministry of Agriculture and Farmers Welfare, Government of India

Das PC (2019) Development of aquaculture for commercially important finfishes in India. In: Giri SS, Bokhtiar SM, Sahoo SK, Paul BN, Mohanty S (eds) Aquaculture of commercially important finfishes in South Asia. SAARC Agriculture Centre, SAARC, Dhaka, Bangladesh, p 15–46

DoF (2020a) Hand book of statistics. Department of Fisheries, Ministry of Fisheries, Animal Husbandry & Dairying, Government of India, New Delhi, India, p 176

DoF (2020b) Pradhan Mantri Matsya Sampada Yojana - a scheme to bring about blue revolution through sustainable and responsible development of fisheries sector in India. Department of Fisheries, Ministry of Fisheries, Animal Husbandry & Dairying, Government of India, New Delhi, India, p 25

Gopakumar K, Ayyappan S, Jena JK (2000) Present status of integrated fish farming in India and wastewater treatment through aquaculture. In: Kumar MS (ed) Wastewater treatment and aquaculture production. South Australian Research and Development Institute, West Beach, Adelaide, South Australia, pp 22–37

Jena JK, Das PC (2011) Carp culture. In: Ayyappan S, Moza U, Gopalakrishnan A et al (Tech Coordination), Handbook of fisheries and aquaculture. Indian Council of Agricultural Research, New Delhi, India, pp 380–400

Jena JK, Das PC, Panigrahi A (2020) Local self-reliance in aquaculture and fisheries: Gandhian models. In: Pathak H, Pal S, Mohapatra T (eds) Mahatma Gandhi's vision of agriculture: achievements of ICAR. Indian Council of Agricultural Research, New Delhi, India, pp 48–59

Muralidharan CM (2016) FAO Diagnostic review of Andhra Pradesh fisheries (September-October 2015). Office of the FAO Representative for India, Food and Agriculture Organization of the United Nations, New Delhi, India, p 48

Raizada S, Pravin P, Kumar AT, Jena JK (eds) (2019) ICAR technologies: breeding and seed production of finfishes and shellfishes. Indian Council of Agricultural Research, New Delhi, p 66

Ramakrishna R, Shipton TA, Hasan MR (2013). Feeding and feed management of Indian major carps in Andhra Pradesh, India. FAO Fisheries and Aquaculture Technical Paper No. 578, Food and Agricultural Organization, Rome, p 90

Silas EG, Gopalakrishnan A, Ramachandran A et al (2011) Guidelines for green certification of freshwater ornamental fish. The Marine Products Export Development Authority, Kochi, India, p 106

Sood N, Pradhan PK, Swaminathan TR et al (2020) The national surveillance programme for aquatic animal diseases—a stepping-stone for establishing disease governance system in India. Curr Sci 120(2):273–277

Chapter 30
River Basin Management for Sustainable Fisheries: Valuing for River Water Sources

Sharad K. Jain and Amiya K. Sahoo

Abstract Ecosystem approach at river basin level is considered to be the best strategy for conservation and sustainable management of water and aquatic/terrestrial life. Ecohydrology forms a framework within the ecosystem approach protecting both physical alteration and biodiversity change. Fish is considered as one of the best indicators for the river health assessment and management. River water in terms of quantity and quality plays a vital role in biological processes governing their life, including migration, reproduction and feeding. Any alteration in the quantity, quality, frequency and timing of the flows has significant impact on their sustainability and production. To that end, the concept of environmental flows has been developed as a way to protect the river ecology and fisheries. Environmental flows define the quantity, timing and the quality of water flows that are required to sustain freshwater and estuarine ecosystems and the human livelihoods and well-being that depends on the ecosystems. A holistic management approach at river basin level that brings different disciplines and principles from hydrology, engineering, ecology and economics is needed for sustainable development and management of water and associated resources. It is also necessary and important to consider all the uses of water in a river basin, including the fisheries needs. Models that make use of hydrological and ecological approaches to simulate the response of a river basin and biological life to changes in inputs and management practices have been developed and are being refined. With this background, the current paper provides a perspective on river basin approach for sustainable water and fisheries management.

Keywords Ecohydrology · Environmental flows fisheries · Hydrology · Management · River basin

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30.1 Introduction

Water is the fundamental to all the living organisms. Among the different forms of water availability, surface water in the forms of both marine and freshwater contributes to the major share for sustaining these lives. The major source of surface freshwater is inland open waters such as rivers, wetlands, reservoirs, lakes and canals. India has vast network of 12 major river basins in which there exists wide temporal and spatial variability in water resources potential. Furthermore, water is a natural resource whose availability depends upon location and time. Depending upon these and other factors, there are very large variations in water availability. India has monsoonic climate, and more than 75% of the annual rainfall is received during four months of summer monsoon. Of course, some places in the eastern India receive rains during the northeast monsoon, and parts of Northwest India receive rains due to western disturbances.

Water availability and uses have spatial and temporal dimensions. Such assessments are always made over a geographical region, which may be bounded by natural or administrative boundaries. Flow of surface water follows natural boundaries, and hence, river basin approach is also widely followed in assessment and management of surface water. River basin is also the commonly used unit in integrated water resources management (IWRM). In India, the major uses of river water are agriculture, industrial and domestic uses and hydropower generation. Storage, withdrawal and diversion of water for these uses have led to large alterations in river systems. Tributaries specific to the river basin have been observed to be the most critical for both hydrological and ecological sustainability. Any alterations in the tributaries or in basin significantly impaired the main river channel at both hydrological as well as ecological processes.

30.2 Demand and Use of Water

Water is withdrawn from natural bodies such as lakes, rivers and aquifers to meet a range of needs. In India, most water is withdrawn for meeting irrigation needs. The other important purposes include municipal and industrial water supply, energy generation, environment and recreation.

With the rise in population and growth in industries, the withdrawals and consumption of water are increasing at most place, and in many geographies, these have exceeded the average annual replenishment. This means that the current rate of withdrawals cannot be sustained in such places, and if continued over a long time period, the health of the water body would sharply deteriorate.

For sustainable management of water resources, it is necessary to estimate the availability of these resources, and the estimates should be repeated regularly since the factors governing the availability and use of these resources are changing fast.

30.3 River Basin Planning and Management

The area contributing to flow of water at a given point on a river is called its catchment area. A river basin is the basic and most suitable unit for planning and management of water resources since the catchment area at a location will govern how much water is available at that location.

Planning for optimal resource use in a river basin begins with assessments of demands and supply and then the gap between the two for the various seasons. Next step is to find what are the possible interventions to fill the gap. A number of criteria such as hydrologic, engineering, economic, environmental, social are used to rank the alternatives in order of preference.

River basin planners and managers have to overcome a number of challenges. These arise because of resource constraints—the demand for water is typically more than the supply. There may be a mismatch in terms of time when water is available and when it is required. The quality of water may not be as per the uses. Further, water-triggered disasters, say floods and droughts, may harm water security in a basin.

30.4 Why Integrated Water Resource Management?

In a river basin, typically, a large number of organizations are associated with management of water to ensure that their own sectorial demands are met to the best extent. The list of such departments include agriculture department, forest department, electricity department, rural and urban water supply departments (Fig. 30.1). Although they all are involved in use of a common resource, often there is little coordination among these departments, leading to sub-optimal decisions. Clearly, it will help if the various departments work in close coordination.

According to a popular definition, Integrated Water Resource Management (IWRM) is a process which promotes the coordinated development and management of water, land and related resources, to maximize the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems.

While practicing IWRM, the best idea would be to integrate within and between natural and human system. Till about 1980s, in water management, focus was mainly on water quantity. After 1990s, water managers started focusing on water quality also since there were signals of deteriorating water quality of many natural resources. Subsequently, it was realized that water is central to the health of environment, and hence, maintaining healthy ecosystems became an important goal of water managers.

Fig. 30.1 Various uses of water in a river basin and departments involved in management. *Source* Internet

30.5 Facets of River Ecosystem

A river ecosystem has four dimensions. In a river basin, the channels form an intricate network that evolves with topography, geomorphology and climate. Thus, the longitudinal connectivity is the first dimension of the river ecosystem. Connection between river channels and flood plains forms the second dimension. In a river basin, water moves in horizontal as well as vertical directions—moisture seeps into ground and groundwater may reappear on the surface in the form of springs and base flow. Stream-aquifer interaction forms the third dimension. Finally, the river basins, their elements and the responses of living and non-living components have an evolutionary history, and this is the fourth dimension of a river ecosystem. These four dimensions are shown in Fig. 30.2.

A river is defined by hydrology, morphology, habitats and biodiversity. Together, these constitute and define the health of a river. A river ecosystem faces many threats due to obstructions to flow, water abstraction and climate change. In river management, solutions have to be found so as to maintain a balance between needs and availability and to keep in minds that the health of the river is of paramount importance.

Among the four components listed above, flow is considered to be "the master variable" because it is the controlling factor in riverine physical, biological and chemical processes. Variables of importance from ecological view point, water temperature, dissolved oxygen, available habitat, spawning cues, channel shape, substrate type, etc. depend on flow.

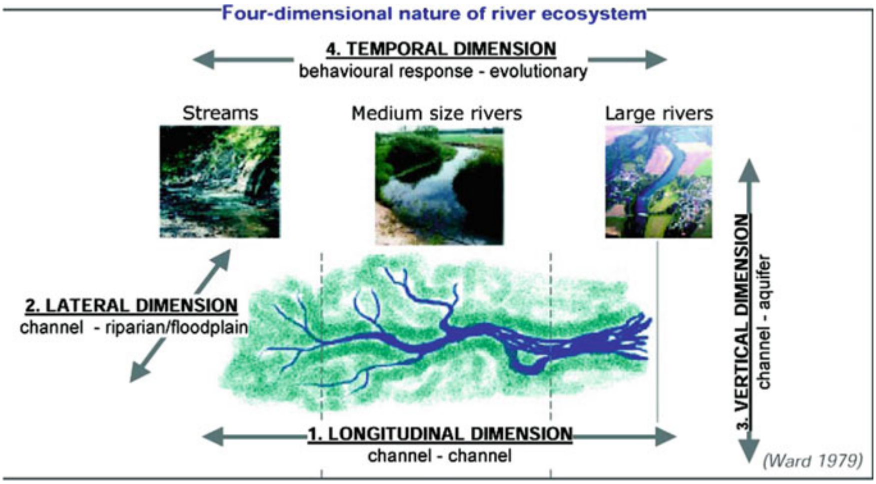

Fig. 30.2 Four-dimensional nature of river ecosystem. *Source* Ward et al. (1979)

According to the natural flow regime paradigm, flow regime is composed of flow magnitude, frequency, duration, timing and rate of change. Flow pulses help re-establish longitudinal connectivity, deliver nutrients and organic matter and flush sediments within the river channel. Flood flows spill over the banks, establish lateral connectivity and shape channel and floodplains. The concept, need and importance of environmental flows are largely based on the critical role flow regime in river health. A number of definitions of environmental flows can be found in the literature. According to the widely followed definition adopted in Brisbane Declaration (2007), "environmental flows describe the quantity, timing and quality of water flows required to sustain freshwater and estuarine ecosystems and the human livelihoods and well-being that depend upon these ecosystems" (Jain and Acreman 2017).

Environmental flows are best considered in a river basin wide assessment by following a holistic approach. The concept of ecohydrology integrates river hydrology and ecology at the river basin scale.

Ecohydrology is a scientific concept developed by the International Hydrological Program (IHP) of UNESCO. This concept quantifies and explains the relationships between hydrological processes and biotic dynamics at the catchment scale, bearing the principles of integration of catchment and biota into a plantonian super-organism, understanding the evolutionarily established resistance and resilience of such super-organisms to stress and use ecosystem properties as management tools (Fig. 30.3) (Zalewski 2000).

Ecosystem-based approach is considered as the best strategy for integrated management of water, land and living resources promoting conservation and sustainable use in an equitable manner in the rivers. Ecohydrology forms a framework within the ecosystem approach protecting both physical/hydrological alteration and biodiversity change. Basically, the concept leads to the integrated catchment management, linking water management with abiotic factors for enhancing energy enhancement and increasing productivity. Furthermore, ecohydrology is an integral part of hydrology that focuses on ecological processes occurring within the hydrological cycle and strives to utilize such processes for enhancing environmental sustainability. Ecohydrology has a profound role in river ecosystem and biodiversity management including fish production and conservation.

30.6 Functional Components of Ecohydrology in River Management

See Fig. 30.3.

30.7 Fishery and River Basin Management

Fishes are considered to be a global source of animal protein, contributing about 17% of the total animal protein intake and 7% of all proteins (Fish Site 2020).Currently, the global fish production is estimated to have reached about 179million tons (FAO 2020). Out of these, only about 18 million tons comes from inland open freshwater

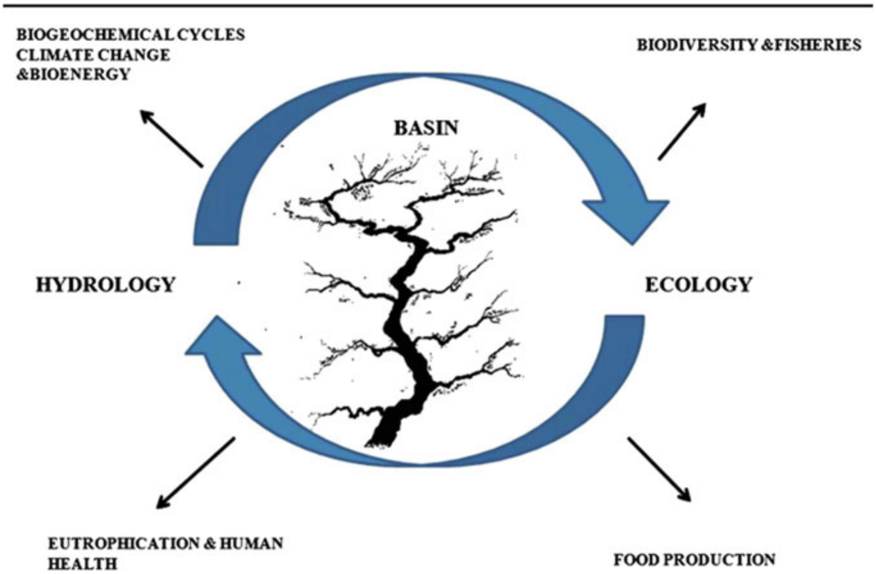

Fig. 30.3 Concept of ecohydrology (Sahoo et al. 2016)

resources as capture fisheries from rivers, reservoirs, lakes and canals. The extensive network of Indian rivers (length about 29,000 km) constitutes the major inland fishery resource of the country. Nearly, 14 millions small and marginal fishers are directly or indirectly dependent on these inland aquatic resources for their livelihood. However, the analysis of the data shows that the present day riverine fishery is below the subsistence level with average yield of 26.62 $kgkm^{-1}$. The biologically and economically important fish species have given away to low value species, exhibiting an alarming swing in the population structure.

A steep fall of over 95% in the fisheries of Hilsa above Farakka barrage, after its commissioning in 1974, is a glaring example of the adverse impacts of river course modification on fishes. The Mahaseer fishery of various river systems in the country, like Narmada and upland Himalayan Rivers, has also suffered due to increased incidence of river valley modifications. In addition, the invasion of exotic fishes to riverine ecosystem has adversely affected the sustainability of endemic fish fauna. Recent studies at ICAR-Central Inland Fisheries Research Institute (CIFRI) have conclusively shown that the environmental aberrations, like marked reduction in water volume in the river due to increased abstraction and sedimentation, accompanied with river course modifications are the key factors responsible for decline in riverine fishery. The decrease in water volume in river has led to habitat loss, both in terms of breeding and feeding grounds, for the commercially important fish species affecting their recruitment and growth and, thus, resulting in decline of fisheries in general. Reduced water volume and river flow has also reduced the diluting and flushing properties of the rivers and thus increased impact of the pollutants that are routinely being added to the river water through partially treated municipal and industrial effluents. Due to the lack of required river flows leading to declined fish catch, there is huge economic loss to the country. At the same time, the fisher folk also suffers large economic losses as their major source of income is under constant threat.

30.8 Environmental Flows for Sustainable Fisheries

Environmental flows are also synonymously known as ecosystem reserve, in-stream flows, ecological flows, environmental water allocations and the normative flow regime. The common definition of environmental flows is “water that is left in a river ecosystem, or released into it, for the specific purpose of managing the condition of that ecosystem.” It needs to be understood that many human requirements, which are not directly consuming water, such as navigation, flood control and land reclamation for urban development and agriculture, also influence the ecologically favored patterns of flow. They modify the hydrographs driven by natural precipitation to those resulting from the increased control over flows by artificial structures with negative impacts on discharge patterns. The river hydrographs can also change due to landscape changes, such as deforestation or bad agricultural practice, by influencing the speed of run-off and the capacity of soils to retain water for release over a period of time. Such changes are likely to affect the flashiness and duration of peak flows but do not substantially alter the quantity of water flowing through a system during the year or the timing of flood peaks. Large dams, that store water for power generation or for irrigated agriculture, and abstractions, that remove large quantities of water from rivers, exert major control over flows. They also affect the total amount of water in the system and the timing with which it is discharged. Thus, many on-stream and off-stream events influence the river flows, adding more complicacies to the efforts to assess the environmental water requirements. Maintenance of natural variability in flows and water levels is essential to underpin conservation strategies for freshwater or water-associated biodiversity and their habitats (Poff et al. 1997; Richter et al. 1997; Pollard and Huxham 1998; Arthington and Pusey 2003).Water regimes not only provide a minimum level, but also one which includes a range of flows that mimics natural variability (Dudgeon et al. 2006) (Fig. 30.4).

Reproducing natural variability is essential to incorporate the temporal and spatial aspects of the flow conditions. Dudgeon et al. (2006) established four principles to describe the different stages which must be taken into account in order to mimic a natural flow regime.

The relationship between biodiversity and the physical nature of the aquatic habitat is likely to be driven primarily by large events that influence channel form and shape (Principle 1, Fig. 30.4). However, droughts and low flow events also play a role by limiting overall habitat availability and quality. Many features of the flow regime

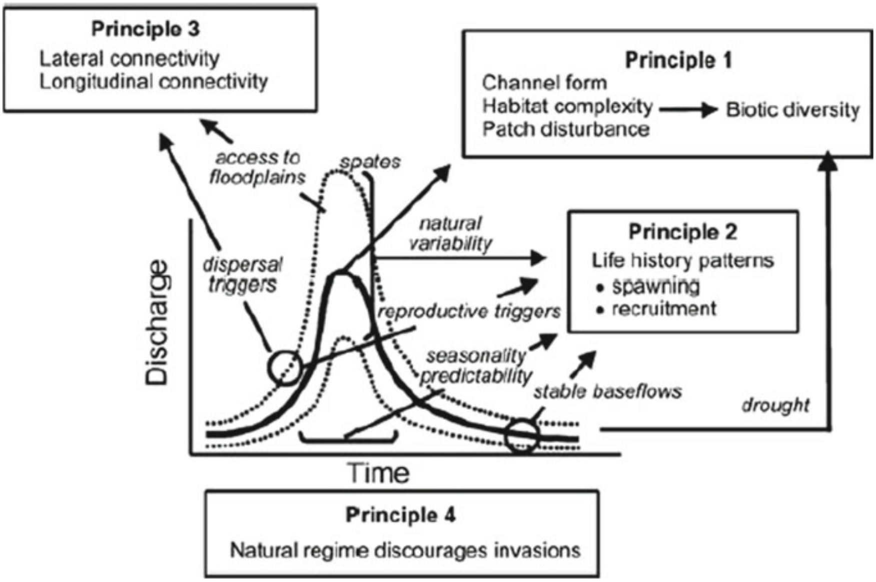

Fig. 30.4 Graphical representation of the natural flow regime of a river showing how it influences aquatic biodiversity via several, inter-related mechanisms (Principles 1–4) that operate over different spatial and temporal scales. Adapted from Dudgeon et al. (2006) and Bunn and Arthington (2002)

influence life-history patterns, especially the seasonality and predictability of the overall pattern, but also the timing of particular flow events (Principle 2, Fig. 30.4). Some flow events trigger longitudinal dispersal of migratory aquatic organisms, and other large events allow access to otherwise disconnected floodplain habitats (Principle 3, Fig. 30.4). The native biota of rivers has evolved in response to the local flow regime. Catchment land-use change and associated water resource development inevitably lead to changes in one or more aspects of the flow regime resulting in declines in aquatic biodiversity via these mechanisms. Invasions by introduced or exotic species are more likely to succeed at the expense of native biota if the former happen to be adapted to the modified flow regime (Principle 4, Fig. 30.4).

Two major motives drive the protection of flows in rivers: (i) preservation of the diversity of species (food chain) and (ii) fisheries. Accordingly, the approaches to the conservation of river fish generally adopt either a "species" or "ecosystem" approach. Ecosystem approach is a strategy for integrated management of land, water and living resources that promotes conservation and sustainable use in an equitable manner. It strives to balance diverse societal objectives by taking into account the biotic, abiotic and human components of the aquatic ecosystems and their interactions. However, due to the great diversity of river fish faunas, especially in large, tropical systems, it is almost impossible to consider the flow requirements of all species. Therefore, an ecosystem approach is generally preferred by fishery biologists, who would prefer to fix flow requirements for a few fishes selected on the basis of their conservation or commercial value.

As discussed earlier, in a river basin, water is used for a number of purposes. Freshwater fishery is a sector that critically depends on good quality water flowing in a river and presence of right kind of habitats. Water needs for fishery fall in the in-stream use. Water need not be removed from the river, and it is not consumed in any appreciable quantity. However, fishery has huge importance in many states in India where fishes are a major source of food (nutrition), and a large segment of population depends on fishery for their livelihood. Hence, it is argued that the demands for fishery in terms of water depth, velocity and habitat conditions should be considered along with other sectors/demands. In India, a large variety of fishes are found in the river basins. Table x contains a partial list of fishes found in India rivers along with the water depth, velocity and other requirements at different life stages.

30.9 Conclusions

This article suggests that the requirements from fishery sector should be made an integral part of river basin planning and management. This can be accomplished quite easily as it will not require any additional tool or technique but will bring the current practices closer to IWRM. For sustainable fisheries in the inland open waters including rivers, wetlands and estuaries, water flows in terms of environmental flows should be ensured, which must be taken into account both at basin level as well as at ecosystem-based participatory approach, therefore, ensuring the sustainable fisheries through effective water resources management under the approach of integrated water resources management practices.

References

Arthington AH, Pusey BJ (2003) Flow restoration and protection in Australian rivers. River Res Appl 19:377–395

Bunn SE, Arthington AH (2002) Basic principles and ecological consequences of altered flow regimes for aquatic biodiversity. Environ Management 30:492–507

Dudgeon D, Arthington AH, Gessner MO (2006) Freshwater biodiversity: importance, threats, status and conservation challenges. Biol Rev 81:163–182

FAO (2020) The state of world fisheries and aquaculture 2020. https://doi.org/10.4060/ca9231en

Fish Site (2020) The state of world fisheries and aquaculture 2020 (fao.org)

Jain Sharad K, Acreman MC (2017) Environmental flows. In: Singh VP (ed) Handbook of applied hydrology. McGraw-Hill, New York

Sahoo AK, Sharma AP, Suresh VR (2016) Managing rivers: ecohydrology an effective tool under changing climate. Natl Acad Sci Lett (May–June 2016) 39(3):229–232

Poff NL, Allan JD, Bain MB et al (1997) The natural flow regime: a paradigm for river conservation and restoration. BioSci 47:769–784

Pollard P, Huxham M (1998) The European water framework directive: a new era in the management of aquatic ecosystem health? Aquat Conserv Mar Freshwat Ecosyst 8:773–792

Richter BD, Baumgartner JV, Wigington R et al (1997) How much water does a river need? Freshwater Biol 37:231–249

Ward JV, Stanford JA (eds) (1979) The ecology of regulated streams. Plenum, New York, p 398

Zalewski M (2000) Ecohydrology—the scientific background to use ecosystem properties as management tools toward sustainability of water resources. Guest Editorial. Ecol Eng 16:1–8

Chapter 31
Genetic Resources of Livestock and Poultry in Coastal Ecosystems of India

Ajoy Mandal, Ishani Roy, Mokidur Rahman, and M. Karunakaran

Abstract Animal husbandry has an important role along with agricultural activities and provides considerable income for the farmers of the coastal regions. The coastal region of India is enormously rich in animal genetic diversity, which includes 35 well-recognized livestock and poultry breeds. The coastal region constitutes about 14.2% of the total Indian landmass of the country, but the region possesses 19.5% of the livestock population of total Indian livestock. The cattle and buffalo population in the coastal region of India is 19.41 and 9.08 million, respectively. The coastal region registered a significant increase in sheep, goat and poultry population over the years. However, a decrease (17.6%) in the pig population was observed over the years in coastal regions. Different cattle breeds like Gir, Kankrej, Tharparkar, Dangi, Ongole, Vechur, Malnad Gidda, Shweta Kapila, etc., are available in the coastal regions of India. Different buffalo breeds like Banni, Jaffarabadi, Mehsana, Murrah, Surti, Chilika and Gounti/local breeds are found in the coastal region of India. Goat breeds like Ganjam, Gohilwadi, Kutchi, Mehsana, Konkan Kanyal, Kanni Adu, Attappady Black, Teressa and Black Bengal are prevalent in the coastal region. Sheep breeds like Ganjam, Kendrapara Patanwadi, Marwari Nellore, Chevaadu, Kilakarsal, Madras Red, Vembur, Garole and Chottanagpuri cover large areas in these coastal regions. Backyard poultry breeds such as Ankaleshwar, Danki, Kalasthi, Bursa, Haringhata Black, Nicobari, Tellichery and Giriraja are boon to rural areas of coastal regions. Crosses of Yorkshire, Agonda Goan and Nicobari pigs are identified as the suitable breeds for coastal tropical humid climates and popularized. Shortage of feeds and fodder and availability of quality germplasm for breeding of the animals are the

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major constraints for livestock development in coastal regions of India. Some of the local cattle breeds like Ongole and Vechur are on the verge of extinction due to non-scientific breeding practices and need immediate intervention. Due to high human population density and influx of floating population, there are more threats in the form of outbreaks of diseases and recurrence of infectious diseases. To increase the productivity of the livestock to achieve self-sufficiency for the coastal regions, efforts are to be made to adopt better breeding practices for the livestock, improve the feed and fodder resources, healthcare facilities and support rural poultry and piggery development.

Keywords Coastal ecosystems · Genetic resources · Livestock · Poultry

31.1 Introduction

The coastal ecosystem commands the world's highest importance by virtue of its biological diversity and productivity. In India, the coastal region is spread across nine states (Gujarat, Maharashtra, Goa, Karnataka, Kerala, Tamil Nadu, Andhra Pradesh, Odisha and West Bengal) and five union territories (Andaman and Nicobar, Lakshadweep, Puducherry, Daman and Diu and Dadra and Nagar Haveli) and is broadly classified into four agro-ecological regions, viz., Gujarat region, west coast, east coast and the islands. The west coast is located between Kerala and Gujarat and extends from the Arabian Sea to the Western Ghats and comprises of five states, namely Gujarat, Maharashtra, Goa, Karnataka, Kerala and four Union territories (Puducherry, Daman and Diu, Lakshadweep and Dadra and Nagar Haveli) and is characterized by sandy beaches, mudflats, sand dunes, alluvial tracts, estuaries, lagoons and residual hills. The east coast is washed by the Bay of Bengal and extends from the Ganga delta to Kanyakumari comprising four states, namely Tamil Nadu, Andhra Pradesh, Odisha, West Bengal and one union territory (Andaman and Nicobar). Animal husbandry has a major role in agricultural development and provides livelihood to rural families in the coastal region. The livestock sector plays an important role in the national economy as it contributes about 5.2% to the total gross domestic product (GDP) of India and 28.4% of the GDP/gross value added (GVA) in the agriculture and allied sectors (DAHD 2021). As per the Ministry of Statistics and Programme Implementation (MOSPI 2019–2020), the contribution of livestock to the economy of coastal states was estimated as about 2.4% to the total GDP of India and 13.3% of the GDP/GVA of agriculture and allied sector. The coastal area is dominated by cattle followed by goats, sheep, buffaloes and pigs. Different native breeds along with crossbreds are available in the coastal regions of India. The vast population and diversity of livestock in coastal India are vital assets for the country, and a sustainable livestock production system will continue to propel coastal agriculture through sound integration.

Table 31.1 State/UT wise livestock population in coastal regions of India

States/UTs	Population (′000)					
	Cattle	Buffalo	Sheep	Goat	Pig	Total livestock
Andaman and Nicobar (AN)	36.44	3.70	0.01	64.76	40.49	145.39
Dadra and Nagar Haveli (DN)	39.74	0.997	0.08	7.55	0.00	48.37
Daman and Diu (DD)	1.84	0.374	0.07	0.99	0.00	3.27
Lakshadweep (LD)	2.49	0.016	0.00	43.19	0.00	45.70
Puducherry (PY)	71.98	2.40	2.45	73.63	0.88	151.33
Andhra Pradesh (AP)	2659.74	4940.94	7147.87	2913.70	60.97	17,723.22
Goa (GA)	60.25	27.21	0.01	9.45	35.48	132.39
Gujarat (GJ)	3136.99	3314.58	1191.35	1532.87	0.43	9176.22
Karnataka (KA)	841.66	78.23	9.26	45.55	10.84	985.53
Kerala (KL)	1342.00	101.50	1.48	1359.16	103.86	2908.01
Maharashtra (MH)	600.63	271.58	5.72	225.72	4.37	1108.03
Odisha (OD)	4101.17	136.63	370.30	1717.34	24.41	6349.84
Tamil Nadu (TN)	3700.93	152.74	1328.62	4227.72	24.83	9434.82
West Bengal (WB)	2810.60	46.42	122.56	2046.82	16.48	5042.87
Total	19,406.44	9077.31	10,179.76	14,268.43	323.04	53,254.98

Sources BAHS 2019 and Livestock Census 2019

31.2 Livestock Population in Coastal India

While constituting 12.14% of the total Indian landmass of the country, the coastal region possesses 19.5% of the total livestock population of the country with 53.25 million heads in which Andhra Pradesh has the highest livestock population (33.28%) followed by Tamil Nadu (17.72%), Gujarat (17.23%), Odisha (11.92%) and West Bengal (9.47%). These five states possess more than 89% of the total coastal livestock population (Table 31.1).

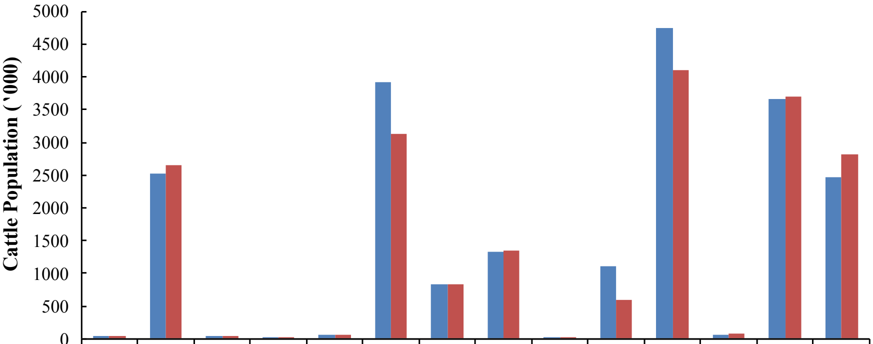
31.3 Livestock and Poultry Resources in Coastal India

The coastal region of India is enormously rich in animal genetic resources with 53 registered livestock breeds (NBAGR, 2020) in this region, including 12 cattle, 5 buffalo, 12 goat, 11 sheep, 2 pig, 2 camel, 2 horse, 2 donkey and 7 poultry breeds, besides some non-descript animals. Animals of coastal belts possess the capability to thrive in the harsh and diverse coastal climate.

31.3.1 Genetic Resources of Cattle

The total population of cattle in the coastal region of India is 19.41 million (Livestock census 2019) which shows a decline of 6.64% from 2012 (Livestock census 2012). Among the coastal states/UT, Odisha has the highest population of cattle followed by Tamil Nadu and Gujarat, whereas Daman and Diu and Lakshadweep have the lowest cattle population (Fig. 31.1). Most of the coastal states/union territories showed negative growth of cattle population except in Puducherry, West Bengal, Andhra Pradesh, Goa, Kerala and Tamil Nadu where the cattle population was increased by 20.18, 14.04, 5.78, 4.81, 1.00 and 0.95%, respectively, from 2012 to 2019. Among the 50 cattle breeds of India, 12 recognized breeds, viz., Gir, Kankrej, Tharparkar, Dangi, Ongole, Vechur, Malnad Gidda, Shweta Kapila, Umblachery, Konkan Kapila, Ghumusari and Binjharpuri, belong to the coastal region of India.

Gir is a well-known cattle breed for its performing ability under harsh conditions with sub-optimal nutrition and for its longer herd life (Gajbhiyeet al. 2016). The average lactation yield of Gir cattle is 2110 kg with 4.6% milk fat. Kankrej, a dual-purpose cattle breed, has its origin in the Kank area in Banaskantha district of coastal Gujarat (Sodhi et al. 2006). The milk yield of this breed ranges from 800 to 1800 kg with an average of 1738 kg per lactation. Tharparkar, a well-known milch breed of India, is found along the Indo-Pak border covering Western Rajasthan up to Rann of Kutch in Gujarat. This breed is considered as the hardiest, disease-resistant,



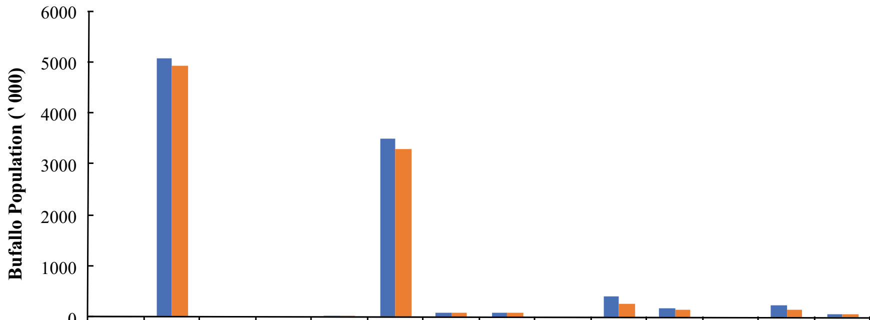
	AN	AP	DN	DD	GA	GJ	KA	KL	LD	MH	OD	PY	TN	WB
2012	45.625	2514.5	41.87	2.096	57.48	3915.5	842.74	1328.6	3.099	1106.3	4738.6	59.896	3666.2	2464.5
2019	36.438	2659.7	39.736	1.84	60.247	3137	841.66	1342	2.493	600.63	4101.2	71.984	3700.9	2810.6

Fig. 31.1 State-wise cattle population in the coastal region of India during 2012 and 2019

heat-tolerant and tick-resistant indigenous cattle of India and is being widely used for upgrading the low productive non-descriptive cattle under Indian conditions (Choudhary et al. 2018). The average lactation yield of this breed was recorded as 1749 kg with 4.88% of milk fat. Dangi is a medium-sized cattle breed found in the coastal region of the Thane district of Maharashtra. The breed is well known for its excellent working capabilities in heavy rainfall areas, rice fields and hilly tracts. The skin exudes an oily secretion that protects them from heavy rain. The Ongole is an extremely docile and dual-purpose cattle breed found in East Godavari, Guntur, Ongole/Prakasam and Nellore districts of Andhra Pradesh. Majestic gait, stumpy horns and large fan-shaped and fleshy dewlap are the characteristics of this breed. The average lactation yield of this breed is estimated as 798 kg with 3.79% milk fat. Vechur, an extremely small-sized cattle with a compact body, is found in the Alappuzha/Alleppey, Kottayam, Pathanamthitta and Kasaragod districts of Kerala. Vechur cattle are well adapted to hot and humid climates (Iype 2013). They are mostly reared for milk and manure purposes. The average milk yield of this breed is 561 kg per lactation. Malnad Gidda, a small-sized cattle breed, is found in the Dakshina Kannada, Udupi and Uttar Kannada districts of Karnataka. The milk yield of this breed ranged from 0.5 to 3.7 L per day (Ramesha et al. 2013; Murugeppa et al. 2020). Shweta Kapila is the only cattle breed found in the coastal region of the North and South Goa districts. This breed is well adapted to hot and humid weather and is reared mainly for milk production. Farmers of North Goa believe that milk of Shweta Kapila has medicinal properties. Umblachery is a light built draught cattle of India, which is distributed in Nagapattinam and Thiruvarur coastal areas of Tamil Nadu. This breed is well suited for ploughing in marshy paddy fields and also in the alluvial types of soil. The average lactation yield was about 494 kg with 4.94% milk fat (Rajendran 2007). Konkan Kapila, a small to medium-sized cattle, is predominantly available in Thane, Raigad, Ratnagiri and Sindhudurg coastal areas of Maharashtra. The milk yield of the Konkan cows varied from 0.5 to 6 kg per day with an average of 2.23 kg per day (Singh et al. 2019). The average lactation yield of this breed was observed as 450 kg with 4.5% milk fat. Ghumusari is a small-sized, strong and draft type of cattle distributed in the Ganjam coastal area of Odisha. Ghumusari cattle are mostly reared under a semi-intensive management system with very low input without any concentrates or feed supplement (Das et al. 2011). The lactation yield of this breed was about 450 kg. Bullocks are well known for their draftability and can be used in agricultural operations. Binjharpuri is a medium-sized, predominantly white colour, dual-purpose cattle distributed in the Jajpur, Bhadrak and Kendrapara districts of Odisha. They are primarily reared under the extensive system of management. The lactation yield of this breed ranges from 915 to 1350 kg.

31.3.2 Genetic Resources of Buffalo

The coastal region of India is one of the repositories of diverse buffalo genetic resources accounting for five breeds (Chilika, Banni, Jaffarabadi, Mehsana and Surti)



	AN	AP	DN	DD	GA	GJ	KA	KL	LD	MH	OD	PY	TN	WB
2012	7.863	5098.	4.062	0.43	31.79	3504.	100.3	102.2	0	396.8	185.3	2.109	226.7	46.62
2019	3.7	4940.	0.997	0.374	27.20	3314.	78.23	101.5	0.016	271.5	136.6	2.395	152.7	46.41

Fig. 31.2 State-wise buffalo population in the coastal region of India during 2012 and 2019

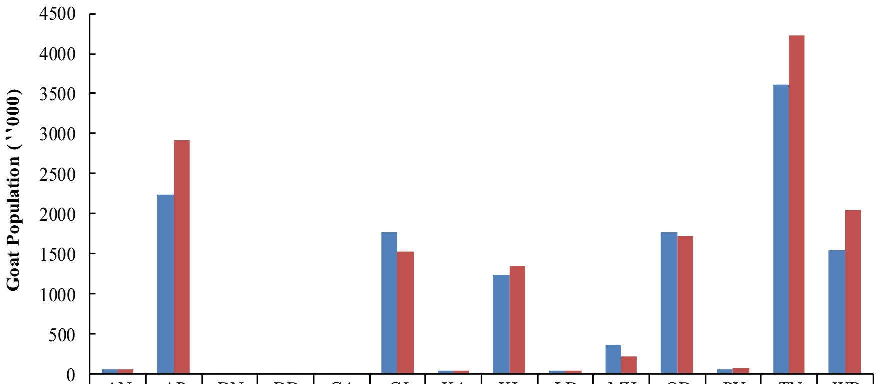
out of 17 registered buffalo breeds of the country (NBAGR 2020). The total buffalo population of the coastal region is 9.08 million which contributes 8.27% of the total buffalo population of India (Livestock Census 2019). Andhra Pradesh, Gujarat, Maharashtra and Tamil Nadu are the leading states having the highest buffalo population of coastal regions (Fig. 31.2). There is a declining trend (−6.47%) of buffalo population dynamics from 2012 to 2019 in the coastal region of India.

Chilika, a medium-sized and dual-type buffalo, is generally distributed in Cuttack, Ganjam, Puri and Khurda coastal areas of Odisha. The animals are familiar with night grazing on weeds of Chilika Lake, with a herd size ranging from 10 to 70. This breed possesses the unique capability of converting the saline biomass into milk and manure (Singh et al. 2017). Chilika buffalo produces approx. 500 kg milk with 8.7% of milk fat per lactation. Banni is a medium to large-sized, predominantly black-coloured buffalo found in the Kutch district of Gujarat. Banni buffaloes have a very good genetic potential for milk production and are the major source of livelihood for the Maldhari communities of Gujarat (Mishra et al. 2009). The average lactation yield and milk fat content are estimated as 2857.2 kg and 6.65%, respectively. Jaffarabadi is a large-sized buffalo breed found in Amreli, Bhavnagar, Jamnagar, Junagadh and Porbandar regions of Gujarat. This breed is the heaviest buffalo breed in the country and is known for its fighting ability with lions in Gir forest. These buffaloes are high yielders and produce 2239 kg of milk per lactation with 6.8 to 8.5% of milk fat. Mehsana is another buffalo breed found in the Ahmedabad coastal belt of Gujarat. Mehsana buffaloes are known for their persistent milking and regular breeding capability. The lactation yield of Mehsana buffalo ranges from 598 to 3597 kg. Surti is a medium-sized, grey to black-coloured buffalo with characteristics sickle-shaped horns and is found in the Bharuch and Surat districts of Gujarat. This buffalo breed is mainly kept for milk production. The average milk yield per lactation and fat % are 1667 kg and 7.02%, respectively.

31.3.3 Genetic Resources of Goat

The goat population in the coastal region of India is 14.27 million comprising 9.58% of the total goat population of India. There is an upward growth of the goat population (11.63%) in the coastal region from 2012 to 2109 (Livestock Census 2019). Among the states/UTs, the coastal region of Dadra and Nagar Haveli (80.88%), Puducherry (33.99%) and West Bengal (31.99%) showed the highest growth rate of goat population, whereas Daman and Diu (−51.97%), Maharashtra (−37.57%) and Goa (−27.10%) showed the highest declining rate of goat population from 2012 to 2019 (Fig. 31.3). These regions have a tremendous diversity of goat population and are the home tract of 12 registered goat breeds.

Ganjam goat belongs to Ganjam, Gajapati, Khurda and Nayagarh districts of Odisha. This breed is maintained by the Gola tribe native to the Ganjam district for their milk production. The average milk yield of these goats is reported to be 350 mL day^{-1}, whereas total milk production of 75 L in 160 days of lactation period (Rao et al. 2009). Fat percentage is as high as 3.92. Adult body weights for males and females are 35.05 and 28.87 kg, respectively. Attappady Black is a meat-type goat breed that belongs to the Attappady region of Palakkad district in Kerala. Adult body weights for males and females are reported as 34.5 and 31.3 kg, respectively (Stephen et al. 2005). Malabari, a highly prolific goat, is mainly found in Malappuram, Wayanad and Kannur districts of Kerala. The breed is having a good prolificacy rate, i.e., 50% twinning, 25% triplets and 5% quadruplets. The milk yield varied from 0.5 to 1.5 L day^{-1} (Verma et al. 2009). Adult body weights for males and females are recorded as 41.2 and 30.7 kg, respectively (Verma et al. 2009). The home tract of the Konkan Kanyal goat breed is the Sindhudurg district of Maharashtra. The breed is



	AN	AP	DN	DD	GA	GJ	KA	KL	LD	MH	OD	PY	TN	WB
2012	65.324	2239.2	4.173	2.055	12.958	1766.8	40.189	1246.1	46.497	361.54	1774.8	54.95	3616.2	1550.8
2019	64.761	2913.7	7.548	0.987	9.446	1532.9	45.546	1359.2	43.188	225.72	1717.3	73.63	4227.7	2046.8

Coastal States and Union Territories

Fig. 31.3 State-wise goat population in the coastal region of India during 2012 and 2019 well adapted to the hilly region of the Konkan coast having high rainfall and humid conditions. Kanyal goats are maintained by the Dhangar and Maratha communities of Konkan region mainly for meat purpose (Verma et al. 2012). The dressing percentage is as high as 53% for these goats. Adult body weights for males and females are 49.9 and 31.8 kg, respectively.

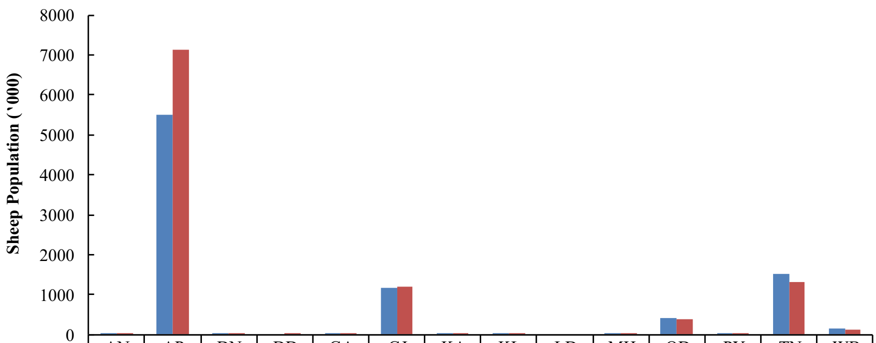
Gohilwadi goat, a dual-purpose breed, is native to Amreli, Bhavnagar, Junagadh and Porbandar districts of Gujarat. These goats are adapted to a wide range of climatic conditions from arid in the west to humid in the coastal region (Singh et al. 2009). Milk yield per lactation is as high as 250 kg, and fleece weight is 3.17 kg yr^{-1}. Adult body weights for males and females are 52.04 and 41.67 kg, respectively. The Kahmi goats are found in Jamnagar, Junagadh and Devbhumi Dwarka districts of Gujarat. Mainly, nomadic communities maintain this breed as these animals are good milk yielders, having approx. 326 kg milk per lactation with about 3.4% of fat. Meat production is also good with 52% of dressing percentage. Adult body weights for males and females are 56.4 and 48.35 kg, respectively. Kutchi/Kathiwari goat breed is native to the coastal Kutch district of Gujarat. The breed is reared for its meat, milk and fibre. A high (58%) dressing percentage is observed in this breed. Kutchi goat produces 70–95 kg milk in 90–120 days of lactation. Kidding and twinning rate of this breed are reported as 70 and 11.68 %, respectively (Kumar et al. 2006). The adult body weight was 58.45 and 38.78 kg for males and females, respectively (Kumar et al. 2006). Mehsana goat is found in the coastal Ahmedabad district of Gujarat. This is a dual-purpose breed, reared for both meat and milk. The dressing percentage is about 58% for this breed. Patel and Pandey (2013) reported the total milk yield was 70.23 ± 1.37 L and fat percentage of 3.17% for Mehsana goat. Adult body weights for males and females are 37 and 32 kg, respectively. Surti, also popularly known as Khandeshi/Kungi/Nimari/Patiri, belongs to Bharuch, Valsad, Surat and Navsari districts of Gujarat. This breed is reared for milk and meat purpose. Twin births are very common (50–60%) for this breed. Milk yield per lactation was recorded as about 317 kg. The adult body weights of males and females were 29.3 and 31.6 kg, respectively. Kodi Adu/PoraiAdu goats are found in Ramanathapuram and Tuticorin district of Tamil Nadu. This breed is reared for meat, skin and manure by small, marginal and landless farmers of that region. The dressing percentage is observed as 48% for these animals. The adult body weights of males and females were 23.43 and 30.94 kg, respectively. Teressa/Pookore goat breed is a newly registered breed native to the Nicobar district of Andaman and Nicobar Islands. The pure form of this breed is reared by Nicobari tribal farmers of Teressa Island, Car Nicobar and the Nancowrie group of Islands. This is a meat-type breed with a dressing percentage of 47%. Its body weight reaches about 60–65 kg in 4 years as reported by Sunder et al. (2016). For this breed, the average milk yield may go up to 1.0 L per day with a lactation yield of 56 kg. The adult body weights of males and females were 39.85 and 31.94 kg, respectively. Black Bengal goat is native to Midnapore, North and South 24 Parganas districts of West Bengal. This breed is famous for its high prolificacy, excellent chevon quality and morocco leather production from its skin. The dressing percentage is quite high, i.e., 56%. Twin and triplet births are common in this breed. The total distribution of types of birth in Black Bengal goats was reported as 35.8%

singlet, 47.6% twins and 16.6% triplets in the first year, 30.6% singlet, 58.4 twins and 11% triplets in second year and 40.4% singlet, 54.6% twins and 5% triplets in third year (Tudu et al. 2015). The adult body weights of males and females were 32.37 and 20.93 kg, respectively.

31.3.4 Genetic Resources of Sheep

The coastal region of India possesses 10.18 million sheep which is 13.71% of the country's total sheep population. The sheep population of this region showed positive growth (16.55%) from 2012 to 2019 (Livestock Census 2019). The maximum growth of the sheep population was observed in the coastal region of Kerala (80.87%) followed by Maharashtra (62.83%) and Puducherry (52.72%). However, coastal regions of a few states/UTs such as Dadra and Nagar Haveli, West Bengal, Tamil Nadu, Odisha and Goa have a declining trend of sheep population from the previous livestock census (Fig. 31.4). Out of 43 sheep breeds of the country, these regions possess 11 registered sheep breeds.

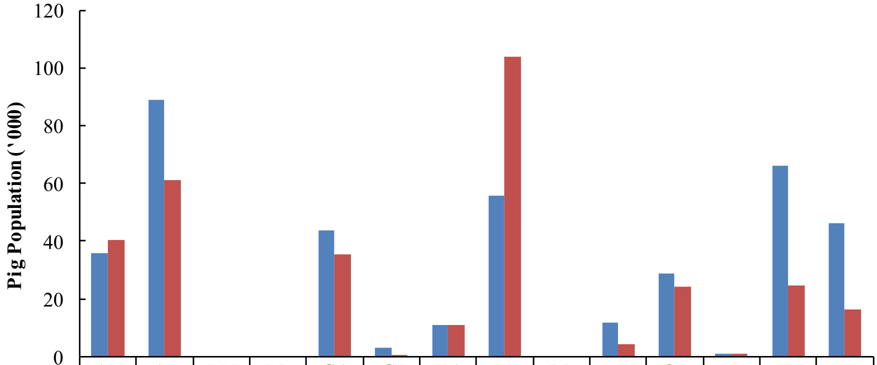
Chevaadu or Arichevaadu is, a small breed of sheep, mainly found in the coastal Tirunelveli district of Tamil Nadu. This breed is unique and economically important due to its survivability on dry land as well as near coastal area ecosystem and low-input system and has better disease resistance. This sheep is reared for meat, skin, manure and religious and cultural use (Ravimurugan 2017). Adult body weights for males and females were 26.12 and 21.30 kg, respectively (Ravimurugan et al. 2012). The breeding tract of Kilakarsal (Keezhakkaraisal, Karuvai, Keezha Karuavai) sheep breed falls under coastal Tirunelveli and Thoothukudi/Tuticorin districts of Tamil Nadu. Kilakarsal is mainly reared for meat purpose. This breed has an inherent



	AN	AP	DN	DD	GA	GJ	KA	KL	LD	MH	OD	PY	TN	WB
2012	0.003	5498.9	0.124	0.001	0.024	1156.9	5.118	1.446	0	3.514	399.23	1.601	1504.5	162.77
2019	0.005	7147.9	0.084	0.068	0.008	1191.3	9.257	1.482	0	5.722	370.3	2.445	1328.6	122.56

Coastal States and Union Territories

Fig. 31.4 State-wise sheep population in the coastal region of India during 2012 and 2019 capacity to utilize coarse feeds efficiently (Sundararaman and Ravimurugan 2008). Adult body weights for males and females were 24.75 ± 1.04 and 23.28 ± 0.37 kg, respectively (Ravimurugan et al. 2012). Madras Red, a meat-type sheep breed, is generally found in Chennai, Villupuram, Kancheepuram, Thiruvallur and Cuddalore districts of Tamil Nadu. This breed is a good yielder, and the dressing percentage was 48–49% (Raman et al.2003). Adult body weights for males and females were 35.20 ± 0.32 and 23.12 ± 0.14 kg, respectively (Raman et al. 2003). Vembur or Karandhal sheep breed is found in the coastal Thoothukudi/Tuticorin district of Tamil Nadu. Vembur sheep have better sustainability in both dry land and coastal areas under the low-input management system. This is a large type of sheep breed, and adult male and female animals had body weights of 40.0 and 27.9 kg, respectively (Ravimurugan et al. 2012). Chottnagpuri sheep is found in the coastal region of Midnapore district of West Bengal. This meat breed is maintained by tribals in its breeding tract. The dressing percentage of this breed is about 48%. Adult body weights for males and females are 19.5 and 19.7 kg, respectively. Garole sheep, also called Meda or Bheda, is a highly prolific micro-sheep breed and is found in the coastal North and South 24 Parganas districts of West Bengal. The breed is popular for its main characteristics like high prolificacy rate, adaptability to hot humid conditions and saline marshy land of Sunderban, survivability under low-input system, grazing capability in knee-deep water, resistance to foot rot disease and high mothering instinct for the lambs. The dressing percentage of Garole sheep varied from 48.3 to 66.6% as reported by Banerjee and Banerjee (2000) and Banerjee et al. (2009). Ganjam sheep, a mutton producing breed, belongs to the Ganjam and Puri districts of Odisha. The average body weights at puberty for males and females were 13.95 ± 0.18 and 16.69 ± 0.16 kg, respectively (Nayak et al. 2008). The breeding tract of Kendrapada (Kuzi) sheep is Cuttack, Puri, Jagatsinghpur, Jajpur, Bhadrak and Kendrapara districts of Odisha. This sheep is popular for low-fat mutton, good quality skin and manure. Kendrapada sheep is the second most prolific sheep breed of India after Garole sheep (Dash et al. 2017). Twining percentage is reported to be very high during the second (74%) and third (78%) lambing (Patro et al.2006). Adult body weights for males and females are 28.35 and 27.29 kg, respectively. The dressing percentage of this breed is reported as 48%. Nellore is the tallest sheep breed of India, which belongs to the coastal Ongole/Prakasam and Nellore districts of Andhra Pradesh. The dressing percentage of this sheep is nearly 47%. Adult body weights for males and females are 36.69 and 30.00 kg, respectively. Panchali sheep, also known as Baraiya/Dooma/Dumma/Panchali-dumma, belongs to the Bhavnagar, Kutchchh districts of Gujarat. They are generally reared as milch breed, as they are very good milk yielders. Male lambs of 3–6 months of age are used for meat purpose. Patanwadi sheep breed is found in Amreli, Bhavnagar, Jamnagar, Junagadh, Kutch districts of Gujarat. This sheep is maintained for wool and meat purpose. The fleece production by this breed is around 1.05 kg yr^{-1}.



	AN	AP	DN	DD	GA	GJ	KA	KL	LD	MH	OD	PY	TN	WB
2012	35.92	88.88	0	0	43.57	3.01	11.05	55.78	0	11.95	28.94	1.01	66.05	46.08
2019	40.49	60.97	0	0	35.48	0.431	10.84	103.9	0	4.372	24.41	0.88	24.83	16.48

Coastal States and Uniton Territories

Fig. 31.5 State-wise pig population in the coastal region of India during 2012 and 2019

31.3.5 Genetic Resources of Pig

Pig can be considered as one of the important and valuable livestock in the coastal region of India. The total pig population in the coastal region of India is 0.32 million, which constitutes 3.53% of the country's pig population (Livestock Census 2019). There was a noticeable decline in the pig population (−17.64%) of the coastal region from 2012 to 2019. Among the states/UTs, coastal regions of Kerala, Andhra Pradesh, Andaman and Goa are the leading states holding the highest pig population (Fig. 31.5). The pig population in the coastal region of most of the state/UTs showed negative growth of pig population except Kerala and Andaman Nicobar where the pig population increased by 86.19 and 12.71%, respectively, from 2012 to 2019 (BAHS 2019). The pig population of this region is mostly of non-descriptive and crossbred types. Among the ten registered pig breeds, only two pig breeds belong to the coastal region. Agonda Goan and Nicobari pigs were identified as suitable breeds for coastal tropical humid climates and have been popularized.

31.3.6 Genetic Resources of Poultry

The coastal region of India is one of the major hubs in the diversity of poultry genetic resources. Out of the 19 registered chicken breeds, seven breeds belong to the coastal region of India. Besides, several non-descript and commercial chicken varieties are also available in this region. The poultry population in the coastal region of India is 143.84 million which contributes 19.73% of the total poultry population of the country (Livestock Census 2012). Andhra Pradesh and Tamil Nadu, which comprise long coastal areas, have emerged as the powerhouse of poultry production. Among the different states/UTs, the coastal region of Andhra Pradesh is the leading with the highest poultry population which alone contributes 44.1% of the total poultry population of this region. Kerala and West Bengal contribute 16.9 and 8.9% of the total poultry population of the coastal region of India. Backyard rearing of poultry like Ankaleshwar, Danki, Kalasthi, Bursa, Haringhata Black, Nicobari, Tellichery, Giriraja and dual-purpose poultry would be a boon to rural areas of the coastal region of India.

Ankaleshwar breed is distributed in the Bharuch coastal region of Gujarat. This breed is reared in a free-range backyard system with flock sizes of 5–10. They are mainly used for meat and egg production. The average slaughter weights of cock and hens were 1.49 and 1.76 kg, respectively, and hen produces about 789 eggs annually (Tantia et al. 2006). Bursa is a small-sized poultry breed found in the coastal area of Surat. Danki is the fastest-growing heavy and large-sized poultry breed found in coastal Srikakulam, Vizianagaram and Vishakhapatnam districts of Andhra Pradesh. They are mostly reared under the backyard management system. These birds are reared for game (fighting) purpose and can fight continuously for 1 to 1½ hours (Vij et al. 2005). The average body weights of males and females were recorded as 3.1 and 2.2 kg, respectively. Kalasthi birds are distributed in the Nellore district of Andhra Pradesh. Kalasthi birds, mainly reared for meat production, are having an average body weight of 2.5 and 1.9 kg for males and females, respectively, and the annual egg production was about 34 (Vijh et al. 2005). Haringhata Black is a meat-cum-egg-type backyard poultry breed found in coastal areas of North 24 Parganas district of West Bengal. Birds of this breed are agile and able to dodge predators. The average body weights of male and female birds were 1.28 and 1.12 kg, respectively, and annual egg production was 45 (Vij et al. 2015). Nicobari is a brown-coloured, medium-sized and hardy bird found in Andaman and Nicobar districts. Body weights of cock and hen of this breed are 1.8 and 1.3 kg, respectively. The annual egg production ranged from 112 to 237 in Nicobari birds. Tellichery chicken is a breed native to the Malappuram and Kannur districts of Kerala. This breed is thought to have medicinal value and is used for the preparation of ayurvedic medicine for asthma treatment. Vij et al. (2008) reported that the average body weight of cock and hen was 1.62 and 1.24 kg, respectively, and the egg production ranged from 60 to 80 per year.

31.3.7 Genetic Resources of Other Livestock

Besides cattle, buffalo, sheep, goat and pig, the coastal region is also the home tracts of some other important livestock such as camel, horse and donkey. This region has two registered camel breeds. Kharai breed is well adapted in the coastal ecosystem of Kutch district and can tolerate water with high total dissolved solids (TDS) and can be utilized for transportation, border security and tourism. Kutchi is another camel breed found in the coastal region of Kutch and is generally known for its adaptability in harsh climatic conditions and salty and marshy lands of the coastal region. They are mainly reared for milk as well as draft purpose. Among the three donkey breeds, two breeds, like Halari and Kachchhi, belong to the coastal region. Two well-known horse breeds, viz., Kathiawari and Kachchhi Sindhi, are also the pride of the coastal region of India.

31.4 Challenges in Livestock Production

The livestock production system in the coastal region is less stable than the other regions of the country due to climatic and non-climatic stresses affecting coastal agriculture in a complex manner (Burke et al. 2001). Due to its proximity towards the ocean and sea, the coastal ecosystem is more prone to natural disasters like cyclones, tsunamis, sea rise as well as heavy rainfall which directly and indirectly affected agricultural as well as livestock production systems (Singh 2020). Climate changes have harmful effects on the coastal ecosystem (NIBIO 2019), which become potential threats to the survival and production efficiency of many livestock species. Thornton et al. (2007) also stated that heavy rainfall and fluctuation in ambient temperature may lead to an increase in stress, high incidence of metabolic diseases and outbreak of many vector-borne parasitic diseases in the coastal region. Salinity is one of the most common problems faced by farmers affecting both crops and livestock. The salinity of water often leads to diarrhoea, loss of body weight and decreased immune system of animals (Alam et al. 2017), which ultimately increases herd mortality and lowers the production potential of animals. Shortage of feed and fodder and non-availability of superior germplasm for breeding of animals are some of the major constraints for livestock development in the coastal region of India. To increase the milk production of indigenous breeds, cross-breeding with exotic germplasm may often lead to the dilution of native gene pools of indigenous animals of this region. Thus, many of the indigenous breeds are in vulnerable status and facing the potential risk of being extinct. Cattle breeds like the Ongole breed of coastal Andhra and Vechur breed of Kerala are on the verge of extinction due to non-scientific conservation practices, and they need immediate scientific intervention for conservation. Besides, with the increased urbanization, industrialization, population density/pressure on coastal ecosystem and enhanced importance of other new sectors such as tourism and mining, the agricultural and livestock sectors are being given lesser economic importance, and the number of people engaged in the livestock sector is declining day by day. Increasing productivity of the livestock through breeding, improving feed and fodder sources, improved health care, rural poultry and piggery development are the key concerns for livestock development in the coastal regions of India.

31.5 Actions Required

Attempts should be made towards sustainable livestock husbandry practices considering the existing climatic conditions in coastal India. Identifying the most vulnerable areas for natural calamities and developing mitigation strategies may reduce the adverse impact of natural calamities on livestock production. Efforts should be made to identify local germplasm with their region-specific adaptability to cope up with climate change. Development of economic feeding strategies to enhance milk and meat production by scientific exploitation and evaluation of alternate feed resources to fill the gaps between demand and availability of feedstuff or livestock and poultry is also required for sustainable productivity of animals/poultry in this coastal region. Exploring strategies like the use of locally adapted breeds/varieties that sustain well in the climate and genetic improvement of animals by improving the local breed through cross-breeding with climate and disease tolerant breeds may be a viable option to increase the productivity of animals sustainably in this coastal region. Further, providing animal healthcare facilities including regular deworming and vaccination to prevent the outbreak of infectious diseases will also boost up the production performance of animals. Moreover, *in situ* and *ex situ* conservation of local indigenous breeds may be adopted to conserve the threatened or endangered breeds of livestock in the coastal regions of India.

31.6 Conclusions

The coastal ecosystem is potentially rich in livestock genetic resources with ecological and social significance. Animals of the coastal region not only provide livelihood security but also lead to ecosystem diversity. Climate change associated with increased incidences of extreme events in coastal areas is a matter of concern for livestock rearing. Hence, suitable mitigation strategies with modern scientific technologies need to be implicated for sustainable and economic livestock production in the coastal region of India. Multidisciplinary approaches should be taken to address the livestock-related problems, and specified solutions may be obtained to meet the farmers' needs and aligned industries. A holistic strategy encompassing breed improvement, nutrition, health care, management, product development and quality control in livestock and poultry should be undertaken for livestock and poultry development in coastal India.

References

Alam MZ, Carpenter-Boggs L, Mitra S et al (2017) Effect of salinity intrusion on food crops, livestock, and fish species at Kalapara coastal belt in Bangladesh. J Food Qual 2017:2045157. https://doi.org/10.1155/2017/2045157

BAHS (2019) Basic animal husbandry statistics—2019. Department of Animal Husbandry andDairying, Ministry of Fisheries, Animal Husbandry and Dairying, Government of India. http://dahd.nic.in/sites/default/filess/BAHS%20%28Basic%20Animal%20Husbandry%20Statistics-2019%29_0.pdf

Banerjee R, Mandal PK, Bose S et al (2009) Quality evaluation of meat, skin and wool from Garole sheep-a promising breed from India. Asian J Anim Sci 3:39–46

Banerjee S, Banerjee S (2000) Garole sheep of Bengal. Asian Livestock 24(3):19–21

Burke L, Kura Y, Kassem K et al (2001) Coastal ecosystems. World Resources Institute, Washington, USA, pp 1–77. http://www.wri.or.g/wr2000

Choudhary S, Yamini BD et al (2018) Tharparkar: the pride of desert. J Entomol Zool Stud 6(2):1915–1919

DAHD (2021) Annual report 2020–2021. Department of Animal Husbandry and Dairying, Ministry of Fisheries, Animal Husbandry and Dairying, Government of India, New Delhi, India

Das K, Prakash B, Sethi BP (2011) Phenotypic, genetic and cytogenetic characterization of Ghumusari cattle of Odisha-a newly accredited breed. J Livestock Biodivers 3(1):1–10

Dash S, Maity A, Bisoi PC et al (2017) Coexistence of polymorphism in fecundity genes BMPR1B and GDF9 of Indian Kendrapada sheep. Explor Anim Medical Res 7(7):33–38

Gajbhiye PU, Gadariya MR, Ahlawat AR et al (2016) Present status and future prospects of Gir cow. Indian J Anim Sci 86(5):553–558

Iype S (2013) Vechur cattle—from extinction to sustainability. Anim Genet Resour 52:105–110

Kumar A, Kumar SK, Mishra AK et al (2006) Characteristics of Kutchi goats of Gujarat. Indian J Small Ruminants 12(2):162–168

Livestock Census (2012) 19th Livestock Census, Department of Animal Husbandry, Dairying and Fisheries, Ministry of Agriculture,Government of India, New Delhi. http://dahd.nic.in/sites/default/filess/Livestock%20%205.pdf

Livestock Census (2019) 20th Livestock Census, Animal Husbandry Statistics Division, Department of Animal Husbandry & Dairying, Ministry of Fisheries, Animal Husbandry & Dairying, Government of India, New Delhi. https://dahd.nic.in/sites/default/filess/20th%20Livestock%20census-2019%20All%20India%20Report_0.pdf

Mishra BP, Singh KP, Chavan DB et al (2009) Characterization of Banni buffalo of Western India. Anim Genet Resour Info 44:77–86

Murugeppa A, Tandle MK, Shridhar NB et al (2020) Study of certain reproductive and productive performance parameters of Malnad Gidda cattle in its native tract. Pharm Innov J 9(9):270–274

Nayak S, Sahu G, Mohapatra AK (2008) Study on management practices, phenotypic and reproductive characteristics of Ganjam sheep under range conditions of Orissa, India. SAARC J Agric 6(2):93–106

NBAGR (2020) Animal genetics resources of India.http://14.139.252.116/agris/breed.aspx

NIBIO (2019) Food security threatened by sea-level rise. www.sciencedaily.com/releases/2017/01/170118082423.htm

Patel AC, Pandey D (2013) Growth, production and reproduction performance of Mehsana goat. J Livest Sci 4:17–21

Patro BN, Mallick CR, Rao PK et al (2006) Production performance of indigenous meat type sheep in Kendrapada district of coastal Orissa. Indian J Small Ruminants 12(1):42–47

Rajendran R (2007) Lactation performance and milk constituents of Umblachery breed of cattle (*Bos indicus*) in its native coastal ecology of Tamilnadu, India. Livest Res Rural Dev 19(5):71. http://www.lrrd.org/lrrd19/5/raje19071.htm. Assessed 7 Sept 2021

Raman KS, Sundararaman MN, Haribhaskar S et al (2003) Biometrics and breed characteristics of Madras Red sheep. Indian J Small Ruminants 9(1):6–9

Ramesha KP, Jeyakumar S, Kataktalware MA et al (2013) Geographical distribution, present status and characteristics of Malnad Gidda cattle-an unique dwarf cattle of Western Ghats in Karnataka. Biodiversity Documentation and Taxonomy, Indian Biodiversity Congress 2013:429–434
Rao PK, Dash SK, Singh MK et al (2009) Ganjam goat of Orissa and its management practices. Indian J Small Ruminants 15(1):44–50
Ravimurugan T, Thiruvenkadan AK, Sudhakar K et al (2012) Sheep genetic resources of southern Tamil Nadu, India. Int Res J Agric Sci Soil Sci 2(3):81–88
Ravimurugan T (2017) Chevaadu-a new registered sheep breed of Tamil Nadu, India. Int J Curr Microbiol Appl Sci 6(9):1553–1557. https://doi.org/10.20546/ijcmas.2017.609.190
Singh MK, Rai B, Kumar A et al (2009) Production performance of Gohilwadi goats under range conditions. Indian J Anim Sci 79(6):587–593
Singh R, Mishra SK, Rajesh C et al (2017) Chilika-a distinct registered buffalo breed of India. Int J Livest Res 7(9):259–266. https://doi.org/10.5455/ijlr.20170704044822
Singh PK, Pundir RK, Dangi PS et al (2019) Physical features, management and performance of Konkan cattle. Indian J Anim Sci 89(4):413–418
Singh A (2020) Coastal agriculture and future challenges. In: Singh A, Fernando R, Lalitha S et al (eds) Development in coastal zones and disaster management, Palgrave Macmillan, London, pp 61–86. https://doi.org/10.1007/978-981-15-4294-7
Sodhi M, Mukesh M, Pundir RK et al (2006) Cattle genetic resources of India: Kankrej-the finest dual purpose breed. Monograph 30, ICAR-National Bureau of Animal Genetic Resources, Karnal, Haryana, India
Stephen M, Raja TV, Sosamma I (2005) Survey and characterization of Attappady Black goats of Kerala, India. Anim Genet Resour 37:43–52. 1017/S1014233900001954
Sundararaman MN, RavimuruganT (2008) Kilakarsal sheep breed needs to be conserved. The Hindu, November 27, 2008
Sunder J, Kundu A, Kundu MS (2016) Scientific goat farming in Andaman & Nicobar Islands. In: Integrated farming system for tropical islands of India, ICAR-Central Island Agricultural Research Institute, Port Blair, Andaman and Nicorbar Islands, pp 81–85
Tantia MS, Khanna K, Vij RK et al (2006) Chicken breeds of India: Ankaleshwar. Leaflet no 37, ICAR-National Bureau of Animal Genetic Resources, Karnal, Haryana, India.
Thornton PK, HerreroM FHA et al (2007) Vulnerability, climate change and livestock-opportunities and challenges for the poor. J Semi-Arid Tropic Agric Res 4(1):1–23
Tudu NK, Goswami KK, Ghosh N (2015) Black Bengal goat farming: an important component of integrated farming system. J Crop Weed 11:80–85
Verma NK, Dixit SP, Dangi PS et al (2009) Malabari goats: characterization, management, performance and genetic variability. Indian J Anim Sci79(8):813–818
Verma NK, Aggarwal RAK, Dixit SP et al (2012) Konkan Kanyal-characters and performance of a newly discovered goat germplasm of Maharashtra. Indian J Anim Sci 82(9):1079
Vij PK, Tantia MS, Vijh RK et al (2005) Chicken breeds of India: Danki. Leaflet no 23, ICAR-National Bureau of Animal Genetic Resources, Karnal, Haryana, India
Vij PK, Tantia MS, Kumar KA et al (2008) Phenotypic and genetic characteristics of Tellicherry breed of chicken. Indian JAnim Sci 78(12):1420–1422
Vij PK, Tantia MS, Pan S (2015) Performance of Haringhata Black chicken under field conditions. Indian J Anim Sci 85(8): 930–932
Vijh RK, Vij PK, Tantia MS e al (2005) Chicken breeds of India: Kalasthi. Leaflet no 21, ICAR-National Bureau of Animal Genetic Resources, Karnal, Haryana, India

Chapter 32
Ornamental Fish Culture for Enhancing Livelihood of Coastal Farming Communities

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Abstract India is enriched with diverse aquatic biodiversity which includes a large group of water bodies, and most of the ornamental fish are wild being caught from streams, rivers, canals, reservoirs, irrigation tanks, cold water lakes and ocean. The mangroves, wetlands and coral reef ecosystems of Tamil Nadu, Gujarat, Kerala and Lakshadweep provide suitable breeding and nursery grounds of marine ornamental fish. Among marine ornamental species, 113 finfish species are reported from the Gulf of Mannar, 150 species from the Andaman and Nicobar Islands and 300 species in the Lakshadweep Islands. Looking at the vast resources and huge domestic as well as international demand, the present article describes the coastal farming of ornamental fish. The list of threats seems obvious that is bothering ornamental fish farming in coastal communities; nevertheless, the resources and technologies represent good opportunities for marine ornamental fish farming. It also includes the opportunities of various interventions in the field of coastal water ornamental fish farming and possible outcomes especially for local farmers.

Keywords Coastal farming · Marine ornamental fish · Livelihood · SWOT analysis

32.1 Introduction

The ornamental fish industry is a sunrise sector, having tremendous potential to contribute locally as well as in the international market. It is an important economic

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activity across 125 countries with global trade of around US$ 18–20 billion. India's share of global ornamental fish export is 0.4%, and India's rank is 31st among exporting countries (DOF 2020). But resource-wise India is dominating with diverse groups of fish species and biodiversity. An estimate carried out by the Marine Product Export Development Authority (MPEDA) of India shows that there is one million ornamental fish hobbyists in India. The internal trade is estimated to be about 3.26 million US$, and the export trade is about 0.38 million US$ in India with an annual growth rate of 14%. A rich diversity of species and favourable climate, and cheap labour make India suitable for ornamental fish farming. About 700 indigenous and 374 exotic marine ornamental fishes have been identified in India. Freshwater ornamental fish contribute about 80%, while 20% is from brackish and marine waters in the ornamental fish trade. India's domestic ornamental fish trade is about 5000 million rupee crores (Raja et al. 2019). There are about 5000 production units of ornamental fish culture in India comprising West Bengal (55%), Tamil Nadu (30%), Kerala (5%), Maharashtra and others (7%), North East and Island (3%). Major fish exported from India are of wild varieties collected from rivers of the north-east and southern states. The north-east region contributes about 85% of total market comprising about 250 ornamental fish species of which 58 indigenous fish species (e.g. *Botia dario, Danio dangila, Puntius shalynius* and *Schistura reticulofasciatus*) are exported. In the Western Ghats region, 155 fish species are reported of which representative groups are barbs, rasboras, killifishes, glass fishes, catfishes, Catopra, hill trout and danios. About 13 indigenous freshwater ornamental fish species have been successfully bred, mostly from backyard breeding and rearing units, small size and cluster-based production units**.** More than 70% of fishes are caught from the wild, and there are very few indigenous fishes whose breeding has been standardized. The ICAR-Central Marine Fisheries Research Institute (CMFRI), Kochi, Kerala, has standardized 20 marine ornamental fish breeding and hatchery rearing technologies (Madhu et al. 2013), and this provides a very good opportunity.

Looking at the vast marine resources of India, the present article describes opportunities for various interventions in the field of coastal water ornamental fish farming and possible outcomes especially for local farmers.

32.2 Advantages of Ornamental Fish Culture

The market demand for ornamental fish is increasing and maximum from the USA and Europe. It fetches more than 100 times compared to food fish price. As a profit-oriented farming practice, it is a very good alternate livelihood for the coastal people. Other than profit, the unsustainability of marine biodiversity is another issue that is being addressed by this activity indirectly or directly. The report says 75% of the world's reefs are at several risks from local and global activities including natural phenomena such as hurricanes, El Niño and diseases; local threats such as overfishing, destructive fishing techniques, coastal development, pollution and careless tourism; and the global effects of climate (Earth Institute 2011).

Approximately, a quarter of this is already damaged beyond repair and it may reach 100% damaged by 2050. In this situation, adoption of coral farming and ornamental fish farming will partially divert the people from destructive fishing methods and the illegal business of collecting endangered species. Williams et al. (2014) have reported a business model demonstrating that a land-based culture project for an endangered seahorse (*Hippocampus barbouri*) in the Spermonde Islands of Indonesia can increase family income by seven times. There are 50-plus species of seahorses and with seahorse fisheries for medicine and aquarium claiming the numbers to have gone down by at least 50% in five years (https://seahorse.com). The culture system is not only helping the local fishing communities but saving the endangered species.

Other than conservation and rehabilitation, coastal farming also promotes marine tourism. Marine tourism not only provides entertainment and education to the people but generates additional revenue for the local people. For example, the Indonesia Coral Reef Garden (ICRG) programme was launched in support of the tourism sector in Bali (Xinhua 2020). This programme promotes coral gardening, community empowerment and capacity building activity along with tourism. The main motive behind the activity was the recovery of the country's tourism loss due to the COVID-19 pandemic. These kinds of projects are really helpful for promoting a sustainable farming system besides increasing the income of local people.

32.3 Coastal Farming Conditions

Unlike freshwater farming, rearing and breeding marine ornamental fishes are not so easy. Most of the fishes are collected from the coral reefs and shallow waters by divers through hand picking, use of scoop nets and trap fishing. The invertebrates like corals, anemones, polychaete, molluscs, decapod crustaceans and echinoderms are a new field of interest for marine aqua farmers. Around 50 million coral reef animals including fish, coral reefs and invertebrates are wild-caught and sold annually to the aquarium hobbyist. In places, marine resources remain either unexploited or overexploited for food fishing. Due to lack of awareness and high use of destructive fishing methods like trawling a good share of the marine, captured ornamental fishes are simply discarded. It has been reported that around 62 species of ornamental fishes are caught as bycatch in the trawl netting (Sajeevan and Somvanshi 2013). However, these fishes can provide an additional profit to the fishermen community. It needs special effort to transport them alive from the fishing harbour to the rearing tanks. The culture condition is entirely different from food fish rearing as ornamental fish needs more sophistication in water and feed and it varies with regard to different species. It is a relatively new sector and often ignored by mainstream aquaculture producers, yet it pushes the boundaries of aquaculture by exploring the culture of new species and improved culture methods. Few entrepreneurs have successfully bred and reared ornamental fishes in marine tanks with the help of local fishing communities.

Collection of fish through traps and gill nets, scoop nets and different gears which imparts minimum stress to the fish is the best method. It needs to be handled carefully with minimum stress during transportation such as proper aeration, lesser duration of haul and transportation, and if necessary anaesthetics can be used to minimize transport stress.

32.4 Rearing Conditions

The marine ornamental fishes need to be reared in unpolluted water with less stocking density. Minimum water quality parameters need to be maintained like the temperature of 30–32 °C, salinity 30 ppt and pH of 8–8.2. Exchange of 75% water after one hour of collection and 50% of water exchange twice a day are found to be more appropriate. The unused feed has to be removed from the tank bottom, and proper aeration is required. Fishes are fed with fresh meat, fish pieces, live feed, small prawns, etc. Most of them are predators and hence need to be segregated properly. The breakthrough developments in the field of live feed production especially marine copepods and other zooplankton which are the preferred food of fishes have provided additional benefit for better growth and maturation. Some of the entrepreneurs have developed their own live feed facilities of copepods and zooplankton side by side with the fish rearing. The large fishes need to be separated and aggressive ones also kept separately. In case of any disease symptoms, remove the fishes and keep in quarantine condition with medicine. Sudden fluctuation of water quality is harmful to the fishes, especially temperature, dissolved oxygen and ammonia (Table 32.1). These have to be monitored regularly for better management.

There are many fishes with peculiar breeding patterns, nutrition requirements and environmental condition needs. The habitat requirement also varies with different species. There are three crucial points, i.e., breeding and maturation, larvae and adult rearing, which has to be addressed for success in the rearing of marine ornamental animals (Olivotto et al. 2009). To know about the reproduction strategies, one has to keenly observe their life stages and mating in nature. Some are dimorphic and choose their mates based on colour, body shapes and size or other peculiar habits. Some are hermaphrodites, i.e. simultaneous (killifish) or sequential development (anemone fish or clownfish) of both sexes in one animal. The reproductive behaviour is mainly based on evolutionary adaption to the ecosystem and environmental conditions. The maturation depends on photoperiodicity, temperature, water quality and food availability. The well-known clownfish reproductive nature is based on social

Table 32.1 Standard water quality parameter for rearing of marine water ornamental fish

Parameters	ASEAN marine environmental quality criteria
Dissolved oxygen (DO)	5 mg L^{-1}
pH	6.5–8.5
Ammonia (unionized)	0.07 mg L^{-1}
Nitrite	0.055 mg L^{-1}

status; i.e., the largest one acts as female and the second largest as male, whereas the smaller one acts as non-spawner. The pelagic fishes mostly spawn during winter and early spring, while temperate spawning occurs in midsummer. Spawning occurs during evening time, and eggs are fertilized in the water column. The demersal fish spawning depends on the lunar cycle, tidal flow of water and habitat availability. The coastal demersal fish spawn in the mangrove or coral reef regions near the coastal zones. Their eggs remain in the intertidal region exposed to periodic water currents, whereas the deep-sea ornamental fish lay their eggs in caves or rocky substratum or on sea bottoms. Most of them show parental care or mouthbrooder behaviour.

Larval rearing and survivability depend on food availability. Some of them accept artificial feed in the culture system but perform better when given live feed. Food and feeding habit of most of the ornamental fish depend on their habitat preference. They are mostly carnivores, herbivores, omnivores, planktivores and detritivores. The carnivores feed on other small fish, crustaceans and molluscs, whereas herbivores feed algae (e.g. *Petrochromis*), plants (e.g. *Etroplus suratensis*) and sponges. Some prefer eating detritus called Aufwuchs. The coastal demersal fish mostly feed on corals and invertebrates, i.e., coral polyps, tentacles of feather dusters and Christmas tree worms. Based on their food and feeding habits, the larval feeding has to be standardized with a combination of artificial and live feed.

32.5 Important Indigenous Marine Ornamental Fishes

Some of the important marine ornamental fishes from the Indian coast are given below (Fig. 32.1).

Plectorhinchus chaetodonoides: It inhabits coral-rich areas of clear lagoon and seaward reefs. It is a carnivorous species that preys on benthic invertebrates such as crustaceans and molluscs, as well as fishes at night.

Lutjanus indicus: It usually prefers coral reefs with clean water. It prefers to eat small crustaceans. The spawning occurs in large groups, and eggs are released in columns. The eggs are minute and spherical and take 18 h or so to hatch into larvae.

Lutjanus quinquelineatus: It inhabits sheltered lagoons and coral reefs. It is a carnivorous species, and they feed mainly on fishes and crustaceans.

Lutjanus decussatus: It inhabits both inshore and offshore coral. It is a carnivorous species, and they feed on fishes and crustaceans. This species spawned during June and October, their spawning events being determined by lunar cycles.

Lutjanus bohar: It inhabits coral reefs, including sheltered lagoons and outer reefs. It is a carnivorous species and feeds mainly on fishes but also takes shrimps, crabs, amphipods, stomatopods, gastropods and Urochordates.

Cephalopholis miniata: It is found in coral reefs which are naturally filled with clean water and surplus food. Similar to most of the groupers, they eat small fishes, shrimps and insects. It is a protogynous hermaphrodite, and they change sex from female to male.

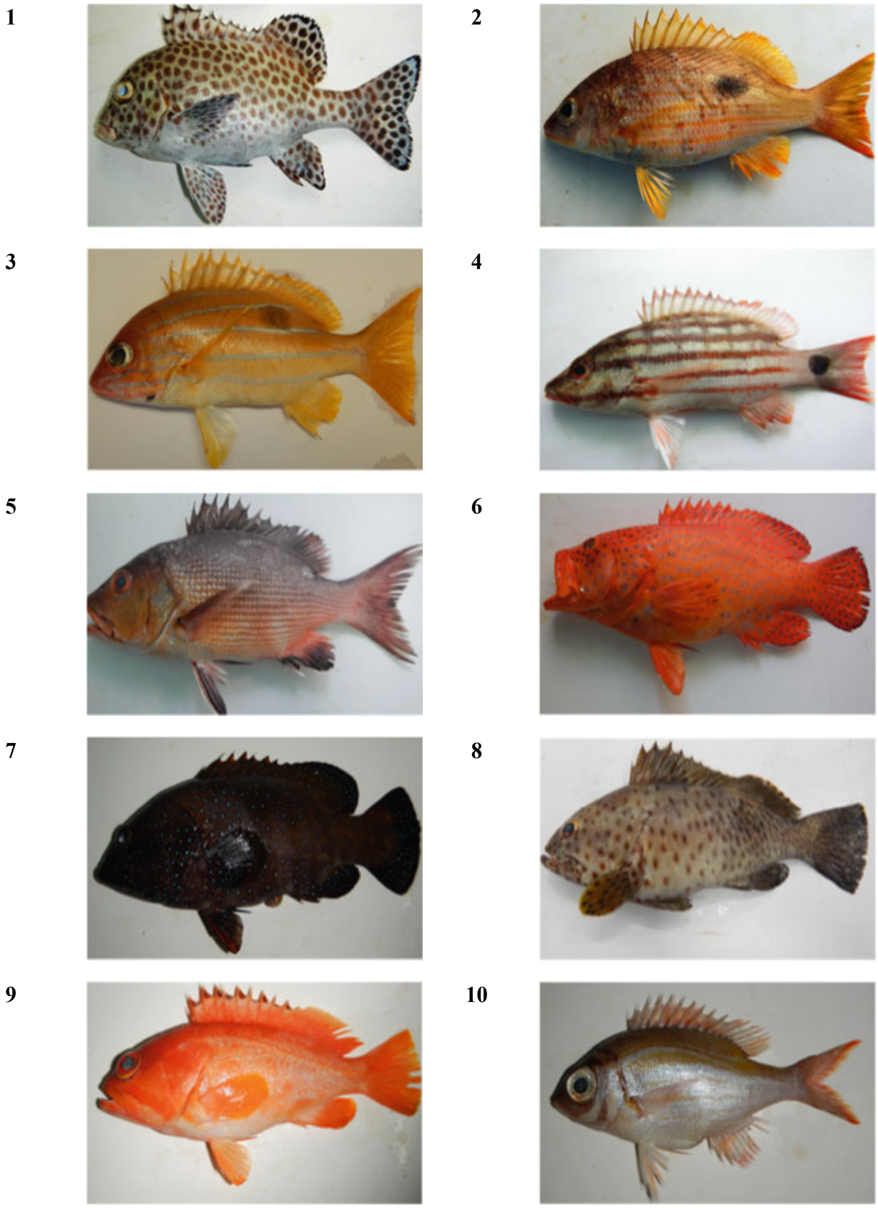

Fig. 32.1 Few marine ornamental fish from Indian coast: 1. *Plectorhinchus chaetodonoides*, 2. *Lutjanus indicus*, 3. *Lutjanus quinquelineatus*, 4. *Lutjanus decussatus*, 5. *Lutjanus bohar*, 6. *Cephalopholis miniata*, 7. *Cephalopholis cyanostigma*, 8. *Epinephelus coioides*, 9. *Epinephelus retouti*, 10. *Holocentrus adscensionis*, 11. *Odonus niger*, 12. *Priacanthus hamrur*, 13. *Cheilinus fasciatus*, 14. *Epinephalus fasciatus*

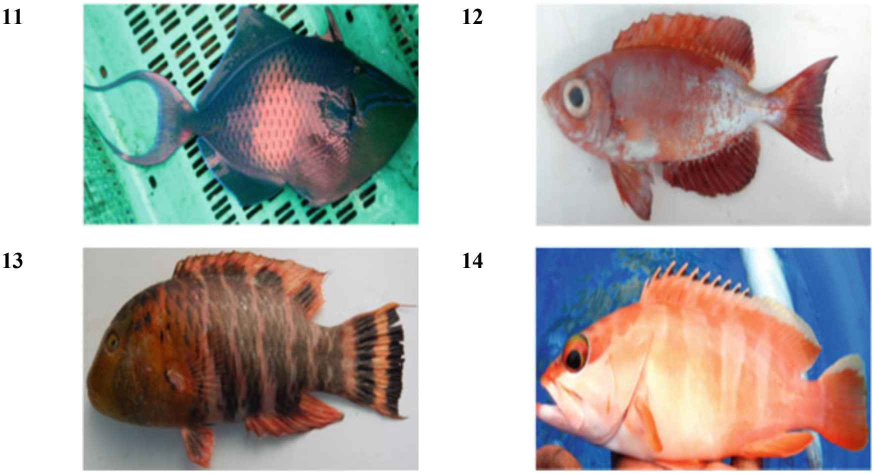

Fig. 32.1 (continued)

Cephalopholis cyanostigma: It inhabits shallow protected coastal reefs, seagrass beds and coral-rich areas. It is a carnivorous species and fed on crustaceans and fishes. It is a protogynous hermaphrodite.

Epinephelus coioides: It inhabits turbid coastal reefs and is often found in brackish water over mud and rubble. It is a carnivorous species and fed on small fishes, shrimps and crabs. It spawns during restricted periods and forms aggregations when doing so. Females mature at 25–30 cm (2 to 3 years old), and sexual transition occurs at 55–75 cm. Eggs and early larvae are probably pelagic.

Epinephelus retouti: It inhabits outer reef slopes. It is a carnivorous species, which feed on larger invertebrates, mostly crustaceans, and other fishes taken on or close to the substrate.

Holocentrus adscensionis: It inhabits shallow coral reefs, as well as deeper offshore waters. It is a nocturnal species; it usually moves over sand and grass beds. It is a carnivorous species, which feed mainly on crabs and other small crustaceans.

Odonus niger: It inhabits reef channels. It feeds on zooplankton as well as sponges. It is oviparous. It is a plankton feeder.

Priacanthus hamrur: It is found in outer reef slopes and deep lagoons. It is a carnivore species and feeds on small fish, crustaceans and other small invertebrates.

Cheilinus fasciatus: It inhabits the lagoon and seaward reefs. It feeds mainly on benthic, hard-shelled invertebrates, including molluscs, crustaceans and sea urchins. It is an oviparous, distinct pairing during breeding.

Epinephelus fasciatus: It inhabits outer reef slopes and lagoons. It feeds night and day on brachyuran crabs, fishes, shrimps and galatheid crabs. It feeds on crabs, stomatopods, fishes, ophiuroids and octopuses.

Acanthurus lineatus (**lined surgeonfish**): It protects its area from the entry of other males and protects the females. The spawning occurs in a gathering while the juvenile is solitary. The fish is mostly herbivorous but sometimes may prefer crustaceans. Most of its diet is algae.

Amphiprion akallopisos (**skunk clownfish**): It prefers a wide range of food varieties and is mostly omnivorous. In the wild, they feed on algae, worms, amphipods, tunicate and crustacean larvae, very small crabs, barnacle appendages, isopods, gastropod fragments and spoiled eggs from their clutch.

32.6 Marine Ornamental Fish Farming Methods

There are three commonly practised culture systems, i.e., intensive, semi-intensive and extensive commonly practised. The basic phases remain the same, i.e., (i) broodstock collection and maintenance; (ii) breeding and spawn collection; (iii) larval rearing; and (iv) juvenile grows out until marketable size. Depending on the culture system, all the phases are practised in the farm.

In case of intensive culture units, the broodstocks are maintained for a long time rather than wild collection and the rest of the phases are also followed consequently. Additionally, there are live feed units that produce rotifers, Artemia and other copepods and larval feed units producing micro-algae and planktons for an uninterrupted supply of healthy and nutritious diet. There are separate facilities for corals reef and underwater plants where different corals and plants are grown on a unique substratum, and it provides breeding and nursery grounds for many ornamental fishes. The farms utilize water from near the ocean and filters to remove debris. Fishes are maintained in several glass or fibre-reinforced plastic (FRP) tanks with individual water supply, aeration and lighting facilities. A quarantine facility is also given to the new fishes or diseased fish. The brood tanks are provided with additional accessories for hiding, pairing, breeding and bottoms suitable for egg-laying. The juveniles are maintained in larger tanks that mimic the natural habitat of corals or other ocean ecosystems.

In semi-intensive type, the broodstock is not maintained, rather collected from ocean bed for spawning. Sometimes, the small fishes are collected and raised in captive condition until marketable size. There is no separate coral reef or underwater plant growing facility in the farm. The extensive culture practice usually depends on installing cages or pen enclosures in the ocean water and releasing wild-caught ornamental fishes to grow based on natural food availability.

32.7 Broodstock Development, Breeding and Larval Rearing

Reproduction in marine fishes is categorized into 4 basic patterns: (1) release of tiny, transparent, free-floating eggs without parental care; angel fishes, butterfly fishes, etc., are among those with this type of reproductive pattern; (2) attachment of the eggs to a secure substratum, near the bottom with nesting standard; gobies, blennies, damselfish and clownfish are the typical nest-building marine tropical fishes; (3) exhibit oral incubation of eggs or mouthbrooding; cardinal fishes are examples of this category; and (4) give birth to well-developed young ones. Sea horse is an example of this category.

Globally marine ornamental fish is still in their infancy. The major steps are broodstock raising, breeding and larval rearing. Food is the major requirement need to be standardized for both adult and larvae. While adults accept supplementary diets but larvae and juveniles mostly depend on the live feed. The stage immediate after yolks absorption is critical to know about their feeding habits. As most of the time, high mortality is noticed during this period. Different varieties of live feed culture have to be standardized to enhance their preferability by marine ornamental fishes. The success rate of breeding and spawning is far behind due to the lack of effort and expertise in this area. Out of 800 species, only 5% are captive bred and the rest of them are wild-caught.

32.8 Involvement of Coastal Farming Community

The coastal part of India covers an area of approximately 7516 km. It includes nine states, two union territories and two island territories. As many as 171 million people are living in the coastal districts. Most people of the coastal community are fishermen and do fishing or related work, i.e., making boats and gear for their livelihood. The major activity of men is fishing, whereas women are involved in fish marketing other than household work. Most of them live below the poverty line because of the harsh effect of natural calamities like floods and cyclones. Nevertheless, they do agriculture and fish culture activities in the wetland and dryland areas adjacent to the sea. The profit-oriented progressive farmers construct ponds adjacent to creeks or canals and culture fish and prawn and grow a different vegetation. Very few people do an extraordinary job of growing seaweeds and molluscs or pearl cultivation in the intertidal region. In some of the places, aquaculture is limited to the culture of seaweed, corals and clams for the marine ornamental trade. Another activity that is least entertained by the coastal communities of India is ornamental fish culture or related activity. Though it is intensive farming and will be expensive for the local people, they can get involved in additional practices and generate livelihood by growing coral reefs, capturing and rearing ornamental fish through installing small cages and pen-like enclosures.

32.8.1 Growing Corals

Many entrepreneurs produce small reef fish species that are in high demand in Europe and the USA. They also produce soft, colourful corals, which are cultured in coastal sites, under the watch of local fishing families. There are low investment coral growing techniques well adapted by the coastal communities of Indonesia and Philippines. It is a very good alternative livelihood generation method.

Coral cultivation is profitable and one type of biodiversity conservation activity, but it requires a pristine and calm water source. The corals breed asexually by budding or sexually by spawning. The spawn collection can be performed annually, and collected spawns can be grown in a tank and further shifted to the coral colonies. Another technique is called micro-fragmentation which requires cutting the fragments, tips and branches of coral and transplanting them on a mesh-like structure for establishment. It has a unique disc-like structure on which coral fragments are fixed by nylon thread and tied to a wooden stick to make sure they are under water. It can be incubated for four months in tanks before transferring to an underwater nursery. After that, it is shifted to a floating underwater nursery installed in 6 m water depth and covered with nets to protect from predation. Later on, they are transplanted in the natural sea bed or in land-based commercial coral farm nurseries. The corals like *Acropora austere, A. selago* and *Pocillopora damicornis* show 100% survival rate. The southern parts of India, i.e., Muttom and Enayam in Tamil Nadu and Adimalathura to Thangassery in Kerala, are known for their productive biodiversity of coral reef, reef fishes and sponges. Some of the reefs, i.e., *Favia speciosa, Favia pallida, Goniastrea pectinata, Goniastrea retiformis, Hydnophora microconos* and *Echinopora lamellose,* have been identified by ICAR-CMFRI. The institute has also taken initiative for rehabilitation and propagation of the diseased reefs in Vizhinjam Bay. Different substrata, i.e., plastic baskets, cement-coated bricks and acrylic sheets, are used for coral plantation in floating rafts near the coastal water. The success of reef propagation implies that there are opportunities for coastal reef farming, but the main problem is pollution and undesirable water condition which makes the reefs prone to diseases.

32.8.2 Fish Culture in Coral Triangles

The inhabitants near the coral triangle mostly depend on coral farming, seaweed farming, pearl oyster, clams and ornamental fish farming. With the collaboration of different government and non-government organizations and funding agencies, some of the people are establishing ornamental fish farming projects. The local people are very well involved in these projects. The facilities that need to be constructed are the breeding and rearing facility, live feed unit, etc. Apart from constructing breeding facilities in drylands, the semi-intensive culture practices are being carried out through sea floating cages and pen enclosures. The low-cost cages with FRP pipe frames can be used for rearing the wild-caught ornamental fishes. They are sold at a marketable size. The pen enclosures are also used similarly. The low-cost rearing units can be prepared with glass tanks in dry land for larvae and large cement, or FRP tanks are used for raising the juveniles. Examples of such communities practising fish farming near coral triangles are Spermonde Islands, Sulawesi of Indonesia, Malaysia, Papua New Guinea (PNG), the Philippines, Solomon Islands and Timor Leste (Williams et al. 2014).

Though fish farming in coral triangles is not so well practised in India according to the reports from ICAR-CMFRI, the southern coastal lines, i.e., Thirumullavaram temple point, Thangassery harbour, Paravoor, Odayam, Varkala, Vizhinjam and Enayam harbour, have a rich assemblage of reef fishes which mostly belongs to Chaetodontidae (butterflyfish), Pomacentridae (damsels), Siganidae (rabbit fish), Balistidae (triggerfish), Lutjanidae (Snapper), Acanthuridae (surgeon fish) and Apogonidae (cardinal fish). It shows a good opportunity for the local community to initiate land or sea-based fish farming practice.

32.8.3 Ornamental Fish Farming—A Boost Towards Livelihood Security

The increasing demand for aquarium fishes in Indian as well as the global market has paved the way for generating large-scale employment to small-scale fish farmers of the coastal region through ornamental fish farming. Through ornamental fish culture, farm women and elder people can run small-scale aquarium units and improve their social and economic upliftment. These types of small-scale aquarium businesses can be started in small areas like the backyard or roof of a house. Rural women can easily breed the important indigenous species in a small aquarium, earthen pots, plastic tubs and cemented cistern in their backyard, inside their house or rooftop. Women belonging to the coastal region can rear and culture different indigenous and exotic ornamental fish. Live feed culture like Tubifex worm can also be collected from local water bodies by coastal farm women. So live fish food collection and culture also prove to be very good alternatives as a source of income generation for coastal farm families. Artificial feed preparation and marketing also are very good alternative livelihood opportunities for house women. Preparations and marketing of aquarium accessories are a very well-opportunistic livelihood option for rural women especially for housewives and elderly women. They can earn around Rs. 2000–10,000 per month. Fish packaging industry is also very popular among farm women who can involve themselves in packaging of fish and fish products. West Bengal is a pioneering state in culturing and marketing ornamental fish. Several self-help groups from the coastal region of West Bengal are involved in the culture, breeding and marketing of ornamental fishes. The Department of Fisheries, Government of West Bengal, has established 150 women fisher cooperatives and formed over 5000 women SHG groups mainly on ornamental fish culture. Presently only in South 24 Parganas, there are approximately 33 women's ornamental fish cooperatives which include about 800 women, and they have begun to breed and rear ornamental fish in their backyards. In West Bengal, rural women form self-help groups in Howrah, Hooghly, North and South 24 Parganas and suburban of Kolkata and take up this activity in the backyard of their homes. In the past few years due to the implementation of the National Agricultural Innovation Project (NAIP), farmers were motivated and production units for ornamental fish culture were installed in their backyards.

32.9 Development of Ornamental Fish Villages

The success of ornamental fish culture has attracted several farmers to adopt the culture technology and package of practices for livelihood generation of coastal communities. Several other institutes are also providing technical support for the culture of ornamental fish. ICAR-Central Institute of Freshwater Aquaculture (CIFA), Bhubaneshwar, Odisha, has demonstrated the ornamental fish culture in the coastal farm communities of Odisha in 2011 through skill development programmes and several farmers, farm women were successfully trained, and they have adopted the technology at the local level for their livelihood security. At present, 70% of women from several states of Odisha have adopted the ornamental fish culture as a livelihood option. The successful farmers earn an average income of Rs. 7000–8000 per annum (Swain et al. 2014). Ornamental fish rearing (black molly, red molly, angel fish, gold fish, etc.) in the backyard has caught up with the women in Landijhari (Deogarh district of Odisha) with as many as 60 cement tanks being used for this purpose (Nath et al. 2012). The scientists of Krishi Vigyan Kendra, Deogarh, has popularized the new vocation in the village by organizing awareness camps. With all the families engaged in rearing ornamental fish, the village came to be known as ‘ornamental fish village’ (De et al. 2012). Another ornamental fish village has also been developed recently at Sarouli in the same district with the partnership of ICAR-CIFA, ATMA and State Fisheries Department to promote livelihood development of women SHGs. The skill-building of farmers on aquarium making has helped them to augment their earning. The progress of the farmers has influenced the state department and centrally sponsored scheme for financial support for the construction of tanks for the ornamental fish culture farmers in the coastal farming communities.

32.10 Strength, Weakness, Opportunity and Threats (SWOT) of Ornamental Fish Culture

Unlike European Union and South-East Asian countries, India is lagging behind in ornamental fish culture. But there is tremendous scope for production and marketing in the domestic as well as international markets. The major bottleneck has to be identified to achieve a better production rate. It seems to have multiple reasons for shortfall in the ornamental sector including research interventions, lack of awareness and personal interest of people in our country. In order to address the lacunae and find

Table 32.2 SWOT analysis of the ornamental fish culture in India

Strength	Weakness	Opportunity	Threat
1. Large group of indigenous fish	1. Lack of technologies for indigenous fish breeding and rearing	1. Huge domestic as well as international market demand	1. Decreasing biodiversity due to pollution and urbanization
2. Vast biodiversity of mangroves, wet lands and coral ecosystem	2. Unutilized water bodies and other resources	2. Large number of water bodies and unutilized marine resources	2. Over-exploitation of wild resources
3. Favourable climate	3. Poor technology dissemination and awareness	3. Wide group of beautiful ornamental fish	3. Dominance of exotic/invasive species
4. Man power	4. Lack of proper marketing and trading strategies	4. Livelihood generation with minimum investment	4. Dominance of exotic/invasive species
5. Available financial institutes and subsidies			5. Natural calamities

out ways of improvement, a SWOT analysis is presented which depicts that India is lacking sustainable utilization of resources of ornamental fishes (Table 32.2).

32.11 Challenges

Most of the coastal farmers of India are engaged in marginal or small business practices. They adopt extensive or semi-intensive farming of molluscs, oysters, seaweeds and fish and shellfish near the coastal water. So livelihood of people in the coastal region depends on the direct collection of corals and seaweeds rather than farming. But the people of Indonesia and Philippines do small-scale businesses of coastal water ornamental fish and reef farming. The problem which was faced by these farmers also applies to others intending to do similar coastal farming.

One of the reports from the BBC news (Gercama and Bertrams 2020) had mentioned the ban on coral export by the Indonesian government in 2018 to stop illegal harvesting of wild coral. The trade bans not only curbed illegal export but hundreds of sustainable farms across the country collapsed. The hardest hit was small coral cultivators who usually live in coastal communities and depend entirely on their offshore farming for income. The trade ban of marine ornamental fish is also similarly getting affected. What is the real challenge faced by most government-empowered conservation activists is to distinguish between what is genuinely farmed and what is wild-sourced. Though marine farming is a hard job, it often faces trade bans due to such conservation measures.

Another issue is related to the harsh climatic conditions in most of the southern countries including India. The coastal water is highly vulnerable to natural calamities like cyclones, tsunami and low pressure which destroys the local farming and the inhabitance of coastal people. The coastal water bodies often face pollution issues in our country which is due to the river runoff, connectivity with lakes and reservoirs, oil spillage from ships and oil refineries. Besides, the anthropogenic activities-induced global warming is another issue that is negatively impacting on coastal farming system.

32.12 Conclusions

India is one among the 12 mega-biodiversity nations in the world having a 7516-km-long coastline and an exclusive economic zone (EEZ) of 2.17 million km^2. Nearly 30% of its human population directly or indirectly depend on the rich exploitable coastal and marine resources. Although India does not have the advantage of extensive shallow seas, pristine and calm sea waters, many potential sites remain unutilized, offering tremendous scope for mariculture. The Gulf of Mannar and Palk Bay coasts are highly productive regions for commercial collection of agarophytes and alginophytes, coral reefs and oysters. The Gulf of Mannar is known to harbour over 3,600 species of flora and fauna, making it one of the richest coastal regions in Asia. A long and wide coral reef (140 km length), running along the southern side of the 20 islands of the Gulf of Mannar, carries 117 hard coral species and supports luxuriant growth of seaweeds, especially *Sargassum* spp., *Turbinaria* spp. and *Gelidiella acerosa.* Some of the rare sea animals including sea turtles, sharks, dugongs and dolphins are frequently found in this area. However, the over-harvesting by the local people has seriously declined the quality of coastal biodiversity. The anthropogenic activity of local fishermen combined with the stress of pollution has reduced the number of many species including dolphins, dugongs, whales and sea cucumbers and coral species. In these circumstances, promoting sustainable coastal farming of corals and other suitable aquaculture commodities will firmly enhance the local people income along with biodiversity conservation.

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References

De HK, Saha GS, Radheyshyam (2012) Training and sensitizing the farmers in fish farming through Aquaculture field school. Indian Farming 62(2):31–33

DOF (2020) Department of Fisheries, Ministry of Fisheries, Animal Husbandry & Dairying, GOI. www.dof.gov.in/sites/default/files/202007/Ornamental_fisheries_development_under_PMMSY.pdf

Earth Institute (2011) https://www.earth.columbia.edu/articles/view/1012

Gercama I, Bertrams N (2020) BBC news business reporters, Nusa Lembongan, Indonesia, 27 February 2020. https://www.bbc.com
http://zeenews.india.com/news/eco-news/endangered-seahorses-could-be-extinct-in-next-three-decades_1640158.html
https://www.fishbase.se/summary/6364
https://www.frankbaensch.com/marine-aquarium-fish-culture/my-research/
https://www.nationalgeographic.com/animals/2018/07/wildlife-watch-seashells-illegal-trade-handicrafts.htm
Madhu K, Madhu R, Gopakumar G (2013) Present status of marine ornamental fish breeding and technology developed under captivity. J Basic Appl Biol 7(3):164–170
Nath SK, Sahu P, Sar BK (2012) Institutional linkage helping rural women of an under developed district to become self-employed. Aquac Asia 17(2):34–36
Olivotto I, Holt GJ, Carnevali O (2009) Advances in marine ornamental aquaculture: breeding and rearing studies. In: Davin TB, Brannet AP (eds) Corel reefs: biology, threats and restoration. Nova Science Publishers, New York, pp 1–40
Raja K, Aanand P, Padmavathy S et al (2019) Present and future market trends of Indian ornamental fish sector. Int J Fish Aquat Stud 7(2):6–15
Sajeevan MK, Somvanshi VS (2013) Collection and rearing of marine ornamental fishes from coastal trawl fishery. Indian J Geo-Mar Sci 42(4):476–480
Swain SK, Sahu P, Baliasingh BK et al (2014) Ornamental fish farming, an alternative livelihood security for rural women. In: Kurup BM, Jayachandran KV, Boopendranath MR et al (eds) Souvenir of the international seminar on ornamental fish breeding, farming and trade, Kochi, Kerala, 26–27 January 2014
Williams SL, Janetski N, Abbott J et al(2014). Ornamental marine species culture in the coral triangle: seahorse demonstration project in the Spermonde Islands, Sulawesi, Indonesia. Environ Manag 54(6):1342–1355
Xinhua (2020) Indonesia works to restore coral reefs in recovering Bali tourism; Xinhua.13 November 2020. http://www.xinhuanet.com/

Chapter 33
Brackishwater Aquaculture: Options for Livelihood Improvement of Farmers in Indian Sundarban

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Abstract Brackishwater area of Indian Sundarban is around 30,000–50,000 ha of which only 20–30% is under aquaculture. Brackishwater farming is mainly confined to the *bheries* in Sundarbans. Adoption of modern and scientific technologies developed by research institutes and government agencies has improved the fish/shrimp production in the region and meeting the livelihood needs through different livelihood options. Growth of Indian aquaculture industry is synonymous with the growth of shrimp culture and has gained its momentum with the introduction of *Penaeus vannamei* during 2009. Demonstration of *Penaeus indicus* farming using hatchery-produced seed by ICAR-Central Institute of Brackishwater Aquaculture (CIBA) showed its potential as an alternate species in Indian aquaculture basket. In addition, breeding, seed production and feed development of certain brackishwater fish such as seabass, mullets, milkfish, whisker catfish, pearl spot and hilsa have shown a lot of promise. About 28% of 2.1 lakh ha potential brackishwater areas in West Bengal are under use, and the state has been the Indian leader in *Penaeus monodon* production whilst farmers started culturing *P. vannamei* after successful demonstration by ICAR-CIBA at its research centre at Kakdwip, West Bengal. CIBA also demonstrated the use of cost-effective feed, Poly^{Plus} and use of plankton booster, Plankton^{Plus} for brackishwater polyculture and shrimp culture, respectively, to get higher return. There is vast scope for sustainable development of brackishwater aquaculture in Sundarbans to meet the livelihood demand utilizing the unused and

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underused areas and adopting advanced technologies like integrated multitrophic aquaculture, integrated livestock-horti-aquaculture, multispecies culture with suitable species combination using cost-effective feed, culture of Asian seabass with formulated feed, etc. Challenges like availability of seed and species specific formulated feed, lack of proper communication facilities, disease outbreak, lack of cold chain facilities, frequent natural calamities, etc., faced by Sundarban'saqua farmers need to be tackled by appropriate management tools.

Keywords Sundarban · Brackishwater aquaculture · Technology development · Cost-effective feed · Biosecurity measures · Species diversification · Sustainable development · Livelihood · Challenges · Opportunities

33.1 Introduction

Amongst the global water resources, brackishwater and sea water are not used for human use and crop production and are lying unutilized or underutilized. These saline water resources are having vast potential to produce quality animal protein. Amongst a variety of food items present in the aquatic system, fishes are considered as the most important group of the organisms suitable for human consumption. Aquaculture in India has evolved as a viable commercial farming practice from the level of traditionally backyard activity over last three decades with considerable diversification in terms of species and systems and has been showing an impressive annual growth rate of 6–7%. Coastal aquaculture emerged as a sunrise sector in India during the 1990s. It was identified as a sector full of promise for expanding exports and for adding to foreign exchange. The sector has more than fulfilled its promise and has more in store. Indian brackishwater aquaculture comprising of shellfish and finfish farming is an economic engine in the Indian aquafarming sector. India is a major shrimp producing nation in the Asian region with an export of nearly 13 lakh MT of seafood valued at INR 46 thousand crores during 2019–20.

Internationally, the growing awareness about 'fish as high health food' has increased the demand for food fish. Therefore, we need to produce more by enhancing our productivity, diversifying our species and utilizing the vast untapped resources as we have utilized only 15% of our brackishwater and 40–50% of freshwater resources so far.

33.2 Potential Brackishwater Species for Aquaculture

Shrimp culture is broadly accepted by aqua farmers of Sundarban due to its high economic return. Currently, successful demonstration of finfish farming in different place of Sundarban has given confidence to the farmers to go for commercial culture of finfishes. In West Bengal, Asian seabass, grey mullet, pearl spot and milkfish are presently under farming. Initiative has also been taken for propagation of Hilsa culture in Sundarban. Apart from shrimp and fish, crab culture is getting momentum due to its high demand and export market. Potential fish/shellfish species for brackishwater aquaculture in Sundarbanare *Lates calcarifer*, *Mugil cephalus*, *Chanos chanos*, *Etroplus suratensis*, *Penaeus monodon, Penaeus indicus, P. vannamei*, *Scylla serrata* and *S. olivacea.*

33.2.1 Asian Seabass

The Asian Seabass or *L. calcarifer*, known as 'Bhetki' in India, is a popular euryhaline brackishwater species. It is a high valued species in domestic as well as international market. Successful technology for the seed production of Asian Seabass under controlled conditions and farming has been developed, standardized and demonstrated for the first time in India by ICAR-CIBA since 1997 (Thirunavukkarasu et al. 2001, 2004). Two private hatcheries also promoted for seed rearing and to supply the seed to meet the demand from the local farmers. The culture of seabass involves nursery rearing in hapas, pre grow-out culture and grow-out culture in ponds or cages. In the nursery phase, 25 days old hatchery reared seabass fry (size: 1–1.5 cm) is stocked either in pond (10×10 m^2) or in net cage hapa fixed in pond ($1 \times 2 \times 1$ m^3), or in tank (5–10 t) @20–30 nos. m^{-2}, 250–300 nos. m^{-3}, 1000 nos. m^{-3}, respectively. They are reared with formulated feed (45–48% protein)/minced meat/Artemia biomass/zooplankton, etc., for a period of maximum 45–60 days.

Seabass culture using formulated slow sinking feed and farm-made feed developed by CIBA is becoming popular. Farmers of Indian Sundarban have started practicing seabass culture using the farm-made feed. Farmers can prepare cost-effective feed easily by using locally available ingredients (low value fish, acetes, mustard cake, soybean cake, ground nut oil cake, low value wheat flour, poultry offal, fish oil, lecithin, mineral, vitamin, amino acid mixture and binder) with simple machineries and can reduce the cost of seabass production. Seabass culture with farm-made feed in Sundarban showed impressive result in terms of net profit and benefit cost ratio.

Recently, ICAR-CIBA has promoted low volume low-cost cage culture technology for Asian Seabass which is easily adaptable to small farmers and serves as an alternate livelihood income. Farmers can fabricate the cages by themselves and culture this high valued fish within 240–300 days. After nursery rearing in hapa, the fry is transferred to pre grow-out cages for 60–90 days and fingerlings are stocked into the grow-out cages where they are reared until they attain adult size. During pre grow-out phase, the cages are provided with internal partitions to stock different size group of the species which prevents the cannibalism within the species. The fish is fed with slow sinking nursery and grow-out feeds Seebass Nursery^{Plus} and Seebass Grow-out^{Plus}, respectively. In grow-out cage, fingerlings attain 300–800 g weight with a 30–71% survival rate. This unique culture technology has emerged as a successful livelihood option for fisher communities including women.

33.2.2 Grey Mullet, Mugil cephalus

This species is euryhaline and capable of surviving in wide variety of marine, estuarine and freshwater environments of varying turbidity, salinity and dissolved oxygen levels (Thomson 1955; Ibanez and Guitierrez 2004). Grey mullet is a diurnal feeder, consuming mainly zooplankton, dead plant matter and detritus. The fish is abundant in both coasts of India. In a major breakthrough, CIBA has successfully bred the grey mullet in captive condition for the first time in India. Mullets from east coast and west coast collected and reared under uniform captive condition and their reproductive performance also studied. They are fed with pellet feed which accelerates gonadal maturation. The induced breeding in captivity gives better fertilization rate in west coast mullet (45–85%) than east coast one (1–35%). It is reported that the reproductive periods of mullets on two coast of India are asynchronous and shorter for east coast (Sukumaran et al. 2021). Grey mullet is cultured in two phases, such as nursery rearing and grow-out culture. In case of nursery rearing of grey mullet, well prepared earthen pond with the provision of periphyton substrate is suitable for mullet nursery rearing compared to complete feed-based system (Biswas et al. 2017). In grow-out phase, fingerlings are stocked in monoculture or polyculture system. Inpolyculture system, grey mullet is stocked with tilapia, milkfish, pearlspot in brackishwater and with common carp, silver carp in freshwater. In polyculture system, mullet is fed on natural feed, feed leftovers and detritus and gives better yield (4.3–5.6 t ha^{-1}) than the monoculture system (2.3–3.7 t ha^{-1}). Study revealed that pond fertilization with formulated feed with stocking density of 15,000 fry ha^{-1} would be appropriate for production of striped grey mullet fingerlings in brackishwater pond (Biswas et al. 2012). Formulated feed supplemented with 30% protein (De et al. 2012) and 6% lipid (De et al. 2011) is reported to be optimum for better growth performance, lower FCR, better feed utilization and digestive enzyme activity in grey mullet.

*33.2.3 Pearlspot (*Etroplus suratensis*)*

Pearlspot, *Etroplus suratensis*, also known as ‘green chromide’, is mainly cultured in Kerala in traditional manner in the Pokkali fields. Though farming of this species is practiced in West Bengal in a small scale, it is an economically important food fish in Kerala with a market price ranging between INR 250 and 500 kg^{-1} depending upon the size and season. The seed of the fish is generally abundant in west coast. Captive breeding can be carried out either in ponds, tank and cage systems provided with artificial substrates and breeding pits. Modular tank-based breeding and seed production have been achieved successfully by CIBA. In this hatchery technology, pearl spot is bred in tank (1000 L capacity) containing a single pair of fish under the recirculatory aquaculture system (RAS). The species exhibit a high degree of parental care and have very low fecundity as compared to other brackishwater fishes. The frequency (@ every 15–18 days by laying of 2000–2500 eggs per batch) of breeding was increased by curtailing the parental care of the species. The technology can be taken up as homestead activity by the family or self-help groups for their income generation activity. The seed produced can be sold either for farming or for ornamental purposes. Being an omnivorous species, this is a suitable species for culture by the small scale farmers. The species can adapt in different culture systems. Low-cost low volume net cage culture with formulated floating feed, the species can attain 100–150 g after 150–240 days (Patil et al. 2020).

*33.2.4 Milkfish (*Chanos chanos*)*

Milkfish is an important brackishwater species. It is able to tolerate a wide range of salinity. Generally, milkfish seeds are available in wild environment of Andhra Pradesh, Tamil Nadu, Kerala and Karnataka. The fish can be farmed in brackishwater and freshwater ponds, pens and cages. Due to its resemblance with hilsa, the fish is popularly known as Deccan Hilsa in West Bengal. Being an herbivorous species, milkfish grow rapidly by eating on lab-lab, green algae, epiphytes, phytoplankton, zooplankton, filamentous green algae, copepods and detritus. Nylon nets can also be provided in order to produce periphyton, used as feed of milkfish. It can be cultured in low input-based pond by small and marginal farmers. In order to promote and popularize milkfish farming, ICAR-CIBA has achieved the first breakthrough in captive breeding for the species in June 2015 and standardized seed production and farming technology. For grow-out culture, milkfish fingerling (body weight 5–8 g) can be stocked @1 no m $^{-2}$ in the ponds and fish attains 300–400 g body weight within 6 months with productivity of 2.3–2.8 t ha^{-1}. Farmers can earn a profit of INR 60 per kg within a short period of 6 months. The fish can be cultured in abandoned shrimp ponds. Periphyton-based culture of the species reduces the demand of pellet feed (Biswas et al. 2020). The species is suitable for low depth water system.

33.2.5 Whisker Catfish, Mystus gulio

Mystus gulio is a commercially important brackishwater catfish locally known as 'nuna tengra'. It is an important small indigenous fish species (SIS) of the Sundarban delta. It is an important cultivable fish, in paddy fields and *bherries* of the Sundarban. The fish has a good market price. ICAR-CIBA has developed and popularized a cost-effective, farmer friendly Homestead Modular Hatchery Technology (HMHT) of *M. gulio*. In this technique, 100 L tanks are used to rear 15–20 pairs of *M. gulio*. All can be bred at a time and eventually produce 45,000–60,000 fry. The survival rate of fry is also high (80–90%). This hatchery model is affordable as well as simple technology to produce *M. gulio* seeds by the fisher communities, even women can also be involved in this process. The fish can attain 40–60 g within 6 months in grow-out culture. It is a profitable option for small and medium scale farmers of

Sundarban to spend INR 90–100 kg $^{-1}$ production of the fish and earn a profit of INR 300–400 kg $^{-1}$.

33.2.6 *Hilsa,* Tenualosa ilisha*, Potential Species for Culture in Sundarban*

Tenualosa ilisha, commonly known as Hilsa, is considered as 'king of the fish' in West Bengal, India because of its unique taste and high commercial value. This is a migratory fish. The species is an active sight feeder. At young stages, hilsa mainly relies on zooplankton, whilst as adult, turn to become microphagous planktivore (De et al. 2013). Hilsa sub-adults (66.76 g, 184.75 mm) cultured in brackishwater pond using formulated feed rich in lipid (15%) reported to attain ovarian maturity (upto stage V) with an increase in body weight and total length of 358.18–425.52 g and 352–370 mm, respectively, in 2 years period (De et al. 2020a). To propagate hilsa culture in Sundarban, hilsa larvae were produced by protocol developed by ICAR-CIBA using dry-stripping method of breeding of wild collected hilsa brood followed by larval rearing in indoor tanks (De et al. 2019) and nursery rearing in outdoor ponds for 4 months. Pond reared fingerlings (1.5–4.0 g) were distributed to farmers of Sundarban for propagating its culture using Hilsa^{Plus} feed. As primary food of hilsa is plankton, farmers were advised to use plankton booster (Plankton^{Plus}) developed by ICAR-CIBA in ponds. Farmers were trained regarding handling of the delicate hilsa fingerling, feed requirement and pond management for hilsa culture.

33.2.7 *Shrimp Culture*

33.2.7.1 Periphyton-based Culture of Tiger Shrimp, *Penaeus monodon*

Periphyton-based shrimp farming is an eco-friendly approach of shrimp farming method for sustainable shrimp culture. In substrate-based aquaculture, submerged substrates provide sites for the development of autotrophic and heterotrophic organisms, which serve as a quality natural food. It also provides shelter for cultured organisms and improves water quality through nitrification. Velon nets can be installed in ponds to develop the periphyton. Shrimp utilizes the natural feed more in periphyton-based system. Periphyton-based shrimp farming model showed 8.8% improvement in productivity and 10% improvement in FCR compared to the control ponds (Deo et al. 2012).

33.2.7.2 Indian White Shrimp, *Penaeus indicus*

Penaeus indicus is native shrimp species which can be cultured as an alternative to exotic *P. vannamei*. This species has the ability to tolerate wide variation of salinity. Culture of the species in biosecured zero water exchange system has been standardized by CIBA using formulated feed Indicus^{Plus} with 35% crude protein (Lalramchhani et al. 2019). The shrimp post larvae can be stocked at a density of 25 nos. m^{-2} in ponds and reared for 120 days. After 4 months rearing, an average body weight of 18–20 g with a production upto 3.08 t ha^{-1} and a survival upto 75% can be achieved in spite of low saline conditions during culture.

33.2.7.3 *Penaeus vannamei*

Since 1995, *P. monodon* culture was affected with white spot syndrome virus (WSSV) disease, and the Asian shrimp industry was almost collapsed. Govt. of India took initiative for alternative species and *P. vannamei* was introduced in India. After risk analysis study, in 2009, large scale culture of the species was permitted. This is a native species of the pacific coast of Mexico and South America. Nowadays, it is the most wildly cultivated shrimp across the world. It can withstand a wide range of temperature and salinity. The shorter duration of culture, dependence on organic matter, high density culture and easier to breed are the main advantages of culturing this species. The first scientific farming of this shrimp in West Bengal was conducted at Kakdwip Research Centre of CIBA. Productivity of 4.6–6.29 t ha^{-1} and 7.21–8.46 t ha^{-1} was achieved with stocking density of 20 and 40 nos. m^{-2} shrimp, respectively. The seed, feed, water quality and their management are the most important factors on which success of culture depends.

33.2.8 Crab Culture

Though technology for seed production, culture and fattening of green crab, *S. serrata*, has been developed by ICAR-CIBA (CIBA 2000), but seed production technology of orange mud crab, *S. olivacea,* major culturable crab species available in Sundarban, is yet to be standardized. Culture of orange crab is being practiced by farmers of Sundarban in different systems viz., grow-out culture in earthen pond, grow-out culture in box, fattening in box or in cement tanks. In grow-out culture, major problem faced by farmers is less recovery percentage at harvest due to cannibalism and burrowing habit of the species. Survival or recovery percentage can be increased in box culture, where crabs are held individually in the containers or cells.

Monosex culture of crab minimizes aggressive behaviour between crabs associated with sexual maturity, hence increases the survival rate. In case of fattening, soft shell crabs are cultured for fattening. 70–80% survival is achieved after 20–30 days of fattening. Currently, demand of soft shell crab has been increased and farmers are also inclined to produce soft shell crab but major concern is seed and feed. At present, no commercial crab hatchery is available in India producing crab seed. Though commercial crab feed is not available in the market, farmers can do crab culture with farm-made feed using locally available resources.

33.3 Other Options for Livelihood Improvement

Most of the low lands of Sundarban region are saline in nature and hence not suitable for cultivation round the year. During kharif season precipitation is very high (annual rainfall 1600–1800 mm) and maximum amount of rainfall occur within short period of time and causes water logging up to 2–2.5 ft and field remains muddy up to December. Therefore, farmer can grow only indigenous paddy varieties which take long time for its maturity and gives very low yield (1.2–1.5 t ha^{-1}) and farmers could able to earn only INR 5000–8000 ha^{-1} yr^{-1}. During winter and summer season, salt arises on soil surface and soil become more degraded. Moreover, due to scarcity of irrigation, water crop cultivation is not possible during this period. Sundarban farmers are having very small land holdings and very limited financial resources. Farmers cultivate paddy during monsoon as a rainfed crop, and in other season, farmers move to other places for job as a daily labour, and other farmers are involved in catching fishes, crabs from local brackishwater river/creeks.

There are different opportunities to improve livelihood of farmers. Amongst them, integrated farming system, improved traditional system of aquafarming using cost-effective input and low-cost farm-made feed, introduction of multispecies culture with compatible species to increase the productivity are the best options available.

33.3.1 Polyculture

Polyculture is the best economical approach of aquaculture as a suitable multispecies combination allows the species to explore all the strata of water column as well as increase productivity. For getting the best result in polyculture, selecting appropriate species and using cost-effective feed are the keys to the success. Poly^{Plus}, a cost-effective polyculture feed developed by CIBA using locally available cheap ingredients (rice bran, mustard cake, sunflower cake, pulse husk, low value wheat flour, low value fish meal and mineral-vitamin- amino acid mixture), resulted in a better growth of species in polyculture and high economic return. For brackishwater polyculture, many studies were taken up to optimize the combination of species which can yield better productivity. Polyculture of *M. cephalus*, *Liza tade, Liza parsia, Scatophagus argus, M. gulio* and *P. monodon* with Poly^{Plus} feed was reported to yield a productivity of 3.2–4.8 t ha^{-1} with a net profit upto INR 456,204 ha^{-1} yr^{-1} (De et al. 2018).

33.3.2 Integrated Livestock-Horti-Aquaculture

Integrated livestock-horti-aquaculture involves aquaculture with rearing of poultry and livestock and also vegetable cultivation. A model chick-horti-aqua/duck-horti-aqua integrated farming may have pond of 1500–3000 m^2 area for aquaculture, land of 350–400 m^2 area for vegetable cultivation and a floating cage of 9–12 m^2 area for 50 chicks/ducks. Under vegetable cultivation, spinach, amaranthus, cabbage, knolkhol, cauliflower, brinjal, beetroot, raddish and other leafy vegetables may be cultivated. For aquaculture, *Chanos chanos* (23.4–25.0 g), *Liza tade* (47.6–49.9 g), *M. cephalus* (61.8–68 g), *L. parsia* (26.3–27.6 g), *E. suratensis* (52.1–53.2 g), *Oreochromis mossambicus* (24.4–26.6 g), *M. gulio* (1.7–2.4 g) and *P. monodon* (3.14–3.78 g) can be stocked @ 0.5, 0.25, 0.25, 0.25, 0.5, 0.75, 0.5, 1.0 m^{-2}, respectively. Floating sheds to be made for the birds to avoid accumulation of dropping in same place of ponds. After 360 days, farmers can get net profit of INR 236,609–296,724 ha^{-1}.

Demonstration of integrated horti-livestock-aquaculture at CIBA, KRC revealed that chick-horti-aqua integration performs better than the duck-horti-aquaculture in terms of production as well as net profit. Farmers can adopt integrated farming system after proper understanding and hands-on training on the system.

33.3.3 Integrated Multitrophic Aquaculture-IMTA

IMTA is an economic approach towards livelihood improvement of farmers. An integrated multitrophic aquaculture (IMTA) model involving mullets (*M. cephalus* and *L. parsia*) and tiger shrimp (*P. monodon*) as fed-species and estuarine oyster (*Crassostrea cuttackensis*) and seaweed, *Enteromorpha* spp. as extractive species is a viable aquaculture option in brackishwater of the Indian Sundarban. IMTA system shows better water quality, higher productivity, higher growth of species and lower feed conversion ratio (FCR) as well as higher income and profit compared to the control system devoid of extractive species (Biswas et al. 2019). Different vegetables like radish, carrot, bhindi, brinjal, pumpkin, beans, beat root, green chilli, tomato, spinach, malabar spinach, red amaranth, cauliflower, etc., also can be grown on the pond dykes.

33.3.4 Production of Plankton Booster

Plankton booster production from fish waste may be one lucrative livelihood option for the fishers of Sundarban. Fish waste is converted into a liquid product, Plankton^{Plus}, having protein content of 45–55% and lipid of 15–20% which boost the production of phyto and zooplankton in pond within 7–10 days after application. This technology can be adopted by farmers for production of plankton booster on a commercial scale. Study conducted by CIBA revealed that plankton booster (Plankton^{Plus}) could enhance shrimp/fish productivity in ponds through increased plankton density (De et al. 2020b). Plankton booster produced from fish waste can improve survival of shrimp and fish to the tune of 10–15% and enhances average body weight of shrimp and fish to the tune of 9–19%. The plankton booster (Plankton^{Plus}) is reported to enhance the productivity of *P. vannamei* to the tune of 1.71 t ha^{-1} (De et al. 2020b). For production of 40 tonnes of Plankton^{Plus} per year, fixed capital of INR 200,000 and working capital of INR 196,100 is required. Farmers can realize net profit of more than 600,000 yr^{-1}. This technology is having potential for doubling the farmers income and also to enhance their socio-economic status.

33.3.5 Small Scale Aquafeed Plant

A small scale aquafeed plant for producing pellet feed can be an important livelihood improvement option for Sundarban. An investment of INR 1,500,000 for the machineries in the mini aquafeed plant can produce 150–200 kg pellet feed per day for the fish or shrimp using available feed ingredients.

33.4 Challenges and Mitigation

Sundarban farmers face a lot of challenges viz., higher input cost, nonavailability of quality seed and feed, lack of transportable road to reach the main market apart from disease outbreak, fluctuating price of end product, etc. (Ghoshal et al. 2019). These challenges need to be overcome by adopting appropriate measures like mobilization of aquafarmers, adoption of scientifically validated technology, creating awareness amongst stakeholders on different aspects of culture and through capacity building of the aqua farmers.

33.4.1 Inputs-related Issues—Seed, Feed etc.

Getting quality seed and feed are the major challenge faced by farmers of Sundarban. Due to absence of shrimp hatcheries in West Bengal, farmers are compelled to buy seeds with a high cost from commission agent who bring shrimp seed from hatcheries located at southern states of India. To avoid this commission agent, farmers should form club or co-operative and put purchase order directly to Govt. approved hatchery for their cumulative seed requirement with a cheaper rate. Establishment of seed bank can make the seed available to the farmers. Feed constitutes 50–60% of total production cost in aquaculture. Cost of commercially available feed is very high leading to the increased cost of production. Govt. institute like CIBA developed cost-effective technology for preparation of shrimp and fish feed of different growth stages. This technology dissemination and establishment of one feed mill with capacity of 1–2 t hr^{-1} in every 200 ha aquaculture area can help to get quality feed with less cost which can ultimately help in increasing the net profit of aquafarmers of Sundarban.

33.4.2 Lack of Communication and Cold Storage Facility

Sundarban is having 54 inhabited islands, and all are not properly connected with main land with motorable road. Hence, anything and everything require additional cost to reach to the common people/farmers. As a result, farmers need more investment for their aquaculture inputs which leads to higher cost of aquaculture production. Moreover, fish is a perishable product. It needs to be sold immediately unless there is proper cold chain facility. Due to lack of cold chain facilities in Sundarban, farmers are compelled to sell their product in nearby local market compromising their profit. Therefore, Govt. should take initiative to establish cold chain facilities, so that farmers get reasonable price for their product.

33.4.3 Aqua Clinic Facility

Absolutely, no facility for testing soil and water or PCR testing for virus screening is available in Sundarban. Setting up of aqua clinic with soil, water, feed analysis and with PCR facility in different aqua hub is essential for proper culture management.

33.4.4 Natural Calamities

Sundarban is very much prone to natural calamity. Almost every year, this area is experiencing one or two cyclone which makes the life of inhabitant of this area miserable. Though, mangrove tree act as natural shield to protect the Sundarban area but due to intrusion of saline water, soil quality of cultivable land gets degraded. This degraded land can be used for brackishwater aquaculture. Farmers should be made aware about environmental issues and the way of tackling the situation by adopting aquaculture practices.

33.5 Conclusions

Different research institutes developed several technically feasible, environment friendly and economically viable technologies of shellfish and finfish culture and the same need to be scaled-up through strategic planning and implementation of development schemes in convergence with State Government, aqua farmers and other stakeholders. Scientific adoption and scaling up of these technologies would definitely increase farmers' income by three to four folds in a span of one to two years itself with shorter crop duration in aquafarming. This can be a model for doubling of farmers' income by 2022.

References

Biswas G, De D, Thirunavukkarasu A, Natarajan M et al (2012) Effects of stocking density, feeding, fertilization and combined fertilization-feeding on the performances of striped grey mullet (*Mugil cephalus* L.) fingerlings in brackishwater pond rearing systems. Aquaculture 338:284–292

Biswas G, Sundaray JK, Bhattacharyya SB et al (2017) Influence of feeding, periphyton and compost application on the performances of striped grey mullet (*Mugil cephalus* L.) fingerlings in fertilized brackishwater ponds. Aquaculture 481:64–71

Biswas G, Kumar P, Kailasam M et al (2019) Application of integrated multi trophic aquaculture (IMTA) concept in brackishwater ecosystem: the first exploratory trial in the Sundarban, India. J Coastal Res 86:49–55

Biswas G, Bera A, Mandal B et al (2020) A sustainable and profitable brackishwater finfish farming model for milkfish, *Chanos chanos*. Aquaculture Spectrum 3:17–19

CIBA (2000) Captive broodstock development induced breeding and larval stages of mud crabs (*Scylla* sp.). Bulletin no 12. Central Institute of Brackishwater Aquaculture (Indian Council of Agricultural Research)

De D, Ghoshal TK, Kundu J et al (2011) Optimal dietary lipid requirement for grey mullet, *Mugil cephalus*. Indian Journal of Animal Nutrition 28(3):433–439

De D, Ghoshal TK, Kundu J (2012) Effect of feeding different levels of protein on growth performance, feed utilization and digestive enzyme of grey mullet (*Mugil cephalus* L.). Anim Nutr Feed Technol 12:179–186

De D, Shyne Anand PS, Sinha S et al (2013) Study on preferred food items of Hilsa (*Tenualosa ilisha*). Int J Agric Food Sci Technol 4:647–658

De D, Biswas G, Ghoshal TK et al (2018) Poly^{Plus}-a cost effective feed for brackishwater polyculture. CIBA Technology Series 15. ICAR-Central Institute of Brackishwater Aquaculture, Kakdwip Research Centre, Kakdwip, West Bengal, India, p 12

De D, Kumar P, Anand PS et al (2019) Embryonic development, larval rearing, and digestive tract and enzyme ontogeny of Hilsa shad, *Tenualosa ilisha*. In: Jithendran KP, Saraswathy R, Balasubramanian CP et al (eds) BRAQCON 2019: world brackishwater aquaculture conference. J Coastal Res 86(SI):73–81

De D, Shyne Anand PS, Mukherjee S et al (2020a) Broodstock development and captive maturation of Hilsa (*Tenualosa ilisha*) in a brackishwater pond-based system. J Fish Biol 97:720–733

De D, Sandeep K, Kumar S et al (2020b) Effect of fish waste hydrolysate on growth, survival, health of *Penaeus vannamei* and plankton diversity in culture systems. Aquaculture 524:735240

Deo AD, Sundaray JK, Biswas G et al. (2012) Growth production and FCR of shrimp *Penaeus monodon* in earthen ponds with velon net as a substrate for periphyton development in Book of abstracts. National conference on new vistas in Indian aquaculture, p 83, 23–24 February 2012

Ghoshal TK, De D, Biswas G et al (2019) Brackishwater aquaculture: opportunities and challenges for meeting livelihood demand in Indian Sundarbans. In: Sen HS (ed) The Sundarbans: a disaster-prone eco-region, Coastal Research Library Volume 30, Springer Nature, Switzerland, pp 321–349

Ibanez AL, Gutierrez BO (2004) Climate variables and spawning migrations of the striped mullet and white mullet in the north-western area of the Gulf of Mexico. J Fish Biol 65(3):822–831

Lalramchhani C, Panigrahi A, Anand PS et al (2019) Effect of varying levels of dietary protein on the growth performances of Indian white shrimp *Penaeus indicus* (H. Milne Edwards). Aquaculture 519:734736

Patil P, Hussain T, Palav K et al (2020) Cage culture of seabass and pearlspot in mangrove-based creeks as an alternate livelihood for the mangrove coastal community of Sindhudurg, Maharashtra-a success story. Aquac Spectrum 3:21–26

Sukumaran K, Thomas D, Rekha M et al. (2021) Reproductive maturation and induced breeding of two geographical groups of grey mullet, *Mugil cephalus* Linnaeus, 1758. Aquaculture 536:736423

Thirunavukkarasu AR, Kailasam M, Kishore Chandra P et al. (2001) Captive broodstock development and breeding of seabass *Lates calcarifer* (Bloch) in India. In: Menon NG, Pillai PP (eds) Perspectives in mariculture. The Marine Biological Association of India, Cochin, pp 111–124

Thirunavukkarasu AR, Abraham M, Kailasam M (2004) Hand book of seed production and culture of Asian seabass, *Latescal carifer* (Bloch). CIBA Bulletin 18, ICAR-Central Institute of Brackishwater Aquaculture, Chennai,Tamil Nadu, India, p 51

Thomson J (1955) The movements and migrations of mullet (*Mugil cephalus* L.) Marine and Freshwater Research 6(3):328–347

Chapter 34
Water Management for Sustainable Brackishwater Aquaculture in Coastal Ecosystem-Innovative Approaches

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Abstract Brackishwater aquaculture is a coastal farming activity, which aims at deriving maximum benefits from unproductive and marginally productive coastal lands and brackish water bodies, and it has contributed significantly to the progress of the country's economy as well as the economic well-being of the rural poor. It is a fast-growing food industry, and the success mainly depends on the availability of good and adequate quality source water and water management during culture. Hence, the water management in coastal brackishwater aquaculture is paramount, which starts with the identification of good quality and adequate water resources, water monitoring during culture for maintenance of the optimum water quality, and discharge water management by reducing, reusing recycling, and remediation technologies. Coastal watershed-based integrated water resource management using the advancement in geospatial modeling, remote sensing, and geographical information system (GIS) helps to identify the potential site, water source, and its salinity regime during different seasons and to minimize the impact of upstream activities on the coastal aquaculture as well as the impact of aquaculture on coastal ecosystem. Of late intensive coastal aquaculture is rapidly expanding with the introduction of *Penaeus vannamei* which uses large water volume and high protein content in feed which results in significant nutrient-rich effluents. Recirculating aquaculture systems (RASs) seem to be a solution. Development and advancement of RAS, raceways, integrated multi tropic aquaculture (IMTA), zero water exchange systems, biofloc, seaweed bioremediation, algal bioreactor-based RAS, and aquaponics offer scope for higher productivity with better water management practices that maintain the serenity of coastal ecosystems. In the present article, all the above-mentioned water management technologies in brackish water aquaculture have been discussed for pristine coastal ecosystems.

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34.1 Introduction

Brackishwater aquaculture in India has evolved as a viable commercial and economic farming practice from the level of traditional backyard activity over the past few decades with the advancement in scientific culture practices and has been showing an impressive annual growth rate of 6–7%. India is blessed with 3.9 million ha of estuaries and 3.5 million ha brackish water resource of which 1.2 million ha is potential brackish water area available in India. However, the total area under brackish water farming is only just over 15%. To bring this vast resource under sustainable aquaculture, coastal watershed-based planning and water management are of prime importance. Brackish water aquaculture is synonymous with shrimp culture. The introduction of exoticwhite-leg shrimp, *P. vannamei*, has fascinated the farmers' attention for the reason of its profligate growth, high survival rate, acceptance to high stocking density, lower dietary requirements, more effective utilization of plant protein in the formulated diet, low incidence of native diseases, availability of specific pathogen free (SPF) domesticated strains, and culture feasibility in wide salinity range. The production of this species has reached a level of 6,22,327 tons during 2017–2018 (MPEDA 2018). At present, not only in India, worldwide, the most important brackishwater-cultivated species is *P. vannamei* which contributes approximately 52.9% among crustaceans in world aquaculture production (FAO 2020).

Generally, shrimp farming systems are categorized into traditional, modified-traditional, extensive, semi-intensive, and intensive systems. These classifications are made based on the degree of management inputs provided. At present, 90% of the farming is done by introduced SPF white shrimp, *P. vannamei*. Three kinds of intensive culture systems are in practice, depending on the quality of the water supply viz., open system. recirculation system. minimal water exchange system. Though *P. vannamei* is started in a semi-intensive culture system of late, it is usually cultured in the intensive and high and super-intensive system. Hence, the water management in coastal brackishwater aquaculture is paramount which starts with the identification of suitable water resources, water monitoring during culture, and discharge water treatment like screening, sedimentation, settlement, and bioremediation or phytoremediation before let into stream or waterbodies. Intensive coastal aquaculture is rapidly expanding which uses large water capacity and high protein content in feed which outcomes in a significant volume of nutrient-rich effluents. Therefore, the present review has reflected the innovative approaches targeted to have better water management in the three phases of brackishwater aquaculture practices toward an economic and sustainable production system.

Water management of shrimp farming includes three phases viz.,

- Influent/intake water management
- Pond water management
- Effluent/discharge water management

34.2 Intake Water Management

All aquaculture conveniences require a sufficient amount of quality water. It is imperative to have a dependable and efficient, good quality water source and equipment to transfer water to and within the facility of the farm site. The volume of water required depends on the facility size, the species, production system, and scale of operation. Accurate design and structure of the water inlet system are a complete necessity to avoid complications during the culture of shrimp farms. Brackishwater aquaculture utilizes saline water either from sea or estuary or creek (Fig. 34.1a, b). Water quality and quantity determine the success or failure of an aquaculture operation. The estimate of the quantity of water essential in a farm and the conducts and means to meet

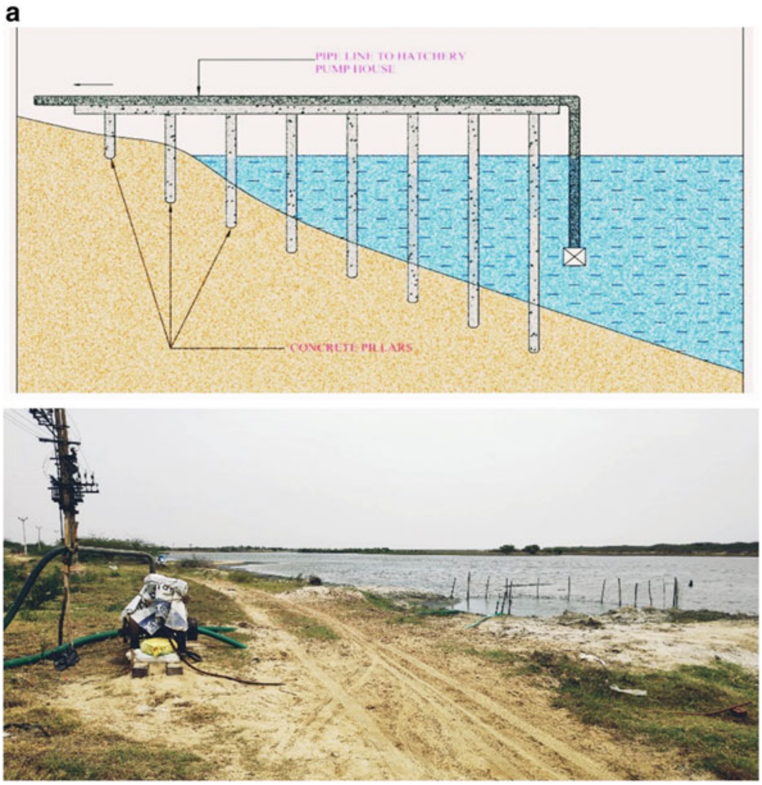

Fig. 34.1 **a** Intake of water from brackishwater resource. **b** Pumping water into culture pond

Fig. 34.1 (continued)

the requirements are the essential factors to be considered in selecting a suitable site. For farming, an estimation of evaporation and seepage losses is required in addition to water exchange during culture. In addition to that, a large supply of water should be on hand to flush ponds if needed or refill them after draining.

34.2.1 Site Selection and Pond Design

Identification of potential and suitable site for brackishwater aquaculture is necessary to expand aquaculture scientifically and sustainably. Therefore, the most important criteria for site selection are water source and its quantity and quality. Possible sites were defined after seeing the importance of ecosystems, soil and water quality, and coastal aquaculture authority (CAA) guidelines using GIS and remote sensing by coastal watershed approach. ICAR-CIBA has developed a methodology for demarking potential zones for Tamil Nadu coastal districts. viz., Chengalpattu and

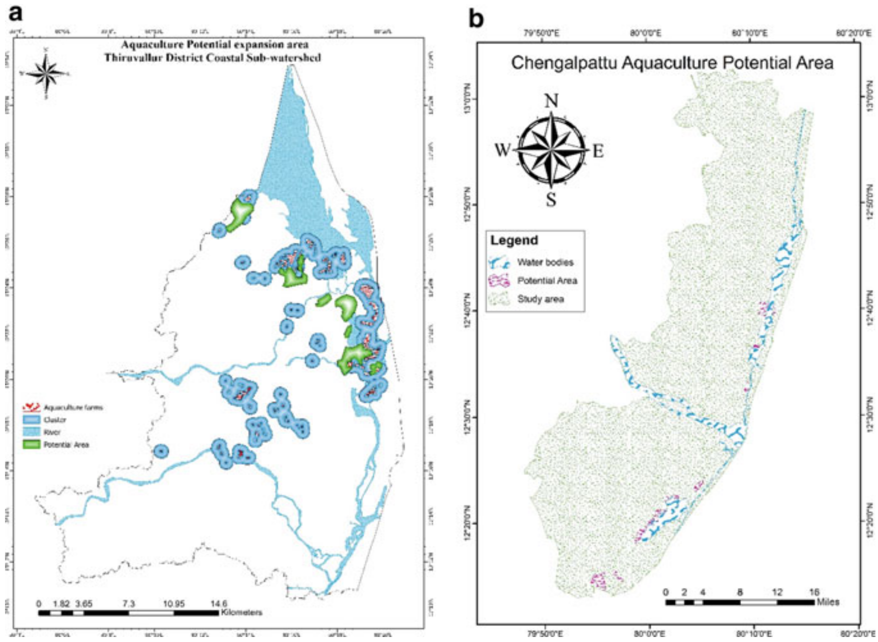

Fig. 34.2 **a** Aquaculture potential area for Thiruvallur district, Tamil Nadu. **b** Aquaculture potential area for Chengalpattu district, Tamil Nadu

Tiruvallur by coastal watershed-based geospatial modeling through analytical hierarchy process (AHP) (Fig. 34.2a, b). Site specific pond design should be made with engineering consideration so that water inlet and water draining during water exchange and harvest could be done with ease.

34.2.2 Water Pumping

The traditional and most economical method of water management for a coastal farm is through tidal flow, but nowadays, mostly in many cases of scientific farming, it is necessary to pump water. For *P. vannamei* culture usually, water is taken through pumping from canals, creeks, or sea. Monoblock or centrifugal pumps are used. Solar pumping is being encouraged. Evaluation study of solar pumping at ICAR-CIBA proved to be economical and efficient (Fig. 34.3).

Fig. 34.3 Solar water pumping

34.2.3 Reservoir/Disinfection

Water treatment is necessary for the maintenance of good water quality during culture which ultimately decides the success of the crop. Before stocking seeds, water from the source should be filtered through 60μ filters to prevent the entry of parasites and crustaceans that are carriers of diseases. A reservoir pond is necessary for most of the farming systems. Chlorination should be done in a reservoir pond to sterilize the water by applying enough chlorine (approximately 30 ppm). Chlorine dosage varies with pH, concentrations of organic matter, and ammonia. Water must be pumped in the grow out pond when the permissible levels of chlorine residuals are less than 0.001 ppm. Aeration, adding of 1 mg L^{-1} of sodium thiosulfate for every mg L^{-1} of chlorine, and contact with sunlight are some of the management measures for dechlorination. In addition to chlorination, ozonation, and UV disinfection also can be applied based on the necessity and requirement of the production system.

34.3 Water Monitoring and Management during Culture

34.3.1 Pond Preparation

Pond preparation includes pond bottom soil conditioning by tilling, liming, and fertilization. Fertilization of pond water for phytoplankton and zooplankton blooms is by either with organic or inorganic fertilizers. A stable pH, algal bloom which is brown with a yellowish hue in color, and water temperature above 25 °C are the major indicators to ensure that the pond is prepared for stocking. Culture must be initiated with at least 1.2–1.5 m of water. Ponds should be constructed to prevent dike erosion, to enable complete drainage of water, to minimize the area of sludge accumulation, and to facilitate ease of draining of sludge. Drainage and harvesting openings should be constructed in low-lying locations and coordinated with the water flow regime.

34.3.2 Pond Lining

Ponds used for aquaculture are mostly earthen ponds in India. The sandy areas and wastelands in many parts of the country can also be utilized effectively if proper seepage reduction systems are in place. The development of intensive farming system warrants ponds lining. Polythene lining, clay compaction, the lean mixture of sand cement, etc., are used to reduce the seepage rate. In sandy soils, one can mix cement with a top layer of soil and obtain a stable lining (Rekha et al. 2005). When considering the cost economics of different lining materials, high-density polythene lining is feasible (Fig. 34.4).

34.3.3 Water Monitoring and Maintenance

Aquaculture ponds are living active systems that show constant and continual fluctuations. Water quality comprises all the essential physico-chemical and microbiological characteristics of water. pH is normally measured as one of the most vital parameters. In any selected site, the pH of the water rather ranges from 7.5 to 8.5. The other similarly important chemical characteristic of water is dissolved oxygen (DO). The water must not be too turbid. Consistent monitoring of water quality is very crucial. The optimum range for water quality parameters is given in Table 34.1.

Fig. 34.4 High-density polythene lining

Table 34.1 Optimum range for water quality parameters

S. No:	Parameter	Optimum range
1	Temperature (°C)	28–32
2	pH	7.5–8.5
3	Salinity (ppt)	15–25
4	Total dissolved solids (TDSs) (ppm)	< 100
5	Dissolved oxygen (DO) (ppm)	4.0–7.0
6	Total ammonia-N (ppm)	< 3.7
7	Free ammonia (ppm)	< 0.1
8	Nitrite-N (ppm)	< 0.25
9	Nitrate–N (ppm)	0.2–0.5
10	Dissolved-P (ppm)	0.10–0.20
11	COD (ppm)	< 70
12	BOD (ppm)	< 10
13	Hydrogen sulfide (ppm)	0.002

34.3.4 Aeration

Aeration is necessary for oxygenation (DO) which is the main factor controlling the pond dynamics. DO levels should be maintained above 4 ppm and paddle wheel/long

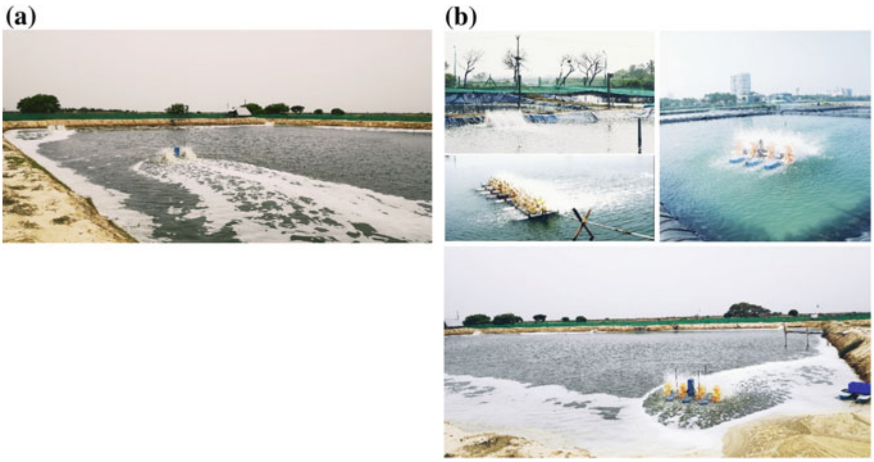

Fig. 34.5 Aerators used in intensive prawn culture systems **a** paddlewheel aerator and **b** longline aerator

arm aerators are commonly used (Fig. 34.5a, b). The location of the aerators should be adjusted in such a way the sedimentation occurs at the center of the pond, which will help in its easy removal. With the intensive culture system, this has become a prime necessity in *P. vannamei* farming. The number of aerators essential is about 1 HP per every 300 kg of biomass.

34.3.5 IoT-Based Water Quality Monitoring System

Real-time monitoring of water quality is highly essential for ensuring better management practices in shrimp aquaculture (Zhang et al. 2011). Internet of things (IoT)-based sensors for wireless water quality monitoring (Lim et al. 2010) using an android application and Web application for pH, turbidity, temperature, and DO have been fabricated and evaluated in the experimental farm at ICAR-CIBA, Chennai (Fig. 34.6). Evaluation of their sensing capability, data storage, and the alert system was carried out. Three types of sensor pH, temperature, and turbidity are integrated and used for monitoring water quality automatically. It would send an alert system if the water quality crossed the threshold which helps the farmers to take remedial action, then and there.

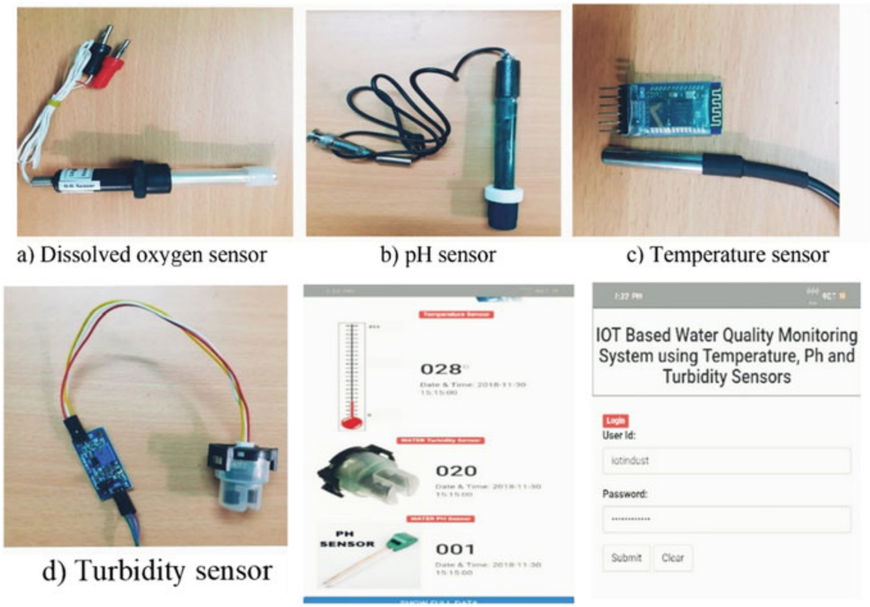

Fig. 34.6 IoT sensors

34.3.6 Feeding and Water Quality

The major challenge in scientific shrimp farming is to provide artificial feeds in proper quantity at the right time as per requirement, which is best done by automatic feeder in addition, there are other potential advantages such as maintenance of better water quality, clear pond bottom, and better feed conversion ratio (FCR) by using an auto feeder. Feeding frequency is usually dependent on farm size, as well as the species and size of the species being cultivated. But mostly, it has been observed that to a greater extent, the feeding and feeding frequency depend on labor availability. Automatic feeders are found to be suitable for *P. vannamei* culture owing to its feeding behavior, which is a column dweller, A solar-powered 125 kg capacity timer-controlled automatic feeder has been designed and developed by ICAR-CIBA and demonstrated in the farmer's field (Fig. 34.7). Results show auto feeder installed ponds provide a better growth rate and low FCR compared to manual feeding. This auto feeder was found to be highly suitable for *P. vannamei* farms with a water spread area ranging from 0.8 to 1 ha (Rekha et al. 2017).

Fig. 34.7 Solar-powered auto feeder

34.4 Effluent Water or Discharge Water Management

Shrimp aquaculture wastewater/released during the culture period is high in volume but moderately dilute in nature. whereas during harvest, discharge is of substantial amounts mainly suspended solids, containing uneaten feed, fecal matter and plankton, and dissolved nutrients such as ammonia, nitrite, phosphorus, carbon dioxide, and hydrogen sulfide. The organic enrichment leads to environmental deterioration of the receiving water bodies especially nitrogen and phosphorous. In general, 52–92% of the nitrogen and 85% of the phosphorus enter the aquatic environment which may easily induce eutrophication and algal bloom leading to anoxia. Intensive coastal aquaculture is rapidly expanding which uses large water volume and high protein content in feed which results in a significant number of nutrient-rich effluents. The national fisheries policy concerning aquaculture is to enhance production and product diversity, but also to enhance product quality to recover the competitive position of the sector and encourage environmental, economic, and social sustainability.

34.4.1 Waste Management—Central Drainage

The topography of the land determines the type and shape of ponds to be constructed. A well-made pond will enable easy management of water transfer, harvesting of the fish/shrimp, and waste collection. It would allow circulation of the water such that wastes will be gathered at the center of the pond. The construction of the dike for the pond including the height, slope, and width of the dike should be pre-determined for effective water recirculation. A central drain is in the center, operated using a standpipe or a valve. Drainage and sludge removal are important parts of pond operation (Fig. 34.8). Ensuring proper slope and water release capacity of the drainage canals toward the final outlet should be encompassed in the planning process.

34.4.2 Discharge Water Treatment Management

The discharge water from shrimp farms should be treated by screening, sedimentation, settlement pond before discharging into an adjacent aquatic ecosystem to avoid the issue of pollution.

34.4.3 Mangroves as Biological Filters

The adaptability of mangrove species (*Rhizophora*) as a biological filter in the shrimp farm discharge water under different types of soils prevailing in coastal areas in Tamil Nadu viz., sandy loam, loamy sand, and clay loam was studied. The study revealed that the mangroves can be developed as a biofilter in the buffer zone along the coast. The mangroves planted along the coast acts as shelterbelts during natural calamities viz., storms cyclones and tsunami in addition to the nutrient sequestering of the shrimp farm discharge water.

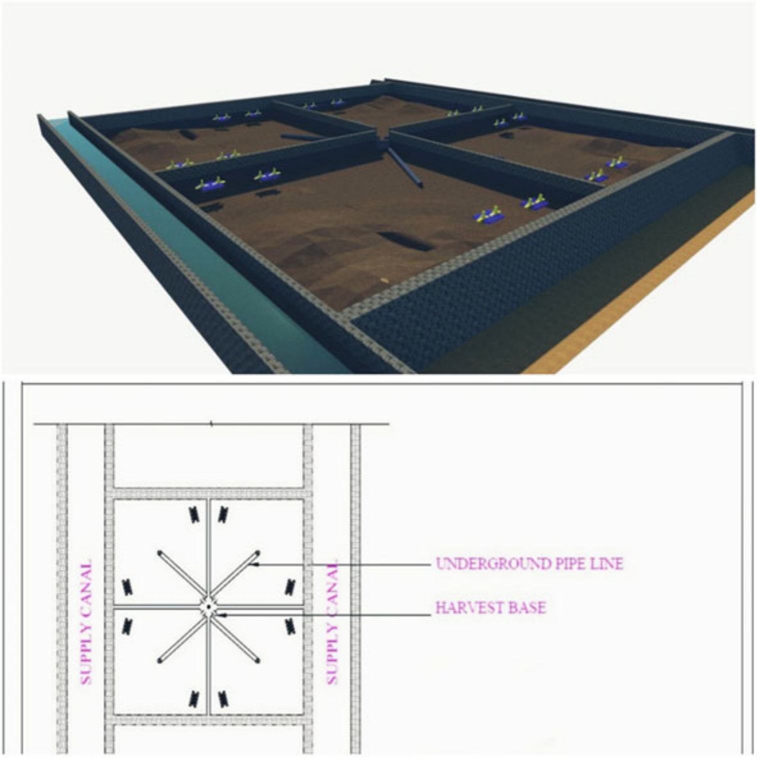

Fig. 34.8 Three-dimensional view of a pond with central drain

34.4.4 *Seaweed Bioremediation*

Macroalgae well known for the name seaweed can utilize the availability of nutrients viz., nitrogen and phosphorus and makes them an effective instrument for bioremediation (Marinho-Soriano et al. 2009). Algae, particularly seaweeds, are the most appropriate for biofiltration because they probably have the highest production of all plants and can be economically cultured (Neori et al. 2004). The red algae *Gracilaria* spp. and the green algae *Ulva* spp. are effective biofilters. *Gracilaria* spp. has been examined for their usefulness in laboratory using tank (Zhou et al. 2006; Marinho-Soriano et al. 2009; Skriptsova and Miroshnikova 2011, Marinho-Soriano et al. 2014), outdoor pond, and field cultivation experiments (Zhou et al. 2006; Yang et al. 2006, 2015). The bioremediation potential of macroalgae would help to sequestrate the nutrient nitrogen and phosphorus (Marcella et al. 2011). The faster expansion of high-density brackishwater shrimp farming increases the importance of phytoremediation. Based on studies at ICAR-CIBA, it is proved that *Agarophyton tenuistipitatum* could be utilized as a potential species to improve water quality at a biomass density ranging from 3.5 to 4.5 g L^{-1} as this species showed better growth in the brackish water salinity regime (Sarkar et al. 2021).

34.5 Integrated Multi-trophic Aquaculture (IMTA)

Integrated multi-trophic aquaculture (IMTA) includes the cultivation of fed species with extractive species that use the inorganic and organic wastes from aquaculture for their growth. A combination of species from different trophic levels in the same system is called multi-trophic. It involves more intensive cultivation of the different species in the nearness of each other, linked by nutrient and energy flow-through water. Filter-feeding organisms as nutrient extractors have proven to be an effective system that reduces extreme pollution from fed farming. The most frequently used organisms are mollusks, which filter organic particles and phytoplankton and macroalgae, which can absorb inorganic nutrients. IMTA provides utilization of nutrients at all trophic levels effectively (Troell et al. 2009).

Seaweed-based co-culture finds significant importance in this context (Castelar et al. 2015). *Agarophyton tenuistipitatum* had notable nutrient bioremediation efficiency and assimilative capacity. Its co-culture with shrimp *P. vannamei* could be an environment-friendly method that reduces nutrient loads from shrimp culture. Economic utilization of seaweed biomass is also possible. *Agarophyton tenuistipitatum* is potentially a fast-growing species with higher specific growth rate (SGR) compared to *Holothuria edulis* in the brackishwater culture system and hence, multiple crops may be obtained from an IMTA system with lesser input. An outdoor trial was conducted to arrive at the effective biomass density of seaweed *A. tenuistipitatum* for efficient bioremediation as well as growth and survival of *P. vannamei* in brackishwater system (Annual Report CIBA 2019). An experiment with five treatments (different biomass intensity, (0, 0.5, 1.5, 2.5, and 3.5 g L^{-1})) revealed that at a biomass density of 3.5 g L^{-1}, NH_4-N, and PO_4-P significantly reduced by 95.71% and 95.74%, respectively, in three weeks. Specific growth rate and average body weight of *P. vannamei* were not significantly increased but survival (99.17%) was significantly higher. The total bacterial count was also significantly reduced. IMTA of seaweed (3.5 g L^{-1}) and shrimp improves the water quality and has bioremedial benefits in the culture system (Fig. 34.9).

34.6 Biofloc

Biofloc production systems can be used for improving environmental control over production. More intensive forms of aquaculture with biofloc can be practiced in places where water is scarce, or land is expensive. A basic criterion in developing a biofloc system is the species to be cultured. Direct consumption of floc gives nutritional benefits to cultured species. Only a few types of biofloc systems are

Fig. 34.9 Seaweed-based IMTA

presently using commercially and are not much evaluated in research. The two basic types are system exposed to natural light and without exposure to natural light. Biofloc systems exposed to natural light include lined ponds or tanks outdoor, for the culture of shrimp and lined raceways in greenhouses. A complex mixture of bacterial and algal processes control water quality in such "greenwater" biofloc systems. Green water biofloc systems are commercially used. However, some biofloc systems (raceways and tanks) are operating in closed buildings with no exposure to natural light. These systems are operated as "brown-water" biofloc systems, where only bacterial processes control water quality (Panigrahi et al. 2018). This is indeed a zero water exchange system with monitoring and managing the water quality by developing bioflocs.

34.7 Aquaponics

Aquaponics is the combination of traditional aquaculture with hydroponics in a symbiotic environment enabling sustainable food production. Fish, prawns, or shrimp can be reared in tanks, and the water is directed into separated raceways of hydroponics, in which salt-tolerant vegetables can be grown. The aquaponics can be integrated with brackishwater fin fishes and small-scale seaweed farming. The fecal matter, feed remains, etc., will be turned into a rich nutrient system that supports plant growth.

34.8 Recirculatory Aquaculture System

A recirculating aquaculture system (RAS) can be defined as an aquaculture system where the water is treated and re-used with less than 10% of total water volume exchanged per day. Based on system water exchange, it is possible to distinguish between flow-through (>50 $m^3\,kg^{-1}$ feed), reuse (1–50 m^3 kg^{-1} feed), conventional recirculation (0.1–1 $m^3\,kg^{-1}$ feed), and "next generation" or "innovative" RAS (<0.1 m^3 kg^{-1} feed). RAS is a potential solution for the increasing environmental restrictions in countries with restricted access to water and land Badiola et al. (2012). Treatment of aquaculture water for its reuse purposes is a sensible means to support the further growth of the aquaculture industry without extreme water demands that are environmentally unsustainable. Water and area savings, reduced risk of contamination, and better environmental control can be achieved by the development of simple, cost-effective, water reuse systems using quite basic techniques without much technical sophistication (Martins et al. 2010). The treated discharge water would be suitable and ideal for recirculation within the farm, making the farming practice conform to the zero discharge norms. Use of nitrifying trickling filters in recirculating aquaculture is preferred (Eding et al. 2006).

Different models of RAS exists for fish culture for more than a decade, whereas the application for shrimp culture and that too maturation is not in vogue due to practical problems. But the intensive *P. vanamei* culture heralded many customized RAS models starting from a small capacity for hatchery use to grow out culture models of industrial production capacity. The initial investment is high, but the production is high if managed properly. Thus, the customized design of the RAS system can be fabricated as per the affordability, need, and requirement of the species being cultured.

34.8.1 RAS for Shrimp Maturation—Single Pair Mating

The concept of single pair mating of *Penaeus monodon* was evaluated in a prototype recirculation system designed in the experimental station of ICAR-CIBA which consists of 8 no's cylindrical tanks of capacity 500 ml liters connected in series with two filter units, reservoir tank, sedimentation tank, settlement tank, and half HP pump. The filter unit was designed after a series of trials to screen the best combination of materials for effective biofiltration, like oyster shell, bio balls, plastic balls which

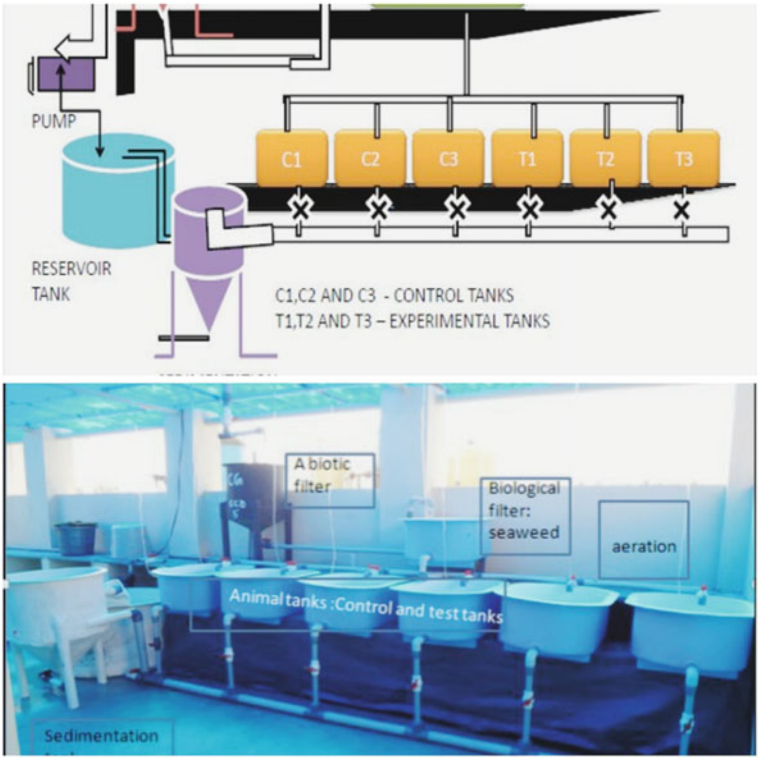

Fig. 34.10 RAS for single pair mating

have a more specific surface area. The study proved the efficacy of RAS for shrimp maturation (Fig. 34.10).

34.8.2 RAS for Shrimp Maturation—Community Mating

Similarly, the study on community mating for shrimp maturation was also evaluated by a series of statistically designed experiment trials of shrimp maturation in both the RAS system and traditional water exchange system with 1:2 male; the female ratio in 5 t capacity tanks. It was conclusively shown that the RAS for shrimp maturation is on par with the traditional water exchange system. The circular tanks with central drainage were appropriate for RAS. In the case of rectangular tanks, the central drainage system was efficient when compared to lateral drainage in removing the metabolites in rectangular tanks as about 37% showed maturation in the central drainage system.

34.8.3 Algal Bioreactor-based Recirculation System

The construction of recirculating aquaculture system with seaweed-based bioreactors for intensive shrimp culture is one of the advanced approaches to solve problems related to discharge water treatment. Different models were developed and field tested. Raceway type model (Fig. 34.11) is found to be very efficient in managing water quality followed by tubular model (Fig. 34.12). Raceway reactor was found to be reducing a significant amount of NH_4-N, NO_2-N, NO_3-N, and PO_4-P. It also helped to maintain alkaline pH throughout the entire culture cycle. The system does not require any degasser to remove CO_2 as algae can absorb CO_2 for photosynthesis and produce an ample amount of O_2. A quite impressive growth rate (4.63% day^{-1}) was recorded in the system with almost 100% survival. Feed was also utilized quite efficiently with an FCR value of 1.4.

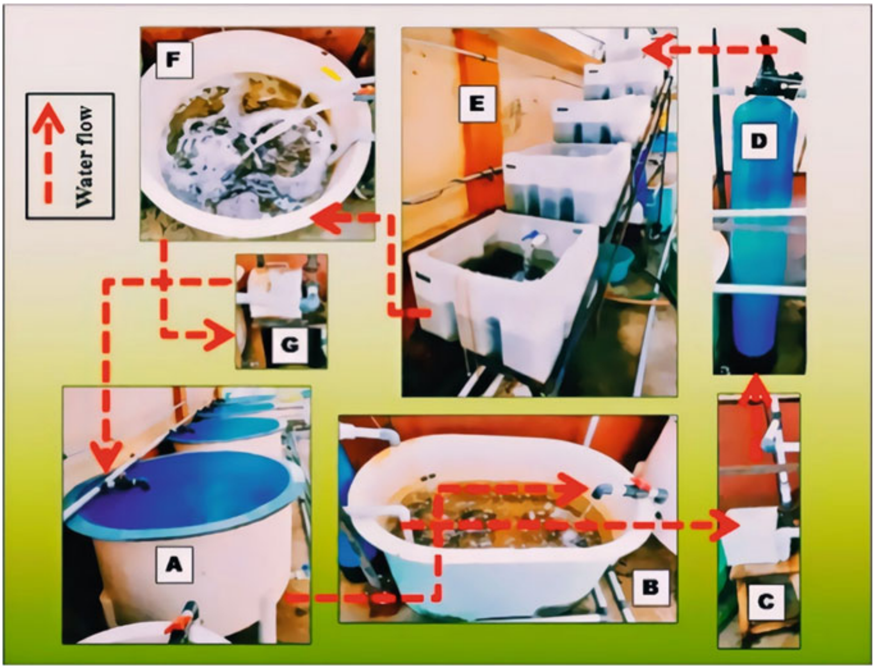

Fig. 34.11 RAS with raceway type bioreactor **a** shrimp culture tanks, **b** Sump, **c** Pump, **d** pressure sand filter, **e** seaweed bioreactor. Red color arrow indicates the flow cycle of water in the system

Fig. 34.12 RAS with tubing bioreactor **a** shrimp culture tanks, **b** sump, **c** pump, **d** pressure sand filter, **e** seaweed bioreactor. Red color arrow indicates the flow cycle of water in the system

34.9 Conclusions

Water management in coastal brackish water aquaculture is paramount which needs innovation in all three phases viz., influent, during culture, and effluent of water management. The concepts of delivering high production with a sustainable approach through evolving eco-friendly technologies started getting momentum worldwide viz., development and advancement of RAS, raceways, IMTA, zero water exchange systems with biofloc, seaweed bioremediation, and aquaponics. The research efforts by ICAR-CIBA as discussed above starting from site selection using GIS and remote sensing, water intake by solar pumping, disinfection protocols, cost-effective lining materials for pond, water monitoring using IoT, feed management by auto feeder, central drainage for managing the waste inside the pond, seaweed bioremediation, IMTA model, zero water exchange system with biofloc offer scope for higher productivity with better water management practices that maintain the serenity of coastal ecosystems.

References

Badiola M, Mendiola D, Bostock J (2012) Recirculating aquaculture systems (RAS) analysis: main issues on management and future challenges. Aquacul Eng 51:26–35. https://doi.org/10.1016/j.aquaeng.2012.07.004

Castelar B, Pontes MD, Costa WM, Moura LCF, Dias GE, Landuci FS, Reis RP (2015). Biofiltering efficiency and productive performance of macroalgae with potential for integrated multi-trophic aquaculture (IMTA). Bioletim do Instituto de Pesca 41:763–770. https://doi.org/10.20950/1678-2305.2015v41nep763

CIBA (2019) Annual report 2018–19, ICAR-Central Institute of Brackishwater Aquaculture (CIBA), Chennai, Tamil Nadu, India

Eding EH, Kamstra A, Verreth JAJ, Huisman EA (2006) Design and operation of nitrifying trickling filters in recirculating aquaculture. Aquacul Eng 34(3):234–260. https://doi.org/10.1016/j.aquaeng.2005.09.007

FAO (2020) The state of world fisheries and aquaculture 2020. Sustainability in Action, FAO. Rome. https://doi.org/10.4060/ca9229en

Lim Y, Kim H-M, Kang S (2010) A design of wireless sensor networks for a power quality monitoring system. Sensors 10:9712–9725. https://doi.org/10.3390/s101109712

Marcella AA, Carneiro Fúlvio Aurélio de M, Freire Eliane Marinho-Soriano (2011) Study on biofiltration capacity and kinetics of nutrient uptake by *Gracilaria cervicornis* (Turner) J. Agardh (Rhodophyta, Gracilariaceae). SciELO Bras SciELO Sci Electron Libr (Online). https://doi.org/10.1590/S0102-695X2011005000074

Marinho-Soriano E, Panucci RA, Carneiro MAA et al (2009) Evaluation of *Gracilaria caudata* J. Agardh for bioremediation of nutrients from shrimp farming wastewater. Bioresour Technol 100(24):6192–6198.https://doi.org/10.1016/j.biortech.2009.06.102

Marinho-Soriano P He, He Q, Zhang J et al (2014) *Gracilariopsis longissima* as biofilter for an integrated multi-trophic aquaculture (IMTA) system with *Sciaenops ocellatus*: bioremediation efficiency and production in a recirculating system. NISCAIR-CSIR, India. http://nopr.niscair.res.in/handle/123456789/28642

Martins CIM, Eding EH, Verdegem MCJ (2010) New developments in recirculating aquaculture systems in Europe: a perspective on environmental sustainability. Aquac Eng 43(3):83–93. https://doi.org/10.1016/j.aquaeng.2010.09.002

MPEDA (2018) Total tiger shrimp, *L. vannamei*, and scampi production. https://www.mpeda.gov.in/MPEDA/cms.php?%20id=eWVhci13aXNlLXNwZWNpZXMtd2lzZS1zdGF0ZS13aXNl

Neori A, Chopin T, Troell M et al (2004) Integrated aquaculture: rationale, evolution and state of the art emphasizing seaweed biofiltration in modern mariculture. Aquaculture 231:361–391. https://doi.org/10.1016/j.aquaculture.2003.11.015

Panigrahi A, Sundaram M, Saranya C et al (2018) Influence of differential protein levels of feed on production performance and immune response of pacific white leg shrimp in a biofloc–based system. Aquaculture 503. https://doi.org/10.1016/j.aquaculture.2018.12.036

Rekha PN, Jayanthi M, Muralidhar M et al (2005) Studies on cost effective seepage control measures for brackishwater aquaculture ponds. Indian J Fish 52(1):105–110

Rekha PN, Ambasankar K, Stanline S et al (2017). Design and development of an automatic feeder for *Penaeus vannamei* culture. Indian J Fish 64 (SI): 83–88. https://doi.org/10.21077/ijf.2017.64.special-issue.76209-12

Sarkar S, Nila Rekha P, Ambasankar K et al (2021) Bioremediation efficiency of indigenous seaweeds of Chennai coast in brackishwater system. Aquac Int 29:1–19. https://doi.org/10.1007/s10499-020-00621-1

Skriptsova AV, Miroshnikova NV (2011) Laboratory experiment to determine the potential of two macroalgae from the Russian Far East as biofilters for integrated multi-trophic aquaculture (IMTA). Bioresour Technol 102:3149–3154. https://doi.org/10.1016/j.biortech.2010.10.093

Troell M, Joyce A, Chopin T et al (2009) Ecological engineering in aquaculture-potential for integrated multi-trophic aquaculture (IMTA) in marine offshore systems. Aquaculture 297(1–4):1–9. https://doi.org/10.1016/j.aquaculture.2009.09.010

Yang Y, Fei X, Song J et al (2006) Growth of *Gracilaria lemaneiformis* under different cultivation conditions and its effects on nutrient removal in Chinese coastal waters. Aquaculture 254:248–255

Yang Y, Chai Z, Wang QS et al (2015) Cultivation of seaweed Gracilaria in Chinese coastal waters and its contribution to environmental improvements. Algal Res 9:236–244. https://doi.org/10.1016/j.algal.2015.03.017

Zhang M, Li D, Wang L et al (2011) Design and development of water quality monitoring system based on wireless sensor network in aquaculture. In: Li D, Liu Y, Chen Y (eds) Computer and computing technologies in agriculture IV. CCTA 2010. IFIP advances in information and communication technology, vol 347. Springer, Berlin, Heidelberg. https://doi.org/10.1007/978-3-642-18369-0_76

Zhou Y, Yang H, Hu H et al (2006) Bioremediation potential of the macroalga *Gracilariale maneiformis* (*Rhodophyta*) integrated into a fed fish culture in coastal waters of North China. Aquaculture 252:264–276. https://doi.org/10.1016/j.aquaculture.2005.06.046

Chapter 35
Feed and Feeding Strategies in Freshwater Aquaculture

G. H. Pailan and G. Biswas

Abstract Feed and feeding management in aquaculture constitute around 50–60% of operational expenditure. Therefore, in scientific aquaculture practices, feeding management should be strategically performed to make them economically lucrative. On the other hand, to feed the accelerating global population which is expected to reach 9 billion in 2050, fish is the cheapest source of protein. As the fish production from capture sector is static, aquaculture is the only option available to meet up the fish demand. Therefore, feed-based aquaculture will have a pivotal contribution to achieve the targeted fish production in near future. Freshwater aquaculture comprising of production of carps, tilapia, catfishes, prawns, etc., contributes a major share to the global aquaculture production of 82 million tons in 2018. Although various species in freshwater aquaculture have different nutrient requirements, a common feed that meets up the requirement of many species is the most sought after one. Moreover, feeding management as a crucial step for successful aquaculture venture varies with culture species and systems. Research on aquaculture nutrition focusses mainly on nutrient requirements of various life stages of fish and crustaceans, and thereby development of low cost but nutritionally balanced feeds. Freshwater species require less costly feed compared to marine species for their aquaculture. Therefore, there is a huge scope for development and wide application of low-cost feed using location-specific ingredients. This chapter provides a comprehensive information on feeding ecology, nutrient requirements, different feed additives used for feed preparation and feeding management practices of commercially important freshwater species.

Keywords Carps · Prawns · Feed management · Aquaculture · Nutrient requirement

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35.1 Introduction

The concept of feeding system of different aquatic organisms in aquaculture is not simple like that of terrestrial animals, where feed, feeding and animals can be observed closely and manipulated at once. In case of aquaculture, both biotic and abiotic factors play important role in feeding as well as growth of the animal. Factors like water temperature, dissolved oxygen, light intensity, etc., regulate the intake of feed, its digestion and assimilation. Condition factor, feed conversion ratio, survival rate, weight gain percentage, daily weight gain and specific growth rate are some of the parameters used routinely to monitor the effects of feed on growth performance of fish.

In aquaculture, supplementary feed is provided in conjunction with the available natural foods, such as plankton, periphyton, benthic organisms and aquatic plants. Aquaculture is a feed-based industry, with artificial feed accounting for major expenditure, exceeding 60% of total operational cost (Daniel 2017). In India, freshwater aquaculture is mainly carp-based, which accounts for about 95% in total aquaculture production (Jayasankar 2018). Success and sustainability of aquaculture depend on the provision of nutritionally adequate, eco-friendly and economically viable artificial feeds (Singh et al. 2006). Effective utilization of feed depends upon many factors, such as acceptability of the feed, its digestion and assimilation apart from other rearing management protocols.

Artificial feeds need to be formulated and prepared in order to supply all the required nutrients in adequate quantity for optimum growth, immunity and reproduction. Inappropriate nutritional formulation obviously leads to poor growth and nutritional diseases, and moreover, due to poor physiological condition, susceptibility to infection is elevated. Development and production of nutritionally balanced diets for fish need immense endeavours in research, quality control and biological evaluation. Moreover, feeding management is important to reduce feed wastage, environmental deterioration and cost of production and improve the fish condition status or welfare (Watanabe 2002; Wu et al. 2015). Feeding strategy differs based on species cultured, culture system and life stages of species. Therefore, a nutritionally balanced feed with proper feeding strategy is of utmost importance for a commercial aquaculture system.

35.2 Food Items of Fish

Fishes feed on a wide range of food materials and obtain their nourishment from plants as well as animals. Depending upon the number of food items consumed by fish, they may be called stenophagic (feeding on a few different types of foods) or euryphagic (feeding on a variety of foods). Various kind of protozoans, microcrustaceans, microscopic invertebrates, larvae and eggs of various animals form the food of fishes. Among the larger animals eaten by fish are the annelid worms, snails, mussels, crustaceans, insects, insect larvae, small fishes, tadpoles and even frogs. Some species consume unicellular and filamentous algae, and fragments of aquatic plants. Some species depend exclusively on zoo- and phyto-planktons and are called plankton feeders. Fry and fingerlings have different feeding habits than the juveniles, sub-adults and adults. They possess a small and short intestine and usually prefer zooplankton consisting of microscopic animals, protozoans, rotifers, cladocera and crustacean larvae (Volkoff and Peter 2006). These are easily digested than the phytoplankton.

35.3 Feeding Habits of Fish

Generally, fishes are described as carnivorous, herbivorous or omnivorous. However, only a few can be strictly classified as carnivorous or herbivorous as the availability of plant or animal material determines whether it will be eaten by a particular species or not. Besides these, some species feed entirely on plankton and form a separate group called the plankton feeders. Some specialize on only one type of food and are referred to as insectivorous, crustacean feeders, larvae feeders, larvivorous, piscivorous, etc.

35.3.1 Carnivorous

Several species feed mainly on animals, which constitute a high percentage of their foods (more than 75%). Their food items include crustaceans, insects, their larvae, molluscs, fish larvae and tadpoles.

35.3.2 Herbivorous

A number of freshwater species feed mainly on plant material, and their food items constitute filamentous algae and aquatic plants. The gut content of these fishes when analysed is found to consist of 75% or more plant material and 1–10% of animal matter.

35.3.3 Omnivorous

A number of species feed on a mixed diet comprising of both plant and animal matters and cannot be categorized as carnivorous or herbivorous. The food of these species consists of algae, parts of aquatic plants, rotifers, insects and their larvae, crustaceans and bryozoans.

35.3.4 Plankton Feeders

Some fish species feed on zoo- and phytoplankton and have an efficient filtering mechanism to get food items from water. These species can be either omnivorous or carnivorous.

35.3.5 Detrivorous

These fishes largely feed on detritus, which is a mixture of sediments, decaying organic matter and bacteria.

35.3.6 Surface, Column and Bottom Feeders

Freshwater fishes can also be divided into three groups on the basis of ecological zone (niche) occupied by them for feeding in a water body. These are surface feeders, mid or column feeders and bottom feeders. Food composition and feeding habits of some important finfishes and freshwater prawn are provided in Table 35.1.

35.4 Nutrient Requirement of Freshwater Fishes

Each fish species has specific nutritional requirement for protein, energy, vitamins, minerals etc. which are essential for growth, reproduction and other normal physiological functions (Zhou et al. 2018). A deficiency of one or more of essential nutrients results in a reduced performance, occurrences of disease or even death. These nutrients may come from artificial feed or natural food. To achieve the maximum rate of performance, fish must receive the entire essential nutrient in liberal and balanced quantities. There may be other objectives in feeding programme, such as holding fish at a certain desired size for a long period, pigment enhancement and reproductive purposes. Under these conditions, a nutritionally balanced diet is still important. To formulate the high-quality eco-friendly and cost-effective fish feed with all the required nutrients in proportionate ratio, precise knowledge of the quantitative dietary requirement of nutrients for fish is essential.

Among the nutritional factors, protein, lipid and cholesterol levels are very crucial. In situation when the protein to energy ratio in feed increases, the intake will decrease in fish (Cho and Kaushik 1990). Dietary lipids mainly supply the energy and essential fatty acids in fish (Chatzifotis et al. 2010), and there may be deviation in the feeding behaviour caused by cholesterol in some fish (Yun et al. 2011). Depending on the quality and quantity of dietary protein, requirement of dietary lipid containing the

Table 35.1 Food composition and feeding habits of important finfishes and freshwater prawn

Species (common name)	Food items	Feeding habit
Labeo rohita (rohu)	Unicellular and multi-cellular algae, decaying higher plants, debris, detritus and mud	Herbivorous/ column feeder
Labeo calbasu (calbose)	Pieces of algae, decaying higher plants, vegetable debris, detritus and mud	Herbivorous/ bottom feeder
Cirrhinus mrigala (Mrigal)	Algae, decaying plant and animal matter, detritus and mud	Omnivorous/ bottom feeder
Catla catla (catla)	Unicellular algae, microscopic plants, rotifers, protozoans, larvae of insects and crustacean	Plankton feeder/ surface feeder
Labeo bata (bata)	Algae, microscopic plants, higher plant material, detritus and mud	Herbivorous / bottom feeder
Hypophthalmichthys molitrix (silver carp)	Unicellular algae, rotifers, protozoans and decaying vegetation	Plankton feeder/ surface feeder
Ctenopharyngodon idella (grass carp)	Aquatic vegetation and various weeds	Herbivorous/ column feeder
Cyprinus carpio (common carp)	Algae, macrovegetation, insects, crustaceans and their larvae	Omnivorous/ bottom feeder
Clarias magur (walking catfish)	Aquatic insects, worms and their larvae and other crustaceans	Omnicarnivorous/ bottom feeder
Heteropneustes fossilis (Stinging catfish)	Aquatic insects, worms and their larvae and other crustaceans	Omnicarnivorous/ bottom feeder
Pangasianodon hypophthalmus (striped catfish)	Aquatic insects, worms and their larvae and other crustaceans	Omnicarnivorous/ bottom feeder
Salmo trutta fario (brown trout)	Animal matter, aquatic insects, worms and their larvae and other crustaceans	Carnivorous/ bottom feeder
Oncorhynchus mykiss (rainbow trout)	Animal matter, aquatic insects, worms and their larvae and other crustaceans	Carnivorous/ bottom feeder
Macrobrachium rosenbergii (giant freshwater prawn)	Larvae prefer zooplankton, mainly minute crustaceans and very small worms; post larvae and adults are omnivorous and mainly feed upon algae, aquatic plants, molluscs, aquatic insects, worms and other crustaceans	Omnivorous/ bottom feeder

appropriate levels of essential fatty acids should range from 5–9 to 2–10% for carps and freshwater prawn, respectively. Lipid requirement for carnivores may ranges from 10 to 15% in the diet. Phospholipids are dietarily essential for larvae of fish and prawn for their better growth and survival. Dietary supplementation of phospholipids (lecithin/cephalin) at 2–4% is necessary for carps and freshwater prawn only at young stages, but supplementation of phospholipid to broodstock diet has no beneficial effect on larval quality. The dietary cholesterol requirement of freshwater prawn is approximately 0.5–0.6% (Daniels and D'Abramo 1994). Carps and prawn appear to require a mixture of poly unsaturated fatty acids (PUFA) like linoleic acid (18:3, ω 6) and linolenic (18:2, ω 3) at 1–2% of the dry matter of diet, which can be reduced by feeding ω 3 and ω 6 highly unsaturated fatty acids (HUFA) like 22:6, ω 3, 20:5, ω 3 and 20:4, ω 6 at a dietary level of 0.1–0.5%, because PUFAs can be synthesized from HUFAs but not vice-versa. In addition, feed intake in fish may be influenced by differences in the carbohydrate and vitamin E contents, dietary preferences and other factors (Huang and Huang 2004; Tran-Duy et al. 2008; Xia et al. 2012). Generally, fish has the limited capacity to utilize dietary carbohydrates. However, carbohydrate utilization is more in herbivores and omnivores than the carnivores. In general, carnivores cannot utilize more than 20% of dietary carbohydrates, whereas herbivores and omnivores can utilize about 40–50%. Gelatinization of carbohydrates still improves its utilization. Carps and prawn utilize complex polysaccharides like starch more efficiently than simple sugars like glucose. Crude fibre (CF) in carp diet should not be more than 4–8%, which cannot be digested, but provides the bulk for proper digestion and excretion of faeces. For both fish and prawn, less than 4% CF is desirable. Dietary requirements of different nutrients for fish with composition of vitamin and mineral premixes are presented in Tables 35.2, 35.3, 35.4, 35.5, 35.6 and 35.7.

35.5 Commonly Used Feed Supplements and Additives

35.5.1 Phospholipid

Phospholipid (lecithin) is commonly supplemented at 2–4% in fish diet for optimum growth and survival, whereas in the formulated feed of marine shrimp, supplemental level is 0.2–2% (Tocher et al. 2008). Soy lecithin is a preferable phospholipid for fish diet.

35.5.2 Cholesterol

Shellfish cannot synthesize cholesterol that needs dietary addition at 0.5%. The main function of cholesterol in crustacean is the synthesis of moulting steroid hormone (Briggs et al. 1988).

Table 35.2 Estimated dietary protein requirement of important freshwater fish species

Species	Crude protein level in diet (%)
Cyprinus carpio	38–40* 30–33#
Ctenopharyngodon idella	38–40* 30–33#
Hypophthalmichthys molitrix	37–42* 30#
Labeo rohita	40–45* 28–30#
Catla catla	40–45* 28–30#
Cirrhinus mrigala	40–45* 28–30#
Clarias magur	40–52** 28–32#
Macrobrachium rosenbergii	35–40* 28–30#

*Young and broodstock stages; **Young stage; #Adult stage

Table 35.3 Essential amino acid (EAA) requirements of important freshwater fishes and prawn

EAA (% of protein)	Rohu	Catla	Mrigal	Common carp	Catfish	Freshwater prawn	Rainbow trout
Arginine	4.8	5.8	5.3	4.3	4.3	3.7	5.0
Histidine	2.5	2.3	2.1	2.1	1.5	0.7	1.8
Isoleucine	2.4	3.0	2.8	2.5	2.6	0.6	2.0
Lysine	6.2	5.7	5.9	5.7	5.1	3.2	4.5
Leucine	3.7	4.6	4.3	3.3	3.5	1.0	3.5
Methionine	3.6	2.9	3.2	3.1	2.3	1.2	2.8
Phenylalanine	3.7	4.0	4.0	6.5	5.0	1.7	4.5
Threonine	5.0	4.3	4.1	3.9	2.0	1.6	2.0
Tryptophan	1.0	1.1	1.0	0.8	0.5	0.5	0.5
Valine	3.6	3.8	3.5	3.6	3.0	2.1	3.2

35.5.3 Binders

Binders are used in the formulated diet of finfish and shellfish to improve palatability, to enhance pellet durability for preserving physical form during storage, to prevent disintegration during handling and shipping and to enhance their water stability. Binders used in formulated feeds are mainly complex polysaccharides. Sometimes, few protein sources are also used in fish feed as binder. Though a wide range of binders are available in the market, most commonly used binders in formulated feed

Table 35.4 Dietary vitamin requirements of freshwater fishes and prawn

Vitamin	Warmwater fish	Coldwater fish	Prawn
Thiamin (mg kg^{-1})	20–30	10	50–100
Riboflavin (mg kg^{-1})	20–30	10	30–58
Pyridoxine (mg kg^{-1})	20–30	10	30–50
Pantothenate (mg kg^{-1})	30–40	80	50–100
Niacin (mg kg^{-1})	150	150	100–150
Folacin (mg kg^{-1})	15	3	5–10
Cyanocobalamin (mg kg^{-1})	–	0.02	0.02–0.10
Myo-inositol (mg kg^{-1})	–	400	200–300
Choline (mg kg^{-1})	500–600	800	400–2000
Biotin (mg kg^{-1})	0.6–1.0	1.0	1.0
Ascorbate (mg kg^{-1})	30–50	100	50–100
Vitamin A (IU kg^{-1})	1000–2000	4000	5000–10,000
Vitamin E (IU kg^{-1})	80–100	400	100–200
Vitamin K (mg kg^{-1})	10–20	40	5–20
Vitamin D_3 (IU kg^{-1})	500	-	1000–2000

Table 35.5 Composition of vitamin premix used for preparation of carp and prawn diets

Vitamin	Quantity kg^{-1} diet
A	5000–10,000 IU
D_3	100–200 IU
E	100–200 IU
K	200–400 mg
C	50–100 mg
Thiamine	30–50 mg
Riboflavin	30–50 mg
Pyridoxine	0.02–1 mg
B_{12}	0.5–1 mg
Biotin	400–2000 mg
Choline	5–10 mg
Folic acid	200–300 mg
Inositol	100–150 mg
Niacin	50–100 mg

Table 35.6 Mineral requirements of freshwater fishes and prawn

Mineral	Carps	Rainbow trout	Tilapia	Prawn
Calcium (%)	0.1–0.5, 0.19 (IMC*)	< 0.1	–	0.1–0.5
Phosphorus (%)	0.6–0.7, 0.75 (IMC)	0.6	0.9	0.6–0.7
Magnesium (%)	0.05	0.05	0.06	0.05
Sodium (%)	0.1–0.3	–	–	0.1–0.3
Potassium (%)	0.1–0.3	Trace	Trace	0.1–0.3
Sulphur (%)	0.3–0.5	–	–	0.3–0.5
Chlorine (%)	0.1–0.5	–	–	0.1–0.5
Iron (mg kg^{-1})	50–150	Trace	Trace	50–150
Copper (mg kg^{-1})	1–4	3	3.5	1–4
Manganese (mg kg^{-1})	13	13	12	13
Cobalt (mg kg^{-1})	5–10	–	–	5–10
Zinc (mg kg^{-1})	15–30	15–30	20	15–30
Iodine (mg kg^{-1})	100–300	1.1	Trace	100–300
Molybdenum	Trace	–	–	Trace
Chromium	Trace	–	–	Trace
Fluorine	Trace	–	–	Trace
Selenium	Trace	0.15–0.3	Trace	Trace

*IMC—Indian major carps

Table 35.7 Composition of mineral premix used for preparation of carp and prawn diets

Mineral	Q uantity kg^{-1} diet
Calcium	10–18 g
Phosphorus	18 g
Magnesium	0.8–1 g
Sodium	6 g
Potassium	9 g
Sulphur	0.2 g
Manganese	20 mg
Zinc	50–100 mg
Iron	5–20 mg
Cobalt	10 mg
Selenium	1 mg
Chlorine	Trace
Molybdenum	Trace
Chromium	Trace
Fluorine	Trace
Copper	25 mg

are (i) carboxymethyl cellulose (CMC): 2–4%, (ii) gum acacia: 2–5%, (iii) Na or K bentonite: not more than 2%, (iv) agar: 2–5%, (v) guar gum: 1–2%, (vi) wheat gluten: 10–12% and (vii) starch powder 2–5%.

35.5.4 Antioxidants

Antioxidants are substrate that can be easily oxidized, and thus, they protect other compounds which are sensitive to oxidation. Thus, antioxidants are broken themselves and slowdown the chain reaction involved in peroxidation. In formulated diet, antioxidants are added to vitamin premix or to the lipid to delay the onset of rancidity of these substances. Rancidity makes the feed unpalatable and generates toxic substances such as aldehyde or ketone. Lipid rich in PUFA and vitamin A, E, riboflavin and folic acid is more prone to oxidation. This phenomenon occurs during storage of feed. Thus, diet containing PUFA-rich lipid and vitamins needs to be supplemented with antioxidants. Natural antioxidants are vitamin C and E, and synthetic antioxidants are butylated hydroxyl anisol (BHA) and butylated hydroxyl toluene (BHT) and ethoxyquin (Aklakur 2018). The supplemental doses are (i) vitamin C: 100–300 mg kg^{-1}, (ii) vitamin E: 300–390 mg kg^{-1}, (iii) BHA: 0.1%, (iv) BHT: 0.1% and (v) Ethoxyquin: 0.015%. Better approach is the supplementation of vitamin C and E along with any one of synthetic antioxidants.

35.5.5 Feeding Stimulants or Chemo-attractants

The compounds which stimulate gustatory receptors cells to enhance feed intake called feeding stimulants. Feeding stimulants also enhance flavour. Fish reject unpalatable feed, resulting in less feed intake. Thus, plant-based formulated feed should be supplemented with feeding stimulants which increase palatability of feed, thus increase feed intake. Feeding stimulants are also called gustatory stimulants or palatability enhancers or flavouring attractants. Medicated feed also needs to be supplemented with feeding stimulants. It is also effective to train young fish or larvae to accept formulated diet after weaning from live foods. Chemicals, those that can be used as feeding stimulants are amino acids, betaine, quaternary ammonium bases, nucleoside (inosine) and nucleotide (IMP, inosine monophosphate; AMP, adenosine monophosphate; UMP, uridine monophosphate, etc.) (Varghese et al. 2015), organic acids (propionic acid), bile salts etc. A mixture of proline, alanine, cysteine, glutamic acid and glycine at 0.1–0.5% acts as feeding stimulant. Addition of betaine to this mixture at 0.25% and nucleotide-rich spirulina or yeast at 1% gives better result and also improves immunity.

35.5.6 Preservatives (Acidifiers) and Enzymes

In tropical country, increasing humidity makes the feed moist during storage. Storage conditions like temperature > 25 °C, relative humidity > 65% and moisture 12% facilitate the mould and bacterial growth that deteriorate the feed quality during storage. Moulds like *Aspergillus flavus* contaminate the feed with aflatoxins that produce ill effect on fish. Thus, to prevent mould growth, antifungal agents are used. The antifungal agents used in feed to prevent mould growth during storage are called preservatives. Feed acidifiers as nutraceuticals are yet to be used at commercial scale for different species of livestock such as poultry and cattle as well as for aquatic species. Addition of phytase (at 500 FTU) to plant-based diets increased the bioavailability of P and other minerals, thereby elevating bone mineralization in *Labeo rohita* fingerlings (Baruah et al. 2007). The effect of phytase was increased because of addition of citric acid (3%) which is an acidifier. Commonly used preservatives and their doses in fish feed are (i) Na or Ca propionate: not > 1%, (ii) K propionate: not > 1%, (iii) Na benzoate: not > 1%, (iv) Na or Ca sorbate: not > 1% and v) methylparaben: not > 0.1%.

35.5.7 Carotenoids

Carotenoids are a family of pigments the fish cannot synthesize and are obtained from feeds. These pigments result in red, yellow and orange colours. The oxygenated carotenoids as one of the most important groups of natural pigments are used by fish for pigmentation of skin and flesh. Commonly occurring carotenoids in freshwater are beta-carotene, lutein, taraxanthin, astaxanthin, tunaxanthin, alpha-, beta-doradexanthins and zeaxanthin. As fish cannot synthesize these pigments, dietary supplementation of carotenoids is necessary to develop natural skin colour which is the most important criteria influencing the market value of the most popular ornamental species such as koi carp (*Cyprinus carpio*) and goldfish (*Carassius auratus*) (Paripatananont et al. 1999; Lovell 2000; Gouveia et al. 2003). Under certain adverse environmental conditions (nitrogen depletion, high salinity and light intensity), some of the algal species such as *Chlorella vulgaris*, *Haematococcus pluvialis* and *Arthrospira maxima* (*Spirulina*) will accumulate secondary carotenoids, and these can be utilized to replace costly synthetic colouring materials in ornamental fish feed (Gouveia et al. 2003). Supplementation of spirulina at 4 mg kg^{-1} diet is effective in skin pigmentation of blue gourami (*Trichogaster trichopterus*), and withdrawn of supplementation diminishes the colour intensity. Besides, various plants such as marigold flowers, tomatoes, sweet red peppers, yellow maize, carrots, yam, pumpkin, paprika, beetroot and mushrooms, alfalfa meal, grass meal, chlorella; aquatic animals like molluscs, crustaceans, shrimp, prawns, krill and terrestrial animals and animal products such as bird plumage, insects, butter, egg yolk and cheese are good natural sources of carotenoids, which show better results than synthetic carotenoids (roche carophyll pink). Diets of ornamental fishes should not only contain adequate levels of protein, energy, oils, vitamins and minerals but also a constant supply of carotenoids with correct balance of ingredients. It is reported that supplementation of China rose (*Hibiscus rosasinensis*) petals in the diet of goldfish at 5 mg kg^{-1} increased both skin colouration and gonadal maturation (Sinha and Asimi 2007).

35.5.8 Probiotics

Live microbes used as feed supplements are called probiotics. Different bacterial species such as *Bacillus* sp., *Bifidobacterium* sp. and many others are used as probiotics in formulated fish feed. Thus, probiotics are single or mixture of live microorganisms like *Lactobacillus*, *Streptococcus*, *Bifidobacterium* species, etc. which offer new dietary alternatives to immunotherapy to counteract local immunological dysfunctions and to stabilize the natural gut mucosal barrier mechanisms (Dawood et al. 2018). Addition of probiotic in the diet (2–3%) improves the growth performance of *Macrobrachium rosenbergii* larvae (Venkat et al. 2004). Probiotic feeding has a significant role in larvae as the survival rate of larvae is poor due to their rudimentary immune system. Hence, the mode of delivery of probiotics to larvae is a challenging task. It was reported that higher survival of *M. rosenbergii* was achieved when *Lactobacillus* was fed bio-encapsulated with *Artemia nauplii*.

35.5.9 Prebiotics

Prebiotics are non-digestible oligosaccharides (NDO) that are utilized by probiotic bacteria in gut of host animal (Roberfroid 2005). Some important prebiotics are mannan oligosaccharides (MOS), fructooligosaccharides (FOS), galacto-oligosaccharides (GOS), etc. Prebiotics improve gut health, proliferate probiotic bacteria, suppress harmful bacteria, improve growth of host animal, increase feed intake, digestibility of nutrient and enhance non-specific immunity. Thus, use of prebiotics along with probiotics in diet gives better benefit. Prebiotics can be added in the diet at 1–2%. When probiotics and prebiotics work together, it is termed as synbiotics (Dawood and Koshio 2015).

35.5.10 Phytobiotics

After dietary supplementation, when extracts of different medicinal herbs, such as *Cyanodon dactylon, Aegle marmelos, Tinospora cordifolia, Picrorhiza kurooa, Eclipta alba, Ricinus communis* and many others increase immunity and provide disease resistance to the animals including fish, they are termed as phytobiotics

(Bharathi et al. 2019). Methanolic extract of various medicinal herbs if supplemented at 0.5–1% in the larval diet increases immunity and larval survival rate.

35.5.11 Immunostimulants

Substances like beta glucans, EF203, lactoferrin, levamisole and chitosan are used as immunostimulants or nutraceuticals in aquaculture. Feeding carp with levamisole (5 mg kg^{-1} body weight) resulted in enhanced phagocytic activity of blood leucocytes. Dietary supplementation of immunostimulants at 1% level promotes growth and survival in *L. rohita* fingerlings (Sahoo and Mukherjee 2001). The immunostimulants mainly enhance bactericidal activities of phagocytes. The activation of several immunological functions is associated with increased protection against infectious diseases. Dietary yeast RNA supplementation reduces mortality by *Aeromonas hydrophila* in rohu (*L. rohita*) juveniles (Choudhury et al. 2005). Some researchers reported that *L. rohita* fed with nucleotide-rich ingredients like yeast, yeast extract or spirulina had stimulation in the immunity (Andrews et al. 2011).

35.6 Feeding Strategies

In order to achieve best efficiency of a given feed for maximum growth of fish in a culture system, implementation of appropriate feeding strategies in terms of types of feed, feeding rate, feeding frequency and feeding methods are of utmost importance (Zhou et al. 2018).

35.6.1 Feeding Rate

The amount of feed provided is adjusted based on the biomass of fish or prawn under culture along with the observation on their daily feed intake. Examining daily feed intake using lift nets or check trays for prawns is very important to decide the amount of feed to be offered on subsequent days. Cultured animals of early life-stages such as fry, fingerlings, post-larvae (PL) and juveniles need more food quantity to meet the demand for best growth. Both over feeding and under feeding affect growth, production and FCR (feed conversion ratio). The daily feeding rate for prawn (% of biomass) varies from 25 to 2% during the crop period, maximum during PL stage to the minimum before harvest. Feeding rate should be adjusted as culture progresses. Feeding rates for fish also vary according to water temperature and weather. The daily feed requirement can be calculated as follows:

$$\text{Feed to be given}\left(\text{kg day}^{-1}\right) = \frac{\text{No. of animals} \times \text{average weight in kg} \times \text{feeding rate (\% biomass)}}{100}$$

35.6.2 Feeding Frequency

The number of meals offered daily and time of feeding are also important factors that affect growth and feed efficiency (Biswas et al. 2006a). Frequent feeding reduces starvation, and stunting facilitates uniform growth with minimum feed wastage. In case of fish, daily ration of feed is offered in several meals, often 4 to 6 times. Feeding in finfish is mostly done during the day, between 06:00 and 18:00 h, but during fry stage, a continuous feed supply is suggested. In case of prawns, the number of meals offered daily range from 4 to 6 for PL and juveniles, to 3 to 6 for sub-adults and adults. The total amount of feed for a day is divided into small quantities and applied.

35.6.3 Feeding Methods

Dry pellets, granules for fish and prawns are broadcasted. Fish, in general, are fast feeders and feeds with good palatability are consumed within 15 to 30 min by most species. However, prawns are slow feeders, and granules and pellets are distributed evenly for them. For small ponds (<0.5 ha), broadcasting the feeds from pond dykes can serve the purpose. But in larger ponds (>0.5 ha), broadcasting the feeds from bunds should be supplemented by distribution to slightly interior areas using small boats (Nandeesha et al. 2013). Moist feeds and meals should not be broadcasted but kept on earthen or plastic trays, placed in the peripheral areas of the pond bottom. Another unique feeding method has been adopted in semi-intensive carp culture system. The outline of the method is: feed mixture is kept in perforated fertilizer bags tied to bamboo poles. About 20 to 30 bags are kept per hectare. Fish browse on the feed through perforations in the bags, and within 2 h, most of the feed kept in the bags is consumed (Nandeesha et al. 2013).

35.7 Feeding Management Practices for Carps

35.7.1 Nursery Pond

Though plankton is the main food for carp spawn, egg yolk suspension is fed at 100 g yolk and 5 g yeast per lakh spawn twice daily once at morning (08:00–10:00 h) and another in the evening at 17:00 h for the first 5 days. The suspension is uniformly spread in nursery pond or tanks. Instead of egg yolk suspension, finely powdered mash (50–70 μm) can also be broadcasted during initial period of rearing. Thereafter, finely powdered feed or fine crumbles (>70–400 μm) are broadcasted for spawn rearing in well-prepared nursery ponds up to 13th day out of total 15 days rearing period. The larvae are starved on day 14, and on day 15, harvesting of fry is done. Daily allowance of feed in nursery pond is 4 times or 400% of initial body weight of spawn for first week and 8 times or 800% of initial body weight of spawn for second week in two equal split doses, once at morning 10:00 h and another at late afternoon at 17:00 h (Biswas et al. 2006a). If possible, per day feeding frequency may be increased to 6–8 times, because it is more beneficial for tiny spawn in nursery ponds.

35.7.2 Rearing Pond

For feeding fry in well-prepared rearing pond for 90 days period, initially, crumbles of 0.5 mm dia can be used, and gradually, crumble size can be increased up to 0.8–1 mm dia. Considering the plenty of live food available for larvae, daily allowance of feed in rearing pond is 6–8% of body weight during first month, 5–6% of body weight during second month and 3–4% of body weight during third month and can be fed to the fish in two equal split doses, once at morning 10:00 h and another at late afternoon at 17:00 h, if feed is broadcasted. Feeding frequency of 3–4 times per day is always beneficial (Biswas et al. 2006b). However, feeding frequency is depended on feeding method. Tray (plastic or aluminium) system of feeding method is always preferable for controlling the feed loss. Total amount of required feed per day is taken in tray, which is then hanged from bamboo pole from different places of the pond 3–4 m away from the pond side. A total of 14–16 trays are required per ha area. This method of feeding is done once per day, and in the next day, trays are taken out, washed properly and the feeding is continued in same way.

35.7.3 Grow-out Pond

During 10–12 month culture period, for feeding fingerlings and growers in grow-out pond under composite fish culture system, different types of feeds, such as dry mash, wet ball, cooked paste, cooked balls or dry pellets can be used. Under semi-intensive culture system, supplementary artificial feed and intensive culture system, complete artificial feed should be provided. Fishes are fed at 5% of body weight during first two months, 4% of body weight during next two months, 3% of body weight during next two months, 2% of body weight during next two months and 1% of body weight during final 2–4 months. Depending on the feed types, either broadcast or tray (plastic or aluminium) or basket (bamboo basket) or bag (cement bag or gunny bag) system of feeding method is employed in grow-out pond (Nandeesha et al. 2013). Mixture of floating and sinking pellets at 2:1 ratio can be broadcasted in the pond twice daily, once at morning (10:00 h) and another at late afternoon (17:00 h). Wind may displace the floating pellets which may congregate at the sides of pond. To prevent this, feed may be broadcasted within the plastic ring placed at different places of pond. Floating pellets are suitable for feeding of carps in cages. For other kinds of feeding methods as mentioned earlier, feeding is done once daily. Either wet ball or cooked paste or cooked ball or dry sinking pellets can be offered to the carps through three-tier system of tray or basket method in which total amount of required feed per day is distributed in different trays or baskets which are tied up and hanged from bamboo poles that are placed 3–4 m away from the pond sides and trays or baskets are submerged in water at 1.5, 3.5 and 5.5-ft depth. For easy submersion, heavy stone or brick can be tied at the bottom of the tray or basket. In case of bamboo basket, polythene paper can be placed inside bottom of the basket to prevent loss of disintegrated feed. This kind of arrangement should be done at 14–16 places per ha area. Next day morning, trays or baskets are removed, washed and feeding is continued in the same way. Mash feed and also sinking pellets can be offered to the fish through three-tier bag system of feeding method. Perforated nylon or plastic cement or fertilizer bags of 20 kg capacity are generally used for this purpose. After distributing the daily required feed inside the bag, mouth is tied and bags are hanged in the same way of tray or basket method. This sort of arrangement is required at 14–16 places per ha area. When fish nibbles near holes, a certain amount of feed mixture or pellets come out through holes that are consumed by the fish; thus, this system acts as the indigenous type of demand feeder (which is generally used in developed country). Such feeding method is common in carp farms of Andhra Pradesh. In Punjab, farmers use a number of feed baskets or perforated bags tied in a row in a floating material which is kept floating across water bodies. Tray/basket and bag system of feeding methods are useful for controlling the feed loss or waste.

In polyculture of carps and prawn, carps are fed in similar way as described above, but prawn feed is given in tray or basket hanged from the bamboo pole 1–1.5 ft away from pond side and submerged 1 foot underneath the water. Prawn feed is offered at night 20:00 h since prawn is having nocturnal feeding habit. Wet ball or pellet feed can be used for feeding of prawn. Besides, snail meat/meat meal/fish meal/meat scrapping can also be used at 15-day intervals for feeding of prawn. Prawn juveniles are fed at 25% of body weight for first 2 months and gradually reduced to 3% of body weight towards the end of the culture period on daily basis or at 5–3% of body weight on daily basis for the first month and then at the same rate on alternate days from the second month onwards. Under composite fish culture system, for feeding of grass carp, separate arrangement is required. Chopped aquatic weeds, fooder grasses (Napier, etc.), lawn grass, vegetable waste, etc., can be placed on rectangular bamboo platform fixed at corners of pond at certain depth for feeding of grass carp. The grass carp should be fed until they stop eating. Usually, they consume aquatic weeds about 50% of their body weight on a daily basis. Hence, it is advisable to feed them at least 1 h before the application of supplementary feed to other fish. Sometimes, mixed feeding schedule such as 1–2 days feeding with low protein diet followed by 3 days feeding with high protein diet can also be practiced. Through proper feeding management, FCR in carp culture is possible to maintain as 2:1. Trash fish and floating pellets are used for feeding fish in cages, where fish production of 35–65 kg m^{-3} is achieved after 8–12 months.

35.8 Feeding Management Practices for Walking Catfish, *Clarias magur* Culture

In pond, with high density of zooplankton, artificial feed at 10–5% of body weight is normally dispensed or broadcasted from all sides to provide feeding opportunity to all fish. Feeding should be done twice daily once at very early morning and another at late evening as magur prefers to eat under less light (Imteazzaman et al. 2017). Water quality is very much important for feeding of catfish. At low oxygen level, feeding activity of magur is reduced. Thus, pelleted feeds need to have high degree of water stability. Mash and wet balls are less preferable for catfish. Sometimes molluscan meat, chopped chicken viscera can also be fed to catfish under pond condition. These feeds are placed at shallow zone near the sides of pond. Through proper feeding management, FCR can be maintained as 3–4:1 under pond condition.

35.9 Feeding Management Practices for Striped Catfish, *Pangasianodon hypophthalmus* Culture

Under pond condition, a mixture of rice bran, broken rice and small quantity of trash fish can be fed to the stocked fingerlings for first two months. From third month onward, fish are fed with various formulated diets. The feed is broadcasted to fingerlings at 10% of body weight and gradually reduced to 5% for juvenile, grower and adult stage. Through proper feeding management in ponds, fish can attain an average weight of 1–1.5 kg with FCR of 4–6:1 at the end of 8–12 months culture period (Sayeed et al. 2008).

35.10 Feeding Management Practices for Giant Freshwater Prawn, *Macrobrachium rosenbergii* Culture

In order to enhance the growth and as a precaution against cannibalism, the prawn juveniles are given feed mix (rice bran: oil cake in a ratio of 1: 1) at 25% of body weight for first 2 months and gradually reduced to 3% of body weight towards the end of culture period on daily basis (Table 35.8) or at 3–5% of body weight on daily

Table 35.8 Weight-dependent feeding rates for giant freshwater prawn

Prawn body weight (g)	% of body weight fed daily
< 1	≥ 25
1–2	20
2–5	12
5–10	10
10–15	8
15–20	6
20–25	5
25–30	4
> 30	3

basis for the first month and then at the same rate on alternate days from the second month onwards (Mukhopadhyay et al. 2003).

However, quantity of feed should be adjusted through trial and error after verifying the consumption on the following morning. To avoid cannibalism, prawn should not be hungry. Wet balls may be prepared using these ingredients and provided through plastic or aluminium tray or bamboo basket hanged from bamboo pole fixed 1–1.5 ft away from the pond dike and submerged 1–1.5 ft underneath the water. Per hectare area at 14–16 places, this sort of arrangement should be made. Ball can also be prepared by more ingredients (different oil cakes especially groundnut oil cake, fish meal, shrimp meal, silkworm pupae, beef liver meal, meat meal, squid waste, dry fish, dry *Acetes*, broken rice, rice bran, tapioca root powder, yeast etc.) along with vitamin–mineral mixture following improved formula. Farm-made or commercial sinking pelleted feed may also be used and given through same tray/basket method. Mash feed or sinking pellets can also be given through perforated bag method in which bags are arranged in the similar way to tray method. Feed can also be spread around the periphery of pond in shallow areas. Check trays kept in different areas of the pond will help in deciding the quantum of the feed per day. In general, prawns require 28–30% protein and 8–10% fat in their diet. As prawn has nocturnal feeding habit, the feed should be given at night (20:00 h). Besides, special diets like boiled tilapia flesh, chopped raw meat of gastropods or trash fish, cooked chicken entrails at 10% of body weight are also administered at fortnightly basis. Sometimes, compound chicken feed mixed with trash fish and prawn meal in mincer and formulated shrimp feed may be used. In monoculture, FCR is 7–9:1 for wet feed and 2–3:1for compound dry feed. FCR is reduced when culture period is extended beyond 8 months. Prawn should be sampled using cast net on monthly basis, and based on the average body weight, new feeding rate may be calculated.

35.11 Conclusions

With the target of fulfilling future demand of fish, intensified feed-based aquaculture can only be the successful option using proper feed which can efficiently fulfil the nutrient requirement of cultured animals. Through the implementation of an appropriate feeding strategy in terms of feed type, feeding level, feeding frequency and feeding methods, economically viable fish crops can be obtained. Moreover, feed should be formulated according to food and feeding habits and nutrient requirements of the targeted fish. For the wholesome development of feed-based aquaculture sector, several issues are expected to be addressed. Some of those are, development of functional feeds meeting the requirement of various life stages of fish, reduction on the dependency on fish meal as the prime ingredient by finding out alternate cheap and effective ingredients, utilization of plant-based ingredients, selection and exploration of novel feed additives for improvement of digestion and utilization of ingredients, modulation of growth and immune response through specially developed feeds, easy methods for tracing and removal of contaminants and anti-nutritional factors of feed ingredients and application of nutrigenomics. To meet up the protein requirement of the increasing global population which is expected to reach 9 billion in 2050, fish as the cheapest source could be produced only using formulated feeds. Therefore, to achieve this production level, the feed production capacity by establishing multi-locational feed mills has to be increased so that expansion of aquaculture should not be hindered due to the unavailability of quality feeds.

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References

Aklakur M (2018) Natural antioxidants from sea: a potential industrial perspective in aquafeed formulation. Rev Aquac 10:385–399. https://doi.org/10.1111/raq.12167

Andrews SR, Sahu NP, Pal AK et al (2011) Yeast extract, brewer's yeast and spirulina in diets for *Labeo rohita* fingerlings affect haemato-immunological responses and survival following *Aeromonas hydrophila* challenge. Res Vet Sci 91:103–109. https://doi.org/10.1016/j.rvsc.2010.08.009

Baruah K, Sahu NP, Pal AK et al (2007) Dietary microbial phytase and citric acid synergistically enhances nutrient digestibility and growth performance of *Labeo rohita* (Hamilton) juveniles at sub-optimal protein level. Aquac Res 38:109–120. https://doi.org/10.1111/j.1365-2109.2006.01624.x

Bharathi S, Cheryl A, Rajagopalasamy CBT et al (2019) Functional feed additives used in fish feeds. Int J Fish Aquat Stud 7:44–52

Biswas G, Jena JK, Singh SK et al (2006a) Effect of feeding frequency on growth, survival and feed utilization in fingerlings of *Catla catla* (Hamilton), *Labeo rohita* (Hamilton), *Cirrhinus mrigala* (Hamilton) in outdoor rearing systems. Aquac Res 37:510–514. https://doi.org/10.1111/j.1365-2109.2006.01457.x

Biswas G, Jena JK, Singh SK et al (2006b) Effect of feeding frequency on growth, survival and feed utilization in mrigal, *Cirrhinus mrigala* and rohu, *Labeo rohita,* during nursery rearing. Aquacult 254:211–218. https://doi.org/10.1016/j.aquaculture.2005.08.001

Briggs MRP, Jauncy K, Brown JH (1988) The cholesterol and lecithin requirements of juvenile prawn (*Macrobrachium rosenbergii*) fed semi-purified diets. Aquaculture 70:121–129. https://doi.org/10.1016/0044-8486(88)90011-7

Chatzifotis S, Panagiotidou M, Papaioannou N et al (2010) Effect of dietary lipid levels on growth, feed utilization, body composition and serum metabolites of meagre (*Argyrosomus regius*) juveniles. Aquacult 307:65–70. https://doi.org/10.1016/j.aquaculture.2010.07.002

Cho CY, Kaushik SJ (1990) Nutritional energetics in fish: energy and protein utilization in rainbow trout (*Salmo gairdneri*). World Rev Nutr Diet 61:132. https://doi.org/10.1159/000417529

Choudhury D, Pal AK, Sahu NP et al (2005) Dietary yeast RNA supplementation reduces mortality by *Aeromonas hydrophila* in rohu (*Labeo rohita* L.) juveniles. Fish Shellfish Immunol 19:281–291. https://doi.org/10.1016/j.fsi.2005.01.004

Daniel N (2017) Status of aquaculture with respect to nutrition and feed. Int J Fish Aquat Stud 5:333–345

Daniels WH, D'Abramo LR (1994) Pond production characteristics of freshwater prawns *Macrobrachium rosenbergii* as influenced by the stocking of size-graded populations of juveniles. Aquaculture 122:33–45. https://doi.org/10.1016/0044-8486(94)90331-X

Dawood MOA, Koshio S (2015) Recent advances in the role of probiotics and prebiotics in carp aquaculture: a review. Aquaculture 454:243–251. https://doi.org/10.1016/j.aquaculture.2015.12.033

Dawood MOA, Koshio S, Esteban MA (2018) Beneficial roles of feed additives as immunostimulants in aquaculture: a review. Rev Aquac 10:950–974. https://doi.org/10.1111/raq.12209

Gouveia L, Rema P, Pereira O et al (2003) Coloring ornamental fish (*Cyprinus carpio* and *Carassius auratus*) with microalgal biomass. Aquacult Nutr 9:123–129. https://doi.org/10.1046/j.1365-2095.2003.00233.x

Huang CH, Huang SL (2004) Effect of dietary vitamin E on growth, tissue lipid peroxidation, and liver glutathione level of juvenile hybrid tilapia, *Oreochromis niloticus* × *O. aureus*, fed oxidized oil. Aquaculture 237:381–389. https://doi.org/10.1016/j.aquaculture.2004.04.002

Imteazzaman AM, Das S, Rahman MM et al (2017) Suitable diet for walking cat fish (*Clarias batrachus* Linn. 1758) in earthen ponds. Int J Appl Res 3:56–62

Jayasankar P (2018) Present status of freshwater aquaculture in India—a review. Indian J Fish 65:157–165. https://doi.org/10.21077/ijf.2018.65.4.81300-20

Lovell RT (2000) Nutrition of ornamental fish. In: Bonagura J (ed) Kirk's current veterinary therapy XIII-small animal practice, W.B. Saunders, Philadelphia, pp 1191–1196

Mukhopadhyay PK, Rangacharyulu PV, Mitra G et al (2003) Applied nutrition in freshwater prawn, *Macrobrachium rosenbergii*, culture. J Appl Aquacult 13:317–340. https://doi.org/10.1300/J028v13n03_06

Nandeesha MC, Sentilkumar V, JesuPrabhu AP (2013) Feed management of major carps in India, with special reference to practices adopted in Tamil Nadu. In: Hasan MR, New MB (eds) On-farm feeding and feed management in aquaculture, FAO Fisheries and Aquaculture Technical Paper No. 583, Rome, FAO, pp. 433–462

Paripatananont T, Tangtrongpairoj J, Sailasuta A et al (1999) Effect of astaxanthin on the pigmentation of goldfish *Carassius auratus.* J World Aquac Soc 30:454–460. https://doi.org/10.1111/j.1749-7345.1999.tb00993.x

Roberfroid MB (2005) Introducing inulin-type fructans. Br J Nutr 93:S13–S25. https://doi.org/10.1079/BJN20041350

Sahoo PK, Mukherjee SC (2001) Effect of dietary β-1,3 glucan on immune responses and disease resistance of healthy and aflatoxin B_1-induced immune compromised rohu (*Labeo rohita* Hamilton). Fish Shellfish Immunol 11:683–695. https://doi.org/10.1006/fsim.2001.0345

Sayeed MAB, Hossain GS, Mistry SK et al (2008) Growth performance of thai pangus (*Pangasius hypophthalmus*) in polyculture system using different supplementary feeds. Univ J Zool Rajshahi Univ 27:59–62. http://journals.sfu.ca/bd/index.php/UJZRU

Singh RK, Balange AK, Ghughuskar MM (2006) Protein sparing effect of carbohydrates in the diet of *Cirrhinus mrigala* (Hamilton, 1822) fry. Aquacult 258:680–684. https://doi.org/10.1016/j.aquaculture.2006.03.049

Sinha A, Asimi OA (2007) China rose (*Hibiscus rosasinensis*) petals: a potent natural carotenoid source for goldfish (*Carassius auratus* L.). Aquacult Res 38:1123–1128. https://doi.org/10.1111/j.1365-2109.2007.01767.x

Tocher DR, Bendiksen EA, Campbell PJ et al (2008) The role of phospholipids in nutrition and metabolism of teleost fish. Aquaculture 208:21–34. https://doi.org/10.1016/j.aquaculture.2008.04.034

Tran-Duy A, Ben S, Annea VD et al (2008) Effects of dietary starch and energy levels on maximum feed intake, growth and metabolism of Nile tilapia, *Oreochromis niloticus.* Aquaculture 277:213–219. https://doi.org/10.1016/j.aquaculture.2008.03.004

Varghese T, Mishal P, Sandeep KP et al (2015) Nucleotides in aquafeeds: a right step towards sustainable nutrition. Fishing Chimes 35:49–55

Venkat HK, Sahu NP, Jain KK (2004) Effect of feeding *Lacto bacillus*-based probiotics on the gut microflora, growth and survival of postlarvae of *Macrobrachium rosenbergii* (de Man). Aquacult Res 35:501–507. https://doi.org/10.1111/j.1365-2109.2004.01045.x

Volkoff H, Peter RE (2006) Feeding behavior of fish and its control. Zebrafish 3:131–140. https://doi.org/10.1089/zeb.2006.3.131

Watanabe T (2002) Strategies for further development of aquatic feeds. Fish Sci 68:242–252. https://doi.org/10.1046/j.1444-2906.2002.00418.x

Wu TH, Huang YI, Chen JM (2015) Development of an adaptive neural-based fuzzy inference system for feeding decision-making assessment in silver perch (*Bidyanus bidyanus*) culture. Aquacult Eng 66:41–51. https://doi.org/10.1016/j.aquaeng.2015.02.001

Xia S, Zhao P, Chen K et al (2012) Feeding preferences of the sea cucumber *Apostichopus japonicus* (Selenka) on various seaweed diets. Aquacult 344–349:205–209. https://doi.org/10.1016/j.aquaculture.2012.03.022

Yun B, Mai K, Zhang W et al (2011) Effects of dietary cholesterol on growth performance, feed intake and cholesterol metabolism in juvenile turbot (*Scophthalmus maximus* L.) fed high plant protein diets. Aquacult 319:105–110. https://doi.org/10.1016/j.aquaculture.2011.06.028

Zhou C, Xu D, Lin K et al (2018) Intelligent feeding control methods in aquaculture with an emphasis on fish: a review. Rev Aquacult 10:975–993. https://doi.org/10.1111/raq.12218

Chapter 36
Mapping of Aquaculture Potential Zones Using Geospatial Multi-Criteria Method for Sustainable Aquaculture Development-Thiruvallur District

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Abstract Aquaculture sector has developed rapidly since the last decade and its development have been unregulated, which has caused many ecological problems. In this regard, this study has been undertaken to identify potential zone for sustainable aquaculture development. Thiruvallur district coastal sub-watershed boundary has been taken as the study area which has been delineated using SRTM DEM, toposheet, and also using watershed data collected from the agriculture department, Tamil Nadu. Water sources available in the study area are Pulicat Lake, Buckingham Canal, Arani River, and Kosathalaiyar River. Pulicat and Buckingham Canal are the major sources for aquaculture in the Thiruvallur district since Kosathalaiyar and Arani River are ephemeral in nature. A pair wise comparison matrix has been used to assign weightage to each criterion based on its relative importance. Various thematic maps were integrated into multi-criteria factors such as water quality, soil characteristics, infrastructure factors, and land use type to identify potential aquaculture zone using remote sensing and GIS. To ensure sustainable aquaculture development constrain, parameters have been framed according to coastal aquaculture authority

The original version of this chapter was revised with the table header changed in Table 36.2. The correction to this chapter can be found at https://doi.org/10.1007/978-3-030-95618-9_79

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regulations for mangroves, settlement, drinking water source and ecologically sensitive areas. The existing aquaculture farm in the study area has been mapped using Sentinel 2, it is about 660.65 hectares and the potential extend of the area available for aquaculture development estimated using AHP method is about 630 hectares.

Keywords Aquaculture · Analytical hierarchical process · GIS · Remote sensing · Sentinel 2

36.1 Introduction

Coastal aquaculture has been developing at a faster phase over the past decade, and worldwide aquaculture production has reached 82 million tons in 2018 with a value of 250 billion US dollars. It contributes 46% of total production and 52% of worldwide fish supply. (FAO 2020). Fish represents 16% of animal protein consumed globally; it has become more prominent that fish catch cannot cope up the demand for seafood consumption due to the increasing population. Sustainable supply of seafood without depletion and damage to the aquatic environment is a huge challenge; with increasing demand, aquaculture has shown prominent growth for fish and shrimp production for human consumption (De Silva 2001; Paez-Osuna 2001; Ottinger et al. 2016; Natale et al. 2012). Aquaculture provides a huge advantage in regards to offering a better lifestyle, healthy food, prosperity, employment, and export earnings (Belton and Thilsted 2014). Expansion of aquaculture has been rapid which has caused an unregulated expansion, resulting in many environmental issues such as changes in biodiversity conversion of ecologically important areas viz., mangroves and agricultural land conversion, agricultural land salinization (Perez et al. 2003; Primavera 2006; Richards and Friess 2016; Thomas et al. 2017). These issues would cause a serious problem if not addressed properly (Young et al. 2019). Hence, it is crucial to identify potential areas for further aquaculture expansion sustainable without affecting the environment, multi-user conflict, and to make effective use of brackishwater resources. The growth of remote sensing and GIS has provided a wide usage of practical application. Identification of aquaculture potential zones using remote sensing and GIS has been recognized as a potential tool by many researchers. Multi-criteria decision-support approach (MCDA) like analytical hierarchical process (AHP) has been widely used for aquaculture potential zone identification (Salam et al. 2003; Giap et al. 2005; Radiarta et al. 2008; Hadipour et al. 2015; Falconer et al. 2019), while these researchers have incorporated water, land, and soil characteristic, and environmental regulations, restrictions have not been considered. Hence, this study was undertaken to frame a suitable methodology for identifying potential aquaculture zones by incorporating water, land, and soil characteristic, environmental regulations, and restrictions in a sustainable manner.

36.2 Study Area

The southern part of Pulicat Lake, which is the second-largest brackishwater resource in India forms part of Thiruvallur district in Tamil Nadu. The coastal sub-watershed boundary of the Thiruvallur district has been delineated using SRTM DEM, toposheet, and sub-watershed data collected from the agriculture department. The study area comprises of Arani (4C2D8a, 4C2D8b), Gummidipoondi (4C2E1a), Kosathalaiyar (4C2D5d, 4C2D5f, 4C2D5t), and Pulicat (4C2E2a) sub-watershed located between 13.17°–13.57° N and 80.13°–80.35° E with a total area of about 61,841.5 hectares as shown in Fig. 36.1.

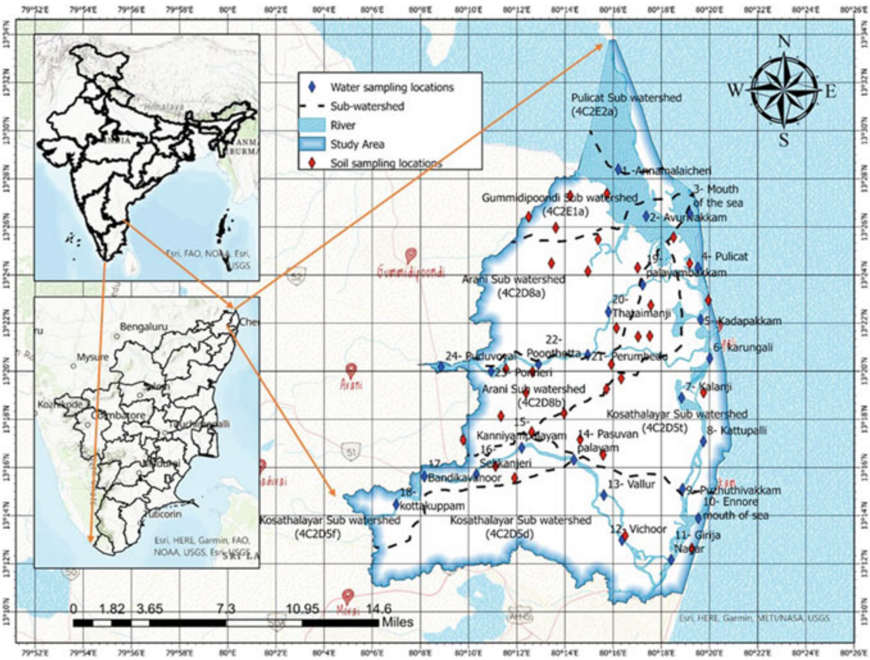

Fig. 36.1 Study area map

36.3 Materials and Method

36.3.1 Data Used

Aquaculture development mainly depends upon good soil quality, good water sources, and the coverage of land availability. Hence, their characteristic is an essential prerequisite for mapping potential area for aquaculture development. Sentinel 2 satellite image downloaded from (https://scihub.copernicus.eu/dhus/) was used to map the Land Use Land Cover (LULC) and SRTM DEM data from (https://explorer.earthengine.google.com/#workspace), the sub-watershed boundary of Thiruvallur district was collected from the agriculture department (https://slusi.dacnet.nic.in/dmwai/TAMILNADU/District/Trivallur.html) and was used to map and name the sub-watershed boundary. Soil texture data were collected from the National Bureau of Soil Survey and Land Use Planning Website (https://esdac.jrc.ec.europa.eu) and digitized in ArcGIS pro. The methodology used for identifying potential aquaculture zones is given in Fig. 36.2.

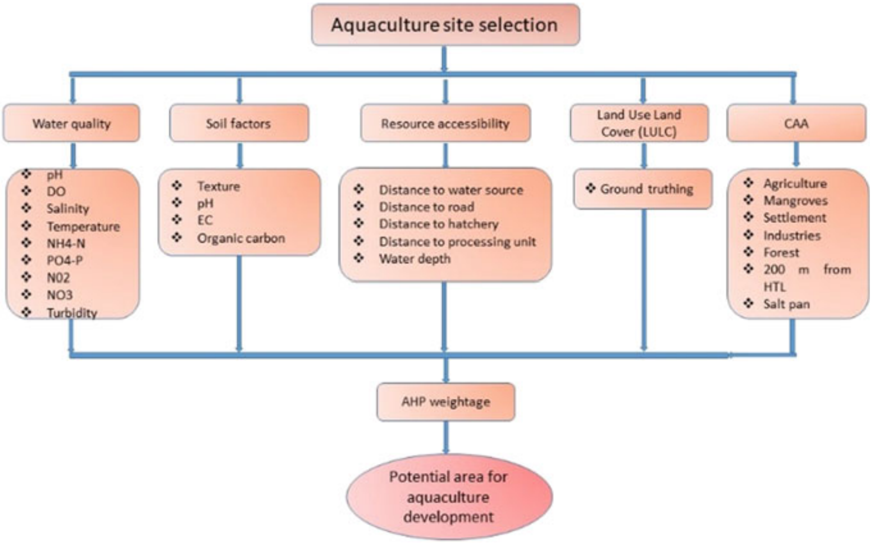

Fig. 36.2 Methodology flowchart

36.3.2 Land Use Land Cover (LULC) Classification

ArcGIS Pro 2.6 was used to preprocess Sentinel 2 satellite image, raster subset tool was used to clip the satellite image of the study area using the sub-watershed boundary of the study area before classification. Images were layer stacked at a band combination of Band 8 (NIR), Band 3 (Green), and Band 2 (Blue). A radiometric correction was carried out to enhance the image quality. 44 N Universal Transverse Mercator projection was applied to the satellite data. LULC map was classified using visual interpretation keys color, texture, tone, pattern, shape, size, and associated features (NRSA 1995; Lillesand and Kiefer 2000). Agriculture land was identified by mild red tone with continuous pattern medium to smooth texture. Mangrove was identified by dark red tone with smooth pattern and medium coarse texture located near creeks or estuaries. Aquaculture farms were identified by dark blue to light blue with rectangular or square shape, whereas salt pan was identified by gray/white color with smooth pattern and smaller in size compared to aquaculture farms. The dense vegetation was identified by light reddish-brown color with fine to medium texture. Scrublands were identified by yellow to light red tone with a medium to smooth texture. Mudflats were in gray with a smooth texture and continuous pattern, located near coastal areas. Abandoned aquaculture farms were identified using google earth, and the absence of water in the farm for more than 2 years was considered. Google earth images were used to verify the authentication of classification along with field verification. Kappa's coefficient (Campbell and Wynne 2011) was used to calculate the overall accuracy, and the area for each class is calculated using calculate geometry tool in ArcGIS pro.

36.3.3 Soil and Water Characteristic Assessment

Twenty-four surface water sampling locations have been identified at 4 km intervals, soil samples have been collected from 32 locations, and samples have been collected from September 2019–September 2020 at a monthly interval. It is observed that Kosathalaiyar and Arani River in the study area are ephemeral; hence, the flow of water is observed only during flood conditions. The southern part of Pulicat Lake is located in the northern part of the study area, which is interlinked with the Buckingham Canal and runs parallel to the coast in the study area. It is the main water source for shrimp farming. Water quality parameters such as water temperature and dissolved oxygen have been tested in field, pH, salinity, turbidity were analyzed using digital meter, while ammonia–nitrogen (NH_4-N) was analyzed using phenol hypochlorite method, phosphate phosphorus (PO_4-P) using phosphomolybdic acid-ascorbic acid method, and nitrite nitrogen (NO_2-N) using sulphanilamide NED method. Soil samples were assessed for organic carbon, pH, and electrical conductivity. All samples were analyzed within 2 days in the laboratory at Muttukadu

Experimental Station (ICAR-Central Institute of Brackishwater Aquaculture, Tamil Nadu, and India) (APHA 2005).

36.3.4 Mapping of Resource Accessibility

Factors such as distance to the water source, water depth, distance to road, distance to the seed source, and distance to processing unit come under this category. Water depth was measured in the field using a depth-measuring instrument. Water source and road networks were digitized from satellite images and topographic maps in ArcGIS pro. Buffer zones were created using a multi-ring buffer tool in ArcGIS pro. The hatchery and processing site source were collected from field surveying, google earth, and from the department of fisheries, Tamil Nadu. The buffer zones were created for 100 km for hatchery, 20 km, and 50 km for the processing unit.

36.3.5 Multi-Criteria Decision-Support Approach - AHP

The main criteria for aquaculture potential zone identification are classified into four parts water quality, soil quality, resource accessibility, and land use. Water, soil, resource accessibility characteristics have been classified as optimum based on literatures and experts' opinions as shown in Table 36.1 (Boyd 1995; Senarath and Visvanathan 2001; Saaty 2008; CAA 2014; Hadipour et al. 2015). Constraints have been framed as per CAA (2014). The weightage for each criteria is given as per the importance for shrimp farming based on works of literature and experts option (Eastman et al. 1993; Salam et al. 2003; Radiarta et al. 2008; Falconer et al. 2019), the weights are derived using (Saaty 2008) method. The consistency index and consistency ratio were calculated using the procedure adopted by various researchers (Saaty 1977; Hossain et al. 2009; Nayak et al. 2018). The relative weightage is given to each parameter as shown in Table 36.2.

pH, water temperature, Dissolved Oxygen (DO), salinity, total ammoniacal nitrogen, nitrate, and phosphate, turbidity were considered as influencing factors (Boyd and Tucker 1998) in deciding sites since they are crucial for the growth of the reared species, they were categorized into a subgroup "water quality."

By considering the optimum water quality parameters for vannamei shrimp (CAA 2014), the source water characteristics, prevailing tropical climate in the study area, source water bodies depth-related turbidity issues, the pH was considered as important with maximum weight (22.8%) followed by turbidity (21.4%). As DO and salinity in the water body reveal the health of the ecosystem and salinity of the water specifies the growth of species. DO was assigned 13.8% weightage, and salinity was assigned 15.8% weightage. The weightage of water temperature, nitrate, nitrite, ammonia and phosphate is 3.9%, they are assigned as per experts opinion. Soil quality, organic carbon, and texture are the most important criteria for which the

Table 36.1 Suitable range of resources for shrimp farming

Water quality	Highly potential	Moderately potential	Marginally potential	Not suitable
pH	6.5–8.0	8.1–8.5	6.1–6.4, 8.6–9	< 6, > 9
DO (mg L^{-1})	> 6.1	5–6	4–4.9	< 4
Salinity (ppt)	15–25	6–14, 26–35	1–5, 36–45	< 1, > 45
Water temperature (°C)	20–30	15–19, 31–35	10—14, 36–40	< 10, > 40
NO_3-N (mg L^{-1})	< 0.5	0.5–1.0	1.1–1.5	> 1.5
NO_2-N (mg L^{-1})	< 0.25	0.25–0.5	0.5–1	> 1
NH_4-N (mg L^{-1})	0–1	1–1.25	1.26–1.5	> 1.5
PO_4-P (mg L^{-1})	< 0.2	0.2–0.4	0.41–0.5	> 0.5
Turbidity (NTU)	25–35	10–24, 36–60	61–80	> 80
Soil factors				
Texture	Clay loam, sandy clay loam	Sandy clay	Sandy loam	Sand
pH	6.5–7.5	6–6.4, 7.6–8	8.1–9, 5.5–5.9	< 5.5, > 9
Organic carbon (%)	0.5–1.5	0.3–0.4, 1.6–2.0	0.1–0.2, 2.1–2.5	< 0.1, > 2.5
Electrical conductivity (dS m^{-1})	> 4	3–4	0.5–2.9	< 0.5
Accessibility factors				
Distance to road (m)	< 500	501–750	750–1000	> 1000
Distance to water source (km)	< 1	1.1–2	2.1–3	> 3
Distance to processing unit (km)	< 20	21–50	51–100	> 100
Distance to hatchery (km)	< 100	101–500	501–1000	> 1000
Water depth (m)	> 4	2.1–4	1–2	< 1
Land use	Abandoned farms, Abandoned salt pans	Mudflats	Scrublands	Agriculture land, mangroves, settlement, Saltpan, land upto 200 m from high tide line

Table 36.2 MCDM based AHP matrix for aquaculture potential zone mapping

Water quality	pH	DO	Salinity	WT	NO_3-N	NO_2-N	NH_4-N	PO_4-P	Turbidity	Weight
pH	1	4	½	3	6	6	6	6	½	22.8
DO	¼	1	3	1	3	3	3	3	½	13.8
Salinity	2	1/3	1	2	3	4	4	4	½	15.8
WT	1/3	1	½	1	3	3	3	3	½	10.5
NO3-N	1/6	1/3	1/3	1/3	1	1	1	1	1/5	3.9
NO2-N	1/6	1/3	¼	1/3	1	1	1	1	¼	3.9
NH4-N	1/6	1/3	¼	1/3	1	1	1	1	¼	3.9
PO4-P	1/6	1/3	¼	1/3	1	1	1	1	¼	3.9
Turbidity	2	2	2	2	5	4	4	4	1	21.4
CR 0.06										
Soil quality	**Organic carbon**			**EC**		**pH**		**Texture**		**Weight**
Organic carbon	1			2		2		1		32.9
EC	½			1		2		½		20
pH	½			½		1		½		14.2
Texture	1			2		2		1		32.9
CR 0.02										
Accessibility factors	**Distance to water source**	**Distance to road**			**Distance to processing unit**	**Distance to hatchery**		**Water depth**		**Weight**
Distance to water source	1	3			8	8		1		38.8
Distance to road	1/3	1			5	4		¼		16

(continued)

Table 36.2 (continued)

Distance to processing unit	1/8	1/5	1	1	1/5	5
Distance to hatchery	1/8	¼	1	1	1/5	5.1
Water depth	1	4	5	5	1	35
CR 0.05						

Land use	**Abandoned farm**	**Mudflats**	**Scrubland**	**Weight**
Abandoned farm	1	2	3	52.5
Mudflats	½	1	3	33.4
scrubland	1/3	1/3	1	14.2
CR 0.05				

Overall factor	**Resource accessibility**	**Soil quality**	**Land use**	**Water quality**	**Weight**
Resource accessibility	1	3	2	1	35.8
Soil quality	1/3	1	1/3	½	10.7
Land use	½	3	1	2	30.4
Water quality	1	2	1/2	1	23.2
CR 0.06					

weightage has been assigned 32.9% each. While EC and pH were assigned 20% and 14.2%, respectively. Accessibility factors were classified into five water depth and water source have been given highest weightage 35% and 38.8%, respectively. While distance to road, distance to processing unit and distance to hatchery was assigned a weightage of 16%, 5%, and 5.1%, respectively. Land use has been classified into three, and the highest weightage is given to abandoned farm 52.5%. While the mudflats and scrubland was assigned a weightage of 33.4% and 14.2%, respectively. The overall factors have been classified into four, and the highest weightage has been assigned to resource accessibility and land use factor 35.8% and 30.4%, respectively. While soil quality and water quality were assigned a weightage of 10.7% and 23.2%, respectively.

36.4 Results

36.4.1 Water and Soil Characteristics Suitability

Successful aquaculture operation depends upon good quality of water and soil. The water quality parameters have been mapped using IDW feature in ArcGIS pro, and the suitability extend has been calculated for each parameter. The spatial distribution of water quality is shown in Fig. 36.3a. Water salinity is a crucial parameter in the study area, it ranges from 2 to 39 ppt, the suitability of salinity in the region is about 38%, 19%, and 43% area is highly potential, moderately potential, and marginally potential, respectively. pH indicates 39.5%, 1.4%, and 6% area is highly potential, moderately potential, and marginally potential, respectively. Water temperature in the study area is favorable for aquaculture activity. DO indicates 21%, 17%, and 11% area is highly potential, moderately potential, and marginally potential, respectively. NH_4-N shows that 98%, 0.5%, and 0.45 area is highly potential, moderately potential, and marginally potential, respectively. Nitrite and nitrate show that 95%, 70% highly potential area and 5%, 30% moderately potential area, respectively. Phosphate indicates 83%, 12%, and 4% area is highly potential, moderately potential, and marginally potential, respectively. Turbidity indicates 42%, 15%, and 7% area is highly potential, moderately potential, and marginally potential, respectively. The overall weightage grid for water quality is given in Eq. 36.1.

$$\begin{aligned}\text{Grid}_{\text{Water quality}} = {} & \text{Grid}_{\text{pH}} \times 0.228 + \text{Grid}_{\text{Turbidity}} \times 0.214 + \text{Grid}_{\text{salinity}} \\ & \times 0.158 + \text{Grid}_{\text{DO}} \times 0.138 + \text{Grid}_{\text{WT}} \times 0.105 \\ & + \text{Grid}_{\text{NO}_2-\text{N}} \times 0.039 + \text{Grid}_{\text{NH4}-\text{N}} \times 0.039 \\ & + \text{Grid}_{\text{PH}_4-\text{P}} \times 0.039 + \text{Grid}_{\text{NO}_2-\text{N}} \times 0.039 \end{aligned} \quad (36.1)$$

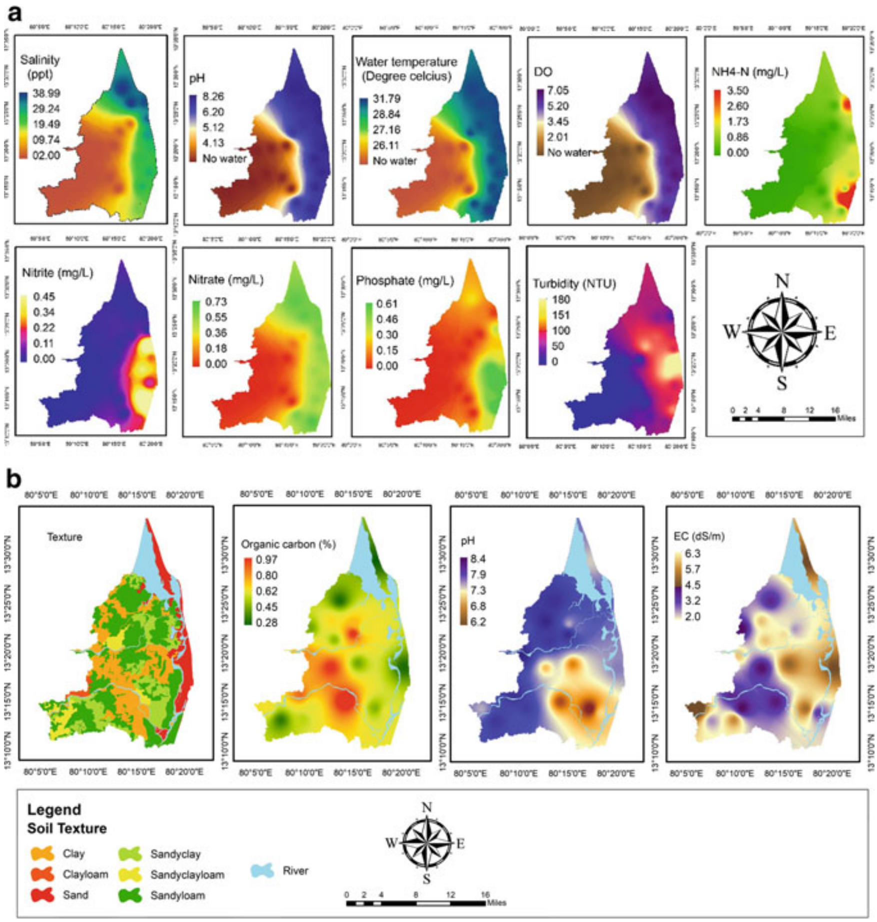

Fig. 36.3 **a** Spatial distribution of water quality. **b** Spatial distribution of soil quality

Soil parameters such as texture, organic carbon, pH, and EC in the study area are shown in the Fig. 36.3b. Soil texture is an important factor for aquaculture site selection as they play a crucial role in production. The clayey soils promote the growth of benthic blue algae and prevent seepage due to excellent water retention capacity; hence, it is considered best suited for farming. Sandy soils are permeable and porous; therefore, they are suitable for aquaculture (CAA 2014). The overall weightage grid for soil quality is given in Eq. 36.2.

$$\mathrm{Grid}_{\text{soil quality}} = \mathrm{Grid}_{\text{Organic carbon}} \times 0.329 + \mathrm{Grid}_{\text{Texture}} \times 0.329 + \mathrm{Grid}_{\text{EC}} \times 0.20 + \mathrm{Grid}_{\text{pH}} \times 0.142 \tag{36.2}$$

36.4.2 Land Use Land Cover Map

Land Use Land Cover map was classified using Sentinel 2 image as shown in Fig. 36.4, result shows that vegetation/agriculture area is about 14,779 hectares, scrubland is about 15,000 hectares, settlement is about 7,212.57 hectares, water body in the study area is about 7,938.87 hectares, mudflat is about 130 hectares, and barren land is about 14,753.61 hectares. Existing aquaculture in the study area is about 660.65 hectares, abandoned aquaculture farm is about 330 hectares, salt pan land in the study area is about 878.82 hectares, and mangroves in the study area are about 157.33 hectares. The overall weightage grid for land use is given in Eq. 36.3.

$$\begin{aligned} \text{Grid}_{\text{land use}} = \ & \text{Grid}_{\text{Abandoned farm}} \times 0.525 + \text{Grid}_{\text{Mudflats}} \times 0.334 \\ & + \text{Grid}_{\text{scrubland}} \times 0.142. \end{aligned} \tag{36.3}$$

The Government of India has regulated certain restrictions for shrimp farming through CAA act, which prohibits conversion of agricultural land, mangroves, salt-pans, and other ecologically sensitive areas for aquaculture, but permits construction in marginally unfit lands with 50 m buffer distance from other productive lands.

36.4.3 Mapping of Resource Accessibility

Resource accessibility is a crucial factor for shrimp farming and the optimum suitability in terms of distance to road, distance to the water source, and the processing facility were 100, 80, and 100% of the lands, respectively. Most of the hatcheries supply the vannamei seed is present in the east coast states of the country, in particular, Tamil Nadu and Andhra Pradesh. The water depth in the water bodies is a major limiting factor in the study area, as such 40% of the land can be supported, and the rest 60% does not have enough water depth for shrimp farming. The spatial distribution of resource accessibility is given in Fig. 36.5. The overall weightage grid for accessibility is given in Eq. 36.4.

$$\begin{aligned} \text{Grid}_{\text{Accessibility}} = \ & \text{Grid}_{\text{water source}} \times 0.388 + \text{Grid}_{\text{hatchery}} \times 0.35 + \text{Grid}_{\text{Road}} \\ & \times 0.16 + \text{Grid}_{\text{Processing unit}} \times 0.05 \end{aligned} \tag{36.4}$$

36.4.4 Potential Area for Aquaculture

The water, soil, resource accessibility, and land use factors have been integrated, and then, the restricted classes were removed the final potential area map is shown in the figure. The finding shows that the already existing aquaculture area is about

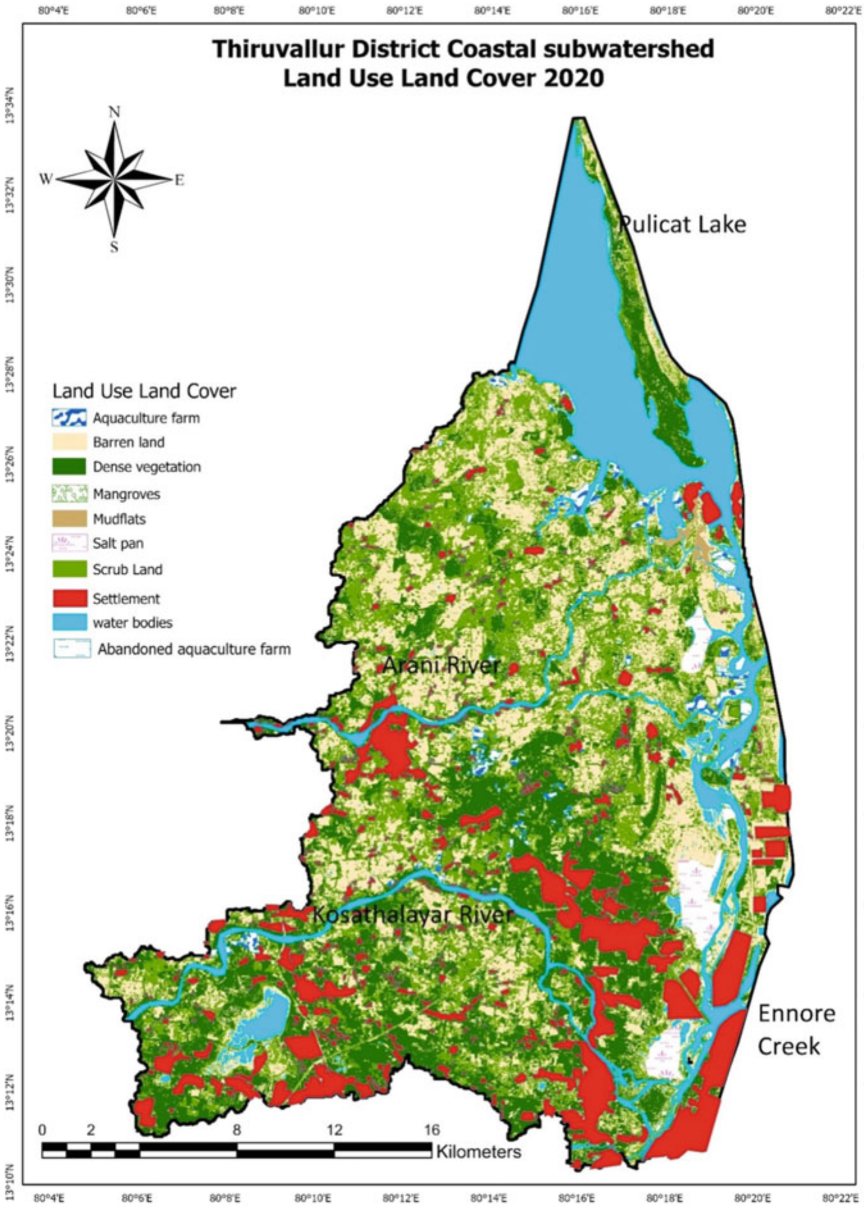

Fig. 36.4 Land use land cover map

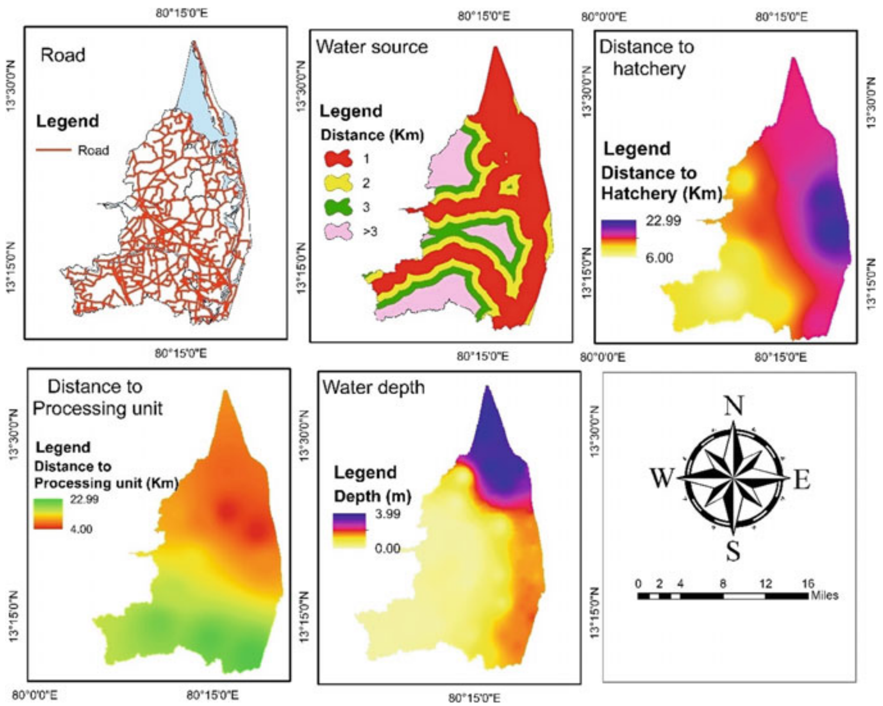

Fig. 36.5 Resource accessibility map

660.65 hectares, while the area available for further expansion is about 630 hectares as shown in Fig. 36.6. The sites were verified using field verification, and it was found the results estimated using the MCDM model were accurate. The overall weightage grid for potential area is given in Eq. 36.5.

$$\text{Grid}_{\text{Potential area}} = \text{Grid}_{\text{Accessibility}} \times 0.358 + \text{Grid}_{\text{land use}} \times 0.304 + \text{Grid}_{\text{water quality}} \times 0.232 + \text{Grid}_{\text{soil quality}} \times 0.107. \tag{36.5}$$

36.5 Discussion

The growth of aquaculture activity without any proper analysis would affect the environmental conditions, which would eventually affect the aquatic biodiversity (Vafaie et al. 2015). There are multiple factors, which need to be considered for site selection. Hence, GIS-based planning is essential for sustainable aquaculture expansion, which would provide a better management of resources. Many studies have been conducted using GIS for aquaculture site selection, while these studies have only

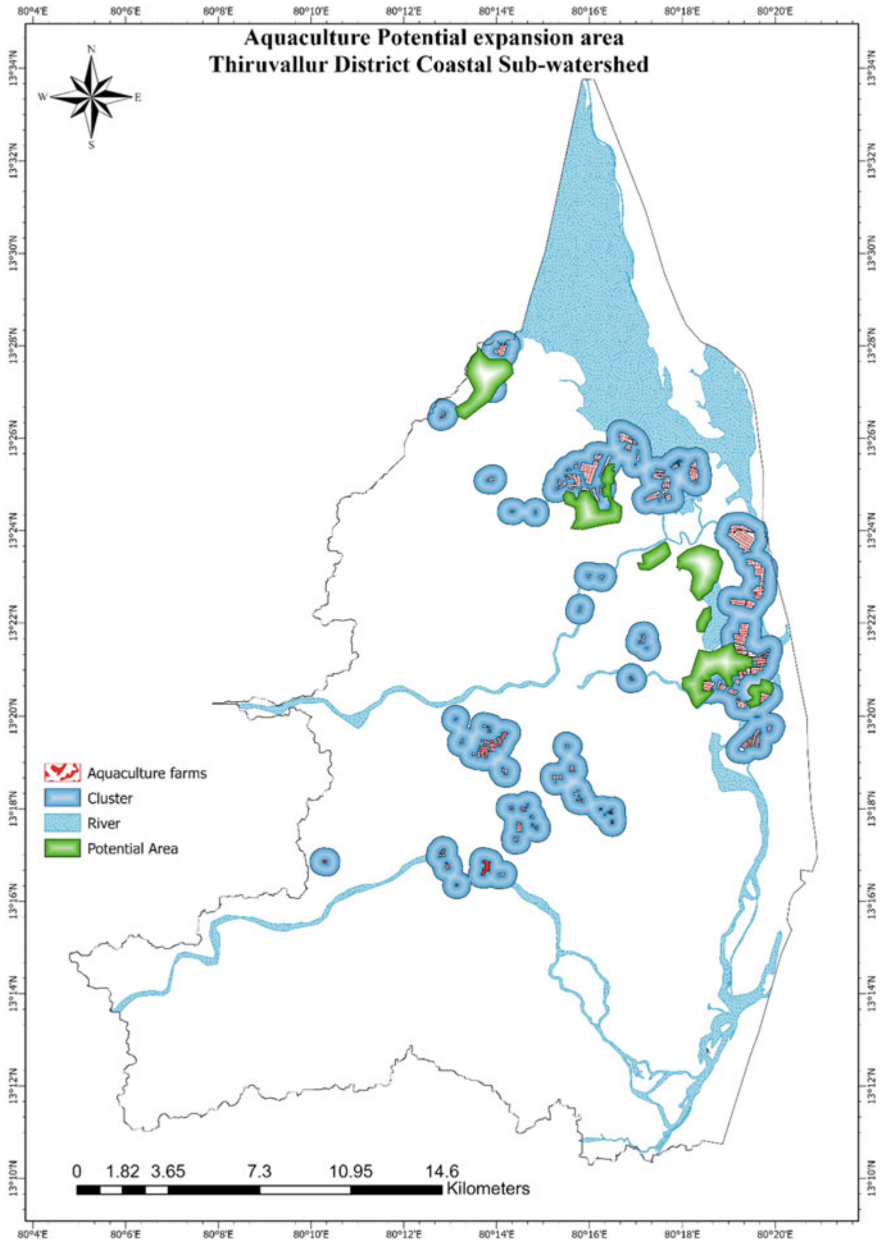

Fig. 36.6 Potential area for aquaculture expansion map

incorporated the resource characteristics such as water quality, soil quality, land use, and resource accessibility. The ecologically sensitive areas have not been excluded from the potential area in these studies (Giap et al. 2005; Hadipour et al. 2015), which would cause conversion of agricultural land, mangroves area and agricultural land salinization, etc. GIS-based mapping would increase the accuracy based on the inputs used, the higher the input factors greater the scale of accuracy. Coastal areas are mostly low lying, and aquaculture farms are mostly situated in these areas due to water accessibility (IPCC 2014). While flooding could not be completely avoided bund elevation could be raised and areas with very low elevation could be avoided to ensure flood damage. Climatic conditions are crucial for aquaculture activity hence incorporation of these factors in addition to the CAA regulations would improve the real-time model accuracy. A database could be created to make automatic delineation of the potential area using these factors which would greatly help the government and policy makers in providing license to the farmers and also improve the unproductive land for farmers livelihood. These management plans would greatly help in the raise of the economy and would decrease multi-user conflict. While many lands have been affected due to salinization if these lands are not used for agriculture for more than 5 years, they could be allowed for aquaculture process. Farmers livelihood depends on their land for survival; hence, government policies would make them to lead a better lifestyle. GIS-based shrimp farm database with farmers details provides great deal in planning (Nila Rekha et al. 2017). Hence, a database for potential aquaculture zone would greatly increase the planning and management efficiency. Water depth is the main limiting factor in many regions, deepest places are mostly creek and bar mouth, which makes it quite inconvenient for farming at a distance of more than 2 km. Water plays a crucial factor for shrimp farming, these resources would be utilized to the best by maintaining proper depth through dredging. Pollution in the coastal environment has been increasing at a rapid pace and proper policy for managing resource would increase the water quality for better farming practice. Hence, the environmental regulation CAA guideline is an important factor, which must be incorporated to obtain environmental sustainability.

Better planning and management would help to develop shrimp farm in a sustainable manner and further promote effective use of brackish water resources. This would help the government to make use of unproductive lands for improving the coastal community's livelihood and promote their status.

36.6 Conclusions

It can be concluded from the study that MCDM-based AHP technique is accurate in locating unproductive land for aquaculture operation. Integration of environmental regulations with the resource factors provides us a holistic approach, which will help to prevent multi-user conflict and promote sustainable farming. This method developed could be used as a tool by policy makers and stakeholders to make better planning for providing licenses to shrimp farmers. This methodology can be used as a base to estimate aquaculture potential areas in other places.

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References

APHA (2005) Standard methods for the examination of water & wastewater. In: Eaton AD, Clesceri LS, Franson MAH et al (eds) 21st ed. American Public Health Association, Washington, DC

Belton B, Thilsted SH (2014) Fisheries in transition: food and nutrition security implications for the global South. Glob Food Sec 3(1):59–66. https://doi.org/10.1016/j.gfs.2013.10.001

Boyd CE (1995) Bottom soils, sediments, and pond aquaculture. Chapman & Hall, New York

Boyd CE, Tucker CS (1998) Pond aquaculture water quality management. Kluwer Academic Publishers, Norwell, MA

Campbell JB and Wynne RH (2011) Introduction to remote sensing, vol 5. Guilford Press, New York, USA, pp 408–428. https://doi.org/10.3390/rs5010282

Coastal Aquaculture Authority (CAA) (2014) Compendium of acts, rules, regulations and other notifications, p 236. http://www.caa.gov.in/uploaded/doc/COMPUPD2014.pdf. Accessed 11 May 2019

De Silva SS (2001) A global perspective of aquaculture in the new millennium. In: Subasinghe RP, Bueno P, Phillips MJ et al (eds) Aquaculture in the third millennium. NACA, Bangkok, pp 431–459

Eastman JR, Kyem PAK, Toledano J et al (1993) GIS and decision making. In: Explorations in geographic information systems technology, vol 4. United Nations Institute for Training and Research, Geneva.

Falconer L, Middelboe AL, Kaas H et al (2019) Use of geographic information systems for aquaculture and recommendations for the development of spatial tools. Rev Aquacult 1–14. https://doi.org/10.1111/raq.12345

FAO (2020) The state of world fisheries and aquaculture 2020. Sustainability in action, Food and Agriculture Organization, Rome. https://doi.org/10.4060/ca9229en

Giap DH, Yi Y, Kwei Lin C (2005) Effects of different fertilization and feeding regimes on the production of integrated farming of rice and prawn *Macrobrachium rosenbergii* (De Man). Aquacult Res 36(3):292–299. https://doi.org/10.1111/j.1365-2109.2005.01244.x

Hadipour A, Vafaie F, Hadipour V (2015) Land suitability evaluation for brackish water aquaculture development in coastal area of Hormozgan, Iran. Aquacult Int 23:329–343. https://doi.org/10.1007/s10499-014-9818-y

Hossain MS, Chowdhury SR, Das NG et al (2009) Integration of GIS and multi-criteria decision analysis for urban aquaculture development in Bangladesh. Landsc Urban Plann 90(3–4):119–133. https://doi.org/10.1016/j.landurbplan.2008.10.020

IPCC (2014) Geneva. In: Pachauri RK, Meyer LA (eds) Climate change 2014: synthesis report. Contribution of working groups I, II and III to the fifth assessment report of the Intergovernmental Panel on Climate Change, vol. 151. http://www.ipcc.ch/pdf/assessmentreport/ar5/syr/SYR_AR5_FINAL_full_wcover.pdf.

Lillesand TM, Kiefer RW (2000) Remote sensing and image interpretation, 4th edn. Wiley, New York

Natale F, Hofherr J, Fiore G et al (2012) Interactions between aquaculture and fisheries. Mar Pol 38:205e213. https://doi.org/10.1016/j.marpol.2012.05.037

Nayak AK, Kumar P, Pant D et al (2018) Land suitability modelling for enhancing fishery resource development in Central Himalayas (India) using GIS and multi-criteria evaluation approach. Aquacult Eng 83:20–129. https://doi.org/10.1016/j.aquaeng.2018.10.003

Nila Rekha P, Gangadharan R, Dharshini S et al (2017) Digital database on shrimp farming in coastal watershed of Cuddalore District, Tamil Nadu. Indian J Fish 64(SI):39–45

NRSA (1995) Integrated mission for sustainable development (IMSD)—technical guidelines. National Remote Sensing Agency, Hyderabad, India

Ottinger M, Clauss K, Kuenzer C (2016) Aquaculture: relevance, distribution, impacts and spatial assessments—a review. Ocean Coast Manag 119:244–266. https://doi.org/10.1016/j.ocecoaman.2015.10.015

Paez-Osuna F (2001) The environmental impact of shrimp aquaculture: causes, effects, and mitigating alternatives. Environ Manag 28(1):131–140. https://doi.org/ https://doi.org/10.1007/s002670010212.

Perez OM, Telfer TC, Ross LG (2003) Use of GIS-based models for integrating and developing marine fish cages within the tourism industry in Tenerife (Canary Islands). Coast Manag 31(4):355–366. https://doi.org/10.1080/08920750390232992

Primavera JH (2006) Overcoming the impacts of aquaculture on the coastal zone. Ocean Coast Manag 49(9–10):531–545. https://doi.org/10.1016/j.ocecoaman.2006.06.018

Radiarta IN, Saitoh SI, Miyazono A (2008) GIS-based multi-criteria evaluation models for identifying suitable sites for Japanese scallop (*Mizuhopecten yessoensis*) aquaculture in Funka Bay, southwestern Hokkaido, Japan. Aquaculture 284(1–4):127–135. https://doi.org/10.1016/j.aquaculture.2008.07.048

Richards DR, Friess DA (2016) Rates and drivers of mangrove deforestation in Southeast Asia, 2000–2012. Proc Natl Acad Sci Unit States Am 113(2):344–349. https://doi.org/10.1073/pnas.1510272113

Saaty TL (1977) A scaling method for priorities in hierarchical structures. J Math Psychol 15(3):234–281. https://doi.org/10.1016/0022-2496(77)90033-5

Saaty TL (2008) Decision making with the analytic hierarchy process. Int J Serv Sci 1(1):83–98. https://doi.org/10.1504/IJSSCI.2008.017590

Salam MA, Ross LG, Beveridge CM (2003) A comparison of development opportunities for crab and shrimp aquaculture in southwestern Bangladesh, using GIS modeling. Aquaculture 220(1–4):477–494. https://doi.org/10.1016/S00448486(02)00619-1

Senarath U, Visvanathan C (2001) Environmental issues in brackish water shrimp aquaculture in Sri Lanka. Environ Manag 27(3):335–348. https://doi.org/10.1007/s002670010153

Stelzenmüller V, Gimpel A, Gopnik M et al (2017) Aquaculture site-selection and marine spatial planning: the roles of GIS-based tools and models. In: Buck B, Langan R (eds) Aquaculture perspective of multi-use sites in the open ocean, Springer, Cham. https://doi.org/10.1007/978-3-319-51159-7_6

Thomas N, Lucas R, Bunting P et al (2017) Distribution and drivers of global mangrove forest change, 1996–2010. PLoS ONE 12(6):1–14. https://doi.org/10.1371/journal.pone.0179302

Vafaie F, HadipourA HV (2015) GIS-based fuzzy multi-criteria decision making model for coastal aquaculture site selection. Environ Eng Manag J 14(10):2415–2425

Young N, Brattland C, Digiovanni C et al (2019) Limitations to growth: social-ecological challenges to aquaculture development in five wealthy nations. Mar Pol 104:216–224. https://doi.org/10.1016/j.marpol.2019.02.022

Chapter 37
Traditional Knowledge on Cast Net Design and Selectivity Along the Coastal Area of Sindhudurg, Maharashtra, India

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Abstract Traditional knowledge of the size selectivity of cast net is crucial to fisheries management in order to maximize a sustainable yield and from the ecological point of view. The fish species and size selectivity of cast net design with monofilament nylon polyethylene netting materials were studied along coastal area of Sindhudurg. Cast nets are operated as falling gear and conical in shape with lead sunken or weights attached at regular intervals on the lead rope forming the circumference of the cone. The nets are operated at a depth ranged from 0.40 to 5.50 m. The cast nets were used for fishing of mullet, lady fish, silver bellies, glass fish, shrimp, snapper

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and crabs, etc. The nets are locally known as *Konashi/Karel Shendi/Pag*. The selectivity of cast net with regards to the catch of fishes depends upon the size of the fish, the direction the fish tries to escape, the area or diameter of the net mouth, the depth of the water, the depth at which the fish is dwelling and the sinking speed of the cast net. This art of designing the fishing net needs to be preserved among the fisher community through dissemination of the traditional indigenous knowledge among young fishers.

Keywords Cast nets · Design · Falling gear · Traditional knowledge

37.1 Introduction

Small-scale fishers throughout the world use cast nets which are operated round the year in the river, estuarine and coastal areas for commercial and subsistence fishing. Traditional knowledge on size selective and information about the size selectivity of fishing gear is essential for studying fish population dynamics, assessing stock status and managing fishery harvest (Zhao and Morbey 2017). Furthermore, the size selectivity of fishing gear is crucial to determining the effects of fishing on life history traits, yield and recovery potential of exploited fish stocks. Adapting the selectivity of fishing gears is the most important strategy and selectivity can be defined as the dependence of a fishing gear's capture efficiency on factors such as size, age, and species (MacLennan 1992).

Cast net is a highly passive gear accounting for 20% of all the fishing methods of the world. The simplicity of its design, construction, operation and its low energy requirement make the gear very popular in all the sectors especially in the traditional sector. Seine, cast and lift net, traps and hooks and lines were recorded as non-selective gear considering the fish species caught at Khulna, Bangladesh (Rahman et al. 1999). Mohammed and Ali (2011) conducted a survey in Al-Kalakla Fishery and Jabel Awlia Dam Fishery in the White Nile River, Khartoum state to identify the selective and non-selective fishing gear.

Generally, cast nets are very common among small-scale fishers due to their simple design, simple construction, easy method of operation and affordable price (Eyo and Akpati 1995; Idowu and Eyo 2005; Okoh et al. 2007). FAO Code of Conduct for Responsible Fisheries highlighted the importance of minimizing waste and discards in fisheries by developing and using selective, environmentally safe and cost-effective fishing gear and techniques (Remesan et al. 2009). Cast nets are operated as falling gear and are conical in shape with lead sunken or weights attached at regular intervals on the lead rope forming the circumference of the cone. The cast nets have taken many changes with respect to the material used, net dimensions, mesh size, mode of operation, etc. (Vijayan et al. 1993). The mullet, lady fish, silver bellies, glass fish, shrimp, snapper and crabs, etc. are crucial species that have a high commercial value among fishes caught in the cast nets. The fish species and size selectivity of cast net design with monofilament nylon polyethylene netting materials were studied along coastal area of Sindhudurg. The study would provide a picture on the present scenario of cast net fishing in Sindhudurg.

37.2 Material and Methods

Information on cast net was collected through intensive field survey and interaction with the local fishers of the Sindhudurg district, Maharashtra, India. The fishers were interviewed from Devgad, Malvan, Vengurla and Sawantwadi the randomly selected talukas of Sindhudurg. The sampling station of district was selected randomly for purpose of collecting data for the study (Fig. 37.1).

Semi-structured interviews and informal conversations were formulated to collect data from local fishers of the knowledge on the design characteristics and technical specifications of the cast nets operated with respective to different fishes. The snow ball methodology also called as chain of the informant was used in the present investigation (Chogale et al. 2018). Each interviewed fishermen was asked to indicate

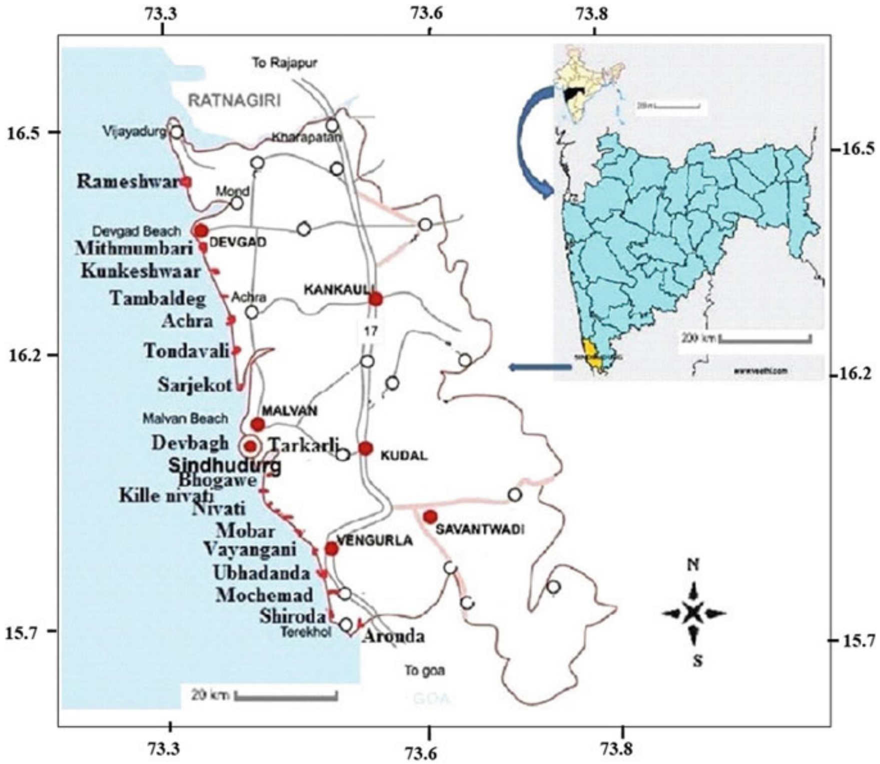

Fig. 37.1 The map of Sindhudurg district showing sampling station

the next respondent to contribute in the study in succession. In this way a total of 100 fishermen were interviewed. The data related to the technical specifications, design details of cast net and other relevant details were recorded according to Miyamoto (1962).

37.3 Results and Discussion

The design and technical details of each category of cast nets are given in Table 37.1 and Fig. 37.2.

Table 37.1 The design and technical details of cast nets

Specification	Cast net with pocket	Cast net without pocket
Local name	*Konashi/Karel Shendi/Pag*	*Sag jale*
Types of net	With pocket	With sting without pocket
Total height of net	3 mt	6 mt
Material of main twine	Polyamide (PA) multifilament/monofilaments	Polyamide (PA) multifilament/monofilaments
Twine diameter	20–32 no	28 no
Stretched mesh size	1–2.5 in	40 mm
Colour	Any	White
Total weight of gear	4–5 kg	5.8 kg
Type of webbing	Knotted	Knotted
Make of knot	Machine made	Machine made
No. of pockets (if with pocket)/stingline	42–80	14–27
Local name for pocket/stingline	*Pot/Khambale*	*Sag*
Length of per pocket/stingline	14 cm	Height of net
Mesh no. in pocket	14–20	40–50 cm
Distance of between 2 pockets	17 cm	30–35 cm
Sinkers no. in pocket/stingline	2 per pocket	3–4 per sting
Total length of chord	12 m	3–8 m
Local name of chord	*Charni*	*Charni*
Material of chord	Polypropylene (PP) twisted multifilament	Polypropylene (PP) twisted multifilament
Diameter of chord	3–5 mm	3–5 mm

a. A variety of cast nets of different mesh sizes

b. Pulling Chord of Cast net with pocket

c. Pulling Chord of Cast net without pocket

d. Joining of upper panel with lower panel

e. Joining of selvedge meshes and attachment of sinkers

Fig. 37.2 The design and technical details of each category of cast nets

Table 37.2 A variety of nets with different mesh sizes

Sr. No	Specification	Mesh	Fish to be caught
1	3–4 mt	14–16 mm	Mullet
2	5–6 mt	16–18 mm	Shrimp/Sardine
3	4–5 mt	60–70 mm	Snapper

The mullet, lady fish, silver bellies, glass fish, shrimp, snapper and crabs, etc. are crucial species which were caught in cast net in Sindhudurg district. Mitra et al. (1987) reported that prawns and small fishes were caught in cast net in Hooghly estuary. Cast net operation was described by Emmanuel et al. (2008) and recorded that twenty-one fish species belonging to 19 families were caught in Lagos lagoon**.** A variety of nets of different mesh sizes starting from 14 to 70 mm were found to be in operation (Table 37.2). Syed et al. (2016) observed cast nets in Dal Lake were categorised in two types on the basis of mesh size, i.e., cast net with large mesh and the other with small mesh.

Cast nets were locally known by different names as *Konashi/Karel Shendi/Pag/Sag jale* in Sindhudurg district of Maharashtra*.* Cast net with fixed pockets are especially used in shallow water, free of obstacles. The net was conical shaped and was fabricated with polyamide multifilament and monofilaments. Two types of cast nets (with pocket and without pocket) types are operated in the estuarine and coastal areas for commercial and subsistence fishing. Design, construction and operation of cast net without strings and with pocket were studied by Saxena, (1966) in a section of the middle reaches of Ganga river system of India. Puthra (2003) studied two types of cast nets (stringed and stringless) types that are operated in the aquaculture farms of northern Kerala. Cast net without central line and without pockets was operated in shallow waters from small non-motorized fishing craft or from the shore (Dongare and Mohite 2016; Dongare et al. 2016).

The length of cast net ranged from 3 to 4 m in case of small meshed cast net and ranging from 5 to 6 m for large meshed cast net operated in Sindhudurg district. The net is either hand-made (Table 37.3) or machine made (Table 37.4) of polyamide twine with 3–7 panels.

In the case of hand braiding, the net is brought to shape by either baiting or creasing at appropriate intervals. In case of machine webbing where ready-made pieces are obtained, the webbings are joined together first 2–3 panels with 1:2 ratio following next panels with 2:3 ratio. Dongare et al. (2016) observed that the cast net of without central line and without pockets was made up of 3–6 panels joined together vertically to form main conical webbing. For first three panels, joining was carried out by 1:2 ratio. It means that one mesh of upper panel and two meshes of lower panel were joined by making knot locally called as *Vasan.* From panel number 4–6 the ratio maintained was 2:3. In which two meshes of upper panel were joined to 3 meshes of lower panel (*Vasan*). Emmanuel et al. (2008) reported that the cast net was constructed using nylon monofilament, polyethylene and polyester (PES) multifilament twine in tropical open lagoons. Whereas, in north Kerala, Remesan

Table 37.3 The specification of hand-made cast net

	Panel 1	Panel 2	Panel 3	Panel 4	Panel 5
Upper edge meshes	84	168	336	672	1344
Lower edge meshes	84	168	336	672	1344
Depth meshes	10	20	40	60	80
Creasing rate	1:2	1:2	1:2	2:3	2:3
Joining pattern	*Ghadap/vasing*	*Ghadap/vasing*	*Ghadap/vasing*	*Ghadap/vasing*	*Ghadap/vasing*

Table 37.4 The specification of machine made cast net

	Panel 1	Panel 2	Panel 3	Panel 4
Upper edge meshes	250	500	1000	2000
Lower edge meshes	250	500	1000	2000
Depth meshes	1.5 ft	3 ft	4.5 ft	6 ft
Creasing rate	1:2	1:2	1:2	2:3
Joining pattern	*Vasing*	*Vasing*	*Vasing*	*Vasing*

(2009) found that main webbing of cast net were fabricated by hand using PA 210 × D3 × 3 multifilament twine. The same twine is used to make the foot rope after hand twisting 13–15 numbers of twine (Syed et al. 2016).

Two mesh depth selvedge made of PA twine of having a mesh size larger than the main webbing is provided both in the anterior and posterior end of the cast net. The selvedge in top portion of the net is fixed to a metal ring sinkers (lead) are attached to the bottom selvedge of the net. Remesan (2009) studied different types of cast nets from north Kerala and found that tubular lead sinkers each having 10–12 mm length and weighing approximately 50 g were used. In Ratnagiri, oval shaped lead sinkers having 3–4 mm diameter at centre were used as weight for fast sinking of cast net with total 180–225 number of sinkers each weighing 18–22 g was attached to the sinker line at a distance of 12–16 cm (Dongare et al. 2016). The sinker line was made of polyethylene of diameter 5–8 mm with attached cylindrical lead or iron sinkers with lengths ranging from 25 to 40 mm in Dal Lake. In the case of stringed cast nets, the main string which is held by hand is made of 4 mm diameter PP material. It branches into four or six strings and then each string is further divided into three or four strings which were attached to the bottom portion of the net where sinkers are attached. These strings are made up of PP twisted multifilament rope of 3–4 mm diameter and 4–8 m length was fixed to the apex of the net, which was used as pulling cord for hauling the net.

37.4 Conclusions

The present study indicated that the fishers from Sindhudurg district have knowledge in designing cast nets for capturing different species of fishes. The information doocumented during the present study on technical specifications and design of cast nets of Sindhudurg district of Maharashtra, would serve as important database, related to the use of indigenous knowledge in the fishing industry of the district and the technological modifications the gears may undergo to increase its efficiency in the coming years. This knowledge will initiate further development of cast nets in fishery management.

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References

Chogale ND, Nirmale VH, Metar SY et al (2018) Assessment of indigenous knowledge on edibility of oyster, *Crassostrea madrasensis* from the Ratnagiri coast of Maharashtra. Indian J Tradit Know 17(l):204–208

Dongare M, Mohite AS, Sharangdhar M (2016) Design, technical aspects and operation of cast net without central line and without pockets of Ratnagiri, Maharashtra. Int J Agric Eng 9(2):150–155

Dongare M, Mohite A (2016) Design and technical specifications of cast net without central line and with pockets of Ratnagiri, Maharashtra. Int J Eng Res Modern Edu I(I):584–590

Emmanuel BE, Chukwu LO, Azeez LO (2008) Cast net design characteristics, catch composition and selectivity in tropical open lagoon. African J Biotech 7(12):2081–2089

Eyo JE, Akpati CI (1995) Fishing gears and fishing methods. In: Ezenwaji HMG, Inyang MN, Orji EC (eds) Proceeding of the UNDP Assisted Agriculture and Rural Development Programme (Ministry of Agriculture Awka, Anambra State). Training course an artisanal fisheries development, University of Nigeria, Nsukka, 29 October–12 November 1995, pp 143–167

Idowu RT, Eyo JE (2005) Fisheries status and fishing gears of a West African arid zone lake. Anim Res Int 2(2):353–357

MacLennan DN (1992) Fishing gear selectivity: an overview. Fish Res 13:201–204. https://doi.org/10.1016/0165-7836(92)90076-6

Mitra PM, Ghosh KK, Saigal BN et al (1987) Fishing gears of the upper and the middle Hooghly estuary. Bulletin Central Inland Fisheries Res Institute 49:1–22

Miyamoto H (1962) A field manual suggested for fishing gear surveys. In: Mimeo, Central Institute of Fisheries Technology, p 15

Mohammed MO, Ali ME (2011) Diversity of selective and non-selective fishing gear and their impact on the White Nile River, Khartoum State, Sudan. African J Environ Sci Tech 5(12):1003–1007

Okoh FA, Eyo JE, Ezenwaji HMG (2007) Species composition and abundance of cast net fishery of a tropical lotic freshwater ecosystem. Bio-Res 5(1):201–206
Puthra P (2003) Studies on shrimp harvesting techniques in aquaculture. PhD Thesis, Central Institute of Fisheries Education, Versova, Mumbai, p 220
Rahman S, Mazid MA, Kamal M et al (1999) Study on fishing gears, species selectivity toward gears and catch composition of BSKB beel, Khulna Bangladesh. Bangladesh J Fish Res 3(1):25–32
Remesan MP (2009) Inland fishing gears and methods of North Kerala. Niseema Printers and Publishers, Cochin, CIFT, pp 1–101
Remesan MP, Pravin P, Meenakumari B (2009) Non-selective fishing gears and sustainability issues in the Hooghly-Matlah Estuary in West Bengal, India. Asian Fish Sci 22:297–308
Saxena RK (1966) The fishing nets and traps in a section of the middle reaches of Ganga river system of India. Proc Indo-Pacific Fish Coun 11(II):250–271
Syed N, Mohite A, Sadawarte R (2016) Cast nets of dal Lake of Kashmir: design characteristics and specifications. J Exp Zool India 19(1):1219–1222
Vijayan V, Varghese MD, Edwin L (1993) Coastal gill nets of Kerala—changes in three decades. In: low energy fishing, fishery technology, (special issue), Society of Fisheries Technologists, India, pp 172–176
Zhao Y, Morbey YE (2017) Estimating the size selectivity of trap nets using a gill-net selectivity experiment: method development and application to lake Whitefish in Lake Huron. North Am J Fish Manag 37:1341–1349

Chapter 38
Genome Wide Characterization and Analysis of Simple Sequence Repeats in Cultrinae Species

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Abstract Simple sequence repeat markers also known as microsatellite markers have been used to answer several biological questions. Cultrinae is one of the thirteen subfamilies of family Cyprinidae encompassing several economically important freshwater aquaculture species. With the advancement of the next generation sequencing technologies and simultaneous development of bioinformatics tools it is now possible to decipher the whole genome sequences of several model and non-model species. The whole genome sequence of three Cultrinae species is available in the public database. In the present study, we identified and compared simple sequence repeat markers in three Cultrinae species, i.e. *Anabarilius grahami*, *Megalobrama amblycephala* and *Culter alburnus*. The genome size of *A. graham*, *C. alburnus* and *M. amblycephala* was found to be 0.9 GB, 1.02 GB and 1.08 GB, respectively. Evaluation of completeness of the genomes using BUSCO revealed 96.8%, 96.6% and 94.9% completeness, respectively. In total, 398,473, 522,850 and 579,378 perfect SSR repeats with 1–6 bp nucleotide motifs were identified encompassing 8,391,632, 11,457,461 and 12,860,863 repeat bases, respectively in *A. graham*, *C. alburnus* and *M. amblycephala*. The simple sequence repeat motifs cover 0.85%, 1.13% and 1.18% of the present *A. graham*, *C. alburnus* and *M. amblycephala* draft genome. The frequency and density of SSR repeat motifs in the three Cultrinae genomes were 401.73, 513.75 and 532.57 and 8460.27, 11,258.12 and 11,821.74, respectively. The mono, di, tri, tetra, penta and hexa nucleotides repeat in *A. graham*, *C. alburnus*

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and *M. amblycephala* genomes were found to be 119,554, 195,336 and 240,710, 134,985, 157,238 and 178,370, 39,066, 51,112 and 51,684, 87,395, 99,004 and 88,985, 14,323, 18,646 and 17,772, 3150, 1514 and 1857, respectively. Mononucleotide repeats were the most frequent repeats and hexanucleotide repeats were least frequent repeat motifs. Among the mononucleotide A, among dinucleotide AT and AC, among trinucleotide AAT, among tetranucleotide AAAT and AGAT, among penta-nucleotide AAAAT, AATAT and AAGTG and among hexanucleotides AAAAAT, AACCCT and AAATGT were the most frequent repeat motifs. The repeat motifs in all the genomes were A + T rich. The information generated in the present study may facilitate research on role of simple sequence repeat motifs in genome organization and gene regulation, etc. in the above species.

Keywords Cultrinae species · Genetic improvement · Genome characterization · Simple sequence repeats

38.1 Introduction

The order Cypriniformes is the largest order of superorder Ostariophysi, home to the most diverse group of freshwater fishes out numbering 4400 currently recognized species (Eschmeyeret al. 2017). The members of this order are of great economic and culture values. Important model organisms such as *Danio rerio* also belongs to the Cypriniformes. The species of this order are widely distributed in North America, Africa, Europe and Asia and shares a lion share of freshwater habitat (Nelson 2006). Further, some of the species have adapted into extreme habitats like caves and acidic peat swamps (Romero and Paulson 2001; Kottelat et al. 2006). Most of the freshwater food and recreational fishes belongs to this order. Ornamental fish species of Cypriniformes order is very popular worldwide. Cyprinidae is one of the important families of order Cypriniformes housing to carps, minnows and barbs. The members of the family Cyprinidae is commonly called as cyprinids. It is the most diverse freshwater fish family of the world having 13 sub families, at least 210 genera and over 2010 species (Nelson 1994). Cultrinae is one of the important sub families of Cyprinidae consisting of 18 genera and 64 species and home to several economical freshwater fish species such as *A. grahami*, *M. amblycephala* and *Culter alburnus* contributing substantially to the freshwater aquaculture production. Development of elite germplasm through genetic improvement programmes is one of the strategies to enhance aquaculture production. Existence of variability is the basis of genetic improvement programme of any economical species.

Morphological plasticity reduces the accuracy of quantification of genetic variation through measuring morphological variation (Manee et al. 2019). In contrast molecular markers are independent of environmental influences as well as life stages (Manee et al. 2019). Microsatellites or simple sequence repeats (SSR) are made up of short nucleotides of 1–6 bp length, abundantly found in prokaryote and eukaryotes and distributed throughout the genome encompassing coding and non-coding regions as well as organellar genomes (Tóth et al. 2000; Chistiakov et al. 2005; Ellegren 2004; Pérez-Jiménez et al. 2013; Phumichai et al. 2015; Adams et al. 2016). Microsatellites repeat motifs are dynamic and undergo rapid expansion and contraction thereby exhibiting extensive length polymorphism (Tautz 1989; Weber & Wong 1993; Kruglyak et al. 1998; Lai and Sun 2003). The underlying mechanism of SSR length polymorphism is replication slippage, creating a loop in one strand resulting in insertion or deletion in successive replications in a strand specific manner leading to increase or decrease in length of microsatellite (Levinson and Gutman 1987; Schlötterer and Tautz 1992; Schlötterer 2000). Microsatellites are considered as an excellent molecular marker due to this characteristic making it most suitable for investigation of genetic diversity and DNA finger printing.

Gene regulation and genome organization is greatly influenced by the presence of microsatellite repeats (Zhang et al. 2006). Further, variation in length of microsatellite repeat motifs affected structural organisation of DNA and protein (Mrázek et al. 2007). Several studies in fruit fly, *Arabidopsis thalina*, and rice supported the belief of non-random distribution of microsatellites in the genomes (Bachtrog et al. 1999; Lawson & Zhang2006; Morgante et al. 2002; Pramod et al. 2014). In a study carried out by Lawson & Zhang (2006) demonstrated the non-random distribution of microsatellites in the genomes of *A. thalina* and *Oryza sativa*. Further, this study showed that distribution of SSRs differently in different coding regions. It has been observed that the abundance of microsatellite repeat motifs are more in non-coding region in comparison to coding region (Hancock 1995; Katti et al. 2001) and appearance of trinucleotide and hexanucleotides are more abundant in exons than non-coding region (Borstnik 2002; Subramanian et al. 2003). Presence of microsatellite repeats in the 5´ upstream region and in the intronic region affects gene regulation and stability of mRNA (Li et al. 2004).

Advancement in sequencing technology and availability of next generation sequencing platforms facilitated whole genome sequencing of several model and non-model organisms. During the last decade draft genome sequences of several important aquaculture species have been generated. The aim of the present study is to identify and compare genome wide SSR motifs of three Cultrinae species, whose genomes have already been sequenced.

38.2 Materials and Methods

38.2.1 Genome Sequence Retrieval and Evaluation

At the time of the study genomes of three Cultrinae species was available in the public database. The whole genome sequence of the three Cultrinae species, i.e., *A. graham*, *M. amblycephala* and *C. alburnus* were downloaded from the NCBI's genome database (https://www.ncbi.nlm.nih.gov/genome/). The quality of the three Cultrinae genomes were evaluated by using the programme BUSCO v3.0 and Actinopterygii odb9 core gene set.

38.2.2 SSR Motif Identification

Genome wide perfect SSR motifs were identified using the programme PERF v0.2.5 (Avvaru et al. 2017). The minimum numbers of repeat motifs used for the mono, di, tri, tetra, penta and hexa nucleotide repeat motifs are as follows: 12 for mono nucleotides, 7 for dinucleotides, 5 for trinucleotides, 4 for tetra, penta and hexa nucleotides as described in other studies (Qi et al. 2015, 2018; Liu et al. 2017). All other settings of PERF were set to default. SSR repeats with unit patterns being circular permutations and/or reverse complements were taken as one for further analysis (Jurka and Pethiyagoda 1995; Li et al. 2009). For clarity different type of repeat motifs were compared based on their relative frequency and relative density. Relative frequency is calculated as number of SSRs per mega base pair of target sequence. Similarly, relative density is calculated as the length of SSRs in base pairs (bp) per Mb of the target sequence.

38.2.3 Statistical Analysis

All graphical and statistical comparisons were performed in R programming environment (version 3.6.3).

38.3 Results

38.3.1 Genome Evaluation of Cultrinae Species

The number of haploid chromosomes of the three studied species is 24. The genomes of three Cultrinae species were assembled up to scaffold level and scaffold number ranged from 5,625 to 80.398. The N50 value and GC percentage were 36 kb, 322 kb and 121 kb and 36.7%, 37% and 36.4%, respectively for *A. graham*, *M. amblycephala* and *C. alburnus*. The genome size of *A. graham*, *C. alburnus* and *M. amblycephala* was found to be 0.9 GB, 1.02 GB and 1.08 GB, respectively. Evaluation of completeness of the genomes using BUSCO revealed 96.8%, 96.6% and 94.9% completeness, respectively (Table 38.1).

Table 38.1 Genome statistics of Cultrinae genomes

Species	Genome size	BUSCO %	total SSR	Percentage of Genome	Frequency	Density
A. grahami	0.9 Gb	96.8	398,473	0.85	401.73	8460.27
M. amblycephala	1.08 Gb	94.9	579,378	1.18	532.57	11,821.74
C. alburnus	1.02 Gb	96.6	522,850	1.13	513.75	11,258.12

38.3.2 Identification and Characterization of Microsatellite Repeats in Cultrinae Genomes

Here, we employed the programme PERF to identify perfect microsatellite repeats from the draft genomes of *A. grahami*, *M. amblycephala* and *C. alburnus*. The total numbers of perfect microsatellites identified in the three Cultrinae genomes were 398473, 522,850 and 579,378 with an average frequency of 401.73 SSRs/Mb, 532.57 SSRs/Mb and 513.75 SSRs/Mb, respectively in *A. graham*, *M. amblycephala* and *C. alburnus*. The relationship between total number of SSRs, frequency, density, genome size and GC content was investigated. The results revealed that number of SSRs was positively correlated with relative frequency (Pearsons $r = 0.984$) and genome size (Pearsons' $r = 0.996$) but negatively correlated with GC% (Pearsons' $r = 0.952$). At the same time it was observed that relative frequency and relative density of SSRs positively correlated with genome size (Pearson $r = 0.965$, and Pearson $r = 0.971$, respectively).

The data in Table 38.2 shows the number, relative frequency, and density of perfect mononucleotide, dinucleotide, trinucleotide, tetranucleotide, pentanucleotide and hexanucleotide repeat motifs for the three Cultrinae genomes. It was observed that the relative frequencies and densities of a given type of microsatellites were varying greatly among the three Cultrinae species. Similarly, the proportion of mono to hexanucleotide microsatellite repeats motifs vary among these species. In the present study the most frequent repeat motifs were found to be the mono nucleotides with exception in *A. graham*, where dinucleotides were found to be the most frequent repeat motifs, followed by di, tri, tetra, penta and hexanucleotides. The frequency and density of mononucleotides ranged from 120.542 to 221.444 SSRs/Mb and 1775.016 to 3660.331 bp/Mb, respectively. The mononucleotides accounts for 30.000% to 37.359% of total SSR numbers of the three Cultrinae species. At the same time hexanucleotides are the least frequent SSR repeat motifs in the Cultrinea species accounting for 0.289% to 0.70% of all perfect microsatellite repeat motifs.

Examination of the GC content and AT content of the SSRs of the three Cultrinae species revealed overall GC contents of SSRs were similar in *M. amblycephala* and *C. alburnus* (74.741% and 73.133%) and slightly lower in *A. graham* (70.234%). Similarly the SSRs AT percentages of three Culturinae species ranged from 25.258% to 29.765%. It was observed that all the SSR repeat type had high AT content (>96%). From the result it was evident that mononucleotides SSR repeat type had highest AT

Table 38.2 Microsatellite repeat motif characteristics of three Cultrinae species

Repeat type	Species	No of SSR	Length	Avg length	Frequency	Density	Repeat range	Percentage	GC%
Mono	*A. grahami*	119,554	1,760,461	14.725237	120.5424	1775.016132	12–318	30.00304	1.632357
	M. abmlycephala	240,710	3,978,780	16.529351	221.4443	3660.331187	012–774	41.54628	2.27950646
	C. alburnus	195,336	3,056,076	15.645227	191.9387	3002.924241	012–368	37.35985	1.64
Di	*A. grahami*	134,985	2,809,879	20.816231	136.101	2833.110506	007–58	33.87557	34.18
	M. amblycephala	178,370	4,515,788	25.31697	164.0938	4154.358786	007–79	30.78646	28.88
	C. alburnus	157,238	3,773,210	23.996807	154.5033	3707.585733	007–1865	30.07325	47.44
Tri	*A. grahami*	39,066	835,492	21.386679	39.38899	842.3996774	005–285	9.803926	19.84
	M. ablycephala	51,684	1,099,944	21.282099	47.54738	1011.908004	005–133	8.920601	16.5
	C. alburnus	51,112	1,072,160	20.976679	50.22305	1053.512823	005–100	9.775653	16.51
Tetra	*A. grahami*	87,395	2,479,188	28.367618	88.11756	2499.68542	004–21	21.93248	30.385
	M. ablycephala	88,985	2,535,457	28.493083	81.86293	2332.527139	004–1013	15.35871	27.566
	C. alburnus	99,004	2,768,293	27.961426	97.28211	2720.146409	004–407	18.93545	28.77
Penta	*A. grahami*	14,323	418,068	29.188578	14.44142	421.5245009	004–168	3.594472	23.68
	M. ablycephala	17,772	674,355	37.944801	16.34959	620.3817847	004–2269	3.067427	13.85
	C. alburnus	18,646	742,638	39.828274	18.32171	729.721922	004–1095	3.566224	13.58
Hexa	*A. grahami*	3150	88,544	28.109206	3.178607	89.27606372	42,826	0.790518	32.548
	M. ablycephala	1857	56,539	30.446419	1.708372	52.01379945	004–27	0.320516	36.09
	C. alburnus	1514	45,084	29.778071	1.487668	44.29989191	004–18	0.289567	34.04

percentages followed by in descending order penta, tri, tetra, hexa and dinucleotides. In the Cultrineae species highest GC percentage was observed in the dinucleotide SSR repeat motifs, in contrast least GC percentage was observed in hexanucleotide SSR repeat type. Upon examination of GC percentages of SSR repeat types of Cultrinae species it was observed that the GC percentages of all the SSR repeat motifs was significantly lower than GC percentages of their genomes except dinucleotide repeat motifs of *C. alburnus* (47.44%). Wide diversity was observed in different microsatellite repeat motifs for number of repeats in each SSR and the maximum repeats of each SSR type across the three fish genomes. No similarity in repeat motifs was observed between the three Cultrinae genomes.

38.3.3 Variation in Microsatellite Motifs of Cultrinae Genomes

Genome wide survey of microsatellites in Cultrinae species revealed AT-rich repeat motifs. To further gain insight into this behaviour, the composition of SSR motifs were examined. It was observed that the most frequent repeat motif for each repeat type varies widely across the species. The repeat motif types (A)n,(C)n, (AC)n, (AT)n, (AG)n, (AAT)n, (AAC)n, (AAG)n, (ATC)n, (AGAT)n, (AAAT)n, (ATCC)n, (AAAC)n, (AAAG)n, (AAAAT)n, (AATAT)n, (AAAAC)n, (AAGTC)n, (AATAG)n, (AAAAG)n, (AAATGT)n, (AACCCT)n, (AAAAAT)n and (ACATAT)n are some of the major shared repeat motifs across the three genomes. In case of mono, di and trinucleotide repeat types the number of degenerate repeat motifs were observed to be 2, 4 and 10, respectively across the genomes, where as it varied between the genomes in tetra, penta and hexanucleotide SSR repeat types.

Mononucleotides were found to be the most frequent SSR repeat type in Cultirnae genomes. Among the mononucleotides the repeat motif (A)n was found to be the most frequently occurring SSR repeat motif accounting for 97–98% of the total mononucleotide microsatellite repeat motifs of the three genomes. Here we observed that the (C)n SSR repeat motifs were the least frequent repeat motifs in each Cultrinae genomes with frequencies ranged from 2.031–5.047 SSRs/Mb. The most frequent repeat motifs in dinucleotide microsatellite repeat types varied between the genomes. The repeat motif (AC)n was most frequent microsatellite in the *A. graham* and *C alburnus* genome accounting for ~ 46–50% of the total dinucleotide SSR repeat motifs, whereas (AT)n repeat motif was observed to be the most frequent SSR repeat motif in *M amblycephala* genome accounting for ~ 45% of the total dinucleotide repeat types. It is interesting to note that the second most frequent dinucleotide repeat motifs in *A. graham* and *C alburnus* genomes was (AT)n repeat motif with 46.106–60.661 SSRs/Mb and in case of *C. alburnus* the second most frequent dinucleotide repeat motif was (AC)n with a frequency of 68.523 SSRs/Mb. The third most frequent dinucleotide SSR repeat motif was observed to be (AG)n in all the three genomes with almost similar frequencies of ~ 21 SSRs/Mb and (CG)n was observed to be the least dinucleotide repeat motif with frequencies lass 1SSRs/Mb in all Cultrinae genomes in the present study. It is interesting to note that the most frequent trinucleotide microsatellite repeat motif in all the Cultrinae genome is (AAT)n accounting for 56.481–58.710% of total trinucleotide SSR repeat types. The second most trinucleotide SSR repeat motif was observed to be (AAC)n with frequency ranging from 4.643 to 6.457 SSRs/Mb. (AAG)n repeat motif was observed to be the third most frequent trinucleotide microsatellite repeat motif followed by (ATC)n, which had almost similar frequencies of approximately 3 SSRs/Mb. In the present investigation the least frequent trinucleotide repeat motif was noted to be (ACG)n across genomes.

The most frequent tetranucleotide SSR repeat motifs was observed to be (AGAT)n in *A. graham* and *C. alburnus*, in contrast to (AAAT)n in *M. amblycephala* with frequencies ranged from 19.604 to 23.445 SSRS/Mb accounting for 26.606, 23.947 and 24.371% of total tetranucleotide repeat motifs, respectively, in *A. graham*, *C. amblycephala* and *C. alburnus*. Interestingly, the second most abundant tetranucleotide repeat motif in *A. graham* was observed to be (ATCC)n with a frequency of 14.927 SSRs/Mb. The third most populated tetranucleotide microsatellite repeat motif in *M. amblycephala* and *C. alburnus* was observed to be (ATCC)n, whereas (AAAT)n was the third most frequent repeat motif in the genome of *A. graham* with frequencies ranging from 9.372–14.303 SSRs/Mb followed by (AAAC)n, (AAAG)n, (AATG)n and (AATC). The least represented tetranucleotide SSR repeat motif in all the Cultrinae genomes was observed to be (CCGG)n. The most frequent pentanucleotide SSR repeat motif varied between the Cultrinae genomes and found to be (AAGTG)n, (AATAT)n and (AAAAT)n in *A. graham*, *M. amblycephala* and *C. alburnus*, respectively accounting for 15.960%, 25.995% and 25.884% of the total pentanucleotide repeat types. The second and third most frequent nucleotide repeat motif was observed to be (AAAAT)n, (AAAAT)n and (AATAT)n and (AATAT)n, (AAAAC)n and (AAAAC)n in *A. grahami*, *M. amblycephala* and *C. alburnus* genomes followed by (AAGTC)n and (AATAG)n with frequencies less than 1 SSRs/Mb. The most frequent hexanucleotide SSR repeat motifs were observed to be (AAATGC)n, (AACCCT)n and (AAAAAT)n in *A. graham*, *M. amblycephla* and *C. alburnus* genome, respectively, with frequencies less than 1 SSRs/MB accounting for 5.548–26.730% of total hexanucleotide microsatellite types.

38.4 Discussion

Here, we employed PERF programme to identify microsatellites with motifs of 1–6 bp with consistent search parameters in three Cultrinae species (*A. graham*, *M. amblycephala* and *C. alburnus*). To get better insight into the structure and SSR diversity in the three freshwater fish species *A. graham*, *M. amblycephala* and *C. alburnus* we analysed the number of SSRs, relative frequency, relative density and GC content. From the results, it is evident that the three freshwater fish genomes have almost similar SSR distribution pattern. We observed that SSR relative density is positively correlated with genome size suggesting the possible role of SSR density in driving significantly the expansion of the genome size of the Cultrinae species in the evolution (Manee et al. 2019). The percentages of perfect SSRs in the three Cultrinae species were observed to be 0.85%, 1.18% and 1.13% of the *A. grahami*, *M. amblycephala* and *C. alburnus*, respectively. The total SSR percentages in the present study were found to be higher than Camelids (0.51%–0.53%) (Manee et al. 2019), Bovids (0.44–0.48%) (Qi et al. 2015; Ma 2015), macaques (0.83–0.88%) (Liu et al. 2017) and lower than humans (3%) (Subramanian et al. 2002). This might have arised due to different methods used for SSR identification and the relative completeness of the genome assemblies or variation in SSR content among these species (Sharma et al. 2007).

The frequencies of the six types of SSR motifs identified in the three Cultrinae genomes were not same suggesting differences in abundance of microsatellites in their genome. Here, we observed that the mononucleotide SSRs were the most frequent repeat types in *M. amblycephala* and *C alburnus* genomes. This result is in consistent with giant panda (Huang et al. 2015), camelids (Manee et al. 2019), bovids (Qi et al. 2015; Ma 2015) and macaques (Liu et al. 2017). Further, it is in congruent with the results reported by Sharma et al. (2007) that mononucleotides are the most frequent repeat motif in eukaryotic genomes. In contrast dinucleotides are the most frequent SSR repeat motifs in *A. grahami* genome in contrast to the results reported by Adams et al. (2016), however in line with rodents (Toth 2000), Drosophila (Katti et al. 2001), dicotyledons (Kumpatla and Mukhopadhyay 2005), *Taenia solium* (Pajuelo et al. 2015) and penguin (Vianna et al. 2017). However, most frequent microsatellite repeat motifs are observed to be trinucleotides in prokaryotes (Kim et al. 2008; Sharma et al. 2007) and yeast (Katti et al. 2001). In *M. amblycephala* and *C. alburnus* genomes the second most frequent SSR repeat motifs are observed to be the dinucleotides accounting for 30.786 5 and 30.073%, respectively of total microsatellites. However, mononucleotide repeats are the second most SSR repeat motif in *A. grahami* contributing 30.003% of total SSR repeat motifs followed by tetra-, tri-, penta- and hexanucleotides. We observed that hexanucleotides are the least frequent SSR repeat motifs in all the Cultrinae genomes occurring at a frequency less than 4SSR/Mb and constituting 0.289–0.379% of total microsatellite repeats. In contrast to trinucleotides as the third most frequent repeat motifs (Adams et al. 2016; Manee et al. 2019) here we observed that tetranucleotide repeat motifs are the third most frequent SSR repeat motifs in the Cultrinae genomes.

We compared different microsatellite repeat types among the three fresh water fish genomes and results suggested that variation across genomes existed for total number, frequency and density of different type of repeat types. As reported earlier we observed that the abundance of SSR motifs decreases with increasing motif length (Karaoglu et al. 2004; Qi et al. 2015; Adams et al. 2016; Liu et al. 2017). Here we observed that the most abundant repeat motif for each SSR type varies across the three Cultrinae genomes. In the present study it was observed that among mononucleotide repeats (A/T)n repeat motifs were the most prevalent repeat motifs and identical across the genomes accounting for 97.720–98.392% of mononucleotide SSRs. In contrast, the (C/G)n were observed to be the least frequent mononucleotide repeat motif. This observation is in congruent with earlier reports (Wang et al. 2014;

Castagnone-Sereno et al. 2010; Adam et al. 2016). However, (C/G)n repeat motifs were observed to be predominant in *Meloidogyne incognita*, *Pristionchus pacificus* (Castagnone-Sereno et al. 2010) and *Schizophyllum commune* (Wang et al. 2014). The most frequent dinucleotide repeat motifs varied among the three Cultrinae fish genomes. The dinucleotides (AC)n, (AT)n and (AC)n were observed to be the most abundant microsatellite repeat motifs in *A. graham*, *M. amblycephala* and *C alburnus*, respectively. The (AC)n dinucleotide repeat motifs were observed to be most frequent in the genomes of carlavirus (Alam et al. 2014), humans (Subramanian et al. 2002), bovids (Qi et al. 2015) and macaques (Liu et al. 2017). In contrast, (AT)n repeat motifs are observed to be the most frequent repeat motifs in *A. mellifera*, *G. gallus*, *A. thalina* and *S. cervisiae* (Mayer et al. 2010). The third most frequent dinucleotide SSR repeat motif was observed to be (AG)n followed by (CG)n motifs, as observed in other study (Ma 2015). The least abundant dinucleotide repeat motif was observed to be (CG)n in all the three genomes, this might be due to the fact that the tendency of AT richness of the genomes and difficulty in strand separation of CG tract than AT and other tract leading to slipped strand mispairing. The SSR repeat motif (AAT)n was observed to be the most abundant repeat motif in the three Cultrinae genomes in agreement with the findings in camelids (Manee et al. 2019), macaques (Liu et al. 2017), *P. pacificus*, *M. hapla*, *B. malayi* (Castagnone-Sereno et al. 2010) and *Ziziphus jujuba* (Xiao et al. 2015). In contrast, in *P. ostreatus*, *Coprinus cinereus* and *S. commune* (AAT)n repeat motif was the least frequent repeat motif as reported by Wang et al. (2014). In contrast to the predominance of AT-rich SSR motifs among tetra, penta and hexanucleotide repeat types as observed in earlier reports (Huang et al. 2015; Adams et al. 2016) a wide variety of repeat motifs was observed to be most abundant SSR repeat motif among tetra, penta and hexanucleotide repeat type having Cs and Gs in the repeat motifs. This observation is in agreement with the observation made by Liu et al. (2019) in cobra genome.

GC content in the genomes of higher vertebrates influences genomic features such as gene density, methylation patterns and repeat element distribution (Duret et al. 1994; Jabbari and Bernardi 1998; Duret and Hurst 2001). It has been observed that high percentages of GC content affect gene expression and stability of the DNA (Vinogradov 2003; Ren et al. 2007). Several genetic diseases observed to be associated with microsatellites having high GC content such as fragile X syndrome and FRA12A mental retardation (Sharma et al. 2007; Winnepenninckx et al. 2007). In the present study we observed that GC content is not consistent within a SSR type among the three genomes surveyed. The most prevalent SSRs in the three genomes were observed to be AT-rich as reported in other eukaryotic genomes (Sharma et al. 2007). This could be one of the reason why (A/T)n motifs were more predominant than (G/C)n motifs. Our observations are in agreement with the reports of Liu et al. (2017) and Manee et al. (2019) that dinucleotide SSRs have highest GC content except *M. amblycephala*, where highest GC content was observed to be present in hexanucleotide microsatellites. In contrast in bovids trinucleotide SSRs are reported to have highest GC content (Qi et al. 2015). Further, evidences have been suggested that high GC content in microsatellite repeat motif affects genomic structure (Li et al. 2004). Here we observed that as the number of repeats increased the number of SSRs decreased drastically. This could be due to the fact that high mutation rates occur in longer repeats compared to shorter repeats within a given SSR type (Leopoldino and Pena 2002).

38.5 Conclusions

We characterized genome wide microsatellites of Cultrinae genomes. The draft genomes were found to be of good quality and AT-rich. Mononucleotides were found to be the most frequent SSR types followed by tetra, tri, penta and hexanucleotide microsatellites. Total number of SSRs, relative frequency, relative density and GC content of different SSR types were varied among the three fish genomes. Further, it was observed that the total SSR number, relative frequency and relative density decreases as the repeat length increase in these genomes. Except *M. amblycephala* highest GC content was observed in the dinucleotide SSRs repeat motifs. The most frequent repeat motif within each SSR type varied among the Cultrinae genomes. Overall, we observed that the distribution of microsatellites among the three genomes were not similar. The data generated in the present study provide a detailed view of the genome wide distribution of the microsatellites in the genomes of the Cultrinae sub-family. Details understanding of the microsatellite characteristics will lead to development of Cultrinae specific DNA markers with wide applicability.

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References

Adams RH, Blackmon H, Reyes-Velasco J et al (2016) Microsatellite landscape evolutionary dynamics across 450 million years of vertebrate genome evolution. Genome 59(5):295–310

Alam CM, Singh AK, Sharfuddin C et al (2014) Genome-wide scan for analysis of simple and imperfect microsatellites in diverse carlaviruses. Infect Genet Evol 21:287–294

Avvaru AK, Sowpati DT, Mishra RK (2017) PERF: an exhaustive algorithm for ultra-fast and efficient identification of microsatellites from large DNA sequences. Bioinformatics 27:573

Bachtrog D, Weiss S, Zangerl B et al (1999) Distribution of dinucleotide microsatellites in the *Drosophila melanogaster* genome. Mol Biol Evol 16(5):602–610

Borstnik B (2002) Tandem repeats in protein coding regions of primategenes. Genome Res 12:909–915

Castagnone-Sereno P, Danchin EG, Deleury E et al (2010) Genome-wide survey and analysis ofmicrosatellites in nematodes, with a focus on the plant-parasitic species *Meloidogyne incognita.* BMC Genomics 11:598

Chistiakov DA, Hellemans B, Haley CS et al (2005) A microsatellite linkage map of the European sea bass *Dicentrarchus labrax* L. Genetics 170(4):1821–1826

Duret L, Hurst LD (2001) The elevated GC content at exonic third sitesis not evidence against neutralist models of isochore evolution. Mol Biol Evol 18:757–762

Duret L, Mouchiroud D, Gouy M (1994) HOVERGEN: a database ofhomologous vertebrate genes. Nucleic Acids Res 22:2360–2365

Ellegren H (2004) Microsatellites: simple sequences with complex evolution. Nat Rev Genet 5(6):435–445

Eschmeyer WN, Fricke R, Laan R van der (eds) (2017) Catalog of fishes, electronic version (31 August 2017). Internet publication, California Academy of Sciences, San Francisco. https://researcharchive.calacademy.org/research/ichthyology/catalog/SpeciesByFamily.asp

Hancock J (1995) The contribution of slippage-like processes togenome evolution. J Mol Evol 41.

Huang J, Li YZ, Du LM et al (2015). Genome-wide survey and analysis of microsatellites in giant panda (*Ailuropoda melanoleuca*), with a focus on the applications of a novel microsatellite marker system.BMC genomics 16(1): 1–12

Jabbari K, Bernardi G (1998) Cpg doublets, CpG islands and Alurepeats in long human DNA sequences from different isochorefamilies. Gene 224:123–128

Jurka J, Pethiyagoda C (1995) Simple repetitive DNA sequencesfrom primates: compilation and analysis. J Mol Evol 40:120–126

Karaoglu H, Lee CMY, Meyer W (2004) Survey of simple sequencerepeats in completed fungal genomes. Mol Biol Evol 22:639–649

Katti MV, Ranjekar PK, Gupta VS (2001) Differential distribution of simple sequence repeats in eukaryotic genome sequences. Mol Biol Evol 18(7):1161–1167

Kim T-S, Booth JG, Gauch HG et al (2008) Simple sequence repeats in neurospora crassa: distribution, polymorphism and evolutionary inference. BMC Genomics 9:31

Kottelat M, Britz R, Hui TH et al (2006) *Paedocypris*, a new genus of Southeast Asian cyprinid fish with a remarkable sexual dimorphism, comprises the world's smallest vertebrate. Proc R Soc b Biol Sci 273(1589):895–899

Kruglyak S, Durrett RT, Schug MD et al (1998) Equilibrium distributions of microsatellite repeat length resulting from a balance between slippage events and point mutations. Proc Natl Acad Sci 95(18):10774–10778

Kumpatla SP, Mukhopadhyay S (2005) Mining and survey of simplesequence repeats in expressed sequence tags of dicotyledonousspecies. Genome 48:985–998

Lai Y, Sun F (2003) The relationship between microsatellite slippage mutation rate and the number of repeat units. Mol Biol Evol 20(12):2123–2131

Lawson MJ, Zhang L (2006) Distinct patterns of SSR distribution in the *Arabidopsis thaliana* and rice genomes. Genome Biol 7(2):1–11

Leopoldino AM, Pena SD (2002) The mutational spectrum of human autosomal tetranucleotide microsatellites. Hum Mutat 21:71–79

Levinson G, Gutman GA (1987) Slipped-strand mispairing: a major mechanism for DNA sequence evolution. Mol Biol Evol 4(3):203–221

Li Y-C, Korol AB, Fahima T et al (2004) Microsatellites within genes: structure, function, and evolution. Mol Biol Evol 21:991–1007

Li C-Y, Liu L, Yang J et al (2009) Genome-wide analysis of microsatellite sequence in seven filamentous fungi. Interdisc Sci Comput Life Sci 1:141–150

Liu S, Hou W, Sun T et al (2017) Genome wide mining and comparative analysis of microsatellites in threemacaque species. Mol Gen Genomics 292:537–550

Liu W, Xu Y, Li Z et al (2019) Genome-wide mining of microsatellites in king cobra (*Ophiophagus hannah*) and cross-species development of tetranucleotide SSR markers in Chinese cobra (Najaatra). Mol Biol Rep 46(6):6087–6098

Ma Z (2015) Genome-wide characterization of perfect microsatellites in yak (*Bos grunniens*). Genetica 143:515–520

Manee MM, Algarni AT, Alharbi SN et al (2019) Genome-wide characterization and analysis of microsatellite sequences in camelid species. Mammal Res 1–15

Mayer C, Leese F, Tollrian R (2010) Genome-wide analysis of tandem repeats in *Daphnia* pulex-a comparative approach. BMC Genomics 11(1):1–28

Morgante M, Hanafey M, Powell W (2002) Microsatellites are preferentially associated with nonrepetitive DNA in plant genomes. Nat Genet 30(2):194–200

Mrázek J, Guo X, Shah A (2007) Simple sequence repeats in prokaryotic genomes. Proc Natl Acad Sci 104(20):8472–8477

Nelson JS (1994) Fishes of the world, 3rd edn. Wiley and Sons, New York, p 600

Nelson JS (2006) Fishes of the world. Wiley, Hoboken, New Jersey

Pajuelo MJ, Eguiluz M, Dahlstrom EW et al (2015) Identification and characterization of microsatellite markers derived fromthe whole genome analysis of *Taenia solium*. PLoS Neglected Trop Dis 9(12):e0004316

Pérez Jiménez D, Rodríguez Salvá A, Herrera Travieso DM et al (2013) Caracterización de la sobrecarga y de los estilos de afrontamiento en el cuidador informal de pacientesdependientes. Revistacubana de higiene y epidemiologia 51(2):174–183

Phumichai C, Phumichai T, Wongkaew A (2015) Novel chloroplast microsatellite (cpSSR) markers for genetic diversity assessment of cultivated and wild Hevea rubber. Plant Mol Biol Report 33(5):1486–1498

Pramod S, Perkins AD, Welch ME (2014) Patterns of microsatellite evolution inferred from the *Helianthus annuus* (Asteraceae) transcriptome. J Genet 93(2):431–442

Qi W-H, Jiang X-M, Yan C-C et al (2018) Distribution patterns and variation analysis of simple sequence repeats in different genomic regions of bovid genomes. Sci Rep 8:14407

Qi W-H, Jiang X-M, Du L-M et al (2015) Genome-wide survey and analysis of microsatellitesequences in bovid species. PLOS ONE 10:e0133667

Ren L, Gao G, Zhao D et al (2007) Developmental stage related patterns of codon usage and genomic GC content: searching for evolutionary finger prints with models of stem celldifferentiation. Genome Biol 8:R35

Romero A, Paulson KM (2001) It's a wonderful hypogean life: a guide to the troglomorphic fishes of the world. The biology of hypogean fishes, pp 13–41

Schlötterer C (2000) Evolutionary dynamics of microsatellite DNA. Chromosoma 109(6):365–371

Schlötterer C, Tautz D (1992) Slippage synthesis of simple sequence DNA. Nucleic Acids Res 20(2):211–215

Sharma PC, Grover A, Kahl G (2007) Mining microsatellites in eukaryotic genomes. Trends Biotechnol 25:490–498

Subramanian S, Mishra RK, Singh L (2002) Genome-wide analysis ofmicrosatellite repeats in humans: their abundance and density inspecific genomic regions. Genome Biol 4:R13–R13

Subramanian S, Madgula VM, George R et al (2003) Triplet repeats in human genome:distribution and their association with genes and other genomic regions. Bioinformatics 19:549–552

Tautz D (1989) Hypervariability of simple sequences as a general source for polymorphic DNA markers. Nucleic Acids Res 17(16):6463–6471

Tóth G, Gáspári Z, Jurka J (2000) Microsatellites in different eukaryotic genomes: survey and analysis. Genome Res 10(7):967–981

Toth G (2000) Microsatellites in different eukaryotic genomes: survey and analysis. Genome Res 10:967–981

Vianna JA, Noll D, Mura-Jornet I et al (2017) Comparative genome-wide polymorphic microsatellite markers in *Antarctic penguins* through next generation sequencing. Genet Mol Biol 40(3):676–687

Vinogradov AE (2003) DNA helix: the importance of being GC-rich. Nucleic Acids Res 31:1838–1844

Wang Y, Chen M, Wang H et al (2014) Microsatellites in the genome of the edible mushroom, Volvariellavolvacea. Bio Med Res Int 2014:1–10

Weber JL, Wong C (1993) Mutation of human short tandem repeats. Hum Mol Genet 2(8):1123–1128

Winnepenninckx B, Debacker K, Ramsay J et al (2007) CGG-repeat expansion in the DIP2b gene is associated with the fragile site FRA12a on chromosome 12q13. 1. Am J Hum Genet 80:221–231

Xiao J, Zhao J, Liu M et al (2015) Genome wide characterization of simple sequence repeat (SSR) loci in Chinese jujube and jujube SSR primer transferability. PLOS ONE 10:e0127812

Zhang L, Zuo K, Zhang F et al (2006) Conservation of non coding microsatellites in plants: implication for gene regulation. BMC Genomics 7(1):1–14

Chapter 39
Estradiol Dependent Stimulation of Brain Dopaminergic Systems in the Female Gold Spot Mullet, *Liza parsia*

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Abstract Goldspot mullet, *Liza parsia* attains maturity in captive condition but fails to achieve final oocytes maturation. Therefore, it is hypothesized that the reproductive failure in captivity might be due to inhibitory role of dopamine (DA) on the release of gonadotropins (LH, Luteinizing hormone). The higher level of 17-β-estradiol (E2) seems to increase dopaminergic inhibitory tone, thereby inhibiting ovulatory surge in LH release. To validate the hypothesis, we evaluated dopamine level in different parts of the brain (forebrain, midbrain and hind brain) and the different sizes of *L. parsia* through the expression of dopamine receptor protein (D2R-45 *kDa*). From this study, it was found that D2R was expressed in all three parts of the brain (forebrain, midbrain and hind brain) and in different size groups fish, i.e., fry, fingerlings, sub-adult and adult. Further, to understand the E2 dependent regulation of dopamine in brain of *L. parsia*, adult mature females were equally distributed to four different treatments and E2 was injected to all fish @ 2 mg kg^{-1}. After injection, fish were sampled at 12 h (0.5 day), 24 h (1 day), 48 h (2 days) and 7 days. Control fish (0 h) was injected with 0.9% physiological saline. Brain tissue proteins were separated in SDS-PAGE and then electro-blotted on to a nitrocellulose membrane. Expression of D2R (45 kDa) and E2R (67 kDa) was visualized by primary antibody (monoclonal

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anti DRD2, E2R-1:1000) and horseradish peroxidase (HRP) conjugated secondary antibody (1:2000). Immunohistochemistry (IHC) of D2R and Vtg (vitellogenin) was performed in brain and gonad tissue, respectively. Primary antibody of D2R and Vtg and secondary antibody (HRP conjugated) were used. Sex hormones such as follicle stimulating hormone (FSH), LH, and E2 were detected using Enzyme linked Immunosorbent Assay (ELISA) kits. Results showed time dependent variations in FSH, LH and E2 levels. FSH and E2 gradually increased at zero/control to 2 days of sampling. IHC showed an intense expression of D2R (brain) and Vtg (ovary) at 48 h of sampling than in the other groups. Western blot analysis of E2R in ovary resulted maximum signal value (band intensity) at 0.5, 1, 2 days after administration of E2. Similar trend was observed for expression of D2R in the brain. Overall, results confirmed that the expression of D2R in brain is directly regulated by E2 in *L. parsia*.

Keywords Broodstock · Dopamine · Estradiol · Gold spot mullet · Reproductive function

39.1 Introduction

In fish, as in all vertebrates, the brain-pituitary-gonad (BPG) or hypothalamic-pituitary-gonad (HPG) axis regulates the reproductive function. Preoptic-hypothalamic neurons of the brain produce the gonadotropin releasing hormone (GnRH) that stimulates the pituitary gland to synthesize and release the gonadotropins (GtH) (Follicle stimulating hormone, FSH/GtH-I, and Luteinizing hormone, LH/GtH-II), which, in turn, stimulate gonadal activities namely, steroidogenesis and gametogenesis. In addition to the GnRH stimulatory system, neurons secreting dopamine (DA) is an inhibitory system over the reproductive axis (Peter et al. 1987). DA may inhibit both basal and GnRH-stimulated LH secretion and thereby regulate the final stages of gametogenesis (Chang et al. 2009; Levavi-Sivan et al. 2010). Role of DA in inhibitory control of reproduction in fish was found in goldfish, *Carassius auratus* (Anglade et al. 1993), African catfish, *Clarias gariepinus* (De Leeuw et al. 1986), rainbow trout, *Oncorhynchus mykiss* (Linard et al. 1995; Saligaut et al. 1999; Vacheret al. 2000), tilapia, *Oreochromis mossambicus* (Yaron et al. 2003), European eel, *Anguilla anguilla* (Vidal et al. 2004; Weltzien et al. 2006) and grey mullet, *Mugil cephalus* (Aizen et al 2005). In Atlantic croaker, *Micropogonias undulates* (Copeland and Thomas 1989) and seabream, *Sparus aurata* (Zohar et al. 1995), no dopaminergic inhibition has been noticed. Inhibitory effects of DA on gonadotropin production are exerted directly at the pituitary level (Chang et al. 1984) and mediated by D2-type dopaminergic receptors (D2R) (Dufour et al. 2010). The D2R like receptors found in both the pre and the postsynaptic terminals and act as auto receptors (Callier et al. 2003), and could, therefore, be expressed in both cells producing dopamine and cells receptive to dopamine.

Goldspot mullet, *Liza parsia* is a euryhaline fish that thrives well in freshwater, brackishwater and seawater (Riede 2004). It is widely distributed in the coastal waters of tropical and sub-tropical regions (Talwar and Jhingran 2001) and is one of the commercially important fish in Southeast Asia, Central and South America (Alam et al. 2008). It is a migratory species that spawns in seawater during December–February months (Talwar and Jhingran 2001) or November–March (Begum et al. 2010). Recently, Kumar et al. (2020) reported that although *L. parsia* attains sexual maturity in brackishwater pond, it fails to spawn. The probable reason for this could be the inhibitory effect of dopamine on release of LH, which is responsible for the final oocyte maturation and spawning. Dopamine inhibition on release of LH is common in members of Muglidae family, such as *M. cephalus* (Aizen et al. 2005). The 17 β-estradiol (E2) dependent regulation of dopamine is well documented in tilapia (Levavi-Sivan et al. 2006) and eel (Weiltzien et al. 2006). With this background, the experiment was carried out to understand the brain dopamine activity and its E2 dependent regulation in *Liza parsia.*

39.2 Materials and Methods

39.2.1 Captive Broodstock Development

Broodstock of *L. parsia* was developed following the procedure of Kumar et al. (2020). In brief, adult *L. parsia* with bodyweight of 30–70 g were collected from nearby brackishwater area of Sundarban, West Bengal, and transported in an open container with oxygen bubbling to Kakdwip Research Centre (KRC) of ICAR-Central Institute of Brackishwater Aquaculture (CIBA), West Bengal, India. Fish were treated with 5 ppm potassium permanganate and stocked in a tide-fed brackishwater pond (1200 m^2) of KRC and reared for 1.5 years. During rearing, it was fed with a pellet diet (32% crude protein and 8% lipid) at the rate of 3% of fish biomass twice daily. During the spawning season (December–February), physico-chemical parameters of broodstock pond water were measured with a probe (HACH-HQ40d)-based analyser. Values of measured parameters, such as temperature, pH, dissolved oxygen and salinity were 19 ± 2.5 °C, 8.2 ± 0.5, 4.9 ± 1.5 ppm and 7 ± 1.5 ppt, respectively.

39.2.2 Experimental Setup and Sampling

During spawning season (December–February), whole brain tissues were collected from different size groups, such as fry (average length: 4.30 cm; average weight: 1.90 g), fingerlings (average length: 7.10 cm; average weight: 4.46 g), sub-adult (average length: 9.10 cm; average weight: 9.00 g) and adult (average length: 14.10 cm; average weight: 25.10 g) of *L. parsia.* We used six fish ($n = 6$) from each size group and brain tissues were pooled. Further, from six adult fish forebrain, midbrain and hindbrain tissues were also collected separately and pooled for D2R expression study. Brain tissues were homogenized in 5% lysis buffer (20 Mm tris HCl, containing 10% of 0.1 mM phenyl methane sulfonyl fluoride, PMSF, pH 8) and centrifuged (12,000 rpm, 20 min at 4 °C) to collect the supernatant. The supernatant was stored at − 40 °C for D2R expression. Total protein content in serum, brain and ovarian samples was estimated using a modified Lowry protein assay kit (Thermo scientific, 23,240).

39.2.3 Preparation and Administration of E2

The E2 injection was prepared by dissolving 5 mg E2 powder in 1 mL of acetone, and 5 mL of coconut oil was added as the carrier. This solution was stirred overnight at room temperature to evaporate acetone (Jena et al. 2012). In this experiment, 24 adult females of *L. parisa* were equally distributed to four different treatments and E2 was injected to all fish at the dose of 0.002 mg g^{-1} (Weltzien et al. 2006). Control fish (0 h) was injected with 0.9% physiological saline. After injection, fish were sampled for brain tissue, ovarian tissue and blood collection at 12 h (0.5 day), 24 h (1 day), 48 h (2 days) and 7 days. Collected tissue samples of brain and ovary were homogenized in 5% lysis buffer as described above.

39.2.4 Gonad Histology

NBF fixed gonad tissue was dehydrated gradually in increasing ethanol concentrations (70–100%), followed by dipping in acetone and cleaning in xylene. The tissues were embedded in paraffin wax and cut into 5 μL thickness with the aid of a microtome (Thermo, HM325). The tissue sections were stained with haematoxylin and eosin, as described by Roberts (1989). After that tissue was cleaned in xylene, mounted in DPX, and observed under the trinocular microscope.

39.2.5 Hormone Assay

Different sex hormones, such as FSH, LH, testosterone (T), and E2 were analysed using Enzyme Linked Immunosorbent Assay (ELISA). All the hormone assay of different samples were carried out in triplicate ($n = 3$). Assay performed using commercially available Enzyme Immunosorbent Assay (EIA) kits from Cayman Chemical Company, USA. FSH, LH, T and E2 were assayed with EIA kit No. 500,710, 500,720, 582,701, 501,250, respectively. The absorbance of samples and standard was read at 450 nm for FSH and LH, and at 415 nm for T and E2 using a microplate reader (Biorad). Data were quantified against standard curve that was linearized through 4-parameter logistic fit for %B/B_0 (bound sample/maximum bound).

39.2.6 SDS-PAGE and Western Blotting

Expression of D2R in whole brain tissue of different maturity stages, different size groups (fry, fingerling, sub-adult and adult) and different brain parts of *L. parsia* was carried out through SDS-PAGE and western blotting technique. Pooled brain tissue samples (186 μg protein) were separated by SDS-PAGE with 10% separating and 5% stacking polyacrylamide gels (Laemmli 1970). Protein standard with a molecular weight of 8–220 kDa (C1992, Sigma) was used at the first well to visualize the separation of different molecular weight proteins. Proteins were separated at 20 mA for 1.45 h in SDS-PAGE and then electro-blotted on to a NC (nitrocellulose) membrane (9 cm × 10 cm, GX-5310AR-04, Puregene) through semi-dry blotter (Trans-blot turbo, Biorad) at 20 V and 0.8 A for 20 min. Two gels were run simultaneously, one gel was stained before blotting, and the other was stained after blotting with coomassie blue. First staining visualizes the separation of denatured proteins, while the second stain was to confirm the transfer of protein from gel to NC membrane. The membrane was blocked with 5% bovine serum albumin (BSA) and washed with Tris-Buffered Saline Tween20 (TBST). Thereafter, the membrane was incubated with primary monoclonal antibody (mouse anti human DRD2, SAB 1,403,744, Sigma) in 1:1000 dilution for overnight at 4 °C. Horseradish peroxidase (HRP) conjugated goat anti-mouse IgG (1:2000 dilution, HRP003-15,002, Columbia, Bioscience) was used to detect primary antibody. Bound antibody was visualized by mouse IgG DAB chromogenic kit (GX-4202E, Puregene). Following the same methodology, expression analysis of Vtg protein in serum (6.40 μg protein ml^{-1}) was carried out. Dilution of primary polyclonal antibody (rabbit anti-seabream vitellogenin, Bioscience Laboratories, V01410201) and HRP conjugated secondary antibody (goat anti-rabbit IgG, HRP 114) were made at the rate of 1:5000 and 1:2000, respectively. Similarly expression of estrogen receptor, ER (rabbit anti-ESR1, SAB4300346, sigma) was made in ovarian tissue. Beta-actin (β-actin) monoclonal antibody (1:1000 dilutions, PG-13002, Puregene) expression in all the samples was used as control. Image Studio Lite Western Blot Analysis Software version 5.2 was used to perform pixel quantification of the images. All pictures were uploaded to the software and signal value was calculated for quantification of each band. Signal is the sum of pixel intensity values for a band minus the product of the background and the area.

39.2.7 Immunohistochemistry of D2R and Vtg

Immunohistochemistry of D2R and Vtg were performed following the methods of Pivonello et al (2006) and Jena et al (2012), respectively. In brief, NBF fixed ovary and brain tissues were used to localize the Vtg and D2R, respectively through immunohistochemistry. Paraffin embedded tissue sections (5 μm) were deparaffinized, hydrated, microwave heating in tris EDTA buffer (pH-9) at 100 °C for 15 min (heat induced epitope retrieval, HIEP), cooled in running water. The slides were kept in humidified chamber and treated for 20 min with 3% hydrogen peroxide (H_2O_2) in methanol to inhibit endogenous peroxidase activity. The slides were blocked (2 h) with 5% skimmed milk prepared in TBST at room temperature and washed thrice with TBST. The ovarian tissue slides were incubated overnight at 4 °C with the primary antibody at 1:100 dilution. Brain tissue slides were incubated overnight at 4 °C with the primary antibody at a dilution of 1:100. Both the tissue slides were washed thrice with TBST and incubated with secondary antibody HRP conjugated secondary antibody (goat anti-rabbit IgG) for 2 h at room temperature. The slides were washed with TBS and stained with 0.05% DAB (3,3-diaminobenzidine) containing 0.01% H_2O_2 for 5 min. The slides were washed with distilled water, counter stained with Mayer's haematoxylin, mounted with DPX and observed under light microscope. Primary and secondary antibodies were diluted in blocking solution (5% skimmed milk). During processing the slides were incubated in a humidified chamber. In negative control the primary antibody was omitted.

39.2.8 Cross Reactivity of D2R and Vtg

Cross reactivity of human DRD2 (D2R) antibody was tested through SDS-PAGE and western blotting. The human D2R monoclonal antibody showed cross reactivity in brain tissue, whereas was not expressed in serum. The Vtg polyclonal antibody was raised in rabbit against seabream Vtg, which was having cross reactivity with other fish Vtg. Cross reactivity of ER was not tested as it is common in all vertebrates.

39.2.9 Statistical Analysis

The comparison of all the studied variables between different maturity stages was made through one-way analysis of variance (ANOVA). All the statistical analysis was performed with SPSS 20.0 for windows. Comparisons were made at 5% probability level.

39.3 Results

Western blot analysis of D2R protein in brain tissue displayed a positive reaction to the monoclonal antibody against DRD2 (Fig. 39.1). This analysis revealed antibody specificity between 41 and 47 kDa (~ 45 kDa) molecular weight protein. Similarly,

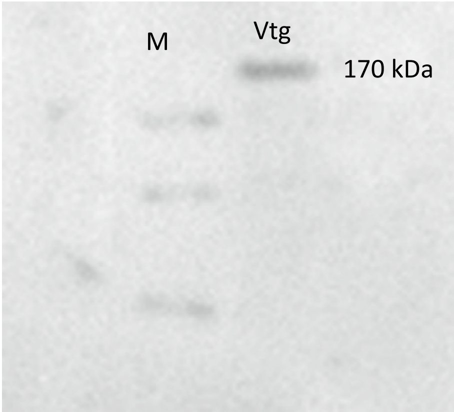


Fig. 39.1 Cross reactivity of polyclonal antibody (rabbit anti-sea bream vitellogenin) with *L. parsia* serum vitellogenin protein. *M*, marker protein; Vtg, vitellogenin protein

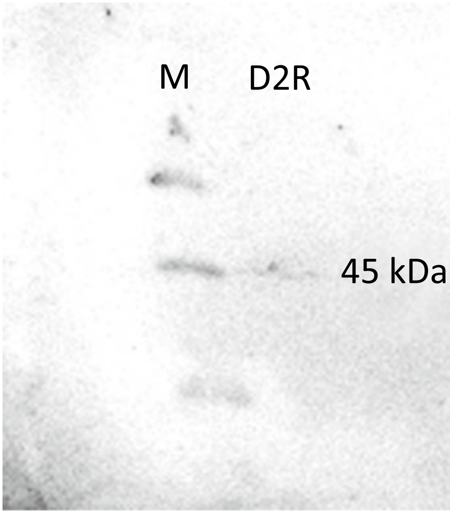


Fig. 39.2 Cross reactivity of primary monoclonal antibody (mouse anti human DRD2) with *L. parsia* brain dopamine receptor, D2R protein. *M*, marker protein; D2R, dopamine receptor protein

positive cross reactivity was observed for seabream polyclonal Vtg antibody in *L. parsia* serum at 170 kDa (Fig. 39.2). Expression of D2R in brain tissue indicated that the D2R expressed in all three parts (forebrain, midbrain and hind brain) of the adult *L. parisia* brain (Fig. 39.3a, b) and minimum signal value was found in midbrain. The expression of D2R in whole brain tissue of different size groups (fry, fingerling, sub-adult and adult) signifies that it expresses even in smaller fry (Fig. 39.3c, d). We also observed the expression of D2R in different size groups (fry, fingerling, sub-adult and adult) of *L. parsia*. To validate the western blotting procedure, expression of β-actin protein as control was performed for both Vtg and D2R.

Result of another experiment showed that the E2 administration directly upregulated the expression of E2R and D2R (Figs. 39.4a, b and 39.5a, b). Compared to control, significantly ($p < 0.05$) highest level of E2 was found in 12 h post injected

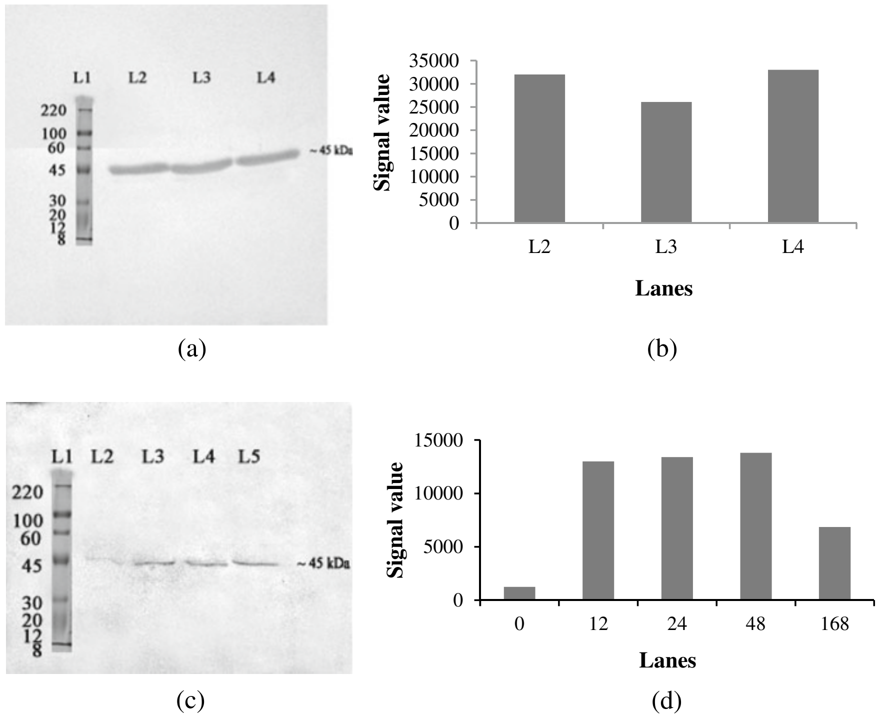


Fig. 39.3 Western blot analysis of dopamine receptor protein (D2R ~ 45 kDa) in brain tissue of *L. parsia*. **a** Lane (L) L1-molecular weight marker and other lanes L2, L3 and L4 represent different brain parts such as forebrain, midbrain and hindbrain, respectively; **b** corresponding signal value of D2R expression in the different parts of brain (forebrain, midbrain and hindbrain) of *L. parsia*; **c** L1-molecular weight marker and other lanesL2-fry (mean size:1.90 g, 4.30 cm), L3-figerlings (mean size: 4.46 g, 7.10 cm) and L4-sub-adult (mean size: 9.00 g, 9.10 cm), L5 adult (mean size: 25.10 g, 14.10 cm) of *L. parsia,* respectively. This figure showed the expression of D2R in whole brain tissue of different size groups of *L. parsia*; **d** corresponding signal value of D2R expression in whole brain of different size groups of *L. parsia*

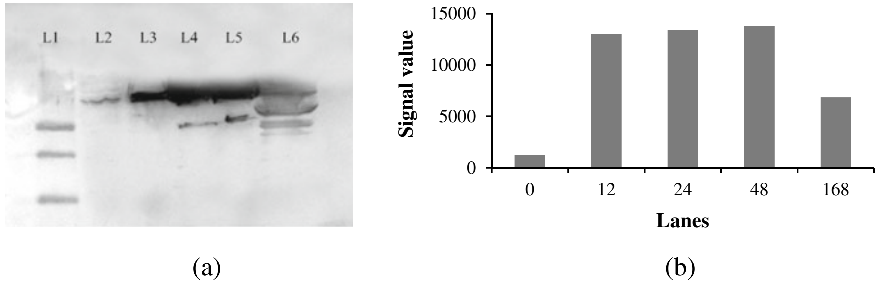
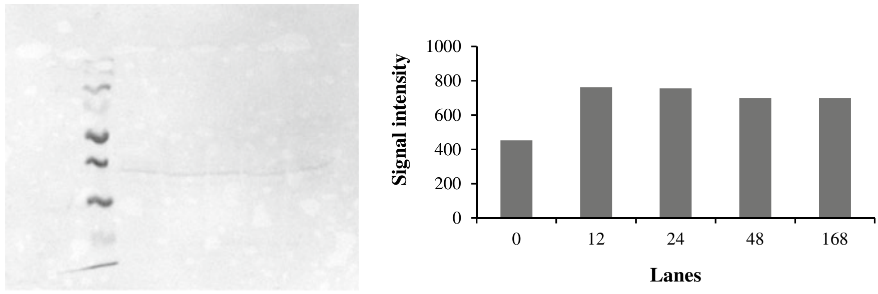


Fig. 39.4 Western blot analysis of estradiol receptor protein (ER ~ 67 kDa) in ovarian tissue of *L. parsia*. **a** Lane (L) is represented as: L1-molecular weight marker, L2-0 h (control), L3-12 h, L4-24 h, L5-48 h and L6-168 h post E2 administration sampling. **b** Corresponding signal value of ER expression



(a) (b)

Fig. 39.5 Western blot analysis of dopamine receptor protein (D2R ~ 45 kDa) in brain tissue of *L. parsia.* **a** Lane (L) is represented as: L1-molecular weight marker, L2-0 h (control), L3-12 h, L4-24 h, L5-48 h and L6-168 h post E2 administration. **b** Corresponding signal value of D2R expression

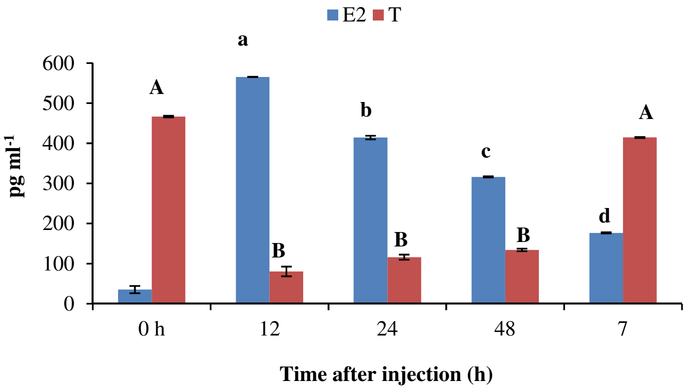


Fig. 39.6 Effect of E2 administration and time dependent (0, 12, 24, 48 and 168 h (7 days) changes in testosterone (T) and 17 β-estradiol (E2) in *L. parsia* serum. Capital alphabets (A, B, C) showed significant difference for T, whereas small letter alphabets (a, b, c) show significant difference among treatments for E2

group, which was decreasing gradually as time progressed (Fig. 39.5a, b). Reverse trend was noticed in case of serum T level (Fig. 39.6). FSH level was significantly ($p < 0.05$) high at 24 h post administration of E2, whereas LH level was not affected to E2 injection (Fig. 39.7). Compared to control, a slight increase in oocyte diameter was observed at 12 h post administration of E2 (Fig. 39.8a, b). Histological observation also showed intense vitellogenesis after 24 h post E2 administration (Fig. 39.8c) and vacuolation after 48 and 168 h (7 days) post E2 injection (Fig. 39.8d, e). Compared to control, an intense expression of Vtg in ovarian tissue during12 and 24 h post injection of E2 was noticed (Fig. 39.9a, b, c). Partial and complete dissolution of Vtg

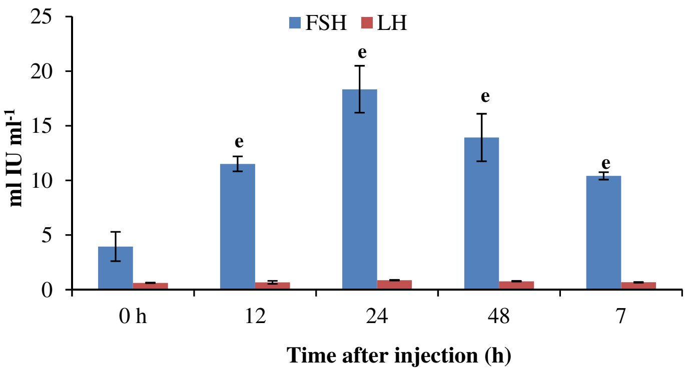


Fig. 39.7 Effect of E2 administration and time dependent (0, 12, 24, 48 and 168 h (7 days) changes in follicle stimulating hormone (FSH) and luteinizing hormone (LH) in *L. parsia* serum. Small letter alphabets (a, b, c) show significant difference among treatments for FSH

protein during 48 h and 168 h (7 days) post injection was found (Fig. 39.9d, e). IHC of D2R in brain tissue was similar for all the groups (Fig. 39.10).

39.4 Discussion

Liza parsia is a commercially important candidate species for brackishwater aquaculture. Farming of this species is completely dependent on wild seed resources. Similar to other mullets, this species attains maturity in captivity but fails to spawn naturally, which might be due to inhibitory role of DA on release of LH. Effect of DA on steroids showed either positive or negative regulation on release of gonadotropin in vertebrates (Pavgi and ; Lichet 1990). Regulatory mechanism of steroid on gonadotropin secretion and dopamine receptors are well studied in mammals and birds, but little is known in fish (Karsch et al. 1987). In tilapia, higher dose of E2 increases drd2 mRNA levels in vivo and in vitro and further inhibits release of LH and *lhb* mRNA levels (Levavi-Sivan et al. 2006). With this background, we studied the expression of D2R in brain and different size groups of *L. paria*. Further, we studied the effect of E2 on FSH, LH, serum E2, serum T, ovarian E2R, serum and ovarian Vtg and brain D2R in vitellogenic adult *L. parsia.*

Expression of D2R in all the three major parts of brain (forebrain, midbrain and hind brain) of adult vitellogenic *L. parsia* showed its probable role in reproductive physiology, which is similar to other fish species (goldfish, African catfish, rainbow trout, tilapia, European eel and grey mullet) (Dufour et al. 2010). Expression of D2R in different size groups of *L. parsia* indicated that it has a probable role in other physiological function. Similarly, expression of D2R is noticed in pubertal stage of European eel (Dufour et al. 2003) and grey mullet (Nocillado et al. 2007).

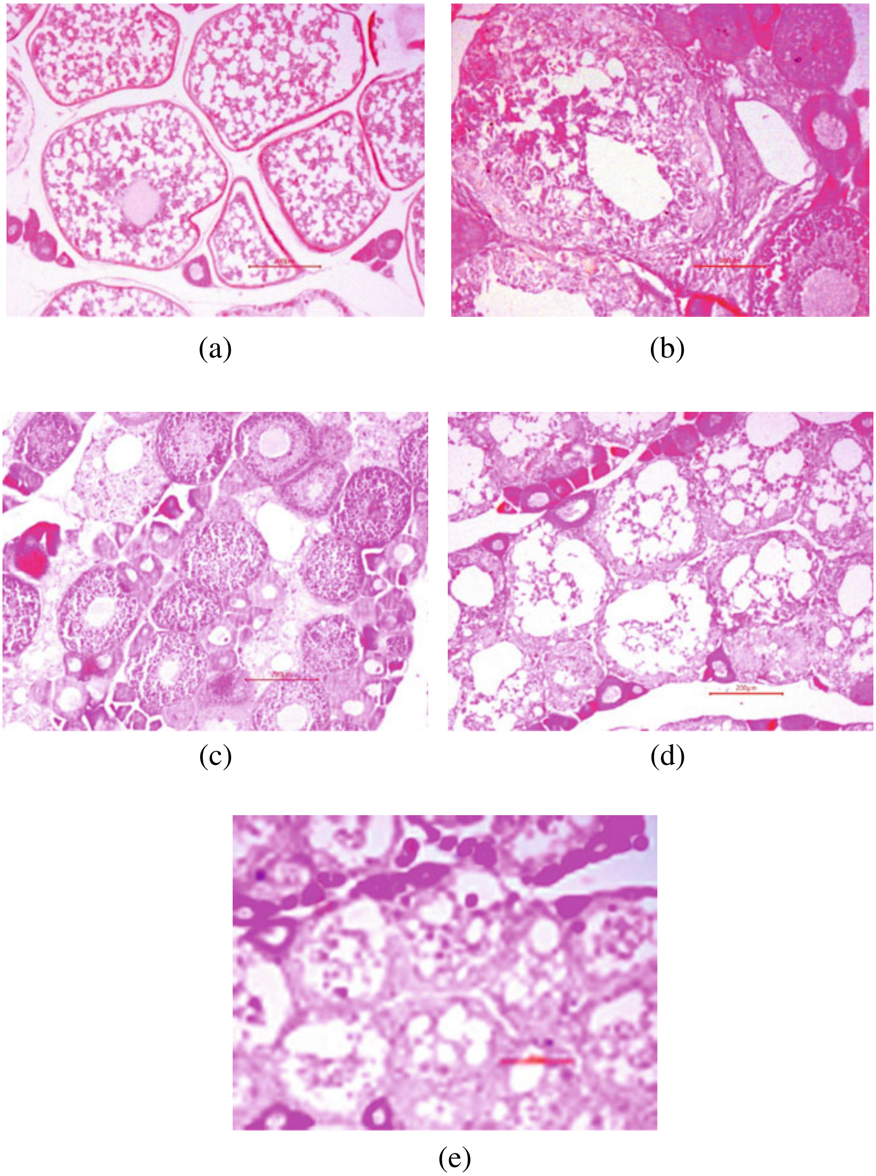
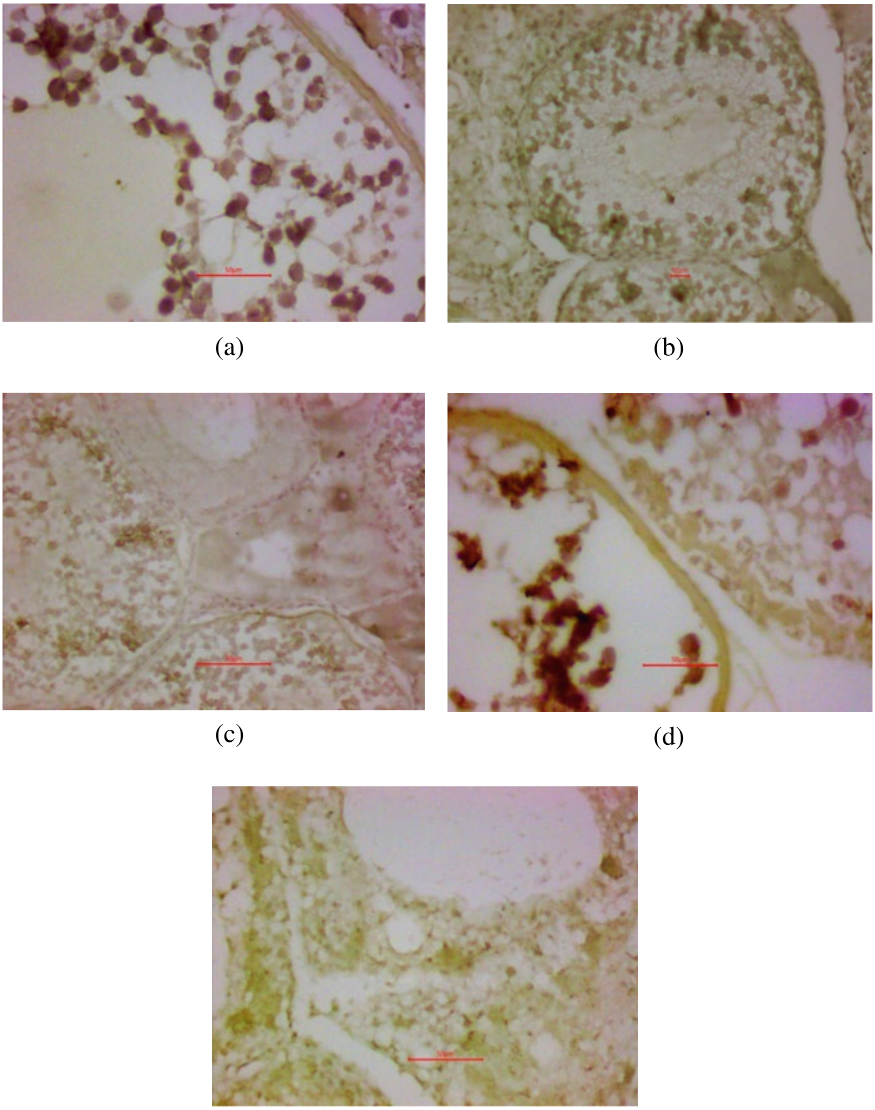


Fig. 39.8 Effect of E2 administration on histological changes in ovarian tissue of *L. parsia* at 10 × magnification. **a** Normal vitellogenic oocytes with yolk granules and oil droplets, **b** 12 **h** post injection of E2, vitellogenic oocytes enlarged, **c** 24 **h** post injection of E2, intense vitellogenesis, **d** 48 **h** post injection, intense vacuolation due to fusion of oil droplets and dissolution of yolk granules, **e** 168 h post injection of E2, with mild vacuolation



(e)

Fig. 39.9 Immune histochemical localization of Vtg protein in formalin fixed paraffin embedded ovarian tissues of *L. parsia*. Brown deposits of DAB indicate localization of Vtg. Effect of E2 administration on the ovarian Vtg of *L. parsia* at 40 × magnification **a** Normal vitellogenic oocytes with clear Vtg protein, **b** 12 **h** post injection of E2, sample of Vtg granules, **c** 24 **h** post injection of E2, intense vitellogenesis **d** 48 **h** post injection, dissolution of Vtg protein, **e** 168 h (7 days) post injection of E2, complete dissolution of Vtg protein

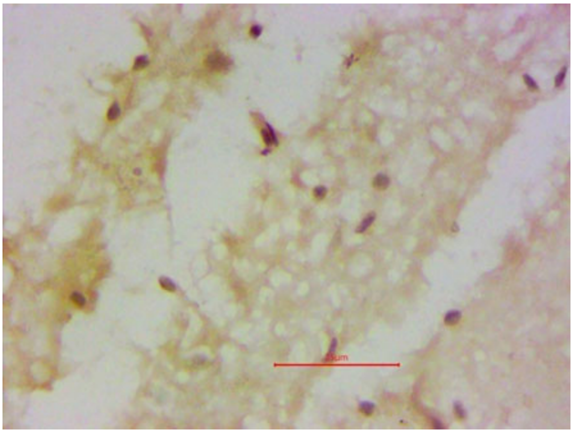


Fig. 39.10 Immunohistochemical localization of D2R protein in formalin fixed paraffin embedded brain tissues of *L. parsia* at 100 × magnifications. All the experimental groups were having similar distribution of D2R in brain

In current study, 12 h post administration of E2 slightly increased the diameter of vitellogenic oocytes. In general, E2 administration increases the accumulation of cortical alveoli and vitellogenin in pre-vitellogenic oocytes (Forsgren and Young 2012). Intense vitellogenesis occurred at 24 h post E2 injection, which is similar to the observation of Hiramatsu et al. (1997) in *Huchoperryi*. In his study, serum Vtg increased within 12–24 h after injection of E2. Further, at 48 h and 7 days post E2 administration, oocytes showed dissolution of yolk granules and vacuolation. There is no published literature to support this finding. Western blot analysis indicated that E2 administration directly upregulated the expression of E2R (67 kDa), Vtg (170 kDa) and D2R (45 kDa). Levavi-Sivan et al. (2006) also found positive effect of E2 administration on the synthesis of *ded2* (dopamine receptor) in tilapia. After 12 h of E2 injection, E2 level was maximum, which decreased gradually as time progressed. Similar to this, administration of E2 in tilapia significantly increased the plasma E2 one day after injection (Davis et al. 2007). In current study, after administration of E2 the trend of FSH was similar to the E2, whereas the LH was not affected. Similar observation was made by Saligaut et al. (1998) who demonstrated that release of FSH but not LH depends on an E2-activated DA inhibitory tone in rainbow trout (*O. mykiss*).

39.5 Conclusions

Overall, reproductive failure of *L. parsia* in captivity might be due to brain DA. Further, administration of E2 directly regulated serum E2, FSH and vitellogenesis in *L. parsia*. Therefore, the use of dopamine antagonist is recommended to trigger final oocyte maturation, ovulation and spawning of *L. parsia* in captivity.

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References

Aizen J, Meiri I, Tzchori I et al (2005) Enhancing spawning in the grey mullet (*Mugil cephalus*) by removal of dopaminergic inhibition. Gen Comp Endocrinol 142:212–221

Alam MJ, Begum M, Pal HK et al (2008) Preliminary success on hormone induced captive breeding of goldspot mullet, *Liza parsia* (Ham.). Bangladesh J Fish Res 12(2):151–156

Anglade L, Zandbergen T, Kah O (1993) Origin of the pituitary innervation in the goldfish. Cell Tissue Res 273:345–355

Begum M, Islam MA, Pal HK et al (2010) Reproductive characteristics of *Liza parsia* (Ham.) inhabiting southwest coast of Bangladesh. J Bangladesh Agric Univ 8(1):173–178

Callier S, Snapyan M, Crom SL et al (2003) Evolution and cell biology of dopamine receptors invertebrates. Biol Cell 95:489–502

Chang JP, MacKenzie DS, Gould DR et al (1984) Effect of dopamine and norepinephrine on in vitro spontaneous and gonadotropin-releasing hormone-induced gonadotropin release by dispersed cells or fragments of the goldfish pituitary. Life Sci 35:2027–2033

Chang JP, Johnson JD, Sawisky GR et al (2009) Signal transduction in multifactorial neuroendocrine control of gonadotropin secretion and synthesis in teleosts-studies on the goldfish model. Gen Com Endocrinol 161:42–52

Copeland PA, Thomas P (1989) Control of gonadotropin release in the Atlantic croaker (*Micropogonias undulatus*): evidence for lack of dopaminergic inhibition. Gen Comp Endocrinol 74:474–483

Davis LK, Hiramatsu N, Hiramatsu K et al (2007) Induction of three vitellogenins by 17 beta-estradiol with concurrent inhibition of the growth hormone-insulin-like growth factor 1 axis in a euryhaline teleost, the Tilapia (*Oreochromis mossambicus*). Biol Reprod 77:614–625

De Leeuw R, Th GHJ, Van Oordt PGWJ (1986) The dopaminergic inhibition of the gonadotropin-releasing hormone-induced gonadotropin release: an in vitro study with fragments and cell suspension from pituitaries of the African catch, *Clarias gariepinus* (Burchell). Gen Comp Endocrinol 63:171–177

Dufour S, Burzawa Gerard E, Belle NL et al (2003) Reproductive endocrinology of the European eel, *Anguilla anguilla.* In: Aida K, Tsukamoto K, Yamauchi K (eds) Eel biology. Springer, Tokyo, pp 373–383

Dufour S, Sebert ME, Weltzien FA et al (2010) Neuroendocrine control by dopamine of teleost reproduction. J Fish Biol 76:129–160. https://doi.org/10.1111/j.1095-8649.2009.02499.x

Forsgren KL, Young G (2012) Stage-specific effects of androgens and estradiol-17beta on the development of late primary and early secondary ovarian follicles of coho salmon (*Oncorhynchus kisutch*) in vitro. Biol Reprod 87:64. https://doi.org/10.1095/biolreprod.111.098772

Hiramatsu N, Shimizu M, Fukada H et al (1997) Transition of serum vitellogenin cycle in Sakhalin taimen (*Hucho perryi*). Comp Biochem Physiol 118C:149–157

Jena G, Trivedi PP, Sandala B (2012) Oxidative stress in ulcerative colitis: an old concept but a new concern. Free Radical Res 46:1339–1345

Karsch FJ, Cummins JT, Thomas GB et al (1987) Steroid feedback inhibition of pulsatile secretion of gonadotropin-releasing hormone in the ewe. Biol Reprod 36:1207–1218

Kumar P, Biswas G, Ghoshal TK et al (2020) Effect of salinity acclimatisation and administration of hormones on oocyte maturation, ovulation and spawning of goldspot mullet *Liza parsia* (Hamilton, 1822) reared in brackishwater pond. Indian J Fish 67(1):56–63

Laemmli UK (1970) Cleavage of structural proteins during the assembly of the head of bacteriophage T4. Nature 227(5259):680–685

Levavi-Sivan B, Jakob B, Einat F et al (2006) Sex steroids are involved in the regulation of gonadotropin-releasing hormone and dopamine D2 receptors in female tilapia pituitary. Biol Reprod 75(4):642–650

Levavi-Sivan B, Bogerd J, Mananos EL et al (2010) Perspectives on fish gonadotropins and their receptors. Gen Comp Endocrinol 165:412–437

Linard B, Bennani S, Saligaut C (1995) Involvement of estradiol in a catecholamine inhibitory tone of gonadotropin release in rainbow trout (*Oncorhynchus mykiss*). Gen Comp Endocrinol 99:192–196

Nocillado JN, Levavi-Sivan B, Carric F et al (2007) Temporal expression of G-protein-coupled receptor 54 (GPR54), gonadotropin-releasing hormones (GnRH), and dopamine receptor D2 (drd2) in pubertal female grey mullet, *Mugil cephalus*. Gen Comp Endocrinol 150:278–287

Pavgi S, Lichet P (1990) Steroidal modulation of pituitary gonadotropin-releasing hormone responsiveness in young turtles, *Pseudemys scripta.* gen compendocrinol 78:331–343

Peter RE, Habibi HR, Marchant TA et al (1987) Vertebrate gonadotropin releasing hormones: phylogeny and structure function relationships. Ann NY Acad Sci 519(1): 299–309

Pivonello R, Ferone D, de Herder WW et al (2006) Dopamine receptor expression and function in corticotroph ectopic tumors. J Clin Endocrinol Metab 92(1):65–69. https://doi.org/10.1210/jc.2006-0728

Riede K (2004) Global register of migratory species: from global to regional scales: final report of the R&D-Projekt 808 05 081

Roberts RJ (1989) Nutritional pathology of teleosts. In: Roberts RJ (ed) Fish pathology. Bailliere Tindall, London, pp 337–362

Saligaut C, Linard B, Mananos EL et al (1998) Release of pituitary gonadotrophins GtH I and GtH II in the rainbow trout (*Oncorhynchus mykiss*): modulation by estradiol and catecholamines. Gen Comp Endocrinol 109:302–309

Saligaut C, Linard B, Breton B et al (1999) Brain aminergic systems in salmonids and other teleosts in relation to steroid feedback and gonadotropin release. Aquaculture 177:13–20

Talwar PK, Jhingran AG (2001) Inland fishes. vol. 2. Oxford and IBH Publishing Co. Pvt. Ltd., New Delhi, India, p 1158

Vacher C, Mananos EL, Breton B et al (2000) Modulation of pituitary dopamine D1 or D2 receptors and secretion of follicle stimulating hormone and luteinizing hormone during the annual reproductive cycle of female rainbow trout. J Endocrinol 12:1219–1226

Vidal B, Pasqualini C, LeBelle N et al (2004) Dopamine inhibits luteinizing hormone synthesis and release in the juvenile European eel: a neuroendocrine lock for the onset of puberty. Biol Reprod 71:1491–1500

Weltzien FA, Pasqualini C, Sébert ME et al (2006) Androgen-dependent stimulation of brain dopaminergic systems in the female European eel (*Anguilla anguilla*). Endocrinol 147:2964–2973

Yaron Z, Gur G, Melamed P et al (2003) Regulation of fish gonadotropins. Int Rev Cytol 225:131–185

Zohar Y, Harel M, Hassin S et al (1995) Broodstock management and manipulation of spawning in the gilthead seabream, *Sparus aurata.* In: Bromage N, Roberts RJ (eds) Broodstock management and egg and larval quality. Blackell Science Press, London, pp 94–117

Chapter 40
Integrated Multi-Trophic Aquaculture (IMTA): A Potential Farming System to Enhance Production of the Red Seaweed *Agarophyton tenuistipitatum* (Chang and Xia) in Brackishwater

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Abstract Globally, intensification in aquaculture leads to concern on both environmental and economic sustainability. In this context, integrated multi-trophic aquaculture (IMTA) is one of the best solutions to bring in sustainability in aquaculture. Earlier studies suggest that raising the ecosystem capacity, i.e., increasing the succession of trophic levels may enhance the biomass production of seaweed. Therefore, IMTA may impact positively for the production of seaweed biomass, which will help to meet up the immense industrial requirement of raw material. Thus, the present

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study focused to evaluate the production performance of red alga *Agarophyton tenuistipitatum* in an IMTA (milkfish-oyster-seaweed) system in comparison to monoculture (only seaweed) in brackishwater tide-fed ponds in Sundarbans. Water salinity ranged between 5 and 7.5 g L^{-1} during the 90-days study period. It was observed that the biomass production increased as time progressed in both systems, but biomass and specific growth rate were significantly higher in IMTA (1657.98 ± 65.905 g and 2.64 ± 0.049% d^{-1}) compared to monoculture (1287.74 ± 86.003 g and 2.32 ± 0.085% d^{-1}) throughout the culture period. Analysis of tissue C and N contents of *A. tenuistipitatum* revealed significantly higher percentage of deposition in IMTA seaweed than in monocultured one. In addition, an average final body weight of milkfish was 214.89 ± 1.665 g from initial 14.57 ± 1.66 g in the IMTA system. An average 10% weight gain of edible oyster was obtained from the IMTA during the culture period. It could be concluded that along with higher growth performance, seaweed utilized a significant amount of carbon and nitrogen which maintained the environmental sustainability. Moreover, higher biomass production and diversification of species in IMTA will certainly provide an economic sustainability to farmers through intensive farming.

Keyword Brackishwater · *Agarophyton tenuistipitatum* · IMTA · Milkfish · Biomass production

40.1 Introduction

Almost half of the world's seafood supply is contributed through aquaculture, and the production is expected to increase over 53% by the year 2030 (FAO 2020). The growth of intensive monoculture practices burst rapidly to mitigate the global fish demand (Wilfart et al. 2013; Ferreira et al. 2014), but the coastal ecosystem is deteriorating due to this anthropogenic pressure (Maroni 2000; Chopin et al. 2001). Algae, mainly seaweed, have a large market, and just in 2018 about 32.4 million tons valued more than US$ 6 billion were sold for human consumption, phycocolliods feed supplements, medicine, cosmetics, water treatment, food industry and as biofuels (FAO 2020). Consumer interest in new protein sources for healthy food supplements plus the industrial need for textural additives and food security creates a rapid demand for seaweed by western markets (Kim et al. 2017). Seaweed biomass production in aquaculture effluents enhanced the seaweed quality as a food product due to higher protein percentage compared with traditional culture conditions (Neori and Shpigel 1999). In Asia, China is the most productive country, producing around 14 million tons annually with a value of greater than US$ 2 billion (FAO 2018). In Asia, China (70%) and Indonesia (28%) contribute the lion's share of *Gracilariacean algal* production. The majority of algal biomass among phycocolloid industries utilizes them for food-grade agar (Pereira and Yarish 2008) and animal feed production (Qi et al. 2010; Johnson et al. 2014). *Gracilariacean algae* contribute almost 66% of total global agar production (Pereira and Yarish 2008).

Diversifying a culture system with algae and fish or shrimp makes sense from both ecological and economic points of view (Neori et al. 2004). Hypothetically, integrated multi-trophic aquaculture (IMTA) may be a suitable option for huge requirements of seaweed biomass, and long-term sustainability could be achieved through this practice. The concept of integrated multi-trophic aquaculture (IMTA) systems was introduced by Ryther et al. (1975) during the eighties decade and became a predominant system in the world (Neori et al. 2004). Troell et al. (2003) and Neori et al. (2004) reported that the IMTA approach utilizes more than one species from different trophic levels to recycle the waste generated from one species for another resulting in the improvement of the system efficiency and productivity of seaweed production at a lower cost. In this system, seaweed helps to stabilize the levels of oxygen and CO_2, balances the pH of the water, and also assimilates the fish or shrimp leftover, which are rich in nutrients (ammonium and phosphate) to convert them into valuable biomass (Hirata et al. 1994; Neori et al. 2004; Chopin 2012; Yang et al. 2015). Lower agriculture productive sites like brackishwater low lands could be helpful to generate revenue through IMTA farming where the residue of one farming subsystem (trophic level) utilize as a source of nutrients for another within the same cultivation system (Edwards et al. 1988). Earlier studies demonstrated that seaweed farmed in the IMTA system was found nutritionally superior with a high content of pigments, polysaccharides, proteins, and other functional compounds. This result attracted various industries for its application in food supplements, fertilizer, and cosmetics (Chopin et al. 1999; Martínez-Espiñeira et al. 2015).

Gracialriacean algae have been demonstrated better growth performance in aquaculture effluent systems with high yields. Several authors (Hanisak 1987; Nagler et al. 2003; Neori et al. 2004; Troell et al. 1997; Pereira and Yarish 2008) proved this fact proved that these groups of algae could be an ideal candidate for any IMTA practices. Among filter-feeding organisms, mollusks are frequently tested as a component of IMTA due to their ability to filter out organic particles and phytoplankton. On the other hand, macroalgae can uptake dissolved nutrients from the system (Marinho-Soriano et al. 2011). With this background, the present study focused to develop an integrated multi-trophic aquaculture system with seaweed (*Agarophyton tenuistipitatum*), edible oyster (*Crassostrea cuttakensis*), and fish (*Chanos chanos*) in brackishwater tide-fed pond system of Sundarban.

40.2 Materials and Methods

40.2.1 Collection of Seaweed, Oyster, and Fish

The seaweed, *Agarophyton tenuistipitatatum*, chosen for this study was collected from Muttukadu Lagoon (12° 48′42.1″ N and 80° 14′39″ E) and transferred to Muttukadu Experimental Station, ICAR-Central Institute of Brackishwater Aquaculture, Chennai, Tamil Nadu, India, for cleaning off the epiphytes and encrusting organisms. After cleaning, it was placed in FRP tanks containing filtered saline water. Seaweeds were packed in transparent polythene bags containing filtered saline water, filled with oxygen, and transported through railway to the Kakdwip Research Centre (21° 51′28.1″ N and 88° 11′02.0″ E) of ICAR–Central Institute of Brackishwater Aquaculture (Sundarbans, West Bengal, India, for conducting the culture trial. After unloading, seaweeds were slowly acclimatized with the farm temperature and salinity and kept in FRP tanks until further studies. Edible oyster, *Crassostrea cuttakensis,* was collected from the local fishermen of the Namkhana region and transported to the experimental station of Kakdwip by road. Oysters were cleaned thoroughly to remove mud and encrusting organisms from its shell. After cleaning, they were kept into FRP tanks and acclimatized with the salinity of the experimental pond before starting the experiment. Juveniles of Milkfish (*C. chanos*) were collected from the in-situ tide-fed ponds of KRC and used for conducting the IMTA trial.

40.2.2 Experiment Design

A 90-days experimental trial was conducted in two tide-fed ponds of similar sizes (500 m^2). Two treatments were designed as one was control (monoculture), and the other one was IMTA. In the control pond, only seaweed was kept in nylon net bags ($n = 5$). Similarly, five numbers of net bags were arranged in the IMTA pond to keep seaweed in addition to oysters and fishes. Open-mouth nylon net bags (2 m × 2 m, mesh size = 2 mm) were tied with bamboo poles at four corners and the center of each pond. The depth between the water surface and bottom of the net bags was maintained within 0.15 m and 0.30 m (Sarkar et al. 2019a). Oysters were kept in plastic trays and suspended in the water nearby seaweed net bags with the help of ropes and bamboo poles. The rest of the places of the IMTA pond were occupied by milkfishes.

40.2.3 Stocking Management of Seaweed, Oyster, and Fish

The initial stocking density of seaweed was kept as 50 g m^{-2} for both culture treatments. The area of a single net bag was 4 m^2; therefore, initial 200 g of seaweed biomass was placed in each net bag. Six trays were arranged for keeping the oyster. In each tray, 14 numbers of oysters were stocked with an initial average body weight of 276.71 ± 13.06 g in the IMTA system. Total 1000 numbers of fingerlings of milkfish (stocking density-2 m^{-2}) with an average initial body weight of 14.57 ± 1.66 g were stocked in the IMTA pond.

40.2.4 Feeding Management for Fish

Fishes were fed with commercially available pellet feed (floating type) daily in two equal quantities in the morning (09:00 h) and afternoon (16:00 h). Feed was provided initially at 3–5% of the biomass of fish and adjusted daily based on the consumption and body weight through periodical sampling. No extra feed was provided for oysters as they fed on natural production and feed waste generated through fish in the pond ecosystem.

40.2.5 Water Quality Analysis

Water pH and dissolved oxygen (DO) were determined and recorded using probes (pH-Scan-Eutech instruments, Singapore for pH, and Lutron DO-5510 for dissolved oxygen) at 30 days intervals. Temperature and salinity were checked using a mercury thermometer and hand refractometer, respectively. The water samples (triplicate) were collected and analyzed for total alkalinity (titration with dilute sulfuric acid), total hardness (titration with EDTA), NH_4–N (phenol hypochlorite method), NO_2–N (sulphanilamide NED method), NO_3–N (sulphanilamide NED method after reduction of NO_3 to NO_2 with cadmium), and PO_4–P (phosphomolybdic acid ascorbic acid method) for the same duration (APHA 1998).

40.2.6 Seaweed Carbon and Nitrogen Analysis

Seaweed wet sample was collected and dried in an oven at 60 °C, ground into powder using a grinding machine for analyzing carbon and nitrogen content (Wu et al. 2015). To assess the carbon and nitrogen content, the average weight of the sample was taken as 0.05 g and 0.2 g, respectively. The amount of carbon in seaweed tissue was analyzed by the chromic acid wet digestion method (Walkley and Black 1934). Nitrogen content (%) of seaweed was measured using a semi-automatic Kjeldahl apparatus (Kjeltec™ 8100) following the method of Wu et al. (2015).

40.2.7 Estimation of Growth Parameters

The growth performance of seaweed was assessed concerning final biomass and specific growth rate (SGR). The fresh weight of seaweed biomass was recorded ($n = 5$) from the two culture systems and calculated the SGR by using the following equation (Rosenberg et al. 1984):

$$\text{Specific growth rate } \left(\% \text{ d}^{-1}\right) = \frac{(\text{Ln final weight} - \text{Ln initial weight})}{\text{Days of culture}} \times 100 \tag{40.1}$$

Individual live weight of fishes ($n = 50$) and oysters ($n = 20$) was recorded using 0.01 precision weighing balance and computed average for initial and final body weight. The growth performance was assessed in terms of average percentage weight gain %, survival %, and SGR for oysters and milkfish. Average weight gain % and survival % were calculated using the following formula after Panigrahi et al. (2017) and SGR was calculated same as Eq. 40.1.

$$\text{Weight gain (g)} = \frac{\text{Final weight (g)} - \text{Initial weight (g)}}{\text{Initial weight (g)}} \times 100 \tag{40.2}$$

$$\text{Survival } (\%) = \frac{\text{Count at the end of experiment}}{\text{Count at the beginning of experiment}} \times 100 \tag{40.3}$$

40.2.8 Statistical Analysis

The data were statistically analyzed using SPSS version 17.0 (SPSS Inc., Chicago, IL, USA). Data indicating all percentage values were transformed into a logarithmic scale before deploying statistical analysis. The parameters were computed and expressed as mean ± standard error. Independent samples t-test was used to determine the significance between two different culture systems for seaweed production and bioremediation. The level of significance was determined at 95% probability levels ($p \leq 0.05$) for all analyses.

40.3 Results

40.3.1 Water Quality

Temperature and salinity ranged between 25–28.6 °C and 5–7.5 g L^{-1}, respectively, during the entire experimental period. The pH value ranged between 7.95–8.40 and 7.99–8.47 in the control and IMTA pond, respectively. The average dissolved oxygen was observed >6.5 mg L^{-1} during the culture period in both systems. Total alkalinity of water found 161.00 ± 1.94 mg L^{-1} and 159.65 ± 1.76 mg L^{-1} for control and IMTA, respectively. An average value of total hardness in water was observed as 1245 ± 98.78 mg L^{-1} and 1234±101.2 mg L^{-1} for control and IMTA, respectively. The highest NH_4–N value was 0.050 ± 0.007 mg L^{-1} and 0.044 ± 0.004 mg L^{-1} for the control and IMTA system, respectively, after 90 days of culture. NO_2–N concentration of water ranged between 0.006 and 0.019 mg L^{-1} for monoculture, whereas it was 0.006–0.013 mg L^{-1} for the IMTA system. The average NO–N concentration observed 0.045 ± 0.03 mg L^{-1} for control, whereas it was 0.039 ± 0.026 mg L^{-1} for IMTA treatment during the experiment. The average PO_4–P concentration was found almost similar for both culture systems and the values were 0.057 ± 0.010 mg L^{-1} and 0.058 ± 0.010 mg L^{-1} for control and IMTA, respectively (Table 40.1).

40.3.2 Seaweed Tissue Carbon and Nitrogen Content

Results showed that tissue carbon percentage of seaweed found increased over time for both culture systems. It was also observed that carbon content was significantly higher in IMTA (32.28 ± 0.327%) compared to monoculture (30.52 ± 0.183%) after three months culture period (Fig. 40.1). Similarly, nitrogen content in tissue was also showed increment as time progressed, and significantly higher nitrogen assimilation was obtained in IMTA (2.95 ± 0.099%) than in control (3.49 ± 0.026%) (Fig. 40.2).

40.3.3 Growth Performance of Seaweed, Oyster, and Milkfish

Results revealed that in both culture systems, the biomass of seaweed was found to increase over time. Besides, in each time interval, biomass was found significantly higher in the IMTA system than in monoculture. After 90 days of culture, seaweed biomass was obtained 1657.98 ± 65.91 g and 1287.74 ± 86.00 g in the IMTA and control system, respectively (Fig. 40.3). The specific growth rate of seaweed was significantly higher in the IMTA than in control throughout the experimental period. During 30 days of culture, it showed the highest value in the IMTA system (3.63 ± 0.27 g d^{-1}), whereas the value was 2.00 ± 0.56 g d^{-1} in control (Fig. 40.4).

Final average body weight of oyster was observed 304.38 ±14.36 g with a 10% weight gain from initial stocking weight in IMTA pond. Almost 80% of survival was recorded for oysters during 90 days of culture period (Table 40.2). An approximately 200 g of weight gain was obtained for milkfish from initial to 90 days of culture period with an average specific growth rate of 3.50 ± 0.11 g d^{-1}. Besides, approximately 90% survival of milkfish was achieved from the IMTA pond after 90 days of culture (Table 40.2).

40.4 Discussion

During the culture period, water quality parameters were quite favorable for the growth of the seaweed, *Agarophyton tenuistipitatum* (Bharathan 1987; Jayasankar

Table 40.1 Physico-chemical parameters of water samples for different treatments along with temporal variations

Time	Treatment	Salinity (g L^{-1})	Temperature (°C)	pH	DO (mg L^{-1})	Alkalinity (mg L^{-1})	Hardness (mg L^{-1})	NH_4–N (mg L^{-1})	NO_2–N (mg L^{-1})	NO_3–N (mg L^{-1})	PO_4–P (mg L^{-1})
Initial	Control	5.0 ± 0.01	28.6± 0.01	7.96 ± 0.014	6.37±0.055	160.0 ± 2.19	1120 ± 20.00	0.011± 0.001	0.006± 0.001	0.009± 0.001	0.034 ± 0.003
	IMTA	5.0 ± 0.01	28.6 ± 0.01	8.09 ± 0.063	6.27 ± 0.053	160.6 ± 2.21	1120 ± 37.42	0.009± 0.001	0.006 ±0.001	0.008 ± 0.001	0.033 ± 0.004
30 days	Control	5.0 ± 0.01	25.0 ± 0.01	7.95 ± 0.014	6.37 ± 0.038	156.0 ± 1.27	1040 ± 24.50	0.014 ±0.001	0.008 ± 0.001	0.136± 0.012	0.047 ± 0.002
	IMTA	5.0 ± 0.01	25.0 ±0.01	7.99 ± 0.043	6.27 ± 0.044	154.8 ± 1.50	1016 ± 21.12	0.014 ± 0.001	0.007± 0.001	0.118± 0.012	0.054 ± 0.002
60 days	Control	5.0± 0.01	25.3 ± 0.01	8.12 ± 0.031	7.39± 0.046	163.2 ± 1.96	1360 ±50.99	0.022 ±0.001	0.013±0.001	0.018±0.003	0.067 ± 0.003
	IMTA	5.0 ± 0.01	25.3 ± 0.01	8.26 ± 0.047	7.33±0.042	160.0 ± 2.53	1340 ± 67.82	0.018 ±0.001	0.010 ±0.001	0.013 ± 0.001	0.064 ± 0.003
90 days	Control	7.5 ± 0.01	28.5 ± 0.01	8.40 ± 0.012	7.61 ± 0.040	164.8 ± 1.50	1460 ± 50.99	0.050 ± 0.007	0.019 ±0.001	0.018± 0.001	0.080 ± 0.007
	IMTA	7.5 ± 0.01	28.5 ± 0.01	8.47 ±0.012	7.51±0.021	163.2 ± 1.50	1460 ± 40.00	0.044± 0.004	0.012± 0.001	0.016± 0.001	0.082 ± 0.005
Average	Control	5.6 ± 0.63	26.9 ± 0.98	8.11±0.106	6.93 ± 0.329	161.0 ± 1.94	1245 ± 98.78	0.024± 0.009	0.011 ± 0.003	0.045± 0.030	0.057 ± 0.010
	IMTA	5.6 ± 0.63	26.9 ± 0.98	8.20 ± 0.106	6.84± 0.334	159.7 ± 1.76	1234± 101.2	0.021± 0.008	0.008 ± 0.001	0.039±0.026	0.058 ± 0.010

* Data expressed as mean ± S.E (n = 5)

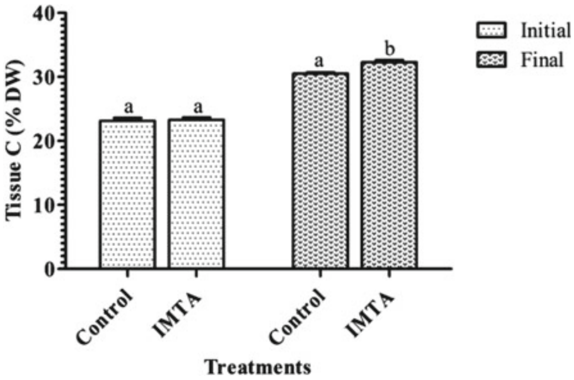

Fig. 40.1 Tissue carbon content (%) of *A. tenuistipitatum* for two culture treatments during the initial and final period. Data represents mean ± SE ($n = 5$). Different lowercase letters indicated statistical significance ($p < 0.05$) between two culture treatments

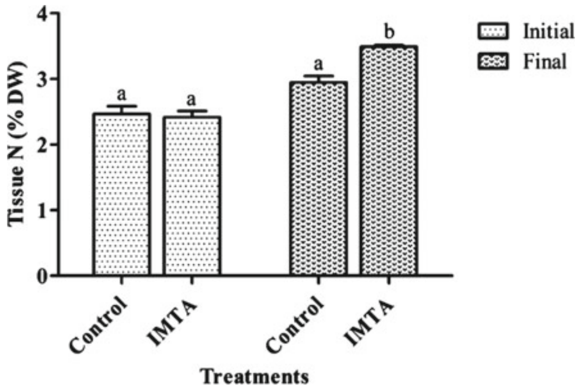

Fig. 40.2 Tissue nitrogen content (%) of *A. tenuistipitatum* for two culture treatments during the initial and final period. Data represents mean ± SE ($n = 5$). Different lowercase letters indicated statistical significance ($p < 0.05$) between two culture treatments

et al. 2006; Sarkar et al. 2019b). The ranges of water quality parameters for the seaweed also agreed with the earlier studies conducted in the tide-fed pond of Sundarbans by Sarkar et al. (2019a). Besides, the water quality parameters recorded in the IMTA system were within the optimum ranges for the growth of edible oysters and milkfish (Mahadevan and Nayar 1987; Biswas et al. 2011; Piyathilaka et al. 2012).

Dissolved inorganic nitrogenous waste was generated in the IMTA pond through the fecal matter of milkfish, feed leftover, and oyster excretion. Several authors reported that marine fish culture operations could add nitrogen and phosphorus into the environment through various sources such as fish excretion, feces, and feed wastage (Marinho-Soriano et al. 2011; Zhou et al. 2006). Earlier studies revealed that bivalve mollusks (e.g., mussels and oysters) nutrients excretion mainly formed with

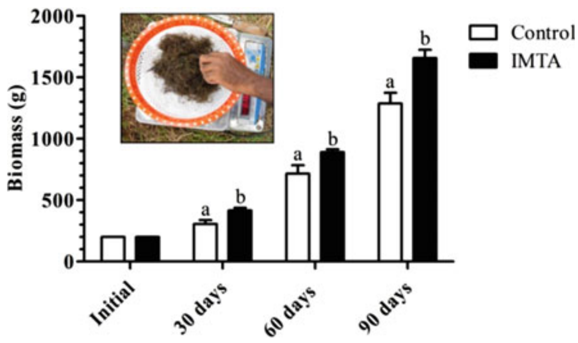

Fig. 40.3 Biomass production (g) of *A. tenuistipitatum* for two culture treatments along with the temporal variation. Data represents mean± SE ($n = 5$). Different lowercase letters indicated statistical significance ($p < 0.05$) between two culture treatments

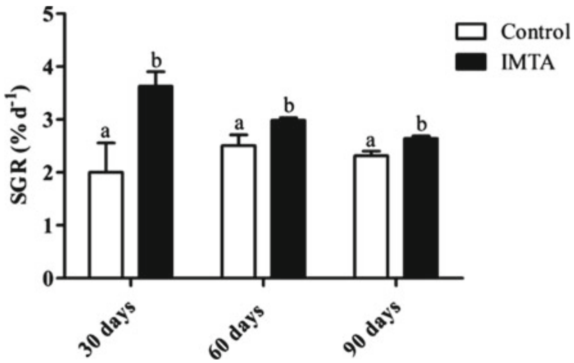

Fig. 40.4 Specific growth rate (% d^{-1}) displayed for *A. tenuistipitatum* between two culture treatments along with temporal variation. Different lowercase letters indicated statistical significance ($p < 0.05$) between two culture treatments

Table 40.2 Growth performance of oyster and milkfish

Organism	Initial average body weight (g)	Final average body weight (g)	Weight gain (%)	SGR (% d^{-1})	Final survival %
Crassostrea cuttakensis	276.71 ± 13.06	304.38 ± 14.36	10.00 ± 2.40	0.12 ± 0.04	80.32
Chanos	14.57 ± 1.66	214.89 ± 1.67	1670.22 ± 134.11	3.50 ± 0.11	90.41

* Data expressed as mean± S.E ($n = 50$ for milkfish; $n = 20$ for oyster)

NH_4–N and PO_4–P (Thomsen et al. 2016). Besides, the carbon dioxide is released in the water column through the respiration activity of a live organism in the same pond. Earlier studies suggested that cultivation of *Gracilariacean algae* may be a new environmentally friendly way of sequestrating CO_2 and can be converted into biofuels (Yang et al. 2015). The lesser concentration of NH_4–N, NO_2–N, and NO_3–N in the IMTA system provided evidence that seaweed was quite efficient in removing nitrogenous metabolites from the system. *Gracilariacean algae* have been identified as efficient biofilters in different IMTA systems (Neori et al. 2004) and examined for their efficacy by using tank (Marinho-Soriano et al. 2011; Sarkar et al. 2021), outdoor pond (Abreu et al. 2011), and field (Yang et al. 2006; Abreu et al. 2009) cultivation experiments. Seaweeds photosynthesize to create new biomass through utilizing solar energy and the excess nutrients in the water, particularly dissolve inorganic C, N, and P (Granada et al. 2015). The presence of a higher percentage of C and N in the seaweed tissue worked as a shred of evidence for the higher amount of carbon and nitrogen input into the IMTA system. It was also clear that seaweed played a vital role in the bioremediation of the C and N waste generated in the multi-trophic (seaweed + oyster + fish) system. Samocha et al. (2015) recorded a higher level of N content in seaweed *Gracilaria tikvahiae* from an IMTA system. Zhou et al. (2006) demonstrated that *Gracilaria lemaneiformis* could effectively improve the water environment by sequestrating a higher amount of C and N content from an integrated fish farming area. The same authors also reported a higher percentage of C and N in seaweed tissue obtained from the open-water IMTA system (seaweed + fish) compared to regular culture practice of seaweed in coastal areas (Fei 2004). Abreu et al. (2011) also reported that higher accumulation of nitrogen content in *Gracilariacean algae* could be obtained in the IMTA system (6% dry weight) than in natural environment (4.8% dry weight). Higher nitrogen content was recorded for red algae (*Porphyra* spp.) from land-based finfish and shellfish mariculture systems (Kim et al. 2007).

Earlier studies showed that the growth rate of *Gracilariacean algae* increased as tissue nitrogen content increased from 1 to 2% (Lapointe 1985). Sufficient amount of dissolved free carbon dioxide is thought to be a triggering factor for seaweed growth in a closed culture system (Hanisak 1987). Lapointe and Tenore (1981) reported that insufficient carbon supply in a culture system may decrease the growth of seaweed. Biomass production of seaweed observed higher in the areas nearby fish cages than in the areas away from aquaculture practices (Troell et al. 1997; Fei et al. 2002). Higher accumulation of nitrogen and carbon in the algal tissue in the IMTA system enhanced the productivity performance of seaweed (Matos et al. 2006; Abreu et al. 2011). Sarkar et al. (2019c) demonstrated that higher assimilation of nutrients (iC, iN, and iP) could stimulate the growth of *A. tenuistipitatum* in shrimp aquaculture system. In the present study, the higher specific growth rate of *A. tenuistipitatum* was recorded in the IMTA system (mean 3.08% d^{-1}) than in the control pond (mean 2.28% d^{-1}). This result could be explained by the nutrients' (C and N) assimilation capacity of the seaweed in two different experiment culture conditions. Significantly higher C and N content was obtained in the tissue of seaweed from the IMTA system than in control, resulting in the higher growth rate and biomass production.

Many researchers recorded similar observations for different red algal growth in the IMTA system. Rodrigueza and Montano (2007) annulated that the growth of *Kappaphycus alvarezii* in tanks containing fish (*C. chanos*) effluent could obtain a higher growth rate compared to control (cultured in normal seawater). Lombardi et al. (2006) reported higher biomass production of *K. alvarezii* co-cultured with *Penaeus vannamei* cultured in cages. Zhou et al. (2006) demonstrated that *G. lemaneiformis* could grow efficiently with fish (*Sebastodes fuscescens*) in an open-water system and effectively uptake the dissolved nutrients from the culture water. Haglund and Pedersén (1993) also found that *A. tenuistipitatum* grows well in a co-culture system with rainbow trout.

In this study, a luxuriant growth with remarkable survival (>90%) of milkfish was achieved in the IMTA system. Several authors reported that the production of seaweed in the IMTA system could be beneficial for the health of reared fish (Bansemir et al. 2006; Diaz-Rosales et al. 2007). Sarkar et al. (2019c) recorded a higher survival of *P. vannamei* in a shrimp–seaweed co-culture system (99%) than in a monoculture system (70%). Stigebrandt et al. (2004) annulated and confirmed that maximization of fish production could accomplish through the IMTA system. Besides, a good survival (80%) of oysters was obtained from the IMTA system. MacDonald et al. (2011) reported that the oyster *Saccostrea commercialis* was quite effective in dropping down the level of total suspended solids, total N, and P from the aquaculture system. Earlier studies suggest that bivalves can act as a reservoir for finfish pathogens, and also its production can change the infection dynamics for fish pathogens in the IMTA system (Pietrak et al. 2012). Hence, bivalves are not only helping to balance the ecological impacts, but also it can serve as a valuable crop to the fisher folks (MacDonald et al. 2011).

40.5 Conclusions

The demand for seaweed products is increasing day by day for a plethora of industrial utilizations. Therefore, there is a need for a suitable aquaculture model to fulfill the future demand for seaweed. In this perspective, the present effort was undertaken, which was confirmed that the IMTA (seaweed + oyster + fish) could successfully enhance the production of the seaweed. IMTA has immense prospects toward becoming the aquaculture of the future because this is not only promoting the economy but also maintains environmental and social sustainability. Moreover, macroalgae can balance the excess entry of dissolved inorganic nutrients (C, N, and P) in the culture system, which is beneficial for other aquatic organisms (fish or shrimps) and also significantly helps to minimize the aquaculture impacts (Granada et al. 2015). The culture of seaweed with high-valued fish or shrimp and oyster may reduce the water exchange rate simultaneously lessening the chance of disease outbreak. Hence, the IMTA can provide multilayer benefits to the farmers by reducing the environmental impacts and operational cost for effluent treatments and producing biomass with less spending on commercial feed.

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References

Abreu MH, Pereira R, Yarish C et al (2011) IMTA with *Gracilaria vermiculophylla*: productivity and nutrient removal performance of the seaweed in a land-based pilot scale system. Aquaculture 312:77–87. https://doi.org/10.1016/j.aquaculture.2010.12.036

Abreu MH, Varela DA, Henriquez L et al (2009) Traditional vs integrated multi-trophic.aquaculture of *Gracilaria chilensis* Bird CJ, McLachlan J, Oliveira EC: productivity and physiological performance. Aquaculture 293:211–220. https://doi.org/10.1016/j.aquaculture.2009.03.043

APHA (1998) Standard methods for the examination of water and wastewater, 20th edn. American Public Health Association, Washington DC

Bansemir A, Blume M, Schroder S et al (2006) Screening of cultivated seaweeds for antibacterial activity against fish pathogenic bacteria. Aquaculture 252:79–84. https://doi.org/10.1016/j.aquaculture.2005.11.051

Bharathan G (1987) Experimental culture of *Gracilaria* at the Mariculture Centre, Muttukadu, Tamil Nadu. J Mar Biol Ass India 29:54–59. http://mbai.org.in/php/journaldload.php?id=1272&bkid=68

Biswas G, Raja RA, De D et al (2011) Evaluation of productions and economic returns from two brackishwaterpolyculture systems in tide-fed ponds. J Appl Ichthyol 28:116–122. https://doi.org/10.1111/j.1439-0426.2011.01909.x

Chopin T (2012) Aquaculture, integrated multi-trophic (IMTA). In: Meyers RA (ed) Encyclopedia of sustainability science and technology. Springer, New York, NY, pp 542–564

Chopin T, Kerin BF, Mazerolle R (1999) Phycocolloid chemistry as a taxonomic indicator of phylogeny in the Gigartinales, Rhodophyceae: a review and current developments using Fourier transform infrared diffuse reflectance spectroscopy. Phycol Res 47:167–188. https://doi.org/10.1046/j.1440-1835.1999.00170.x

Chopin T, Buschmann AH, Halling C et al C(2001) Integrating seaweeds into aquaculture systems: a key towards sustainability. J Phycol 37:975–986. https://doi.org/10.1046/j.1529-8817.2001.01137.x

Diaz-Rosales P, Felices C, Abdala R et al (2007) In vitro effect of the red alga *Hydropuntia cornea* (J. Agardh) on the respiratory burst activity of sole (*Solea senegalensis*, Kaup 1858) phagocytes. Aquac Res 38:1411–1418. https://doi.org/10.1111/j.1365-2109.2007.01830.x

Edwards P, Pullin RSV, Gartner JA (1988) Research and education for the development of integrated crop-livestock-fish farming systems in the tropics. ICLARM Stud Rev 16:1–53. https://hdl.handle.net/20.500.12348/3224

FAO (2018) The global status of seaweed production, trade and utilization. Globefish Res Programme 124. Rome, p 120

FAO (2020) The state of world fisheries and aquaculture (2020) Sustainability in action. Rome. https://doi.org/10.4060/ca9229en

Fei XG (2004) Solving the coastal eutrophication problem by large scale seaweed cultivation. Hydrobiologia 512:145–151. https://doi.org/10.1023/B:HYDR.0000020320.68331.ce

Fei XG, Tseng CK, Pang SJ et al (2002) Transplant of *Gracilaria lemaneiformis* by raft culture on the sea along fish cages in southern China. In: Proceedings of World Aquaculture Society, World Aquaculture Society, Baton Rouge, LA, USA, April 23–27, p 219

Ferreira JG, Saurel C, Lencart e Silva JD et al (2014) Modelling of interactions between inshore and offshore aquaculture. Aquaculture 426–427:154–164. https://doi.org/10.1016/j.aquaculture.2014.01.030

Granada L, Sousa N, Lopes S et al (2015) Is integrated multitrophic aquaculture the solution to the sectors' major challenges? A review. Rev Aquac 6:1–18. https://doi.org/10.1111/raq.12093

Haglund K, Pedersén M (1993) Outdoor pond cultivation of the subtropical marine red alga *Gracilaria tenuistipitata* in brackish water in Sweden. Growth, nutrient uptake, co-cultivation with rainbow trout and epiphyte control. J Appl Phycol 5:271–284. https://doi.org/10.1007/BF02186230

Hanisak MD (1987) Cultivation of *Gracilaria* and other macroalgae in Florida for energy production. In: Bird KT, Benson PH (eds) Seaweed cultivation for renewable resources. Elsevier, New York, pp 191–218

Hirata H, Yamasaki S, Maenosono H et al (1994) Relative budgets of p O_2 and p CO_2 in cage polycultured red sea bream, *Pagrus major* and sterile *Ulva* sp. Aquac Sci 42:377–381

Jayasankar R, Seema C, Leelabhai KS (2006) Pond based grow out system of *Gracilaria verrucosa.* J Aquac Trop 21:161–167

Johnson RB, Kim JK, Armbruster LC et al (2014) Nitrogen allocation of *Gracilaria tikvahiae* grown in urbanized estuaries of Long Island Sound and New York City, USA: a preliminary evaluation of ocean farmed *Gracilaria* for alternative fish feeds. Algae 29:227–235. https://doi.org/10.4490/algae.2014.29.3.227

Kim JK, Kraemer GP, Neefus CD et al (2007) Effects of temperature and ammonium on growth, pigment production and nitrogen uptake by four species of *Porphyra* (Bangiales, Rhodophyta) native to the New England coast. J Appl Phycol 19:431–440. https://doi.org/10.1007/s10811-006-9150-7

Kim JK, Yarish C, Hwang EK et al (2017) Seaweed aquaculture: cultivation technologies, challenges and its ecosystem services. Algae 32(1):1–13. https://doi.org/10.4490/algae.2017.32.3.3

Lapointe B (1985) Strategies for pulsed nutrient supply to *Gracilaria* cultures in the Florida keys—interactions between concentration and frequency of nutrient pulses. J Exp Mar Biol Ecol 93:211–222. https://doi.org/10.1016/0022-0981(85)90240-0

Lapointe BE, Tenore KR (1981) Experimental outdoor studies with *Ulvafa sciata* Delile. I. Interaction of light and nitrogen on nutrient uptake, growth, and biochemical composition. J Exp Mar Biol Ecol 53:135–152. https://doi.org/10.1016/0022-0981(81)90015-0

Lombardi JV, Marques HLA, Pereira RTL et al (2006) Cage polyculture of the Pacific white shrimp *Litopenaeus vannamei* and the Cage polyculture of the Pacific white shrimp *Litopenaeus vannamei* and the Philippines seaweed *Kappaphycus alvarezii*. Aquaculture 258:412–415. https://doi.org/10.1016/j.aquaculture.2006.04.022

MacDonald BA, Robinson SMC, Barrington KA (2011) Feeding activity of mussels (*Mytilus edulis*) held in the field at an integrated multi-trophic aquaculture (IMTA) site (*Salmo salar*) and exposed to fish food in the laboratory. Aquaculture 314:244–251. https://doi.org/10.1016/j.aquaculture.2011.01.045

Mahadevan S, Nayar KN (1987) Ecology of oyster beds. In: Nayar KN, Mahadevan S (eds) Oyster culture—status and prospects. CMFRI bulletin 38, ICAR-Central Marine Fisheries Research Institute, Kochi, India, pp 7–13

Marinho-Soriano E, Azevedo CAA, Trigueiro TG et al (2011) Bioremediation of aquaculture wastewater using macroalgae and Artemia. Int Biodeterior Biodegradation 65:253–257. https://doi.org/10.1016/j.ibiod.2010.10.001

Maroni K (2000) Monitoring and regulation of marine aquaculture in Norway. J Appl Ichtyol-Zeitschr Fur Angew Ichtyol 16:192–195. https://doi.org/10.1046/j.1439-0426.2000.00256.x

Martínez-Espiñeira R, Chpoin T, Robinson S et al (2015) Estimating the biomitigation benefits of integrated multitrophic aquaculture: a contingent behavior analysis. Aquaculture 437:182–194. https://doi.org/10.1016/j.aquaculture.2014.11.034

Matos J, Costa S, Rodrigues A et al (2006) Experimental integrated aquaculture of fish and red seaweeds in Northern Portugal. Aquaculture 252:31–42. https://doi.org/10.1016/j.aquaculture.2005.11.047

Nagler PL, Glenn EP, Nelson SG et al (2003) Effects of fertilization treatment and stocking density on the growth and production of the economic seaweed *Gracilaria parvispora* (Rhodophyta) in cage culture at Molokai, Hawaii. Aquaculture 219:379–391. https://doi.org/10.1016/s0044-8486(02)00529-x

Neori A, Chopin T, Troell M et al (2004) Integrated aquaculture: rationale, evolution and state of the art emphasizing seaweed biofiltration in modern mariculture. Aquaculture 231:361–391. https://doi.org/10.1016/j.aquaculture.2003.11.015

Neori A, Shpigel M (1999) Algae treat effluents and feed invertebrates in sustainable integrated mariculture. World Aquac 30(46–49):51

Panigrahi A, Sundaram M, Jebha J et al (2017) Biofloc based nutrient dense culture system for nursery and grow-out farming of Pacific white shrimp *Penaeus vannamei* boone, 1931. Indian J Fish 64:22–32. https://doi.org/10.21077/ijf.2017.64

Pereira R, Yarish C (2008) Mass production of marine macroalgae. In: Jørgensen SE, Fath BD (eds) Encyclopedia of ecology, vol 3, Elsevier, Oxford, pp 2236–2247

Pietrak MR, Molloy SD, Bouchard DA (2012) Potential role of *Mytilus edulis* in modulating the infectious pressure of *Vibrio anguillarum* 02ß on an integrated multi-trophic aquaculture farm. Aquaculture 326–329:36–39. https://doi.org/10.1016/j.aquaculture.2011.11.024

Piyathilaka MAPC, Hettiarachchi M, Wanninayake WMTB (2012) Growth and health status of cultured edible oyster, *Crassostrea madrasensis* (Preston) in the Panadura estuary, Sri Lanka. J Natn Sci Found Sri Lanka 40(3):201–210. https://doi.org/10.4038/jnsfsr.v40i3.4694

Qi Z, Liu H, Li B, Mao Y et al (2010) Suitability of two seaweeds, *Gracilaria lemaneiformis* and *Sargassum pallidum*, as feed for the abalone *Haliotis discus hannai* Ino. Aquaculture 300:189–193. https://doi.org/10.1016/j.aquaculture.2010.01.019

Rodrigueza M, Montaño MNE (2007) Bioremediation potential of three carrageenophytes cultivated in tanks with seawater from fish farms. J Appl Phycol 19:755–762. https://doi.org/10.1007/s10811-007-9217-0

Rosenberg G, Probyn TA, Mann KH (1984) Nutrient uptake and growth kinetics in brown seaweeds: response to continuous and single additions of ammonium. J Exp Mar Biol Ecol 80(2):125–146. https://doi.org/10.1016/0022-0981(84)90008-X

Ryther JH, Goldman JC, Gifford CE (1975) Physical models of integrated waste recycling-marine polyculture systems. Aquaculture 5:163–177. https://doi.org/10.1016/0044-8486(75)90096-4

Samocha TM, Fricker J, Ali AM et al (2015) Growth and nutrient uptake of the macroalga *Gracilaria tikvahiae* cultured with the shrimp *Litopenaeus vannamei* in an integrated multi-trophic aquaculture (IMTA) system. Aquaculture 446:263–271. https://doi.org/10.1016/j.aquaculture.2015.05.008

Sarkar S, Rekha PN, Balasubramanian CP et al (2019) Bioremediation potential of the brackishwater macroalga *Gracilaria tenuistipitata* (Rhodophyta) co-cultured with Pacific white shrimp *Penaeus vannamei* (Boone). J Coast Res 86(spl): 248–254. https://doi.org/10.2112/SI86-036.1

Sarkar S, Rekha PN, Ambasankar K et al (2021) Bioremediation efficiency of indigenous seaweeds of Chennai coast in brackishwater system. Aquac Int 29(1):233–251. https://doi.org/10.1007/s10499-020-00621-1

Sarkar S, Rekha PN, Balasubramanian CP et al (2019) Culture of the seaweed, *Gracilaria tenuistipitata* in brackishwater pond as well as lagoon of Muttukadu,Chennai, Tamil Nadu. Ind J Fish 66(4):60–68. https://doi.org/10.21077/ijf.2019.66.4.90176-08

Sarkar S, Rekha PN, Biswas G et al (2019) Culture potential of the seaweed, *Gracilaria tenuistipitata* (Rhodophyta) in brackishwater tide fed pond system of Sundarban, India. J Coast Res 86(spl):258–262. https://doi.org/10.2112/SI86-038.1

Stigebrandt A, Aure J, Ervik A et al (2004) Regulating the local environmental impact of intensive marine fish farming III. A model for estimation of the holding capacity in the modelling—Ongrowing fish farm—monitoring system. Aquaculture 234:239–261. https://doi.org/10.1016/j.aquaculture.2003.11.029

Thomsen J, Himmerkus N, Holland N et al (2016) Ammonia excretion in mytilid mussels is facilitated by ciliary beating. J Exp Biol 219:2300–2310. https://doi.org/10.1242/jeb.139550

Troell M, Halling C, Nilsson A et al (1997) Integrated marine cultivation of *Gracilaria chilensis* (Gracilariales, Rhodophyta) and salmon cages for reduced environmental impact and increased economic output. Aquaculture 156(1–2):45–61. https://doi.org/10.1016/S0044-8486(97)00080-X

Troell M, Halling C, Neori A et al (2003) Integrated mariculture: asking the right questions. Aquaculture 226:69–90. https://doi.org/10.1016/S0044-8486(03)00469-1

Walkly A, Black IA (1934) An examination of the degtjareff method for determining soil organic matter and a proposed modification of the chromic acid titration method. Soil Sci 37(1):29–38. https://doi.org/10.1097/00010694-193401000-00003

Wilfart A, Prudhomme J, Blancheton JP et al (2013) LCA and energy accounting of aquaculture systems: towards ecological intensification. J Environ Manag 121:96–109. https://doi.org/10.1016/j.jenvman.2013.01.031

Wu HL, Huo YZ, Hu M et al (2015) Eutrophication assessment and bioremediation strategy using seaweeds co-cultured with aquatic animals in an enclosed bay in China. Mar Pollut Bull 95:342–349. https://doi.org/10.1016/j.marpolbul.2015.03.016

Yang Y, Chai Z, Wang Q et al (2015) Cultivation of seaweed *Gracilaria* in Chinese coastal waters and its contribution to environmental improvements. Algal Res 9:236–244. https://doi.org/10.1016/j.algal.2015.03.017

Yang YF, Fei XG, Song JM et al (2006) Growth of *Gracilaria lemaneiformis* under different cultivation conditions and its effects on nutrient removal in Chinese coastal waters. Aquaculture 254:248–255. https://doi.org/10.1016/j.aquaculture.2005.08.029

Zhou Y, Yang H, Hu H et al (2006) Bioremediation potential of the macroalga *Gracilaria lemaneiformis* (Rhodophyta) integrated into fed fish culture in coastal waters of North China. Aquaculture 252:264–276. https://doi.org/10.1016/j.aquaculture.2005.06.046

Chapter 41
Growout Culture of Red Snapper (*Lutjanus argentimaculatus*) in Cages

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Abstract The mangrove red snapper is a favorite food fish in many Asian countries. Most table-sized snappers are from wild catch while a limited amount is cultured in floating net cages offshore or in ponds. Snapper is important to coastal fisheries and can be an ideal candidate for culture in cages. The popularity of farming food fishes is growing around coastal states. Growout culture of snapper are described in pond culture and culture in cages in ponds. In rearing snapper in cages inside the ponds, fish sampling and harvesting are easily done and also it helps in preventing disease

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infection and securing of fish stocks during flooding. A preliminary assessment of growth performance was undertaken in cages in brackish water ponds of Marine Biological Research Station, Ratnagiri. Seventy-five juveniles of red snapper caught from the wild from the nearby estuaries having initial average length of 19.06 ± 0.42 cm and initial average weight of 115.91 ± 1.29 g were stocked at a stocking density of 300 numbers in 9 m^3 circular cages. The cages were harvested after a period of nine months. The red snapper attained a size range of 600 g to 1 kg weight. The results were encouraging, so fishermen should come forward to adopt the technology as an alternative livelihood option during lean season.

Keywords Circular cage · Red snapper · Brackish water

41.1 Introduction

Mangrove red snapper, *Lutjanus argentimaculatus,* is an important marketable species throughout the Indo-Pacific region, but it is never found in large quantities. It is an excellent food fish and a good aquaculture species. It commands a good export price with no limit on body size. Mangrove red snapper is a euryhaline species; it can tolerate freshwater, brackish water, and marine water (Emata 2003). Juvenile and young adult are found in mangrove estuaries and in the lower reaches of freshwater streams. An adult is often found in groups around coral reefs. It migrates offshore to deeper reef areas, sometimes penetrating to depths in excess of 100 m. It feeds mostly on fishes and crustaceans, mainly at night (Emata 2003).

Snapper belongs to the family *Lutjanidae.* There are 17 genera and 103 species in this family of which 65 species belong to genus Lutjanidae. Snappers are mainly confined to the tropical and sub-tropical waters. They are distributed in the Indo-West Pacific: east from Samoa and the Line Island, west to east Africa, south from Australia an north to the Ryukus Islands, Japan Juveniles of the species are found frequently in brackish estuarine waters an reach freshwater streams where adults grow as large as 1.2 m in total length before migrating off shore to deep reef areas (in excess of 100 m to spawn) (Coniza et al. 2012).

The use of fish by catch or trash fish as feed is the common practices during growout of snapper. However, the supply and quality of trash fish are inconsistent and expensive. Red snapper has a wide acceptance as an excellent food fish, high market price and limited harvests from wild stock; there is considerable interest in culturing a variety of snapper species. Despite the economic importance of this family, information pertaining to culture technique is quite limited (Davis et al. 2000).

The harvesting of wild individuals, either as broodstock whose eggs will hatch and develop under culture in ponds or cages or as early life-history stages for on-growing under confined and controlled conditions, is one of the strategies. This system of aquaculture production has been termed by the Food and Agriculture Organization (FAO) as capture-based aquaculture (CBA). Cage aquaculture is practiced in many parts of the world, and capture-based aquaculture in cages is also popular. Culturing of marine finfishes in cages has proven successful in many maritime states. In this, the adoption of sustainable capture-based aquaculture, fishermen group evinced interest in rearing finfish in suitable farming areas near their backyard and to take up the practice by the traditional coastal fishers of Ratnagiri district. A demonstration of cage culture of red snapper (*Lutjanus argentimaculatus*) was taken in brackish water ponds of Marine Biological Research Station, Zadgaon, Ratnagiri. Red snapper is very popular as a food fish and fetch a high market price throughout the year. The seed availability from the wild have contributed to substantial interest in red snapper aquaculture The participatory approach can give exposure to the local fishers on the finfish rearing aspects besides creating awareness on this lucrative farming technique (Thomas 2013).

41.2 Materials and Methods

41.2.1 Culture of Red Snapper in Cages

Red snapper, *Lutjanus argentimaculatus*, juveniles specimens were collected from the mangrove areas and stocked at an initial stocking density of three hundred

Fig. 41.1 Cages installed for snapper culture

Fig. 41.2 Recording of length and weight parameters of snapper

numbers of red snapper of initial average length 19.06 ± 0.42 cm and initial average weight 115.91 ± 1.29 g in 9 m^3 cage in brackish water ponds at Marine Biological Research Station, Ratnagiri, Maharashtra. Same sized fishes should be stocked to avoid cannibalism. The circular cage was moored with the help of bamboo in ponds. The cage was set in such a manner that when the tide recedes, the distance from the cage bottom to the pond bottom was 0.3 m and the height from the water surface to the highest point of the cage was 1.5 m (Fig. 41.1).

The fishes were fed with trash fish at 5% of body weight. The fishes were fed twice per day in morning and evening. Feed was sliced into pieces before feeding. The cages were checked and routine cleaning of the outer net was done to prevent clogging. The fishes were also checked regularly for diseases and mortality. The fishes were reared for a period of 8 months. As fishes above 100 g weight were stocked, the survival rate was almost 97.33%. The fishes were sampled every forth nightly for their length and weight gain (Fig 41.2). Approximately, price for the fish in local market was Rs. 450 kg^{-1}.

Table 41.1 Length and weight gain details

S. No.	Particulars	Observation
1	Initial average length	19.06 ± 0.42 cm
2	Final average length	34.34 ± 1.42 cm
3	Length gain (%)	175.15
4	Initial average weight	115.91 ± 1.29 g
5	Final average weight	636.91 ± 8.51 g
6	Weight gain (%)	549.49
7	Feed conversion ratio (FCR)	3.6
8	Survival	97.33%
9	Culture period	8 months

Table 41.2 Water parameters range

S. No.	Particulars	Observation
1	Temperature (°C)	26–31
2	pH	7.8–8.3
3	Salinity (ppt)	5–32
4	Dissolved oxygen (mg l^{-1})	5.2–8.0

41.3 Results and Discussion

The observation recorded on length and weight gain (Table 41.1) and water parameters (Table 41.2) are given below.

In capture-based aquaculture, carrying capacity of the water body where the cages are installed is an important factor. If the cages exceed its carrying capacity, it will affect fish growth and survival. Cages should be installed where there is a good water exchange so that uneaten feed and fish excreta do not become an environmental problem. There are constraints such as unreliable seed supply and lack of formulated feeds, but still, culture of red snapper is gaining popularity (Emata 2003). Juvenile Mangrove Red Snapper are mostly collected from waters with salinity range from 10 to 25 ppt (Chi and True 2017). Stocking spotted rose snapper in cages at body weights of around 100 g can be a good strategy, considering the FCR, good growth indicators, high economic return and achieving commercial sizes in less time (Olivares and Boza 1998). Interestingly capture-based aquaculture can provide good returns for depressed classes as an alternative livelihood for coastal communities.

References

Chi VO, True JD (2017) Recruitment and habitat ecology of juvenile mangrove red snapper (*Lutjanus argentimaculatus* Forsskal, 1775) in central Vietnam. Int J Fish Aquatic Stud 5(6):103–107

Coniza EB, Catacutan MR, Caballero PA (2012) Grow-out culture of mangrove red snapper (*Lutjanus argentimaculatus* Forsskal, 1775) in ponds, Aquaculture extension manual No. 54., SEFDEC Aquaculture Department, Tigbauan, Hoilo, Philippines, p 29

Davis DA, Bootes KL, Arnold RC (2000) Snapper (Family Lutjanidae) culture, Encyclopedia of aquaculture, pp 884–889

Emata A (2003) Aquaculture of the mangrove red snapper. SEAFDEC Asian Aquaculture 25(3):24

Olivares O, Boza J (1998) Growth of young spot snapper (*Lutjanus guttatus*) using granulated feed under laboratory conditions (ING). Uniqueness 15–16:45–48

Thomas S (2013) Course manual customized training in mariculture for Maldivian officials capture based aquaculture of red snapper *Lutjanus argentimaculatus* in cages. Mangalore Research Centre, ICAR-Central Marine Fisheries Research Institute, Mangalore, Karnataka, India, pp 184–188

Chapter 42
Better Management Practices and Their Adoption in Shrimp Farming: A Case from South Konkan Region, Maharashtra

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Abstract White leg shrimp *(Litopenaeus vannamei)* farming is getting faster attention in domestic as well as export markets. The shrimp exports are ever increasing during the recent past. Despite this increasing shrimp exports, a high percentage of shrimp consignment is rejected by importing countries because of non-compliance with international standards. It is, therefore, very much essential to adopt better management practices (BMPs) to achieve sustainability in shrimp farming. Considering this, investigation was undertaken in South Konkan districts of Maharashtra

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to study the adoption level among shrimp farmers about better management practices (BMPs). Data was collected with structured interview schedule from 59 shrimp farmers. A total of 40 better management practices recommended by CAA and NaCSA were used as framework to study the adoption level of shrimp farmers. Results revealed that around (43.18%) of the shrimp farmers were having low adoption level followed by 37.03% of shrimp farmers were having were having medium level of adoption regarding BMPs, and only 19.79% of shrimp farmers were found with high adoption about overall better management practices in shrimp farming. Majority of shrimp farmers were unaware of the maximum number of BMPs used during shrimp farming. It is, therefore, suggested to organize capacity development programs on regular basis for shrimp farmers about the current advances with regards to BMPs in shrimp farming which will helps to improve adoption level.

Keyword Better management practices · Adoption · Shrimp farmers · South Konkan · India

42.1 Introduction

The total estimated brackish water area in India is about 12.40 million ha, out of which 1.19 million ha is found suitable for brackish water shrimp farming (Anon 2014). Even though India is having huge potential brackish water area, only 152,595 ha is developed till 2019–2020 (MPEDA 2020). West Bengal is having maximum brackish water area under culture followed by Andhra Pradesh, Kerala, Tamil Nadu, Odisha, Gujarat and Maharashtra. India's total shrimp production during 2019–2020 is 8.0 lakh tons (MPEDA 2020), and Andhra Pradesh ranks first with a total production of 570,235 tons followed by West Bengal with total production of 77,668 tons (MPEDA 2020). Maharashtra occupies sixth position in cultured shrimp production with 6567 tons in the year 2019–2020 (MPEDA 2020).

Maharashtra is one of the major maritime states, offering vast scope for development of brackish water aquaculture. Maharashtra state has about 52,001 ha of potential brackish water area all along its coastline and adjacent creeks. Out of this area, 10,400 ha is reported to be suitable for shrimp farming as per the survey conducted by Government of Maharashtra in 2008. However, only 1356 ha are used for shrimp farming as per MPEDA (2020), and 9044 ha area is left which can be utilized for shrimp farming. Shrimp productivity of Maharashtra is 4.70 tons ha^{-1} yr^{-1}, whereas national average is 6.87 t ha^{-1} yr^{-1}. The main species cultured was black tiger shrimp (*Penaeus monodon*), which has been replaced since year 2009–2010 with white leg shrimp (*Litopenaeus vannamei)*. Seven coastal districts of Maharashtra,

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viz., Palghar, Thane, Greater Mumbai, Mumbai suburban, Raigad, Ratnagiri and Sindhudurg contribute significantly to the shrimp production of Maharashtra.

Pacific white shrimp *L. vannamei* was introduced in India in the year 2009, and it has emerged with a great potential in Indian shrimp culture industry. The culture of *L. vannamei* has been increasing with progressive pace, and its production has reached an all-time high of 353,413 t in the year 2014–2015 (Kumaran et al. 2017). The *L. vannamei* farming area has increased from 283 ha in the year 2009–2010 to 50,241 ha, and the production has also grown from 1731 to 353,413 metric t in 2014–2015. Andhra Pradesh is the leading state in aquaculture, having a contribution of 58% of cultured shrimp production to the total cultured shrimp production of a India. Tamil Nadu state is at the second position with an area of 5087 ha and production of 26,281 t. However, Gujarat state ranks first with an average production of 9 t ha^{-1} due to their superior infrastructure, biosecurity and adoption of better management practices (Kumaran et al. 2015).

Brackish water shrimp farming is one of the important economic activities in Maharashtra. However, shrimp farmers are facing a lot of challenges mainly due to disease incidence. Disease is the major threat to shrimp aquaculture production, profitability and sustainability in shrimp farming is questionable. It is, therefore, very much essential to adopt better management practices (BMPs) in shrimp farming right from the stage of pond preparation till post-harvest activities to achieve sustainability in shrimp farming. Therefore, it is necessary to understand the practices followed by farmers to know the causes of failure. Considering this fact, the present study has been undertaken to assess the extent of adoption of BMPs by the shrimp farmers along the South Konkan coast of Maharashtra in order to achieve sustainable yield in shrimp farming.

Considering above-mentioned facts and present situation, work has been undertaken along the South Konkan coast of Maharashtra, with the objective to study the extent of adoption of better management practices by shrimp farmers.

42.2 Materials and Methods

The study was conducted among shrimp farmers in two selected districts, viz., Ratnagiri and Sindhudurg districts of Maharashtra were selected. Total 72 shrimp farms were operational, out of which 59 shrimp farms were randomly selected from South Konkan region of Maharashtra. Among these, 17 shrimp farms in Ratnagiri district and 42 shrimp farms in Sindhudurg district.

Better management practices (BMPs) in brackish water shrimp farming recommended by Coastal Aquaculture Authority (CAA) (2005) and National Centre for Sustainable Coastal Aquaculture (NaCSA), MPEDA were used as broad framework for measuring the extent of adoption among shrimp farmers. The questions were formulated on the basis of these recommended practices and were categorized into subsections, viz., site selection and pond construction, pond preparation, water quality management, seed selection and stocking, health and biosecurity, feeding management, harvest and post-harvest management. A total of 40 BMPs were selected. The adoption of each BMPs by shrimp farmers were measured on three-point continuum, viz. three for complete adoption, two score partial adoption and one score for no adoption.

The collected data about adoption was analyzed to correlate the relationship with knowledge and adoption of better management practices. Adoption quotient was calculated separately for each farmer and its practices. It is the ratio of total score obtained by farmer to maximum score multiplied by 100. Total score obtained by farmer was calculated by adding scores obtained by farmer for each of the practice, whereas the maximum score was the score which can be obtained by a farmer if he adopts all the recommended practices. The formula for the adoption quotient was used as given by (Sengupta 1967) as follows:

$$\text{Adoption quotient} = \frac{\text{Total score by farmers}}{\text{Maximum score}} \times 100$$

Rank correlation coefficient was estimated Zar (2010) between the variables, i.e. knowledge and adoption by using the below given formula.

$$r_s = 1 - \frac{6\sum_{i=1}^{n} di^2}{n(n^2 - 1)}$$

42.3 Results and Discussion

42.3.1 Adoption Level of Shrimp Farmers About Individual BMPs in Shrimp Farming

The classification of shrimp farmers according to adoption of individual BMPs is given in Table 42.1.

Under site selection and pond construction, 58.99% shrimp farmers were observed with low adoption. The adoption level of shrimp farmers regarding site selection and pond construction practices such as facilities to be developed for good water supply and sedimentation and ideal shape of shrimp pond was very low. About 37.29% shrimp farmers found with medium adoption about site selection and pond construction. The practice which was medially adopted by shrimp farmer was minimum water depth to be maintained in pond, type of soil parameter checked before site selection. Salunkhe (2018) in North Konkan region, Maharashtra, reported medium adoption (69.81%) for practices such as water parameter checking prior site selection, biosecurity measures and low adoption (15.09%) for biosecurity measures for visitors and position of inlet and outlet. Kumaran et al. (2003) in Nagapattinam district, Tamil Nadu, reported 57% farmers had adopted the practices related to site selection.

Table 42.1 Classification of shrimp farmers according to adoption of individual BMPs

S. No.	BMPs in shrimp farming	Adoption categories	Percentage
1	Site selection and pond construction	High adoption	3.72
		Medium adoption	37.29
		Low adoption	58.99
2	Pond preparation	High adoption	18.80
		Medium adoption	43.42
		Low adoption	37.79
3	Water quality management	High adoption	5.08
		Medium adoption	47.46
		Low knowledge	47.46
4	Seed selection and stocking	High adoption	11.86
		Medium adoption	61.02
		Low adoption	27.12
5	Health and biosecurity	High adoption	16.59
		Medium adoption	26.39
		Low adoption	57.02
6	Feeding management	High adoption	59.78
		Medium adoption	19.87
		Low adoption	20.35
7	Harvest and post-harvest management	High adoption	14.57
		Medium adoption	24.75
		Low adoption	60.68

Mohite (2007) observed high adoption (39.49%) and medium adoption (28.94%) in site selection category. Gawde (2004) observed medium adoption of farm design and construction practices. Mohite (2007) observed that 64.54% farmers had high adoption in this category. Rawool (2005) reported that 47.92% of farmers had medium adoption in farm design and pond construction.

Among the pond preparation practices, net size required in water sluice gate followed by various stages of pond bottom preparation for removal of sludge from pond bottom were the major practices adopted by shrimp farmers. Similar result was also reported by Salunkhe (2018) in his study in North Konkan region, Maharashtra, mentioning that 77.36% farmers followed pond preparation practices. In contrast, Randive (2008) observed 90.91% of farmers highly adopted pre-stocking management. Sathe (2008) reported 72.34% respondents in the categories of moderately high and medium adoption level (26.60%) in pre-stocking management.

Around 47.50% shrimp farmers were having medium adoption followed by 47.42% shrimp farmers with low adoption about water quality management practices. The practices which were medially adopted by shrimp farmers were optimum level of water pH, optimum level of oxygen to be maintained in the pond and maintaining plankton bloom in the pond. The adoption level regarding practices such as required range of temperature, required range of salinity and required range of turbidity were low. Similarly, Gawde (2004) and Mohite (2007) observed medium adoption in water quality management practices in South Konkan region and Raigad district of Maharashtra. Salunkhe (2018) reported 81.13% adoption in water quality management practices by shrimp farmers of North Konkan region, Maharashtra. Kumaran et al. (2003) also reported 80% adoption in water quality management practices by shrimp farmers of Nagapattinam district of Tamil Nadu. In contrast to the present study, Balasubramaniam and Perumal (1990) observed 35% adoption of water and soil quality management in fish culture operations in Tamil Nadu, while Swathi Lekshmi et al. (2011) reported that 69.0% of shrimp farmers adopted water quality management. The non-availability of water parameter testing laboratory was the main reason for maximum percentage of medium adoption in water quality management.

Under seed selection and stocking, 61.02% shrimp farmers had medium adoption with regards to the measure to be taken prior to seed stocking in the pond, the ideal size of post larvae (PL) for stocking, type of seed used for stocking and type of hatchery for purchase of specific pathogen free (SPF) seed. Similar observations were reported by Salunkhe (2018) for practices such as quality of seed tested before stocking and stocking density to be maintained in pond.

Under pond health and biosecurity, slightly more than half of shrimp farmers (57.02%) had low adoption regarding practices such as therapeutic agents used to treat the diseases and mandatory farm area for effluent treatment plant (ETP). The cent percent shrimp farmers had low adoption about precaution to be taken when disease is virulent followed by 98.31% shrimp farmers had low adoption about mandatory farm area for reservoir, while 96.61% shrimp farmers had low adoption about measures to be taken to prevent entry of bird in to the pond. On the contrary, Salunkhe (2018) reported medium adoption of shrimp farmers regarding health management. Swathi Lekshmi et al. (2011) documented 88.0% of adoption quotient in health management category. Kumaran and Kalaimani (2005) in their study in Tamil Nadu revealed that 100% farmers adopted the practice of certified seeds. Kumaran et al. (2008) observed that 51.95% farmers adopted disease management in Tamil Nadu, India. The major risk nowadays in shrimp farming is occurrence of various diseases. Every shrimp farmer attempts to avoid these diseases. PCR tested, i.e., certified seed is the only option available with farmer to avoid vertical transmission of the disease. The shrimp industry observed big losses due to white spot syndrome virus (WSSV) in mid-nineties; therefore, farmers were taking due care for prevention of WSSV by stocking PCR tested seed. Majority of the shrimp farmers did not adopt precaution to be taken when disease is virulent, mandatory farm area for reservoir and measures to be taken to prevent entry of bird in to the pond. This is the main reason for low adoption regarding pond health and biosecurity in South Konkan region of Maharashtra.

The results revealed that majority of shrimp farmers (59.78%) had high adoption about feeding management practices. Feed is one of the important and essential inputs in shrimp farming. In the present study, high adoption was observed in feeding management practices. Majority of shrimp farmer in South Konkan region adopted the practices of method of spreading the feed all over the pond, number of feeding trays required for one ha farm area, type of feed to be used and feeding frequency for shrimp. Swathi Lekshmi et al. (2005), Rawool (2005) and Swathi Lekshmi et al. (2011) found more than 80% adoption quotient in feed management practices. On contrary, Salunkhe (2018) reported medium adoption about feeding management practices. Kumaran et al. (2003) did not find high adoption in the practice of estimation of feed quantity as per biomass.

42.3.2 Harvest and Post-harvest Management

A total of 24.75% shrimp farmers were found under medium adoption level regarding harvest and post-harvest management; about 14.57% shrimp farmers had high adoption about harvest and post-harvest management, while only 60.68% shrimp farmers had low adoption level about harvest and post-harvest management. Similar observation reported by Kumaran et al. (2008) in their study in Tamil Nadu and Andhra Pradesh mentioned that shrimp farmers had higher adoption gaps in harvest and post-harvest marketing.

42.3.3 Overall Adoption Level of Shrimp Farmers About Better Management Practices

Results with regard to overall adoption level of shrimp farmers about better management practices in shrimp farming is presented in Table 42.2.

In South Konkan region of Maharashtra, 43.18% shrimp farmers had low adoption level, and 37.03% shrimp farmers had medium adoption regarding overall better management practices in shrimp farming. Only 19.79% of shrimp farmers were found with high adoption about overall better management practices in shrimp farming. Similar results were reported by Srinath (1996) while studying adoption of shrimp culture practices in Ernakulam district, Kerala, and he reported low technology adoption in the traditional and rural sector shrimp farming. In contrast, Salunkhe (2018) in his study in North Konkan region reported that 83.02% farmers were found with high and 16.98% of farmers having medium adoption category. Sahuet al. (2014) in his study found 70% of farmers with medium adoption level in shrimp farming. The reason behind low level of adoption about such BMPs may be due to the fact that maximum numbers of shrimp farmers in Maharashtra were having low to medium

Table 42.2 Classification of shrimp farmers according to overall adoption level about better management practices

S. No.	Adoption categories	Percentage
1	High adoption	19.79
2	Medium adoption	37.03
3	Low adoption	43.18

level of knowledge regarding BMPs as well as improved shrimp farming practices. Also, majority of shrimp farmers were unaware of the maximum number of BMPs used during shrimp farming; hence, adoption level of BMPs in shrimp farming may be low.

42.4 Conclusions

This study has provided a detailed understanding regarding adoption level of shrimp farmers about better management practices in shrimp farming. Shrimp farmers showed low adoption regarding better management practices in shrimp farming. There is need to organize capacity development programs on regular basis to update the knowledge of shrimp farmers about the current advances with regards to BMPs in shrimp farming which will help to improve adoption level. There is need for implementation of strict regulation to adopt BMPs from Coastal Aquaculture Authority (CAA). Department of Fisheries and College of Fisheries/Fisheries Institutions should conduct extension campaigns to get scientific and location-specific information about BMPs in shrimp farming.

References

Anon (2014) Handbook of fisheries statistics. Department of Animal Husbandry, Dairying and Fisheries, Ministry of Agriculture, Government of India, New Delhi, 157 p

Balasubramaniam S, Perumal G (1990) Adoption behaviour and impact of technology transfer among fish farmers. Fish Technol 27:75–78

CAA (Coastal Aquaculture Authority) (2005) Guidelines for regulating coastal aquaculture. Gazette of India, Government of India. No. 528: 81–108. http://caa.gov.in/uploaded/doc/Guidelines-Englishnew.pdf

Gawde MM (2004) Adoption of improved aquaculture practices by shrimp farmers in South Konkan region of Maharashtra, India. MFSc Thesis, Dr. Balasaheb Sawant Konkan Krishi Vidyapeeth, Dapoli, India, p 56

Kumaran M, Kalaimani N (2005) Information utilization and extension needs assessment in shrimp farming Tamil Nadu. Project No. CIBA/SSD/03, Technology transfer, socioeconomic aspects and informatics in brackishwater aquaculture. ICAR-Central Institute of Brackishwater Aquaculture, Chennai, India, p 27

Kumaran M, Ponnusamy K, Kalaimani N (2003) Diffusion and adoption of shrimp farming technologies. Aquac Asia 8(2):20–25

Kumaran M, Alagappan M, Raja S et al (2008) Extent of adoption gaps in good management practices (GMPs) of shrimp farming. Indian J Fish 55(3):267–272

Kumaran M, Kumar JA, Anand P et al (2015) Training needs of extension personnel in Pacific white shrimp (*Litopenaeus vannamei*) farming. Fish Technol 52:265–270

Kumaran M, Ravisankar T, Anand PR et al (2017) Knowledge level of shrimp farmers on better management practices (BMPs) of *Penaeus vannamei* farming: a comparative assessment of east and west coasts of India. Ind J Fish 64:93–99

Mohite YT (2007) Efficacy and constraints in adoption of improved aquaculture practices by shrimp farmers in Raigad district of Maharashtra. MFSc Thesis, Dr. Balasaheb Sawant Konkan Krishi Vidyapeeth, Dapoli, India, p 58

MPEDA (Marine Products Export Development Authority) (2020) Guidelines for better management practices for sustainable shrimp farming. https://www.mpeda.gov.in/MPEDA/lv.php

Randive PC (2008) Adoption of Shrimp health management practices in the South Konkan region of Maharashtra. MFSc Thesis, Dr. Balasaheb Sawant Konkan Krishi Vidyapeeth, Dapoli, India, p 116

Rawool MS (2005) Efficacy and constraints in adoption of improved aquaculture practices by shrimp farmers in Thane district of Maharashtra. MFSc Thesis, Dr. Balasaheb Sawant Konkan Krishi Vidyapeeth, Dapoli, India, p 53

Sahu R, Swadesh P, Kumar NR et al (2014) Adoption of better management practices and constraints in shrimp farming in selected district of Odisha. Ind J Fish 61(2):151–155

Salunke AB (2018) Efficacy and constraints in adoption of Penaeus (*Litopenaeus vannamei* Boone, 1931) culture practices by the farmers of North Konkan region of Maharashtra. MFSc Thesis, Dr. Balasaheb Sawant Konkan Krishi Vidyapeeth, Dapoli, India

Sathe AR (2008) Adoption of shrimp health management practices in the North Konkan region of Maharashtra. MFSc Thesis, Dr. Balasaheb Sawant Konkan Krishi Vidyapeeth, Dapoli, India, p 96

Sengupta T (1967) A simple adoption scale for farmers for high yielding varieties of paddy. Ind J Ext Educ 3:107–115

Srinath K (1996) Adoption of shrimp culture practices by farmers. Seafood Exp J 27(10):9–12

Swathi Lekshmi PS, Balasubramani N, Chandrakandan K (2011) Diffusion of scientific shrimp farming through various stages of the adoption period. Trop AgricRes Exten 14(4):93–98

Swathi Lekshmi PS, Chandrakandan K, Kumaran M et al (2005) Socio-economic profile of shrimp farmers and its influence on the extent of adoption of shrimp culture technologies. Fishery Tech 42(2):225–230

Zar JH (2010) Biostatical analysis, 5th edn. Singapore, Pearson Education, p 945

Chapter 43
Studies on Growth and Mortality of Spineless Cuttlefish, *Sepiella inermis* (Orbigny, 1848) from Ratnagiri (Arabian Sea; Northwest Coast of India)

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Abstract Growth and mortality parameters of spineless cuttlefish, *Sepiella inermis* were estimated based on length-frequency data collected from seawater at Ratnagiri from March 2015 to February 2017. Asymptotic length ($L\infty$) and growth coefficient (K) were estimated to be 107 mm and 1.6 yr^{-1} for Ratnagiri by ELEFAN I (Electronic Length-Frequency Analysis). The instantaneous rate of total mortality (Z), natural mortality (M) and fishing mortality (F) were estimated to be 4.47 yr^{-1}, 3.23 yr^{-1} and 1.24 yr^{-1} respectively along the Maharashtra coast. Age at length zero, t_o was estimated to be 0.00 969 year. *S. inermis* was found to attain a size of 60, 86, 97 and 103 mm at the end of 6, 12, 18 and 24 months, respectively. Length at first capture was found to be 41.10 mm. The current exploitation ratio (E) was determined to be 0.28.

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Keywords Spineless cuttlefish · *Sepiella inermis* · Age and growth · Mortality · Exploitation ratio

43.1 Introduction

Cephalopods including squids, cuttlefishes and octopuses are commercially important marine fishery resources exploited along the entire Indian coast. Squids and cuttlefishes support the largest catches of all molluscan fisheries (King 1995). The production of cephalopods in India during the year 2018 stood at 217,699 tonnes (CMFRI 2019) contributing to 5.9% of the total marine fish production. In India, around six species of cuttlefish are commonly landed namely, *Sepia pharaonis, S. aculeate, S. elliptica, S. prashadi, S. brevimana* and *Sepiella inermis* (Meiyappan and Mohamed 2003). They are widely distributed along both east and west coasts upto depths of about 40 m. *S. inermis* belonging to family Sepidae is an important species of cuttlefish captured off Ratnagiri coast. Trawlers are the main gear used to capture *S. inermis*. In Kerala and Tamil Nadu, shore seines and boat seines are also involved in its exploitation (Silas 1968; Silas et al. 1985). Along the Mumbai coast, *S. inermis* is caught by the artisanal gear dol net and mini trawls (Sundaram and Khan 2011). Cuttlefishes being one of the important seafood commodities are mostly exported in frozen form (Anon 2020).

The perseverance of any species in a particular habitat mainly depends on the life history traits of that specific species (Das et al. 2017, 2018; Gurjar et al. 2017, 2018; Kende et al. 2020; Kumar et al. 2014; Prasad et al. 2012; Raghavan et al. 2011, 2018). Under the existing environmental conditions, life-history traits must produce sufficient recruitment for a particular population to persevere. In this context, adequate information about growth, mortality (fishing and natural), population structure, and exploitation level of a stock is essential for their effective conservation and sustainable management, mainly when the species form an important part of the artisanal fisheries sector (Das et al. 2017, 2018; Gurjar et al. 2018; Kumar et al. 2014). Recently, the cephalopods have gained commercial importance requiring fishery management measures for sustainable exploitation of this resource. Very few studies on growth and mortality of *S. inermis* are reported along the west coast of India. The present investigation was undertaken to study the growth and mortality of *S. inermis* along the coast of Maharashtra.

43.2 Materials and Methods

43.2.1 Sample Collection and Study Area

The Mirkarwada landing centre (16° 59′ 42″ North latitude and 73° 16′ 14″ East latitude) of Ratnagiri located in Maharashtra along the northwest coast of India was selected for the present study. The specimens of *S. inermis* were sampled from commercial trawl by catches at weekly intervals from March 2015 to February 2017. Care was taken to record the length measurements of cuttlefishes of all size groups. A total of 2071 specimens were measured for the present study.

43.2.2 Growth Parameters, Growth Performance Index ($\varnothing'$) and Length at Age

The dorsal mantle lengths (DML) of all samples were measured using a divider and measuring board to the nearest millimeter as described by CMFRI (1995) for the estimation of length-frequency distribution. The length-frequency data were grouped into 4 mm class interval. The day's catch was divided by sample weight and resultant factor was multiplied by the actual number measured and distributed in each group. This way the samples were raised for the day's catch. The length frequency of all four days of observation in a month was added. The raised numbers were then multiplied by monthly raising factor to get the raised number for the month following Sekharan (1962). This formed the basic data for the growth, mortality and population parameters. The growth parameters ($L\infty$ and K) were estimated by ELEFAN-I using FiSAT computer software program developed by Gayanilo et al. (1996). Hypothetical age at which length is zero (t_0) was estimated using von Bertalanffy plot (1934). In order to compare the growth of *S. inermis* from the study area with those from other studies, Ø′ (an index for the comparison of growth performance in marine animals with the von Bertalanffy type of growth) was used. Details on growth comparison using Ø′ as an index are discussed in Munro and Pauly (1983): $\varnothing' = \text{Log}\, K + 2 \times \text{Log}\, L\infty$. The length attained by *S. inermis* at age was estimated using von Bertalanffy growth equation (von Bertalanffy 1934) as $Lt = L\infty\{1 - \exp[-k(t - t_0)]\}$.

43.2.3 Mortality Parameters and Exploitation Ratio

The total instantaneous mortality (Z) was calculated by following the length-converted catch curve (Pauly 1983, 1984) method by employing FiSAT program. The natural mortality coefficient (M) was calculated by using Pauly's method (1980). The fishing mortality (F) was estimated using the relationship, $F = Z - M$. The exploitation ratio (E) was calculated by the formula given by Ricker (1975), $E = F/Z$.

43.3 Results and Discussion

Random samples of spineless cuttlefish collected from commercial trawl catches were ranged in Dorsal Mantle Length (DML) from 22 to 102 mm. The DML ranges observed in the present study are comparable with those recorded by Chakraborty et al. (2013) and Sundaram and Khan (2009).

43.3.1 Growth Parameters, Growth Performance Index (∅′) and Length at Age

Summary of the growth parameters L_∞ (mm) and K (per year) available for *S. inermis* in different localities is given in Table 43.1. Most values referred for earlier studies have been computed separately for males and females of *S. inermis*. However, in the present study, all data was recorded for pooled individuals irrespective of their gender. Therefore, to make the comparisons with earlier studies meaningful, mean values of the growth parameters were derived and are mentioned in parentheses as a combined value for each parameter in Table 43.1.

The values of K obtained in the present study agree with the findings of most of the above authors from southwest coast of India. The slightly higher values of the growth coefficients can be attributed to the shorter life span of *S. inermis*. The value of the growth performance index (Ø′) of *S. inermis* during the present investigation from Ratnagiri was estimated at 4.26. Mean Ø′ values for studies in different localities for *S. inermis* were 4.16 to 4.35 for both sexes and these are similar to the results obtained in the present study, indicating the reliability of estimates of growth parameters. The phi-prime values are very similar within related taxa and have narrow normal

Table 43.1 Summary of the growth parameters and *phi-prime* available for *S. inermis* in different localities

Species	L_∞		K		t_0	Ø′	Locality	Author
	♂♂	♀♀	♂♂	♀♀				
S. inermis	129		1.37		–	4.35	Saurashtra	Kasim (1988)
	89	107	2.0	1.16	–	4.16	Madras	Sarvesan (1996)
	(98)		(1.58)					
	106		1.81		–	4.30	Mumbai	Chakraborty et al. (2005)
	68	97	2.63	2.35	–	4.22	Mumbai	Sundaram and Khan (2009)
	(83)		(2.49)					
	108	102	1.81	1.74	–	4.28	Mumbai	Chakraborty et al. (2013)
	(105)		(1.77)					
	107		1.6		0.0096	4.26	Ratnagiri	Present study

distributions (Sparre and Venema 1998; Parida et al. 2014). A von Bertalanffy growth curve often cuts the length axis at a value different from zero, hence t_o, the theoretical age at length zero often has a small positive or more usually a small negative value (King 1995). The value of t_o in the present study corroborates this fact. *S. inermis* was found to attain a DML of 60, 86, 97 and 103 mm at the end of 6, 12, 18 and 24 months, respectively. Sundaram and Khan (2009) reported that males attained a size of 50 and 63 mm and females 67 and 88 mm at the end of six and twelve months respectively. In above case, the mean values were obtained for the sexes combined. Accordingly, *S. inermis* grew to a size of 56.5 mm and 77.5 mm at the end of six and twelve months respectively. As per Kasim (1988), *S. inermis* reached a mantle length of 56.0 mm and 81.0 mm at the end of six and ten months respectively. The growth of *S. inermis* at 6 and 12 months in the present study appears to be more as compared to published data on the species.

43.3.2 Mortality Parameters and Exploitation Ratio

In a marine environment, many factors affect the survival rates in a population (King 1995). Natural mortality rates, therefore, vary from year to year and are evident from findings of the study when compared with other studies. The mortality rates were estimated for pooled individuals in the present study. The instantaneous rate of total mortality, *Z* (Fig. 43.1), natural mortality, *M* and fishing mortality, *F* were estimated to be 4.47 yr^{-1}, 3.23 $yr^{-1}$and 1.24 yr^{-1} respectively from Ratnagiri coast. Exploitation ratio was found to be 0.5. Wherever gender-wise mortality rates and

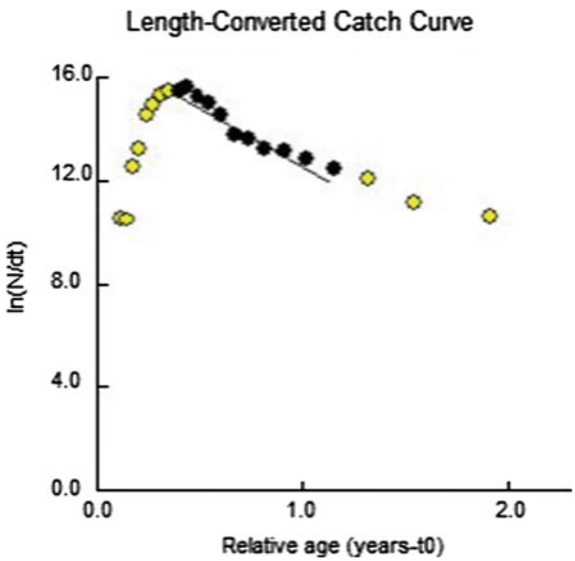

Fig. 43.1 Length converted catch curve for estimation of total mortality coefficient for *S. inermis*

exploitation ratios were earlier reported for *S. inermis*, mean values were obtained and are mentioned in parentheses (Table 43.2). Fishing mortality rate and exploitation ratio in the present study is lower as compared to the results of Kasim (1988) and Chakraborty et al. (2013) but agrees with the findings of Sundaram and Khan (2009). The optimum *E* value 0.5 was suggested by Gulland (1971) for overall fisheries management. The present findings indicate lower fishing intensity on *S. inermis* along the Ratnagiri coast.

Table 43.2 Summary of the mortality parameters and *E* available for *S. inermis* in different localities

Locality	M		F		Z		E		Author
	♂♂	♀♀	♂♂	♀♀	♂♂	♀♀	♂♂	♀♀	
Saurashtra	2.09		4.16		6.25		0.66		Kasim (1988)
Mumbai	5.09		2.39		7.48		0.31		Sundaram and Khan (2009)
Mumbai	3.07	3.94	5.51	7.40	8.58	11.64	0.64	0.65	Chakraborty et al. (2013)
	(3.50)		(6.45)		(10.11)		(0.64)		
Ratnagiri	3.23		1.24		4.47		0.28		Present study

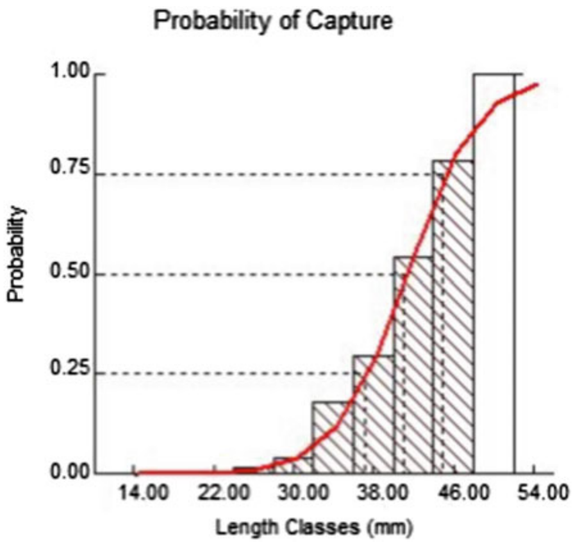

Fig. 43.2 Probability of capture of *S. inermis*

43.3.3 Length at First Capture (Lc)

The probability of capture for trawl type selection was derived using FiSAT computer programme. Length at which 50% fish are vulnerable to gear was found to be 41.10 mm for Ratnagiri (Fig. 43.2). Similar to the present study Sundaram and Khan (2009) also recorded length at capture (L_{50}) for females 43.88 mm and for the males 41.84 mm *S. inermis*. The mesh size of trawl cod end determines the varying estimates of length at first capture described to a great extent, the trawl net's selectivity.

43.4 Conclusions

There is a scope for maximizing the yield of *S. inermis* from the Ratnagiri coast by increasing the fishing pressure from current level upto an optimum level. However, given the nature of multispecies demersal trawl fishery and conservation of *S. inermis,* it is advocated to maintain the exploitation pressure at current level.

References

Anon (2020) Handbook on fisheries statistics 2020. Department of Fisheries, Ministry of Fisheries, Animal Husbandary and Dairying, Government of India, New Delhi, p 176

Chakraborty SK, Biradar RS, Jaiswar AK et al (2005) Population parameters of some commercially important fishery resources of Mumbai coast. CIFE Spl Publ, ICAR-Central Institute of Fisheries Education (CIFE), Mumbai, Maharashtra, India, p 63

Chakraborty SK, Biradar RS, Jaiswar AK et al (2013) Growth, mortality and population parameters of three cephalopod species, *Loligo duvauceli* (Orbigny), *Sepia aculeata* (Orbigny) and *Sepiella inermis* (Orbigny) from north-west coast of India. Indian J Fish 60(3):1–7

CMFRI (1995) A manual for standardised linear measurements of exploited finfish and shellfish. CMFRI Spl Publ, pp78

CMFRI (2019) CMFRI annual report 2018–2019. ICAR-Central Marine Fisheries Research Institue (CMFRI), Kochi, Kerala, India, p 368

Das AK, Manna RK, Rao DSK et al (2017) Status of the River Krishna: water quality and riverine environment in relation to fisheries. Aquat Ecosyst Health Manage 20(1–2):160–174. https://doi.org/10.1080/14634988.2017.1296312

Das I, Hazra S, Das S et al (2018) Present status of the sustainable fishing limits for hilsa shad in the northern Bay of Bengal, India. Proc Natl Acad Sci India Sect B Biol Sci 1–8. https://doi.org/10.1007/s40011-018-0963-3

Gayanilo FC Jr, Sparre P, Pauly D (1996) FAO- ICLARM stock assessment tools (FiSAT) users guide. FAO computerised information series No. 8 (Fisheries). FAO, Rome, pp 124

Gulland JA (1971) The fish resource of the oceans. Fishing News Books Ltd., West Byfleet, Surrey, p 255

Gurjar UR, Sawant MS, Takar S et al (2017) Biometric analysis of white sardine, *Escualosa thoracata* (Valenciennes, 1847) along the Ratnagiri coast of Maharashtra, India. J Exp Zool India 20(2):845–849

Gurjar UR, Sawant MS, Pawar RA et al (2018) Reproductive biology and fishery of the white sardine, *Escualosa thoracata* (Valenciennes, 1847) from the Ratnagiri coast, Maharashtra. Indian J Mar Sci 47(12):2485–2491

Kasim HM (1988) Growth, mortality rates and stock assessment of the cuttlefish *Sepiella inermis* (Ferussac and d'Orbigny) in Saurashtra waters. J Mar BioI Ass India 30(1–2):98–108

Kende DR, Nirmale VH, Gurjar UR et al (2020) Biometric analysis of moustached thryssa *Thryssa mystax* (Bloch and Schneider, 1801) along the Ratnagiri coast of Maharashtra, India. Indian J Fish 67(2):110–113

King M (1995) Fisheries biology, assessment and management. Fishing Books News, Osney Mead, Oxford, OX2, OEL, England, pp 158–160

Kumar RS, Sarkar UK, Gusain O et al (2014) Age, growth, population structure and reproductive potential of a vulnerable freshwater mullet, *Rhinomugil corsula* (Hamilton, 1822) from a Tropical River Betwa in Central India. Proc Natl Acad Sci India Sect B Biol Sci 84(2):275–286. https://doi.org/10.1007/s40011-013-0214-6

Meiyappan MM, Mohamed KS (2003) Cephalopods. In: Joseph MM, Jayaprakash AA (eds) Status of exploited marine fishery resources of India. Central Marine Fisheries Research Institute, Cochin, pp 221–227

Munro JL, Pauly D (1983) A simple method for comparing growth of fish and invertebrates. ICLARM Fishbyte 1(1):5–6

Parida PK, Jaiswar AK, Palaniswamy R et al (2014) Growth and mortality of *Osteogeneiosus militaris* (Linnaeus 1758) from Mumbai waters. Indian J Fish 61(1):12–15

Pauly D (1980) On the inter-relationships between natural mortality, growth parameters and mean environmental temperatures in 175 fish stocks. ICES J Mar Sci 39(2):175–192

Pauly D (1983) Some simple methods for the assessment of tropical fish stocks. Fish Tech Pap 234, FAO, Rome, pp 1–52

Pauly D (1984) Length converted catch curve, a powerful tool in fisheries research in the tropics (part-II). ICLARM FishByte 2(1):17–19

Prasad G, Ali A, Harikrishnan M et al (2012) Population dynamics of an endemic and threatened yellow catfish, *Horabagrus brachysoma* (Gűnther) from River Periyar, Kerala, India. J Threatened Taxa 4(2):2333–2342. https://doi.org/10.11609/JoTT.o2590.2333-42

Raghavan R, Ali A, Dahanukar N, Rosser A (2011) Is the Deccan Mahseer, *Tor khudree* (Sykes, 1839), (Pisces: Cyprinidae) fishery in the Western Ghats sustainable? A participatory approach to stock assessment. Fish Res 110(1):29–38. https://doi.org/10.1016/j.fishres.2011.03.008

Raghavan R, Ali A, Philip S, Dahanukar N (2018) Effect of unmanaged harvests for the aquarium trade on the population status and dynamics of redline torpedo barb: a threatened aquatic flagship. Aquat Conserv Mar Freshw Ecosyst 28(3):567–574. https://doi.org/10.1002/aqc.2895

Ricker WE (1975) Computation and interpretation of biological statistics of fish populations. Bull Fish Res Board Can 191:1–382

Sarvesan R (1996) Investigation on the biology of two commercially important Cuttlefishs (*Sepia brevimana* and *Sepiella inermis*) of Madras Coast. PhD Thesis, University of Madras, p 140

Sekharan KV (1962) On the oil sardine fishery of the Calicut area during the years 1955–56 to 1958–59. Indian J Fish 9(2):679–700

Silas EG (1968) Cephalopoda of the west coast of India collected during the cruises of the research vessel 'VARUNA', with catalogue of the species known from the Indian Ocean. Proc Symp Mollusca Mar Biol Ass India I:277–359

Silas EG, Nair KP, Sarvesan R et al (1985) Cephalopod production in India and constituent maritime states. Bull Cent Mar Fish Res Inst 37:80–87

Sparre P, Venema SC (1998) Introduction to tropical fish stock assessment. Part I: manual, FAO Technical paper no. 306/Rev, 2. FAO, Rome, p 407

Sundaram S, Khan MZ (2009) Stock assessment of *Sepiella inermis* (Orbigny, 1848) from Mumbai waters. Mar Biol Assoc India 51(2):178–183

Sundaram S, Khan MZ (2011) Biology of the spineless cuttlefish *Sepiella inermis* (Orbigny, 1848) from Mumbai waters. Indian J Fish 58(2):7–13

von Bertalanffy L (1934) Untersuchengen uber die Gesetzlichkeiten des Wachstums. W Roux' Archiv f Entwicklungsmechanik 131:613–652

Chapter 44
Effect of Electron Beam Irradiation in Combination with Other Treatments on Shrimp Allergen, Tropomyosin

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Abstract A hurdle technology-based approach for the reduction in immunogenicity of shrimp major allergen, tropomyosin was investigated by combining electron beam irradiation at 5 kGy and boiling, autoclaving, trypsin and chymotrypsin treatments along with peeled raw shrimp as control. Shrimp extracts were prepared from the irradiated sample and evaluated SDS PAGE profile, IgE binding ability and immunogenicity of tropomyosin using pooled sera of shrimp sensitive individuals. Electron beam irradiation resulted in significant ($p < 0.05$) decrease in the IgE activity in the case of all treatments. The SDS PAGE analysis showed the presence of tropomyosin in all the treatments except autoclaving in combination with or without electron beam irradiation. A pronounced reduction in allergenicity was observed in the treatment of

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autoclaving in combination with electron beam irradiation. The combined application of autoclaving and electron beam irradiation can be utilized for the preparation of hypoallergic shrimp.

Keywords Electron beam irradiation · IgE activity · Immunoblotting · Shrimp tropomyosin

44.1 Introduction

Seafood is a preferred food commodity globally because of its enrichment in beneficial nutrients like polyunsaturated fatty acids, vitamins and minerals. Seafood comprises delicacies like shellfishes which include shrimps, an important commodity traded across nations. Shellfishes belong to the eight number groups of food allergens listed by the Food and Agriculture Organization (FAO) of the United Nations and World Health Organization (FAO/WHO 2001). Adverse immunological responses due to food allergens significantly affect food allergic individuals and which can lead to hypersensitive responses including the worst and life-threatening condition of anaphylaxis. Seafood allergy comes under type I immediate hypersensitivity reaction which is mediated through immunoglobulin E (IgE). In addition to allergic reaction mediated through consumption of seafood, it can also result from inhalation of cooking vapours, direct skin contact of material while handling. Among the identified shrimp allergens, tropomyosin is distinguished as a major allergen in many species, which is a myofibrillar protein involved in the muscle contraction process along with actin and myosin. It has a molecular weight ranging from 34 to 38 kDa (Motoyama et al. 2007). Around 80% of shrimp-sensitive individuals are able to produce IgE against shrimp tropomyosin (Daul et al. 1994). It is a highly heat-stable protein having two homodimers of α-helix coiled structure, around the actin filament (Rahman et al. 2010). Other minor allergens known are myosin light chain, arginine kinase and sarcoplasmic calcium-binding proteins (Yu et al. 2003; Ayuso et al. 2008; Shiomi et al. 2008).

Labelling foods containing listed allergens is mandatory and important for sensitive consumers. The main management strategy advised for a sensitive individual is the strict avoidance of allergic food. As complete avoidance can lead to conditions of nutritional deficiencies, alternative measures to tackle the allergens by means of processing are gaining attention. Many processing techniques are employed regularly to enhance the functional and nutritional properties of food materials. In thermal processing, allergenicity is altered by changing protein structure, alteration of conformational epitopes and increased digestibility along with undesirable effects on quality attributes (Ekezie et al. 2018). While in non-thermal processing methods, minimal changes in quality attributes are observed. The application of the 'hurdle technology' concept will be more effective in reducing allergenicity. The consumers demand for minimally processed foods having decreased allergenicity and marginal changes in the organoleptic and nutritional characteristics encouraged the hurdle concept

(Khan et al. 2019) which involves a combination of preservation/processing methods successfully used globally to effectively preserve foods (Singh and Shalini 2016; Pal et al. 2017).

The hurdle technology methods reported for crustacean allergen management include application of gamma irradiation along with boiling in *Penaeus vannamei* by Zhenxing et al. (2007a), application of PUV light with boiling in *Litopenaeus setiferous* by Shriver et al. (2011), application of ultrasound along with boiling in *Scylla paramamosain* by Yu et al. (2011) and application of high-pressure processing along with heating in *Litopenaeus vannamei* by Long et al. (2015). Irradiation techniques using gamma and electron beams are effectively used to improve food safety. In comparison to gamma irradiation, electron beam irradiation is more eco-friendly, efficient, and high-throughput technology (Zygoura et al. 2011). Liu et al. (2017) evaluated the efficacy of electron beams in reducing the IgE binding ability of frozen shrimp. The effectiveness of electron beam in combination with other thermal and non-thermal processes is not reported. So, in this study, a hurdle technology-based approach to reduce the shrimp allergenicity due to tropomyosin by combining electron beam irradiation with thermal and non-thermal processing methods was investigated.

44.2 Materials and Methods

44.2.1 Collection of Human Sera

Blood samples were drawn from 13 shrimp-sensitive individuals with a history of immediate hypersensitive reaction and a positive skin prick test to shrimp was collected from the record of Mary Queens Hospital, Allergy and Asthma Research Centre, Kochi, Kerala. Individual sera were prepared by centrifuging at 2500 rpm for 20 min at 25 °C and stored at −20 °C. The various symptoms of the sensitive individuals are urticaria, breathing problems, diarrhoea, swelling of face and hands and one patient with a history of anaphylaxis and are detailed in our previous report (Laly et al. 2019). Pooled sera from sensitive individuals were prepared by mixing them at equal proportions. Sera from three healthy individuals with no sensitivity to shrimp was pooled and used as a control.

44.2.2 Preparation of Shrimp Samples

Freshly caught flower tail shrimp (*Metapenaeus dobsoni)* samples were procured from Kalamukku landing centre, Kerala and transported immediately after icing at a 1:1 ratio (shrimp to ice) in an insulated box to the laboratory. Beheaded and peeled

M. dobsoni was divided into equal lots and further subjected to thermal and non-thermal processing treatments. The boiled shrimp sample was prepared by boiling for a period of 10 min. Autoclaved shrimp sample was prepared by autoclaving at 121 °C for 15 min. Trypsin treated sample was prepared by the addition of trypsin solution (0.5%, pH 7.5) at a 1:2 ratio to raw peeled shrimp, kept at a water bath temperature of 50 °C. Similarly, the chymotrypsin treated sample was prepared by the addition of chymotrypsin solution (0.5%, pH 7.8) at 1:2 ratio to raw peeled shrimp, kept at a water bath temperature of 50 °C. After trypsin and chymotrypsin treatment the enzyme activity was stopped by boiling for 5 min. Processed samples and raw peeled shrimp samples (control) were packed in a polythene cover and sealed. The samples were transported in iced condition (1:1) in an insulated box for the irradiation process.

44.2.3 Electron Beam Irradiation of Processed Shrimp

The packed samples were subjected to electron beam irradiation of 5 kGy (Fig. 44.1) on both sides using a linear EB RF accelerator (Energy 5 meV, beam power 40 kW, EB tech., Board of Radiation and Isotope Technology, Mumbai). Before the irradiation process, the packed samples were arranged in an aluminium tray kept in the conveyor belt. The conveyor velocity was set at 10 m min^{-1}. The dosimeters (Bruker Instruments, Germany) were used to measure the actual adsorbed dose level. The actual dose obtained in the sample was within ± 0.02 kGy of the target dose. The

Fig. 44.1 Electron beam irradiation of raw and treated shrimp samples

irradiated samples were transported in the insulated boxes in iced condition (1:1) to the laboratory for further analysis.

44.2.4 Preparation of Shrimp Extract

The treated shrimp meat was homogenized and extracted with 0.01 M phosphate-buffered saline (PBS) at 1:4 ratios and followed by centrifugation at 8000 rpm for 20 min as per the method of Motoyama et al. (2006). Then collected the supernatant and subjected to further analysis. The protein content in irradiated shrimp extracts was determined by the Biuret method (Gornall et al. 1949) using bovine serum albumin (BSA) as standard.

44.2.5 Estimation of IgE Activity by ELISA

IgE activity of extracts prepared from electron beam irradiated shrimp samples was estimated as per the method of Ishikawa et al. (1997) using 96 well flat bottomed polystyrene microtitre plates. The microtitre plates were coated with shrimp extracts diluted with 0.05 M carbonate buffer (pH 9.5) at 1:1000. The coated wells were immunoreacted with pooled serum from the patient as well as control at a dilution of 1:50 with 0.1% bovine serum albumin (BSA) in PBS. Horseradish peroxidase (HRP) conjugated goat anti-human IgE antibody (ThermoFisher Scientific) diluted at 1:2500 with 0.1% BSA in PBS was used as the secondary antibody. O-phenylenediaminedihydrochloride solution at 0.1% and 0.03% hydrogen peroxide in 0.05 M phosphate-citrate buffer at pH 5 was added to affect the enzymic reaction for colour development within 30 min at room temperature and the reaction was stopped by adding 2 N H_2SO_4. The colour developed was measured at 490 nm by a microplate reader. Each of the analyses was carried out in triplicate and the results were expressed as mean ± standard error.

44.2.6 SDS-Page

Sodium dodecyl sulphate–polyacrylamide gel electrophoresis (SDS-PAGE) was performed using a mini protean 3 apparatus (Bio-Rad, California, USA) as per the method of Laemmli (1970). Polyacrylamide separating gel of 12% and stacking gel of 4% was used for running the samples. The shrimp extracts were mixed with Lamelli buffer (1:4) and heated at 95 °C for 4 min. Then the samples were loaded onto the gels for separation at 150 V for 50–60 min along with a protein marker as a reference. After running the gels were stained with coomassie blue R-250 and destained with an acetic acid solution.

44.2.7 *Immunoblotting*

The proteins in irradiated shrimp extracts were separated by SDS PAGE. Separated proteins were electrophoretically exchanged to a 0.45 μm nitrocellulose membrane with tris glycine transfer buffer in a mini trans-blot system (Bio-Rad, California, USA) at 80 V for 120 min. Tris-buffered saline (TBS) containing 0.05% tween-20 was used to wash the nitrocellulose membrane. Blocking was done using 3% BSA (w/v) in TBS. The blocked membrane was subjected to reaction with pooled patient's sera (diluted at 1:50 in blocking buffer) at 4 °C overnight. Afterward reaction with HRP conjugated goat anti-human IgE antibody diluted at 1:500 at 37 °C for 1 h was carried out. Then the membrane was incubated with colorimetric HRP substrate using opti-4CN substrate kit (Bio-Rad, California, USA) for visualization of immunoreacted protein bands.

44.2.8 *Statistical Analysis*

Statistical significance of irradiated shrimp samples was determined using one-way analysis of variance (ANOVA) by the statistical software Statistical Package for the Social Sciences, SPSS.16 (SPSS Inc., Chicago, IL, USA). The statistical significance was identified at 95% confidence level ($p < 0.05$). Post hoc analysis was carried out using Duncan's multiple range tests.

44.3 Results and Discussion

IgE activity of raw and processed shrimp by boiling, autoclaving, trypsin and chymotrypsin treatment with and without electron beam irradiation is shown in Fig. 44.2. IgE binding ability showed a declining trend in all the samples subjected to electron beam irradiation. Electron beam irradiation at 5 kGy could significantly ($p < 0.05$) reduce the IgE activity in all treatments and control. Among the irradiated samples, samples processed by boiling and autoclaving didn't show any significant difference from that of irradiated raw shrimp. Both trypsin and chymotrypsin treated samples along with irradiation showed a significant ($p < 0.05$) decrease in IgE activity in comparison to other treatments. Significantly ($p < 0.05$) higher IgE binding ability of boiled extracts of *M. dobsoni* was previously reported by Laly et al. (2019). Similarly, shrimp treated after deshelling and deveining (*Fenneropenaeus merguiensis*, banana prawn) using an autoclave at 121°C for 15 min resulted significantly ($p < 0.05$) higher antigenicity than control (Faisal et al. 2019).

A decrease in IgE binding of shrimp allergen with an increase in dosage of electron beam irradiation was reported by Liu et al. (2017) with maximum efficiency noted at 10 kGy. They also suggested that a combination of electron beam irradiation

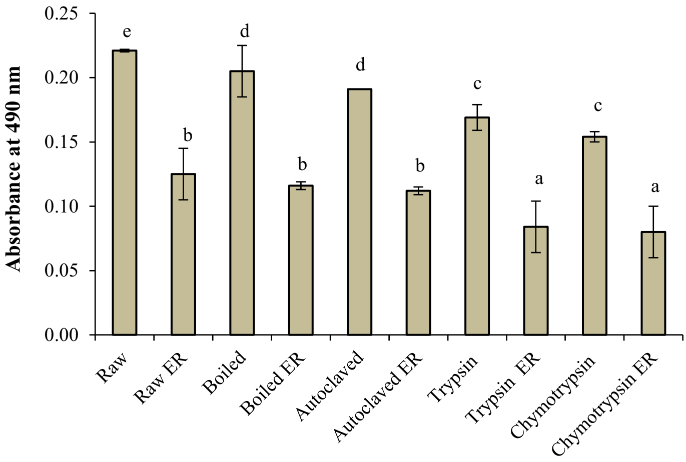

Fig. 44.2 IgE activity of raw, boiled, autoclaved, trypsin and chymotrypsin treated samples with electron beam irradiation (ER) and without electron beam irradiation

with other thermal and non-thermal methods will be more efficient in managing the allergenicity. The effect of low gamma irradiation doses on shrimp was reported by Zhenxing et al. (2007b) while increased allergenicity in a chronic oral challenge due to low-dose gamma irradiation of food protein was reported by Vaz et al. (2013). Electron beam irradiation is an ionizing radiation technique; it is totally differing from gamma irradiation. Gamma irradiation has high power and more penetration than electron beam irradiation at the same dose (Park et al. 2010). This indicates that electron beam irradiation cannot create enough energy to destroy tropomyosin at the same dose as gamma irradiation (Liu et al. 2017). As per the FAO/IAEA/WHO expert committee, the treatment of any foodstuff with radiation up to 10 kGy is recommended and free from any toxic effect (Fallah et al. 2010).

SDS PAGE profile of shrimp with or without electron beam irradiation is shown in Fig. 44.3. All the shrimp samples without electron beam irradiation showed the presence of tropomyosin except autoclaved sample. Also, the tropomyosin band was present in all the samples subjected to electron beam irradiation except autoclaved one. Here the process of autoclaving followed by irradiation effectively affected the tropomyosin band which led to the sharp reduction in the intensity of the band. While Liu et al. (2017) reported the presence of tropomyosin band in all the raw shrimp samples subjected to electron beam irradiation at dosages of 3, 5, 7 and 10 kGy and also reported the absence of significant change in the density of tropomyosin. Hence it clearly indicated that the combination of autoclaving and electron beam irradiation at 5 kGy resulted in the reduction in the intensity of tropomyosin. Byun et al. (2000) evaluated the effect of gamma irradiation on a heat-stable protein isolated from brown shrimp at different dosage levels of 1, 3, 5, 7 & 10 and the tropomyosin band was not detected at dosages above 5 kGy and above. In this case, the effect could be due to the fact that the proteins were exposed to radiation in the form of solution and the

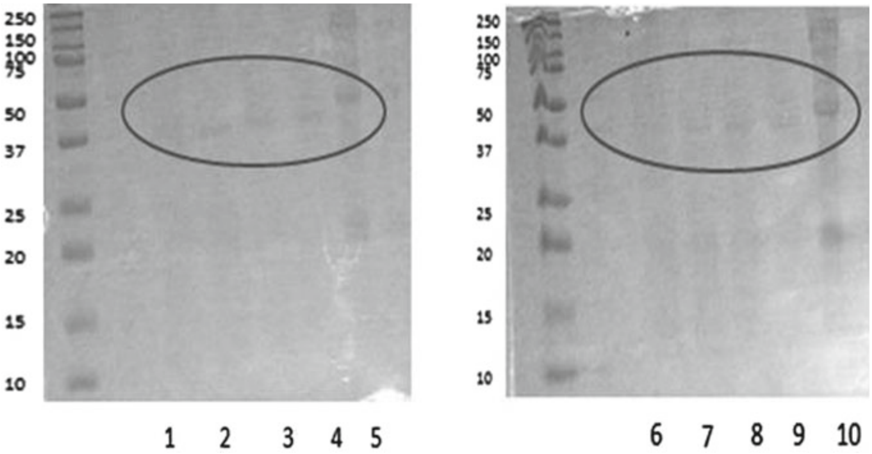

Fig. 44.3 SDS PAGE profile of electron beam irradiated samples. 1—Autoclaved, 2—Trypsin treated, 3—Chymotrypsin treated, 4—Boiled, 5—Raw, 6—Autoclaved + irradiation, 7—Trypsin treated + irradiation, 8—Chymotrypsin treated + irradiation, 9—Boiled + irradiation, 10—Raw + irradiation

gamma radiation is more powerful than the electron beam. Lopez-Gonza'lez et al. (1999) also supported the more powerful nature of gamma irradiation than electron beam by comparing their killing efficiency on *E. coli*.

To understand the immunogenicity of processed shrimp subjected to electron beam irradiation, immunoblotting analysis was performed using pooled sera of shrimp-sensitive individuals. Immunoblotting of processed shrimp samples with or without electron beam irradiation is shown in Fig. 44.4. In the case of processed samples without irradiation, antibody binding at tropomyosin was visible in all cases and the band in the autoclaved sample is very feeble with low intensity. After irradiation, the intensity of the tropomyosin band was slightly reduced in immunoblotting of all processed samples. The tropomyosin band in the autoclaved sample with irradiation was very faint compared to without irradiation one and other treatments. This can be due to the alteration in the IgE binding epitopes of tropomyosin due to the combined effect of autoclaving and irradiation. Hence autoclaving in combination with electron beam irradiation has a pronounced reduction in allergenicity compared to other treatments. Enzymatic treatment using trypsin and chymotrypsin on whole peeled shrimp was not observed to be effective in degrading the tropomyosin.

Similarly, Liu et al. (2017) also reported the antibody binding of tropomyosin in shrimp irradiated at 10 kGy, while purified tropomyosin showed a more intense decrease in the intensity of binding than the shrimp extracts. A significant decline in the blot intensity or immunoreactivity due to gamma irradiation was reported by Zhenxing et al. (2007b). As the energy of the electron beam is lighter than gamma irradiation, it produces a lower concentration of reactive oxygen species which act as the agents for modifying the IgE binding epitopes (Estévez et al. 2011). Radiation alters allergens either by damaging the covalent bonds by transfer of photon

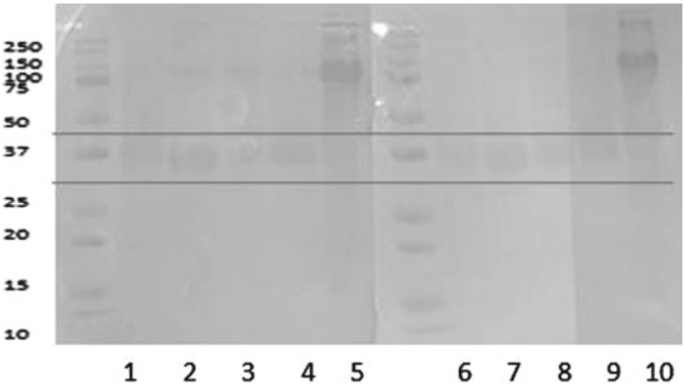

Fig. 44.4 Immunoblotting of electron beam irradiated samples. 1—Autoclaved, 2—Trypsin treated, 3—Chymotrypsin treated, 4—Boiled, 5—Raw, 6—Autoclaved + irradiation, 7—Trypsin treated + irradiation, 8—Chymotrypsin treated + irradiation, 9—Boiled + irradiation, 10—Raw + irradiation

energy (Vaz et al. 2012) or through reactive oxygen species which can affect IgE binding capacity (Vaz et al. 2013). Although the present study was carried out at 5 kGy, a reduction in immunogenicity in autoclaved shrimp was observed due to the combined effect; hence a higher dosage of 10 kGy, the suggested maximum dosage on autoclaved shrimp will be more effective in reducing the immunogenicity while preparing hypoallergic shrimp for shrimp sensitive individuals.

44.4 Conclusions

The effectiveness of electron beam irradiation in combination with processing treatments such as boiling, autoclaving, trypsin and chymotrypsin treatment on the immunogenicity of major heat-stable shrimp allergen, tropomyosin from *M. dobsoni* was investigated. Electron beam irradiation significantly reduced the IgE activity in all the treatments. In the SDS PAGE analysis, the tropomyosin band was not observed in the autoclaved sample with or without irradiation. But in the other cases, the band was retained. While in immunoblotting analysis, the tropomyosin band in the autoclaved sample with irradiation was very faint compared to that without irradiation and other treatments. Hence the hurdle technology effect of autoclaving and electron beam irradiation on shrimp tropomyosin can be used for the preparation of hypoallergic shrimp for shrimp sensitive individuals.

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References

Ayuso R, Grishina G, Bardina L et al (2008) Myosin light chain is a novel shrimp allergen, Lit v 3. J Allergy Clin Immunol 122(4):795–802

Byun MW, Kim JH, Lee JW et al (2000) Effects of gamma radiation on the conformational and antigenic properties of a heat-stable major allergen in brown shrimp. J Food Prot 63(7):940–944

Daul C, Slattery M, Reese G et al (1994) Identification of the major brown shrimp (*Penaeus aztecus*) allergen as the muscle protein tropomyosin. Int Arch Allergy Immunol 105(1):49–55

Ekezie FGC, Cheng JH, Sun DW (2018) Effects of non thermal food processing technologies on food allergens: a review of recent research advances. Trends Food Sci Tech 74:12–25

Estévez M, Ventanas S, Heinonen M (2011) Formation of strecker aldehydes between protein carbonyls–α-aminoadipic and γ-glutamic semialdehydes-and leucine and isoleucine. Food Chem 128(4):1051–1057

Faisal M, Vasiljevic T, Donkor ON (2019) Effects of selected processing treatments on antigenicity of banana prawn (*Fenneropenaeus merguiensis*) tropomyosin. Int J Food Sci Technol 54:183–193. https://doi.org/10.1111/ijfs.13922

Fallah AA, Tajik H, Farshid AA (2010) Chemical quality, sensory attributes and ultrastructural changes of gamma-irradiated camel meat. J Muscle Foods 21(3):597–613

FAO/WHO (2001) Evaluation of allergenicity of genetically modified foods: report of a joint FAO/WHO expert consultation on allergenicity of foods derived from biotechnology. FAO, Rome, Italy

Gornall AG, Bardawill CJ, David MM (1949) Determination of serum proteins by means of the biuret reaction. J Biol Chem 177(2):751–766

Ishikawa M, Shimakura K, Nagashima Y et al (1997) Isolation and properties of allergenic proteins in the oyster *Crassostrea gigas*. Fish Sci 63(4):610–614

Khan MU, Ahmed I, Lin H et al (2019) Potential efficacy of processing technologies for mitigating crustacean allergenicity. Crit Rev Food Sci Nutr 59(17):2807–2830

Laemmli UK (1970) Cleavage of structural proteins during the assembly of the head of bacteriophage T4. Nature 227(5259):680–685

Laly SJ, Sankar TV, Panda SK (2019) Identification of allergic proteins of flower tail shrimp (*Metapenaeus dobsonii*). J Food Sci Technol 56(12):5415–5421

Liu Y, Li Z, Pavase T et al (2017) Evaluation of electron beam irradiation to reduce the IgE binding capacity of frozen shrimp tropomyosin. Food Agricul Immunol 28(2):189–201

Long F, Yang X, Wang R et al (2015) Effects of combined high pressure and thermal treatments on the allergenic potential of shrimp (*Litopenaeus vannamei*) tropomyosin in a mouse model of allergy. Innov Food Sci Emerg Technol 29:119–124

Lopez-Gonzalez V, Murano PS, Brennan RE et al (1999) Influence of various commercial packaging conditions on survival of *Escherichia coli* O157: H7 to irradiation by electron beam versus gamma rays. J Food Prot 62(1):10–15

Motoyama K, Ishizaki S, Nagashima Y et al (2006) Cephalopod tropomyosins: identification as major allergens and molecular cloning. Food Chem Toxicol 44(12):1997–2002

Motoyama K, Suma Y, Ishizaki S et al (2007) Molecular cloning of tropomyosins identified as allergens in six species of crustaceans. J Agricul Food Chem 55(3):985–991

Pal M, Shimelis A, Mamo W et al (2017) Hurdle technology: a novel approach for food preservation. Bev Food World 44(1):20–26

Park JG, Yoon Y, Park JN et al (2010) Effects of gamma irradiation and electron beam irradiation on quality, sensory, and bacterial populations in beef sausage patties. Meat Sci 85(2):368–372

Rahman AMA, Kamath S, Lopata AL et al (2010) Analysis of the allergenic proteins in black tiger prawn (*Penaeus monodon*) and characterization of the major allergen tropomyosin using mass spectrometry. Rapid Commun Mass Sp 24(16):2462–2470

Shiomi K, Sato Y, Hamamoto S et al (2008) Sarcoplasmic calcium-binding protein: identification as a new allergen of the black tiger shrimp *Penaeus monodon*. Int Arch Aller Immunol 146(2):91–98

Shriver S, Yang W, Chung SY et al (2011) Pulsed ultraviolet light reduces immunoglobulin E binding to Atlantic white shrimp (*Litopenaeus setiferus*) extract. Int J Environ Res Pub Heal 8(7):2569–2583

Singh S, Shalini R (2016) Effect of hurdle technology in food preservation: a review. Crit Rev Food Sci Nutr 56(4):641–649

Vaz AF, Souza MP, Carneiro-da-Cunha MG et al (2012) Molecular fragmentation of wheat-germ agglutinin induced by food irradiation reduces its allergenicity in sensitised mice. Food Chem 132(2):1033–1039

Vaz AF, Souza MP, Vieira LD et al (2013) High doses of gamma radiation suppress allergic effect induced by food lectin. Radi Phy Chem 85:218–226

Yu CJ, Lin YF, Chiang BL et al (2003) Proteomics and immunological analysis of a novel shrimp allergen, Pen m2. J Immunol 170(1):445–453

Yu HL, Cao MJ, Cai QF et al (2011) Effects of different processing methods on digestibility of *Scylla paramamosain* allergen (tropomyosin). Food Chem Toxicol 49(4):791–798

Zhenxing L, Hong L, Limin C et al (2007a) Impact of irradiation and thermal processing on the immunoreactivity of shrimp (*Penaeus vannamei*) proteins. J Sci Food Agric 87(6):951–956

Zhenxing L, Hong L, Limin C et al (2007b) The influence of gamma irradiation on the allergenicity of shrimp (*Penaeus vannamei*). J Food Eng 79(3):945–949

Zygoura PD, Riganakos KA, Kontominas MG (2011) Study of the migration behavior of acetyl tributyl citrate from PVDC/PVC film into fish fillets as affected by intermediate doses of electron beam radiation. Euro Food Res Technol 232(6):1017–1025

Part III
Assessment and Management of Natural Resources

Chapter 45
Coastal Ecosystems of India and Their Management to Enhance Blue Carbon Storage

Rattan Lal

Abstract Coastal ecosystems, covering 440,000 km long shoreline globally and 7517 km in India, are the source of numerous ecosystem services for nature conservancy and human wellbeing. These highly diverse ecosystems include mangroves, seagrasses, salt marshes, coral reefs, lagoon and tidal flats. However, both the coastline and the coastal ecosystems are under pressure by anthropogenic activities, the attendant perturbations and global warming. The latter is affecting sea level rise, encroachment of saltwater, erosion of the coastline and degradation of coastal ecosystems. Thus, numerous ecosystem services provisioned by coastal ecosystems are being jeopardized, and a large land area of coastal ecosystems is being destroyed every year. In addition, transport of sediments and associated chemicals from agricultural watersheds are a major threat to coastal ecosystems. Carbon stored in the coastal ecosystem, the so-called "blue carbon", is an important component of the global carbon cycle. However, transport of the soil carbon with the sediments from upland watersheds has a strong impact on the global carbon cycle and emissions of greenhouse gases into the atmosphere. Transport of nutrient-rich sediments has created a global problem of anoxia or the lack of oxygen in coastal waters. Risks of soil degradation, by accelerated erosion (wind, water) and other processes (e.g. depletion of soil organic carbon or SOC, decline of soil structure, salinization), may be aggravated by climate change. Therefore, the adoption of restorative land use at the watershed/landscape scale and recommended soil management practices (e.g. conservation agriculture) on upland watersheds are important to protecting coastal ecosystems. Sustainable management of soil health through SOC sequestration and upscaling of landscape/watershed management options are critical to reducing land-based pollution of coastal ecosystems. Land-based solutions for the protection of coastal ecosystems include conservation agriculture, regenerative agriculture, agroforestry, integration of crops with trees and livestock, farming practices that create a positive soil/ecosystem carbon budget and lead to restoration of soil health and sequestration of carbon in soil and vegetation. Sustainable management of blue

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carbon is also critical to the adaptation and mitigation of anthropogenic climate change.

Keywords Blue carbon · Carbon sequestration · Coastal ecosystems · Ecosystem services · Mangroves · Soil degradation

45.1 Introduction

The global coastline is about 440,000 km long (Ouillon 2018), to which India contributes 7517 km including those of some islands (Dagar et al. 2014). Coastal ecosystems are highly diverse and include intertidal and subtidal areas on and above the continental shelf to a depth of 200 m and immediately adjacent lands (Burke et al. 2001). Thus, coastal ecosystems comprise coral reefs, mangroves, tidal wetlands, seagrass beds, barrier islands, estuaries, peatland swamps, etc. (Burke et al. 2001). Coastal ecosystems are the source of numerous ecosystem services (ESs). Important among these are coastline stabilization, biodiversity, water quality, food production for human and animals, carbon sequestration (blue carbon) for adaptation and mitigation of climate change, mining and tourism and recreation. Coastal ecosystems sequester and store significant amounts of blue carbon in coastal regions, and it has a strong impact on the global carbon cycle (The Blue Carbon Initiative 2020).

India is endowed with a wide range of diverse coastal ecosystems. Important among these are mangroves, seagrasses, salt marshes, coral reefs, lagoons and tidal flats (Ragavan et al. 2020). Sundarbans are the world's largest mangroves and a UN World Heritage site. Cultivated coastal ecosystems are used in India to grow rice. Coastal and islands are also used for fish, fruit, vegetables, plantations, spices and medicinal plants (Dagar et al. 2014). Plantations include coconut, areca nut, oil palm, cashew and cocoa. Important spices grown in these regions are cardamom, clove, black pepper, ginger and turmeric (Dagar et al. 2014). Growing jasmine flowers in coastal Karnataka has been a success story (Handy et al. 2011). Brackish and freshwater aquaculture is also widely used for fish production.

The objective of this article is to deliberate the impacts of anthropogenic activities in India on the storage and dynamics of the blue carbon in relation to provisioning of ecosystem services for human wellbeing and nature conservancy. Legislation issues are also discussed to reverse the degradation trends and enhance the storage of blue carbon in the coastal ecosystems of India.

45.2 Loss and Degradation of Global Coastal Ecosystems

Both the coastline and the associated ecosystems are under pressure by anthropogenic activities. Thus, numerous ESs provisioned by coastal ecosystems are being jeopardized. An estimated 340,000–980,000 ha of coastal ecosystems are being destroyed globally each year. As much as 67%, and at least 35 and 29% of the global coverage of mangroves, tidal marshes and seagrass meadows respectively have been lost (The Blue Carbon Initiative 2020). If these trends continue, with business as usual, an additional 30–40% of tidal marshes and seagrasses and nearly all unprotected mangroves could be lost in the next 100 years (The Blue Carbon Initiative 2020). The global annual loss of seagrass meadows is estimated at 1.5%. Rather than a sink of atmospheric CO_2, degraded and depleted coastal ecosystems can become source of greenhouse gases (e.g. CO_2, CH_4 and N_2O).

Sediment transport from agricultural watersheds is a major threat to coastal ecosystems. Based on the data of 124 global rivers, suspended sediment load is estimated at 11–27 Gt yr^{-1} (average 19 Gt yr^{-1}) (Beusen et al. 2005). Similar estimates of transport of sediments have been made by Walling (2008, 2009). Transport of SOC with sediments to the oceans has strongly influenced the global carbon budget and accelerated global warming (Lal 2003).

Transport of nutrient-rich sediments has created a global problem of anoxia or lack of oxygen in coastal waters. Anoxia is observed in 415 coastal areas around the world and has severe adverse effects on coral reef areas (Selman et al. 2008; Altieri et al. 2017).

45.3 India's Coastal Ecosystems

Similar to global trends, the coastal ecosystems of India are also under pressure of increasing anthropogenic activities. Being highly dynamic and vulnerable to the adverse impacts of anthropogenic perturbations, the Indian coastline is prone to degradation by a range of processes, including coastal erosion, sea-level rise, urbanization, industrialization and resource mismanagement. Suhura et al. (2018) reported that 23% of India's coastline is prone to coastal erosion and restoration is essential. Sea level rise and inundation of coastal regions is also a major concern (Mani Murali and Dinesh Kumar 2015; Pramanik 2017). State of different coastal ecosystems of India are briefly discussed below with specific reference to dynamics of the blue carbon:

45.3.1 Mangrove Ecosystems of India

Coastal mangroves provide numerous ecosystem services, including soil organic carbon (SOC) sequestration and the "blue carbon" domain. They also provide livelihood security to the coastal fishermen, but especially to the women self-help groups (Jeeva 2017). The West Coast of India accounts for 29% of India's mangrove ecosystems and these are under threat of degradation because of the anthropogenic activities. Mangrove landscapes, such as those of the Sundarbans delta, are prone to erosion of the coastline and other degradation processes (Begam et al. 2020; Bhargava et al.

2021). Some examples of degradation of Sundarbans outlined in Table 45.1 indicate the severity of the situation and highlight the need for science-based action that involves full participation of local communities and the bottom-up approach.

Research studies conducted outside of India show that restoration of degraded mangroves can lead to an increase in C storage capacity. Mangroves, tropical forests at the edge of land and sea, have an average rate of carbon sequestration of 1.6–2.2 Mg C ha^{-1} yr^{-1}. Tidal marshes, coastal wetlands with deep soil, can also sequester blue carbon at the rate of 1.6–2.2 Mg C ha^{-1} yr^{-1}. Seagrass, submerged flowering plants with deep roots, can sequester SOC at the seafloor. The SOC stock under seagrass meadows to 0.5 m depth is estimated at 5.1 $\pm$ 0.7 kg C m^{-2}, and the rate of SOC sequestration under seagrass is 23.2 $\pm$ 3.2 g C m^{-2} yr^{-1} (Bedulli et al. 2020; Ricart et al. 2020). Total SOC stock under seagrass of 24.7 Tg C yr^{-1}, is about 10% of C buried in ocean sediments. Seagrass store about 19.9 Gt C (The Blue Carbon Initiative, 2020).

The effect of restoration on storage of carbon in mangroves of India differs among species (e.g. *Avicennia officinalis*, *Rhizophora mucronata*, *Acanthus ilicifolius*, *Achrostichum auresum*, *Bruguiera cylindrica* and *Sonneratia caseolarisare*). The biomass-C was high with *R. muchronata sp.* The above-ground biomass (AGB)

Table 45.1 Examples of degradation of Sundarbans mangroves

Degradation type	Description	References
Anthropogenic perturbation	Stresses affect biogeochemistry of estuaries, illegal felling of trees, degradation of forest	Iftekhar and Islam (2004) Saenger (2011) Islam (2014) Dutta et al. (2019)
Nutrient limitation	Deficit of essential plant nutrients and changes in biogeochemistry and leaching can degrade the ecosystem	Hossain et al. (2014) Ray et al. (2015) Chowdhury et al. (2019)
Salinity intrusion	Sea level rise is increasing the risks of salinization	Islam and Gnauck (2007) Fakhruddinet al. (2018)
Invasive spp.	Decline in nature species and increase in halophytic plants, non-mangrove species	Harun-or-Rashid et al. (2009) Paul et al. (2017) Islam et al. (2019)
Decline of ecosystem services	Deforestation and degradation of ecosystem health can decline essential ecosystem services. The Sundarban Natural World Heritage site is also being affected	Ishtiaque et al. (2016) Islam et al. (2018a) Islam et al. (2018b)
Climate change	Global warming is affecting food security and other ecosystem services (e.g. fuel wood, medicines, food, construction material)	Ghosh et al. (2016) Abdullah-Al-Mamun et al. (2017) Roy and Guha (2017)

of the region was 70 ± 80 Mg ha^{-1}, and the ecosystem C stock of 18 to 139 Mg ha^{-1} (Shylesh Chandran et al. 2020). There is also marked seasonal variation in dormant species among salt marshes of coastal ecosystems in southern India. Kaviarasan et al. (2019) assessed sediment organic C stocks of four dominant salt marsh species viz., *Suaeda maritima*, *Sesuvium partulacastrum*, *Authrocnemum indicum* and *Salicornia brachiata*. The maximum AGB was observed in *A. indicum*, and the maximum below-ground biomass (BGB) in *S. maritima*, but with marked seasonal (wet vs. dry) variations. However, an optimal mangrove restoration can increase SOC stocks. For example, Ranjan (2019) observed that restoration of mangroves through community involvement offered numerous environmental benefits and augmented livelihood. Gnanamoorthy et al. (2019) assessed SOC stock in natural and restored forests in Pichavaram, on the southeast coast of India. The SOC stock for 0–90 cm depth (Mg C ha^{-1}) was 146, 99, 93, 57, 95 and 84 for natural, 21-year, 17-year, 16-year, 15-year and 12-year-old stands respectively.

Agroforestry, an innovative option, is also used to improve soil quality of coastal lands. It includes a wide range of practices such as live fences and plantations in combination with shade trees. Wetland-based agroforestry, tree-based farming (Arunachalam et al. 2014) and carbon farming (Becker et al. 2013) may alleviate poverty by improving the local economy.

45.3.2 Coastal Wetlands of India and Carbon Sequestration

Coastal wetlands have a large C sink capacity both as SOC and as biomass-C. The water quality signature (e.g. pH, alkalinity, hardness, total dissolved solids, NO_3 content and electrical conductivity) are good indicators of soil status, including that of the algal biomass (Jana et al. 2020). Based on their study of the Thalassery estuarine wetland of Kerala, Vinod et al. (2019) observed that *Avicennia officinalis* was the dominant species with an average tree density of 729 ha^{-1}. The mean C stock (Mg C ha^{-1}) was 189 ± 89 for the AGB, 42 ± 20 for the root biomass (RB) and 17 ± 7 for the sediment C (SC) stock. The Thalassery estuarine wetland stored 154 Mg C ha^{-1}. Nideesh et al. (2021) assessed SOC stocks in acid sulphate soils (Histosols) at 1017 Mg C ha^{-1} for 90–120 cm depth and with total SOC sequestration potential of 230 Tg C to 1.5 m depth in the Kole region. Gnanamoorthy et al. (2019) monitored SOC stock in restored mangrove forests on the southeast coast. The SOC stock was 146 Mg C ha^{-1} for natural stand and ranged from 57–99 Mg C ha^{-1} for 12- to 21-year-old restored forests. Ray et al. (2018) computed the C budget of Sundarbans and Hooghly river estuary during pre- and post-monsoon season and reported that the riverine exports were 0.07 Tg C yr^{-1} for particulate organic C, 0.34 Tg C yr^{-1} for dissolved organic C and 4.14 Tg C yr^{-1} for dissolved inorganic C. Thus, Sundarbans mangroves export a large amount of C into the Bay of Bengal.

45.3.3 Sea Level Rise and Seawater Intrusion in Relation to C Sequestration in Coastal Ecosystems of India

Global warming is leading to sea-level rise and seawater regression with impacts on the C sink capacity of coastal ecosystems in India and elsewhere. Deb et al. (2020) observed that soils with occasional encroachment of seawater were a better niche for C storage through the formation of macro-aggregates, which increase the recalcitrance of C through the formation of organo-mineral complexes and decline of the microbial activity due to salinity. Occasional encroachment by brackish water curbed loss of SOC stocks. However, coastal groundwater aquifers are under threat of depletion by excessive pumping and brackish water intrusion because of the sea level rise (Rejani et al. 2009).

45.3.4 Salt Marshes and Carbon Stocks

Salt marshes are inter-tidal halophytic vegetations and geographically located in mid to lower latitudes (Banerjee et al. 2017). Important ecosystem services provisioned by salt marshes include coastal bio-shields, bio-fillers, habitat for diverse biota, transport and redistribution of plant nutrients, and storage of blue carbon and tourism. A high sediment C stock can absorb heavy metals (Hg) and other toxins (Chakraborty et al., 2014). Banerjee et al. (2017) identified 15 salt marsh species distributed over 1600 km^2, and these species have a large C storage capacity. Salt marshes, along with seagrass ecosystems, offer vast potential for blue C sequestration and climate mitigation (Wylie et al. 2016). However, anthropogenic perturbations can destabilize the blue C stock through land-use change and the attendant GHG emissions.

45.3.5 Adaptive Potential Through Sustainable Land Resource Management of Coastal Ecosystems

Traditionally, India's coastal resources were managed as a "common property resource" or "commons" from shores to the sea. However, community control has disintegrated over time (Damodaran 2006). Consequently, coastal ecosystems have become strongly vulnerable to degradation processes, which are aggravated by anthropogenic perturbations due to the loss of community control. Therefore, there is a strong need for sustainable management of these ecologically sensitive ecoregions (Contestabile and Vicinanza 2020) through site-specific legislative measures to regularize the coastal development strategies in India (Ragavan et al. 2020). Rapid expansion of coastal cities in India requires proper planning for sustainable development. New planning methods include geographical technology and a multi-criteria decision-making approach. Growing coastal tourism and related activities need integration of diverse stakeholders through Integrated Coastal Zone.

In the State of Kerala, "Panchayati Raj System" was introduced in 1997 to plan and implement various projects by "Grama Sabhas" (Ramachandran et al. 2005). It is also called the "People's Participatory Programme–PPP." Thus, the responsibility of sustainable coastal zone management lies with the coastal community management (Chaudhary and Pisolkar 2016; Saha and Paul 2020). Because of the severe socio-economic implications of coastal zone degradation, micro-credit schemes are also being proposed in support of environmental protection (Lakshmi and Rajagopalan 2000).

45.3.6 Integrated River Basin Management for Protection and Sustainable Development of Coastal Ecosystems

Tree cover in India, estimated at 15.4% in 2000 (Goparaju and Ahmad 2020), must be improved. Tree cover of 10% in agricultural land is about one-fourth of the global average (Goparaju and Ahmad 2020). Himalayan forests are severely degraded (Prabhakar et al. 2006), and this degradation is the cause of perpetual flood/drought syndrome. It is thus important to realize that fragile and ecologically-sensitive coastal ecosystems cannot be managed in isolation from the associated river basins. Indeed, coastal ecosystems (tail end) are an integral component of the river basin (upstream component). Thus, there is a strong need for the Integrated River Basin Management (IRBM) framework (Sreeja et al. 2016). It is also pertinent to institutionalize integrated coastal zone management and coastal climate change mitigation (Puthucherril 2015), especially since blue carbon is an important component of the regional and global C budget. Some examples of the integrated management systems of the upland systems with clear benefits to the coastal ecosystems of India are outlined in Table 45.2.

The need for sustainable management is also highlighted by the densely populated coastal regions of India. For example, 50% of India's total population lives in the vicinity of coastal ecosystems which are also prone to natural disasters (Puthucherril 2011). Therefore, Krishnamurthy et al. (2014) described the concept of Integrated Coastal Zone Management (ICZM). Along similar lines, the Critical Regulation Zone (CRZ) originally proposed in 1991 was updated in 2011 as a bottom-up and good governance tool (Krishnamurthy et al. 2014). The overall objective of these regulatory measures is to strengthen the coastal community's resilience against unexpected natural disasters.

Anthropogenically-driven degradation of the coastal environment is a major threat to food security, livelihood, economic development and overall wellbeing. It is timely, therefore, to strengthen the resilience of coastal communities to ensure sustainable recovery after frequent and intense events (Guleria and Edward 2012). Principal

Table 45.2 Impact of integrated farming systems in the river basins on soil health and the attendant benefits to coastal ecosystems

Region	Integrated farming system	References
Gulf of Mannar, Southern India	Toxic metal contamination (Cd, Cu, Pb, Zn)	Rajaram et al. (2021)
South India	Preserving the hydrological connectivity of coastal wetlands	Ragavan et al. (2020)
Odisha	Controlling enteropathogens in human and domestic animals in coastal regions	Shrivastava et al. (2020)
East Coast	Heavy metal (Cd, Cr, As, Pb, Ni, Ag) contamination in coastal environment through industrial pollution	Satapathy and Panda (2018)
South India	Nematodes as bio-indicators of soil quality	Lakshmy et al. (2012)
South India	Spatial planning and integrated coastal zone management	Dwarakish et al. (2006) Gangai and Ramachandran (2010)
Gujarat	Remote sensing data for assessing land use/land cover changes	Chauhan and Nayak (2005)
Sundarbans	Landsat images to monitor shoreline changes, remote sensing, multiple-temporal satellite data	Giri et al. (2007) Cornforth et al. (2013)

elements of community resilience proposed by Guleria and Edward (2012) include the following: governance, coastal resource management, land use and structural design, society and economy, risk knowledge, warning and evacuation, emergency response and disaster recovery. With the large and growing population of India living in coastal regions (Puthucherril 2011), it is critically important that India manages its coastline and coastal resources, including the groundwater level. Limited groundwater resources are at risk of excessive draw and seawater intrusion (Rejani et al. 2009). Ecosystem health is adversely affected by the specific property-rights regime (Roy et al. 2013).

45.4 Land-Based Solutions for Protecting and Restoring Coastal Ecosystems: Global Studies

Agricultural activities in the watersheds with drastic impacts on coastal ecosystems are the following: eutrophication of coastal waters by riverine fluxes of sediments (Hedges and Keil 1995; Beusen et al. 2005) and the attendant plant nutrients (e.g.

N, P and K) leading to anoxia (Selman et al. 2008) through inputs of fertilizers, herbicides, pesticides and heavy metals (Nobi et al. 2010); wetland drainage; and deforestation and adoption of plow-based agriculture. Based on the data from 124 global rivers, Beusen et al. (2005) estimated a total suspended sediment load of 19 Gt yr^{-1} (with a range of 11–27 Gt yr^{-1}). Associated particulate organic carbon (POC), particulate nitrogen (PN) and particulate phosphorus (PP) were estimated at 197 Mt yr^{-1}, 30 Mt yr^{-1} and 9 Mt yr^{-1}, respectively (Beusen et al. 2005). Anoxia or hypoxia is a problem in 415 areas around the world (Selman et al. 2008) and can strongly impact the quality of coral reefs (Altieri et al. 2017). Transport of organic carbon into oceans via coastal ecosystems have a strong impact on the global C cycle (Smith and Hollibaugh 1993; Lal 2003). Urbanization and intensification of agriculture lead to an increase in water runoff and coastal salinity and drastic changes in nutrient stoichiometry and biogeochemistry. Coastal areas also receive sediment-borne soil carbon (Hedges and Keil 1995) and contribute to ~25% of the global ocean primary production. Agricultural pollution threatens about 25% of the global coral reef areas (Altieri et al. 2017), and the threat is being exacerbated by the intensification of agricultural activities.

A prudent strategy of sustainable management of coastal ecosystems involves reducing land-based pollution by the adoption of conservation-effective measures include conservation agriculture (Lal 2015), regenerative agriculture (Lal 2020), agroforestry and complex farming systems which create a positive soil/ecosystem, carbon budget (Lal 2004). These measures would reduce runoff and soil erosion, minimize non-point source pollution and decrease fluxes of plant nutrients and other pollutants. Restoration of the soil health of agroecosystems through sequestration of SOC and soil inorganic carbon (SIC) is a prudent strategy to protect and restore coastal ecosystems (Lal 2016). Similarly, protection and restoration of wetlands, afforestation of steep lands and setting aside agriculturally marginal lands can reduce the transport of sediments, plant nutrients and other pollutants into the coastal ecosystems. Land-based solutions for the protection of coastal ecosystems include conservation agriculture, regenerative agriculture, agroforestry, integration of crops with trees and livestock, farming practices that create a positive soil/ecosystem carbon budget and lead to restoration of soil health and sequestration of carbon in soil and vegetation (Lal 2004, 2015, 2016, 2020).

45.5 Conclusions

Coastal ecosystems are the source of numerous ecosystem services both for human well-being and nature conservancy. These critical ecosystems are being destroyed and degraded by anthropogenic activities. Rather than being a sink for atmospheric CO_2, the degradation of coastal ecosystems is changing them to a major source of greenhouse gases.

Restoration of coastal ecosystems is urgently needed to restore numerous ecosystem services and enhance the blue carbon storage. Protection and restoration of wetlands, afforestation of steep lands and setting aside agriculturally marginal lands can reduce the transport of sediments, plant nutrients and other pollutants into the coastal ecosystems.

However, coastal ecosystems cannot be managed in isolation. Uplands and the ecoregions of the river basins must be also managed judiciously so that transport of sediments is reduced.

An important strategy of sustainable management of coastal ecosystems involves reducing land-based pollution by the adoption of conservation-effective measures in the catchments or river basins feeding runoff, sediments and pollutants into the coastal areas.

Risks of soil degradation, by accelerated erosion (wind, water) and other processes (e.g. depletion of SOC, decline of soil structure, salinization), may be aggravated by climate change. Therefore, the adoption of restorative land use at the watershed/landscape scale and recommended soil management practices (e.g. conservation agriculture) are important to protect coastal ecosystems. Sustainable management of soil health through SOC sequestration and upscaling of landscape/watershed management options are critical to reducing land-based pollution of coastal ecosystems.

References

Abdullah-Al-Mamun MM, Masum KM, Raihan Sarker AHM et al (2017) Ecosystem services assessment using a valuation framework for the Bangladesh Sundarbans: livelihood contribution and degradation analysis. J For Res 28(1):1–13. https://doi.org/10.1007/s11676-016-0275-5

Altieri AH, Harrison SB, Seemann J et al (2017) Tropical dead zones and mass mortalities on coral reefs. Proc Nat Acad Sci 114(14):3660–3665. https://doi.org/10.1073/pnas.1621517114

Arunachalam A, Balasubramanian D, Arunachalam K et al (2014) Wetland-based agroforestry systems: balancing between carbon sink and source. In: Dagar JC, Singh AK, Arunachalam A (eds) Agroforestry systems in India: livelihood security & ecosystem services. Advances in agroforestry, vol 10. Springer, New Delhi, India, pp 333–343. https://doi.org/10.1007/978-81-322-1662-9_10

Banerjee K, Sappal SM, Ramachandran P et al (2017) Salt marsh: ecologically important, yet least studied blue carbon ecosystems in India. J Clim Change 3(2):59–72. https://doi.org/10.3233/JCC-170014

Becker K, Wulfmeyer V, Berger T et al (2013) Carbon farming in hot, dry coastal areas: an option for climate change mitigation. Earth Sys Dyn 4(2):237–251. https://doi.org/10.5194/esd-4-237-2013t

Bedulli C, Lavery PS, Harvey M et al (2020) Contribution of seagrass blue carbon toward carbon neutral policies in a touristic and environmentally-friendly island. Front Mar Sci 7:1. https://doi.org/10.3389/fmars.2020.00001

Begam MM, Chowdhury R, Sutradhar T et al (2020) Forecasting mangrove ecosystem degradation utilizing quantifiable eco-physiological resilience—a study from Indian Sundarbans. Sci Rep 10:6683. https://doi.org/10.1038/s41598-020-63586-4

Beusen AHW, Dekkers ALM, Bouwman AF et al (2005) Estimation of global river transport of sediments and associated particulate C, N, and P. Global Biogeochem Cycles 19:GB4S05. https://doi.org/10.1029/2005GB002453

Bhargava R, Sarkar D, Friess DA (2021) A cloud computing-based approach to mapping mangrove erosion and progradation: case studies from the Sundarbans and French Guiana. Estuar Coast Shelf Sci 248:106798. https://doi.org/10.1016/j.ecss.2020.106798

Burke L, Kura Y, Kassem K et al (2001) Pilot analysis of global ecosystems: agroecosystems. World Resources Institute, Washington D.C. Available at: http://pdf.wri.org/page_coastal.pdf

Chakraborty P, Sharma B, Raghunath Babu PV et al (2014) Impact of total organic carbon (in sediments) and dissolved organic carbon (in overlying water column) on Hg sequestration by coastal sediments from the central east coast of India. Mar Pollut Bull 79(1–2):342–347. https://doi.org/10.1016/j.marpolbul.2013.11.028

Chaudhary N, Pisolkar Y (2016) Issues, concerns, and local stakes: future of water resources in coastal villages of Devbag and Tarkarli, Coastal Maharashtra, India. In: Rao P, Patil Y (eds) Reconsidering the impact of climate change on global water supply, use, and management. IGI Global, pp 50–69. https://doi.org/10.4018/978-1-5225-1046-8.ch004

Chauhan HB, Nayak S (2005) Land use/land cover changes near Hazira region, Gujarat using remote sensing satellite data. J Indian Soc Remote Sens 33(3):413–420. https://doi.org/10.1007/BF02990012

Chowdhury R, Sutradhar T, Begam MM et al (2019) Effects of nutrient limitation, salinity increase, and associated stressors on mangrove forest cover, structure, and zonation across Indian Sundarbans. Hydrobiologia 842(1):191–217. https://doi.org/10.1007/s10750-019-04036-9

Contestabile P, Vicinanza D (2020) Coastal vulnerability and mitigation strategies: from monitoring to applied research. Water 12(9):570. https://doi.org/10.3390/W12092594

Cornforth WA, Fatoyinbo TE, Freemantle TP et al (2013) Advanced land observing satellite phased array type L-band SAR (ALOS PALSAR) to inform the conservation of mangroves: Sundarbans as a case study. Remote Sens 5(1):224–237. https://doi.org/10.3390/rs5010224

Dagar JC, Pandey CB, Chaturvedi CS (2014) Agroforestry: a way forward for sustaining fragile coastal and island agro-ecosystems: In: Dagar JC, Singh AK, Arunachalam A (eds) Agroforestry systems in India: livelihood security & ecosystem services. Advances in agroforestry, vol 10. Springer, New Delhi, India, pp 185–232. https://doi.org/10.1007/978-81-322-1662-9_7

Damodaran A (2006) Coastal resource complexes of South India: options for sustainable management. J Environ Manage 79(1):64–73. https://doi.org/10.1016/j.jenvman.2005.05.016

Deb S, Mandal B, Bhadoria PBS (2020) Influence of sea water ingression on carbon sequestration in soils under coastal agro-ecosystems of Eastern India. Agric Res 9(4):622–630. https://doi.org/10.1007/s40003-020-00456-5

Dutta MK, Kumar S, Mukherjee R et al (2019) The post-monsoon carbon biogeochemistry of the Hooghly-Sundarbans estuarine system under different levels of anthropogenic impacts. Biogeosciences 16(2):289–307. https://doi.org/10.5194/bg-16-289-2019

Dwarakish GS, Shetty D, Rao R et al (2006) Integrated coastal zone management plan and coastal zone information system for Mangalore coast, west coast of India. In: Frouin RJ, Agarwal VK, Kawamura H et al (eds) Proceedings of the SPIE Asia-Pacific remote sensing conference. Remote sensing of the marine environment, vol 6406. Goa, India, 13–17 November 2006, p 64060Q. https://doi.org/10.1117/12.698179

Fakhruddin B, Mahalingam R, Padmanaban R (2018) Sustainable development goals for reducing the impact of sea level rise on mangrove forests. Indian J Geo-Mar Sci 47(10):1947–1958

Gangai IPD, Ramachandran S (2010) The role of spatial planning in coastal management - a case study of Tuticorin coast (India). Land Use Policy 27(2):518–534. https://doi.org/10.1016/j.landusepol.2009.07.007

Ghosh MK, Kumar L, Roy C (2016) Mapping long-term changes in mangrove species composition and distribution in the Sundarbans. Forests 7(12):305. https://doi.org/10.3390/f7120305

Giri C, Pengra B, Zhu Z et al (2007) Monitoring mangrove forest dynamics of the Sundarbans in Bangladesh and India using multi-temporal satellite data from 1973 to 2000. Estuar Coast Shelf Sci 73(1–2):91–100. https://doi.org/10.1016/j.ecss.2006.12.019

Gnanamoorthy P, Selvam V, Ramasubramanian R et al (2019) Soil organic carbon stock in natural and restored mangrove forests in Pichavaram south-east coast of India. Indian J Geo-Mar Sci 48(5):801–808

Goparaju L, Ahmad F (2020) Tree cover percent investigation with respect to geographical area, vegetation types, agro ecological regions and in agriculture landscape of India: a geospatial approach. Spat Inf Res 28(1):1–9. https://doi.org/10.1007/s41324-019-00261-5

Guleria S, Edward JKP (2012) Coastal community resilience: analysis of resilient elements in 3 districts of Tamil Nadu state, India. J Coast Conserv 16(1):101–110. https://doi.org/10.1007/s11852-011-0178-8

Handy F, Cnaan RA, Bhat G et al (2011) Jasmine growers of coastal Karnataka: grassroots sustainable community-based enterprise in India. Entrep Reg Dev 23(5–6):405–417. https://doi.org/10.1080/08985626.2011.580166

Harun-or-Rashid S, Biswas SR, Bocker R et al (2009) Mangrove community recovery potential after catastrophic disturbances in Bangladesh. For Ecol Manag 257(3):923–930. https://doi.org/10.1016/j.foreco.2008.10.028

Hedges JI, Keil RG (1995) Sedimentary organic matter preservation: an assessment and speculative synthesis. Mar Chem 49(2):81–115. https://doi.org/10.1016/0304-4203(95)00008-F

Hossain M, Siddique MRH, Abdullah SMR et al (2014) Nutrient dynamics associated with leaching and microbial decomposition of four abundant mangrove species leaf litter of the Sundarbans, Bangladesh. Wetlands 34(3):439–448. https://doi.org/10.1007/s13157-013-0510-1

Iftekhar MS, Islam MR (2004) Degeneration of Bangladesh's Sundarbans mangroves: a management issue. Int for Rev 6(2):123–135. https://doi.org/10.1505/ifor.6.2.123.38390

Ishtiaque A, Myint SW, Wang C (2016) Examining the ecosystem health and sustainability of the world's largest mangrove forest using multi-temporal MODIS products. Sci Total Environ 569–570:1241–1254. https://doi.org/10.1016/j.scitotenv.2016.06.200

Islam SN (2014) An analysis of the damages of Chakoria Sundarban mangrove wetlands and consequences on community livelihoods in south east coast of Bangladesh. Int J Environ Sustain Dev 13(2):153–171. https://doi.org/10.1504/IJESD.2014.060196

Islam MM, Sunny AR, Hossain MM et al (2018a) Drivers of mangrove ecosystem service change in the Sundarbans of Bangladesh. Singap J Trop Geogr 39(2):244–265. https://doi.org/10.1111/sjtg.12241

Islam MM, Jannat A, Dhar AR (2018b) Dataset on the Impact of GO-NGO support on crop intensification and food security in Bangladesh. Data Brief 18:144149. https://doi.org/10.1016/j.dib.2018.03.020

Islam SN, Gnauck A (2007) Effects of salinity intrusion in mangrove wetlands ecosystems in the Sundarbans: an alternative approach for sustainable management. In: Okruszko T, Jerecka M, Kosinski K (eds) Proceedings of the International conference W3M wetlands: modelling, monitoring, management, Wierzba, Poland, 22–25 September 2005, pp 315–322

Islam SN, Reinstädtler S, Gnauck A (2019) Invasive species in the Sundarbans coastal zone (Bangladesh) in times of climate change: chances and threats. In: Makowski C, Finkl CW (eds) Impacts of invasive species on coastal environments: coasts in crisis. Coastal research library, vol 29. Springer, Cham, pp 63–85. https://doi.org/10.1007/978-3-319-91382-7_2

Jana BB, Nandy SK, Lahiri S et al (2020) Heterogeneity of water quality signature and feedbacks to carbon sequestration in wetlands across some districts of West Bengal, India. J Water Clim Chang 11(2):434–450. https://doi.org/10.2166/wcc.2019.102

Jeeva JC (2017) Sustainable livelihood options for women in the coastal ecosystem: a participatory assessment. Curr Sci 113(11):2183–2186. https://doi.org/10.18520/cs/v113/i11/2183-2186

Kaviarasan T, Dahms HU, Gokul MS et al (2019) Seasonal species variation of sediment organic carbon stocks in salt marshes of Tuticorin area, Southern India. Wetlands 39(3):483–494. https://doi.org/10.1007/s13157-018-1094-6

Krishnamurthy RR, DasGupta R, Chatterjee R et al (2014) Managing the Indian coast in the face of disasters & climate change: a review and analysis of India's coastal zone management policies. J Coast Conserv 18(6):657–672. https://doi.org/10.1007/s11852-014-0339-7

Lakshmi A, Rajagopalan R (2000) Socio-economic implications of coastal zone degradation and their mitigation: a case study from coastal villages in India. Ocean Coast Manage 43(8–9):749–762. https://doi.org/10.1016/S0964-5691(00)00057-0

Lakshmy KS, Jaya DS, Mohandas C (2012) Quality assessment of soils in Thiruvananthapuram district, South India using nematodes as bio-indicators. Asian J Water Environ Pollut 9(4):25–32

Lal R (2003) Soil erosion and the global carbon budget. Environ Int 29(4):437–450. https://doi.org/10.1016/S0160-4120(02)00192-7

Lal R (2004) Soil carbon sequestration impacts on global climate change and food security. Science 304(5677):1623–1627. https://doi.org/10.1126/science.1097396

Lal R (2015) A system approach to conservation agriculture. J Soil Water Conserv 70(4):82A-88A. https://doi.org/10.2489/jswc.70.4.82A

Lal R (2016) Soil health and carbon management. Food Energy Secur 5(4):212–222. https://doi.org/10.1002/fes3.96

Lal R (2020) Regenerative agriculture for food and climate. J Soil Water Conserv 75(5):123A-124A. https://doi.org/10.2489/jswc.2020.0620A

Mani Murali R, Dinesh Kumar PK (2015) Implications of sea level rise scenarios on land use/land cover classes of the coastal zones of Cochin, India. J Environ Manage 148:124–133. https://doi.org/10.1016/j.jenvman.2014.06.010

Nideesh P, Sreelatha AK, Anilkumar KS (2021) Sub-soil organic carbon sequestration and USDA soil taxonomy of coastal acid sulphate soils: constraints and their solution learned from a pedon study in the Kole land ecosystem of Kerala, India. Commun Soil Sci Plant Anal 52(10):1089–1099. https://doi.org/10.1080/00103624.2021.1872604

Nobi EP et al (2010) Geochemical and geo-statistical assessment of heavy metal concentration in the sediments of different coastal ecosystems of Andaman Islands, India. Estuar Coast Shelf Sci 87(2):253–264. https://doi.org/10.1016/j.ecss.2009.12.019

Ouillon S (2018) Why and how do we study sediment transport? Focus on coastal zones and ongoing methods. Water 10(4):390. https://doi.org/10.3390/w10040390

Paul AK et al (2017) Mangrove degradation in the Sundarbans. In: Finkl CW, Makowski C (eds) Coastal wetlands: alteration and remediation. Springer, Cham, pp 357–392. https://doi.org/10.1007/978-3-319-56179-0_11

Prabhakar R, Somanathan E, Mehta BS (2006) How degraded are Himalayan forests? Curr Sci 91(1):61–67

Pramanik MK (2017) Impacts of predicted sea level rise on land use/land cover categories of the adjacent coastal areas of Mumbai megacity, India. Environ Dev Sustain 19(4):1343–1366. https://doi.org/10.1007/s10668-016-9804-9

Puthucherril TG (2011) Operationalising integrated coastal zone management and adapting to sea level rise through coastal law: where does India stand? Int J Mar Coast Law 26(4):569–612. https://doi.org/10.1163/157180811X593407

Puthucherril TG (2015) Towards sustainable coastal development: institutionalizing integrated coastal zone management and coastal climate change adaptation in South Asia (Legal aspects of sustainable development). Brill - Nijhoff Publishers, Boston

Ragavan P, Kathiresan K, Mohan PM et al (2020) Ensuring the adaptive potential of Coastal wetlands of India—the need of the hour for sustainable management. Wetlands Ecol Manage 29:641–652. https://doi.org/10.1007/s11273-020-09742-z

Rajaram R, Ganeshkumar A, Vinothkumar S et al (2021) Ecological risk assessment of toxic metals contamination in Tuticorin coast of Gulf of Mannar, Southern India. Chem Ecol 37(2):132–148. https://doi.org/10.1080/02757540.2020.1819986

Ramachandran A, Enserink B, Balchand AN (2005) Coastal regulation zone rules in coastal panchayats (villages) of Kerala, India vis-à-vis socio-economic impacts from the recently introduced peoples' participatory program for local self-governance and sustainable development. Ocean Coast Manage 48(7–8):632–653. https://doi.org/10.1016/j.ocecoaman.2005.03.011

Ranjan R (2019) Optimal mangrove restoration through community engagement on coastal lands facing climatic risks: the case of Sundarbans region in India. Land Use Policy 81:736–749. https://doi.org/10.1016/j.landusepol.2018.11.047

Ray R, Rixen T, Baum A et al (2015) Distribution, sources and biogeochemistry of organic matter in a mangrove dominated estuarine system (Indian Sundarbans) during the pre-monsoon. Estuar Coast Shelf Sci 167:404–413. https://doi.org/10.1016/j.ecss.2015.10.017

Ray R, Baum A, Rixen T et al (2018) Exportation of dissolved (inorganic and organic) and particulate carbon from mangroves and its implication to the carbon budget in the Indian Sundarbans. Sci Total Environ 621:535–547. https://doi.org/10.1016/j.scitotenv.2017.11.225

Rejani R, Jha MK, Panda SN (2009) Simulation-optimization modelling for sustainable groundwater management in a coastal basin of Orissa, India. Water Resour Manag 23(2):235–263. https://doi.org/10.1007/s11269-008-9273-5

Ricart AM, York PH, Bryant C et al (2020) High variability of blue carbon storage in seagrass meadows at the estuary scale. Sci Rep 10(1):5865. https://doi.org/10.1038/s41598-020-62639-y

Roy C, Guha I (2017) Economics of climate change in the Indian Sundarbans. Glob Bus Rev 18(2):493–508. https://doi.org/10.1177/0972150916668683

Roy AKD, Alam K, Gow J (2013) Sustainability through an alternative property-rights regime for Bangladesh's mangrove forest. Geogr Rev 103(3):372–389. https://doi.org/10.1111/j.1931-0846.2013.00004.x

Saenger P (2011) Mangroves: sustainable management in Bangladesh. In: Günter S, Weber M, Stimm B et al (eds) Silviculture in the tropics. Tropical forestry, vol 8. Springer, Heidelberg, pp 339–347. https://doi.org/10.1007/978-3-642-19986-8_22

Saha J, Paul S (2020) An insight on land use and land cover change due to tourism growth in coastal area and its environmental consequences from West Bengal, India. Spat Inf Res. https://doi.org/10.1007/s41324-020-00368-0

Satapathy S, Panda CR (2018) Source identification, environmental risk assessment and human health risks associated with toxic elements present in a coastal industrial environment, India. Environ Geochem Health 40(6):57. https://doi.org/10.1007/s10653-018-0095-y

Selman M, Greenhalgh S, Diax R et al (2008) Eutrophication and hypoxia in coastal areas: a global assessment of water quality, WRI Policy Note, Water quality: Eutrophication and hypoxia. World Resources Institute, Washington, D.C. Available at: www.wri.org

Shrivastava AK, Mohakud NK, Panda S et al (2020) Major enteropathogens in humans, domestic animals, and environmental soil samples from the same locality: prevalence and transmission considerations in coastal Odisha, India. Epidemiol Health 42:e2020034. https://doi.org/10.4178/epih.e2020034

Shylesh Chandran MS, Ravi A, John SM et al (2020) Ecosystem carbon stock of selected mangrove forests of Vypin—Cochin region, southwest coast of India. Wetlands 40(6):2263–2273. https://doi.org/10.1007/s13157-020-01365-7

Smith SV, Hollibaugh JT (1993) Coastal metabolism and the oceanic organic carbon balance. Rev Geophys 31(1):75–89. https://doi.org/10.1029/92RG02584

Sreeja KG, Madhusoodhanan CG, Eldho TI (2016) Coastal zones in integrated river basin management in the west coast of India: delineation, boundary issues and implications. Ocean Coast Manage 119:1–13. https://doi.org/10.1016/j.ocecoaman.2015.09.017

Suhura S, Nithyapriya B, Revanth Reddy L et al (2018) Coastal land use/land cover and shoreline studies for Dakshina Kannada coast, Karnataka, India. In: Singh VP, Yadav S, Yadava RN (eds) Water resources management, Water science and technology library, vol 78. Springer, Singapore, pp 269–281. https://doi.org/10.1007/978-981-10-5711-3_19

The Blue Carbon Initiative (2020) Mitigating climate change through coastal ecosystem management. The Blue Carbon Initiative. https://www.thebluecarboninitiative.org

Vinod K, Asokan PK, Zacharia PU et al (2019) Assessment of biomass and carbon stocks in mangroves of Thalassery estuarine wetland of Kerala, south west coast of India. J Coast Res 86(sp1):209–217. https://doi.org/10.2112/SI86-031.1

Walling DE (2008) The changing sediment loads of the world's rivers. Ann Warsaw Univ Life Sci - SGGW, Land Reclam 39:3–20. https://doi.org/10.2478/v10060-008-0001-x
Walling DE (2009) The impact of global change on erosion and sediment transport by rivers: current progress and future challenges. In: The United Nations world water development report no. 3, Water in a changing world. UNESCO World Water Assessment Programme, Paris, France, pp 1–30. http://unesdoc.unesco.org/images/0018/001850/185078E.pdf. Accessed 20 Mar 2020
Wylie L, Sutton-Grier AE, Moore A (2016) Keys to successful blue carbon projects: lessons learned from global case studies. Mar Policy 65:76–84. https://doi.org/10.1016/j.marpol.2015.12.020

Chapter 46
Soil Quality Assessment for Coastal Agroecosystem—Problems and Perspectives

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Abstract Coastal region is the home of forty percent of the global population, and continuous anthropogenic exploitation impaired the health and ecosystem services of coastal soils. Inherent ecological constraints like intrusion and seepage of brackish water, congestion of ingress saline water, flat and low topography, impeded drainage, waterlogging, shortage of fresh irrigation water, occurrence of acid sulphate soils,

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etc. of the region further aggravated the problem and are responsible for its poor soil quality. Global warming and associated sea-level rise is making things even worse. Assessment of quality of coastal soils is, however, a function of numbers of soil attributes like inherent electrolytes concentration, pH, relative distribution of different ions (Na^+, Mg^{2+}, Ca^{2+}, K^+, and SO_4^{2-}, Cl^-, HCO_3^- etc.) in soil solution, soil aggregation-dispersion, hydraulic conductivity, metabolic activities, and abundance of useful soil microbial populations. The rhythmic changes in electrolytes concentrations in *kharif* and *rabi* season because of intrusion of brackish water damages coastal soil physical structure, imbalances soil nutrients dynamics, decreases bioavailability of nutrients, increases osmotic effect onto plant roots, and retards proliferation of soil microbiomes. Accordingly, a periodic assessment for identifying key soil quality indicators is essential for capturing the stressor(s) and health of soil. Since the productivity of principal agricultural crops in the coastal areas is low, an assessment of critical values (optimum and threshold) of key soil quality indicators might be helpful for capturing the soil-borne constraints and their possible solution for achieving profitable yield and sustainable utilization of soil and water resources of the region. Adoption of land modification, surface or underground drainage, surface water harvesting for *rabi* crops, need-based calcium supplementation for acidity neutralization, adoption of conservation agricultural practices, and integrated nutrient management with locally available organic amendments (farmyard manure, green manure, vermicompost, smart city waste compost, etc.) are advocated for restoring soil quality and improving livelihood security of coastal farm community.

Keywords Coastal ecosystem · Conservation agriculture · Salinity · Seawater intrusion · Soil quality · Soil constraints

46.1 Introduction

Soil is the foundation of human civilization. Soil health impacts eight of the seventeen UN Sustainable Development Goals. Good soil health facilitates better crops, which in turn improves the income and livelihood of the marginal farming communities. The backbone of soil health is carbon involved in the improvement of different physical, chemical, and biological attributes of soils. Additionally, sequestration of carbon in soils plays an important role in mitigating global warming. This is how the biosphere and atmosphere are interlinked with each other through soils. To improve the quality of life on earth, upkeeping of soil health is thus important and our

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societal responsibility. In fact, healthy soil is essential for harvesting nutritious crops to eliminate malnutrition from the society. Soils occurring in coastal regions with varying characteristics are no exceptions. Continuous deposition of clay and organic matter with river carried sediments also causes high fertility of coastal soils which supports production of a good proportion of global food supply. Therefore, there is, an urgent need for assessment of quality of coastal agricultural soils and maintenance of its quality for continuing support to humankind.

46.2 Diversity of Coastal Soils

Global coastlines experience distinctive geomorphological and geo-ecological phenomena yielding soils of different orders (Table 46.1). Of the 12 soil orders reported, Entisols, Inceptisols and Alfisols are of common occurrence in coastlines (http://www.fao.org/soils-portal/data-hub/soil-maps-and-databases/faounesco-soil-map-of-the-world/en/). In the higher latitudes of Asia, Europe and North America, Gelisols are the dominant soil order of the coasts (https://esdac.jrc.ec.europa.eu/resource-type/maps). Some of the coastlines of South-Western Australia, Western and South-Eastern part of South America and Africa also have Aridisols as the major soil order; small patches of Aridisols are also found in coastlines of Asia, Europe and North America. Ultisols, representing high degree of weathering, are spread throughout the coastlines in every continent. Spodosols are observed in the Northern coastal regions of Europe and North America. Small areas of Histosols, Mollisols and Vertisols are observed in some parts. Thus, a variety of soil orders are observed throughout the world's coastal regions representing the combined effect of climate, topography and other geological phenomena over the ages. This huge diversity of soils in coastal plains poses a challenge to have a common comprehensive

Table 46.1 Dominant soil orders in coastal plains of different continent

Continent	Dominant soil orders in coastal plains
Asia	Entisols, Inceptisols, Alfisols, Ultisols, Gelisols, small patch of Histosols, Vertisols, Andisols and Aridisols
Africa	Entisols, Inceptisols, Alfisols, Ultisols, Oxisols, Aridisols and Vertisols
Australia	Entisols, Inceptisols, Alfisols, Aridisols, small patches of Vertisols, Mollisols and Oxisols
Europe	Andisols, Entisols, Inceptisols, Alfisols, Gelisols and small patches of Mollisols
North America	Inceptisols, Spodosols, Alfisols, Ultisols, Gelisols, small patches of Entisols, Vertisols, Histosols, Mollisols, Aridisols and Andisols
South America	Inceptisols, Alfisols, Ultisols, Andisols, Aridisols, Oxisols and small patch of Histosols

Source http://www.fao.org/soils-portal/data-hub/soil-maps-and-databases/faounesco-soil-map-of-the-world/en/

assessment tool to assess its capacity for different ecosystem functions including enhancement of crop production.

46.3 Major Soil Related Constraints Across Coastal Regions

Soils of the coastal regions of the world suffer from a number of constraints. In general, salinity, sodicity, waterlogging, acid sulfate soil, erosion, nutrient availability and soil compaction are identified as the major constraints of soils under coastal ecosystem (Fig. 46.1). However, the problems vary from one continent to another. For example, problems of erosion and salinity dominate in soils of Pacific Ocean, salinity and compaction in Indian ocean coast, compaction in Arctic Ocean coasts, acid sulphate soils in coasts of Antarctic Ocean, etc. Besides, coastal belt of Atlantic Ocean is highly heterogenous, i.e., having diverse constraints in their soils, which create a huge problem to get a specific management practice.

The problems of coastal regions, however, get influenced by three major processes viz. occasional surface inundation of soils by saline sea- and river water (especially during cyclones, tsunami and other natural calamities), continuous sub-surface intrusion of saline water, and sedimentation, i.e., deposition of terrigenous sediment load, carried out by rivers meeting the coast.

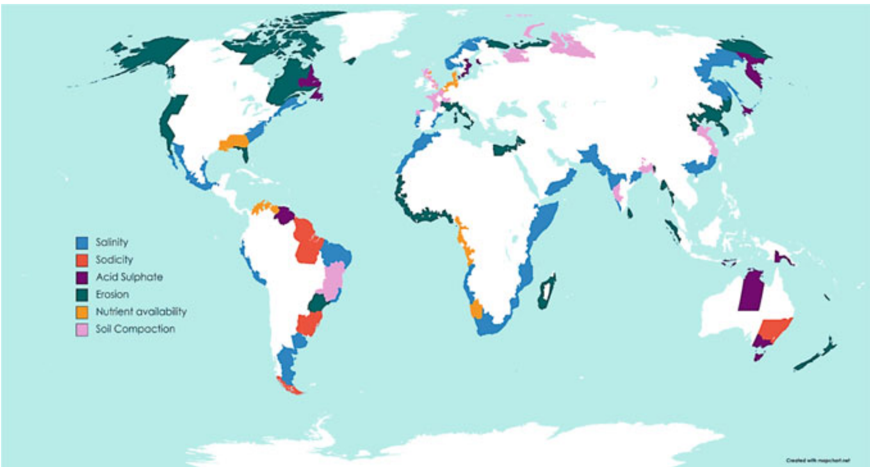

Fig. 46.1 Major soil problems in coastal regions across the globe (FAO 2015)

46.3.1 Surface Visit of Sea Water Through Natural Calamities

The neutral salts of Na, Mg and Ca carried by the seawater get deposited in coasts regularly. However, natural barriers like mangroves (in equatorial-tropical area), marshes (in sub-tropical-temperate area) protect the coastal croplands a lot from these. The projected sea-level rise could aggravate these depositions and faster deterioration of soil quality of a larger area under the coastal agro-ecosystems. Further, the tidal sediments due to high water flash during cyclone (or hurricane/typhoon) or *Tsunami* cause excessive deposition of these salts in coasts. The impact of these depositions can be extended even up to 5 km from the coastal margin and may have prolonged impact on the soils of those areas. While precipitation in some humid regions can cause leaching of the excess soluble salts from soils by two to three years' time, in maximum areas it may take several years for soils to get back to its natural physico-chemical state for supporting good crop growth.

46.3.2 Sub-Surface Intrusion of Sea Water

The second governing factor of coastal soil quality is continuous sub-surface saline water intrusion. There are different pathways of this sub-surface seepage of sea water to contaminate the ground water aquifers. In fact, a significant difference in ground water composition of tube-well and natural springs were reported from Central Italy (Sappa et al. 2019) (Fig. 46.2). It was found that there was higher magnitude of Na^+, Mg^{2+}, Cl^- and HCO_3^- in tube-well waters. As evident from high cationic ratios viz., $Na^+: Ca^{2+}$, $Mg^{2+}: Ca^{2+}$, $Cl^-: HCO_3^-$, which are almost equal to sea water, it was clear that there was a huge intrusion of sea water into tube-well which may deteriorate the quality of soils in coastal areas. The projection for such invading sea water indicates the risk of groundwater contamination by saline water. As it is very difficult to reclaim the groundwater aquifer once contaminated/charged with soluble salts, demarcation

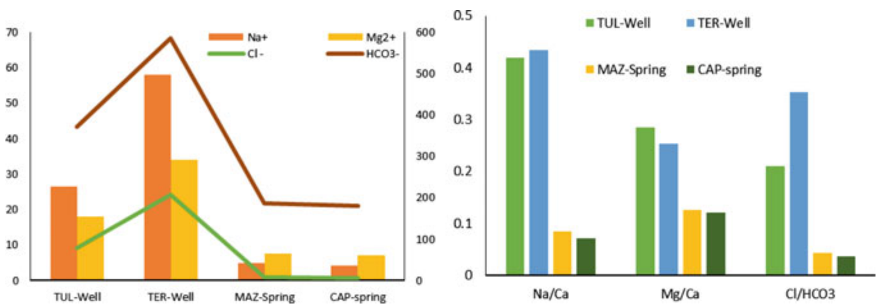

Fig. 46.2 Major composition in the spring and well water samples in coastal soils of central Italy

for groundwater exploitation for well, shrimp or agricultural purpose is important following prescription of local coastal monitoring authorities. It may consequence secondary and tertiary salinization of groundwater aquifer.

46.3.3 Sedimentation Load

Sedimentation is one of the major factors governing soil quality of coastal ecosystem. Sediment loading in coastal areas has both good and bad effects on coastal soil ecosystem. Nutrient enriched sediments increase both crop and fish productivity and thereby support the farming community of coastal areas (Nicholls et al. 2007). This sediment loading also prevents soil erosion and improves soil biodiversity. Coastal sediment deposition also supports the natural coastal ecologies against the sea-level rise (Ellison 1993; Crosby et al. 2016). The silicon-rich sediments increase relative proportion of diatoms in phytoplankton and supply food and oxygen to coastal ecosystem. On the contrary, sedimentation also clogs the coastal area with loading of nitrogen, phosphate, heavy metals thereby causing eutrophication and creating lots of problems for the aquatic environment (Qian et al. 2015; Oelsner and Stets 2019). Such coastal pollution has been reported in coastal belt of China. Sedimentation also resulted in numerous negative human health and environmental impacts including drinking water degradation, loss of habitat and biodiversity, low dissolved oxygen conditions leading to fish kills and other stresses, an increase in severity of harmful algae blooms due to coastal eutrophication, and hypoxia (Seitzinger et al. 2005; Diaz and Rosenberg 2008). Therefore, sediment-led division of coastal zones needs to be done with different management practices as per quantity and quality of sediments.

46.4 Salinity Severity with Moisture Deficit

To tackle the issue of coastal soil salinity, availability of good quality irrigation water and proper drainage system are two essential requirements. An attempt was made to find out the relationship between soil moisture availability and severity of soil salinity along the coasts. It was observed that across the global coasts, the problem of severe soil salinity was associated with high moisture deficit. The graphs plotted between salinity and rainfall in some coastal areas of the world give a picturesque view of the rhythmic relationship between amount of rainfall and intensity of salinity (Fig. 46.3). Salinity intensity was found low under high rainfall areas obviously due to leaching down of the soluble salts. The rhythm of coastal soil salinity also depends on clay content of the coastal soils and also on the elevation of the coast. Therefore, it is important to capture the rhythm of all these variables for efficient management of coastal soil health.

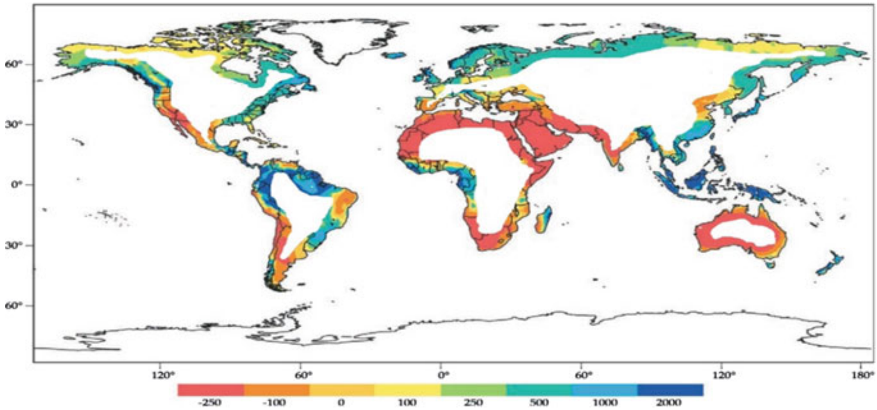

Fig. 46.3 Global map of annual precipitation minus evapotranspiration (Givnish 2002)

46.5 Assessment of Soil Quality

Soil quality (SQ) is the capacity of the soil to function or "its fitness for use". Normally some standard protocols are followed for assessment of soil quality using some cost-effective, site-specific, and farmers' friendly indicators. Sometimes morphological and visual indicators are also advocated for assessment of soil quality due to their low-cost requirement. But in case of coastal soil, there are number of problems in the identification of indicators owing to the uncertainty of the threats posed by natural calamities as well as sea water ingression into arable lands. The major problems of parameterization include huge temporal and spatial variation, governance of soil ecosystem predominately by physical feature and climatic factors, impaired biogeochemical cycling of essential nutrients and the complex relationship of nutrients displacement with salt-loading. It is, thus, advocated that the indicators for assessment of coastal soils should be location specific, and to make a low-cost comprehensive assessment the following principles may be followed for selection of the indicators: (a) a suite of indicators required to capture changes in SQ because of its complexity—(i) inherent indicators; (ii) dynamic indicators, (b) logical sieve not straight jacket approach, (c) cross-functional/all-encompassing (aggregative/black-box) type, (d) early warning type, (e) surrogacy—not apparent for lacking database, (f) meeting peculiar needs, (g) climate change indicators, and (h) farmers' friendly.

46.5.1 Master Indicators of Soil Quality for Coastal Soils

There are only a few numbers of studies which did quality assessment of global coastal agricultural soils. It was found that EC, pH, clay content, ESP and organic carbon are the most common parameters screened out in those assessments of coastal

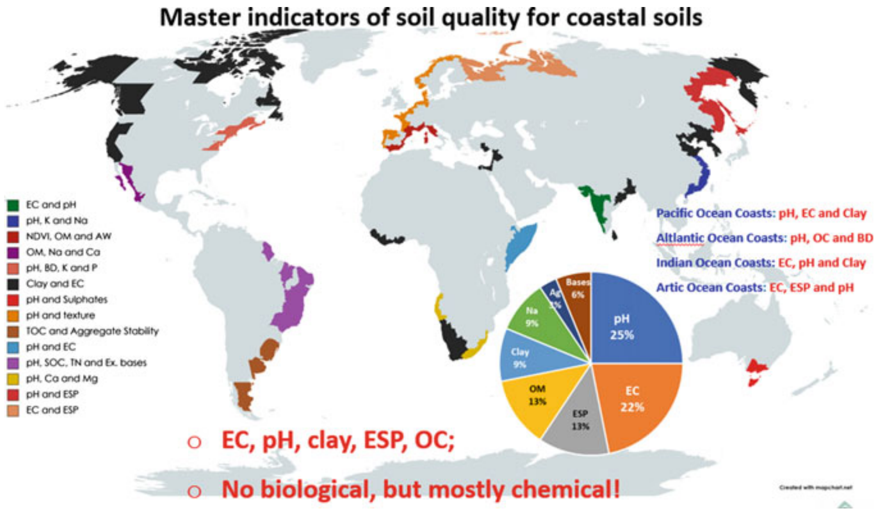

Fig. 46.4 Compilation of master indicators for soil quality assessment studies in coastal soils

soil quality (Wu et al. 2019; Sillero et al. 2020; Mahajan et al. 2020; Rangel et al. 2017) (Fig. 46.4). Among various master indicators, pH and EC contributed about 40% for assessment of coastal soil quality. Though biological parameter is one of the important pillars of soil quality assessment, but so far coastal soil is concerned, there are no biological parameters mentioned for screening. We could find that both the richness and evenness of soil biota governing the biogeochemical cycles of nutrients like C, N, P were impaired under coastal environment due to untimely onset of natural calamities. That's why the intensity of associated genes for enzymatic secretion got diminished leading to impaired biogeochemical cycling of nutrients (Seitzinger et al. 2005). Further, in coastal ecosystem, the loadings of salt of Ca and Mg impart physico-chemical recalcitrance to soil organic carbon either through formation of chelates with soil mineral matrix and metal ions or through compartmentalization of soil organic carbon within the aggregates by making it inaccessible to microbes (Deb et al. 2016, 2018, 2020). This might be the reason behind impaired soil biodiversity under coastal ecosystem. The uneven richness of microbes can be clearly illustrated through the relationship between soil microbial biomass carbon and electrical conductivity (Tripathi et al. 2006, 2007). Hence, for most of the studies, microbial parameters are not taken into consideration for soil quality assessment under coastal regions. Importance of the parameters, however, varies in soils under different coasts. For example, the major parameters screened in soils of Pacific Ocean coasts are pH, EC and clay content, while for soils of Atlantic Ocean coasts are pH, organic C and bulk density, Indian ocean coasts are, EC, pH and clay content, and Artic Ocean coasts are EC, ESP and pH. It is observed that mostly chemical parameters and a very few of it viz., pH, EC and organic C appeared as the most important indicators needing no others for such assessment. Surprisingly, there was hardly any appearance of biological indicators screened during soil quality assessment across the globe.

46.6 Rehabilitation of Coastal Arable Land

There are above 60% of the world population directly or indirectly depends on coastal and marine ecosystems for their livelihood (UNEP-WCMC 2011). However, anthropogenic perturbations and climate change have made these ecosystems fragile through various degradation processes like coastal erosion, sea water intrusion and inundation, and salinization. As a result, the productivity and ecosystem services are severely jeopardized and there is a possibility of even a grim future. Thus, rehabilitation of these ecosystems is of the utmost importance to improve soil quality, agronomic productivity, and livelihood security. It can be done by technological interventions like leaching of salts with high rainfall, land-shaping, conservation agricultural practices, soil organic carbon management and through altering the crop calendars. For example, broad bed and furrow (BBF) system (Fig. 46.5) improved the drainage of the raised beds in different coastal areas. It ultimately resulted in substantial removal of salts and toxic substances from soils over time. The BBF system also promoted harvesting of rainwater in the furrows, which may be used subsequently for raising crops and also for leaching salts from soil (Bakker et al. 2010). In fact, higher organic carbon content, lower bulk density, salt concentration and SAR values were observed in the beds of BBF (Table 46.2). These may ultimately help in improving soil quality, land restoration and can enable different ecosystem processes interlinked with soil, water and plants (Shrestha and Lal 2006).

Mulching also restricts surface soil salinization. It reduces the rate of evaporation and capillary rise of subsoil water and salts while increasing the infiltration capacity. Thus, mulching arrests land degradation in coastal saline croplands. Different types

Fig. 46.5 Broad bed and furrow system

Table 46.2 Effect of land shaping on improving soil quality in *Tsunami* affected area

Parameters	Tsunami affected area (February 2005)	Interventions		
		Bunding	BBF	No intervention
pH	7.24	5.98	6.36	5.88
EC_e ($dS\ m^{-1}$)	22.14	1.72	1.18	1.90
Bulk density ($Mg\ m^{-3}$)	1.47	1.38	1.35	1.42
Organic carbon ($g\ kg^{-1}$)	7.12	11.46	11.73	7.59
Na^+ ($meq\ L^{-1}$)	173.2	38.80	33.20	55.40
Ca^{+2} ($meq\ L^{-1}$)	26.06	15.80	16.20	20.45
Sodium adsorption ratio ($cmol^{1/2}\ L^{-1/2}$)	48.11	13.91	11.75	17.43
HCO_3^- ($meq\ L^{-1}$)	2.38	0.30	0.36	0.50
Cl^- ($meq\ L^{-1}$)	142.8	25.64	30.80	47.00
SO_4^{2-} ($meq\ L^{-1}$)	62.4	14.40	17.46	33.60
Microbial biomass carbon ($mg\ kg^{-1}$ soil)	124.7	193.6	210.3	140.5

Mean value, n = 10; BBF = Broad bed and furrow system (Adapted from Velmurugan et al. 2015)

Table 46.3 Effects of different mulch treatments on some soil properties in maize field

Treatments	Soil pH		Soil EC ($dS\ m^{-1}$)	
	2016	2017	2016	2017
Control	5.23	4.50	13.60	12.80
Rice straw mulch	5.45	4.76	9.21	8.25
Blue plastic mulch	5.35	4.68	6.73	5.15
Black plastic mulch	5.34	4.63	7.94	6.55
White plastic mulch	5.35	4.93	5.61	4.90
CV (%)	2.793	3.51	14.38	12.04
Significance level	NS	NS	***	***
SE(±)	0.035	0.121	1.01	0.741

Adapted from Haque et al. (2018)
'NS' and ''***' indicate nonsignificant and significant differences at $p < 0.01$, respectively

of mulches can be used for this, and they can impact the soil quality to some extent in coastal cultivated soils (Table 46.3).

Conservation agriculture (CA) also has immense potential in reducing soil salinity by the moderating effect of organic matter. These practices can add substantial amount of organic matter in soils through crop rotation while they also restrict decomposition of added carbon. No tillage and surface retention of residues also limits the evaporation and thereby salt movement from lower layers to surface. The

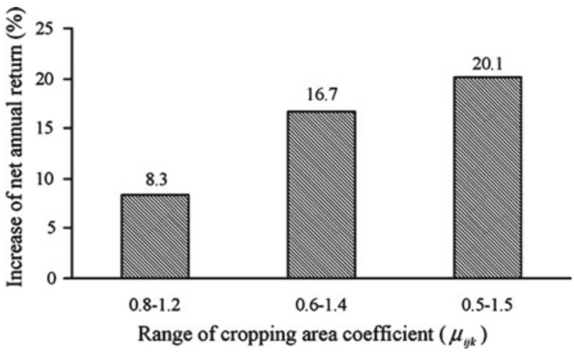

Fig. 46.6 Increase of net annual return at different ranges of cropping area coefficient with respect to existing cropping pattern (%). Adapted from Sethi et al. (2006)

CA with no till or minimum till is also a suitable choice particularly for acid sulphate soil, since it prevents exposure of potential acid sulphate soil to atmospheric oxygen.

Optimum agricultural planning and water management is essential for retarding the salinity hazard under coastal areas. As indicated, efficient use of water through drip irrigation and broad bed and furrow method may be promoted. The hazard may also be circumvented by altering cultivation of crops with different irrigation requirements. Crop establishment programme should be scheduled according to the onset of rainfall. Sethi et al. (2006) have developed a model for optimum allocation of land and suitability of crops under coastal saline area. They have shown that the alternation of crop and their holdings (using crop area co-efficient) by 20% (0.8–1.2), 40% (0.60–1.4) and 50% (0.5–1.5) of the exiting land holding significantly increase the net return by 8.3, 16.7 and 20.1%, respectively (Fig. 46.6). Basically, they have modulated the crop area according to their net water requirement. Less groundwater excavating restricts salinity hazard to the root zone.

46.7 Researchable Issues

Coastal ecosystem is a treasure if managed properly for ensuring livelihood security of a vast community of the world. However, the coastal ecology is under increasing pressure of anthropogenic activity and is very much vulnerable due to shift in land use pattern. There is huge capacity of coastal ecosystem for capturing blue carbon stock and thereby curbing the degradation. Management and conservation activities which improve quality of its soil are needed. To this end, a spatial and temporal map of the coastal regions highlighting location specific major soil-related problems with its master indicators may be developed for use. Attempt may be made to identify a few simple, robust, and low-cost indicators with high throughput for assessment of quality of soils under different coastal regions of the world. The key principle of rehabilitation of coastal system lies upon understanding of the hydrological cycle of the coastal region. A detailed database on the hydrological cycles may be generated for planning different activities in different coastal regions. A suite of site-specific soil management practices needs to be developed to check degradation and improve agronomic performance of coastal soils.

References

Bakker D, Hamilton M, Hetherington GJ et al (2010) Salinity dynamics and the potential for improvement of waterlogged and saline land in a Mediterranean climate using permanent raised beds. Soil Tillage Res 110(1):8–24

Crosby SC, Sax DF, Palmer ME et al (2016) Salt marsh persistence is threatened by predicted sea-level rise. Estuar Coast Shelf Sci 181:93–99

Deb S, Mandal B, Bhadoria PBS et al (2016) Microbial biomass and activity in relation to accessibility of organic carbon in saline soils of coastal agro-ecosystem. Proc Natl Acad Sci India Sect B Biol Sci 88(2):633–643. https://doi.org/10.1007/s40011-016-0801-4

Deb S, Mandal B, Bhadoria PBS et al (2018) Microbial biomass and activity in relation to accessibility of organic carbon in saline soils of coastal agro-ecosystem. Proc Natl Acad Sci India Sect B Biol Sci 88:633–643

Deb S, Mandal B, Bhadoria PBS et al (2020) Influence of sea water ingression on carbon sequestration in soils under coastal agro-ecosystems of eastern India. Agric Res 9:622–630

Diaz RJ, Rosenberg R (2008) Spreading dead zones and consequences for marine ecosystems. Science 321:926–929. https://doi.org/10.1126/science.1156401

Ellison JC (1993) Mangrove retreat with rising sea-level, Bermuda. Estuar Coast Shelf Sci 37:75–87

FAO (2015) Status of World soil resources. FAO, Washington DC, pp 100–146

Givnish T (2002) Adaptive significance of evergreen vs. deciduous leaves: solving the triple paradox. Silva Fenn. 36. https://doi.org/10.14214/sf.535

Haque MA, Muhammad J, Derek C (2018) Effect of plastic mulch on crop yield and land degradation in south coastal saline soils of Bangladesh. Int Soil Water Conserv Res 6:317–324. https://doi.org/10.1016/j.iswcr.2018.07.001

Mahajan GD, Bappa M, Ashwini M et al (2020) Soil quality assessment of coastal salt-affected acid soils of India. Environ Sci Pollut Res 27:26221–26238. https://doi.org/10.1007/s11356-020-09010-w

Nicholls RJ, Wong PP, Burkett VR et al (2007) Coastal systems and low-lying areas. In Parry ML, Canziani OF, Palutikof JP (ed) Climate change 2007: impacts, adaptation and vulnerability. Contribution of Working Group II to the fourth assessment report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, UK, pp 315–356. http://ro.uow.edu.au/scipapers/164

Oelsner GP, Stets EG (2019) Recent trends in nutrient and sediment loading to coastal areas of the conterminous US: Insights and global context. Sci Total Environ 654:1225–1240

Qian Y, Zhang W, Yu L et al (2015) Metal pollution in coastal sediments. Current Pollut Rep 1(4):203–219

Rangel-Peraza JG, Padilla-Gasca E, López-Corrales R et al (2017) Robust soil quality index for tropical soils influenced by agricultural activities. J Agric Chem Environ 6:199–221. https://doi.org/10.4236/jacen.2017.64014

Sappa G, Iacurto S, Ferranti F et al (2019) Groundwater quality assessment in a Karst coastal region of the West Aurunci mountains (Central Italy). Geofluids 2019:1–14. https://doi.org/10.1155/2019/3261713

Seitzinger SP, Harrison JA, Dumont E et al (2005) Sources and delivery of carbon, nitrogen, and phosphorus to the coastal zone: an overview of global nutrient export from watersheds (NEWS) models and their application. Global Biogeochem Cycles 19, GB4S01. https://doi.org/10.1029/2005GB002606

Sethi LN, Panda SN, Nayak MK (2006) Optimal crop planning and water resources allocation in a coastal groundwater basin, Orissa, India. Agric Water Manag 83:209–220

Shrestha RK, Lal R (2006) Ecosystem carbon budgeting and soil carbon sequestration in reclaimed mine soil. Environ Int 32:781–796

Sillero-Medina J, Gonzalez P, Ruiz-Sinoga J (2020) Differences in the soil quality index for two contrasting mediterranean landscapes in Southern Spain. Land 9(11):405. https://doi.org/10.3390/land9110405

Tripathi S, Kumari S, Chakraborty A et al (2006) Microbial biomass and its activities in salt-affected coastal soils. Biol Fert Soils 42:273–327
Tripathi S, Chakraborty A, Chakrabarti K et al (2007) Enzyme activities and microbial biomass in coastal soils of India. Soil Biol Biochem 39:2840–2848
UNEP-WCMC (2011) Marine and coastal ecosystem services: valuation methods and their application. The United Nations Environment Programme World Conservation Monitoring Centre Biodiversity Series No 33. p 46
Velmurugan A, Swarnam TP, Lal R (2015) Effect of land shaping on soil properties and crop yield in tsunami inundated coastal soils of Southern Andaman Island. Agric Ecosyst Environ 206:1–9
Wu C, Liu G, Huang C et al (2019) Soil quality assessment in Yellow River Delta: establishing a minimum data set and fuzzy logic model. Geoderma 334:82–89. https://doi.org/10.1016/j.geoderma.2018.07.045

Chapter 47
Participatory Conservation and Management of the Godavari Mangrove Wetlands, Andhra Pradesh, India

R. Ramasubramanian, R. Nagarajan, and S. Punitha

Abstract Godavari mangrove wetland in Andhra Pradesh is one of the important coastal wetlands providing livelihood security to the coastal community and ecological security to the coastal areas. Mangroves are potential carbon sinks contributing reduction in the impacts of climate change. Despite these benefits, mangroves are being degraded due to both manmade and natural causes. Participatory mangrove conservation and management approach gained greater significance in recent years in South Asian countries. M. S. Swaminathan Research Foundation (MSSRF) is implementing mangrove conservation and management programs from 1996 involving multiple stakeholders, namely the state forest department, revenue department, local self-government and the community. Gender-balanced village-level institutions (VLIs) were formed to plan, implement and monitor the mangrove conservation activities. Participatory rural appraisal was conducted to identify the status of mangrove resources, their utilization pattern and the issues related to its conservation and management. Causes for mangrove degradation were assessed jointly with the stakeholders. Majority of the degraded areas in the wetland were elevated, and tidal flushing was rare for most part of the year leading to hypersaline conditions of the soil. The degraded mangrove areas were restored through digging shallow canals to facilitate tidal water flow into the degraded area. Tidal flow in the canals reduces the soil salinity which enables the mangroves to grow. Nursery-raised mangrove saplings were planted along the canals. Local community played an active role in the mangrove restoration works which provided employment opportunity as well as a sense of ownership of the restored area. Apart from mangrove restoration, socioeconomic activities were carried out to improve the livelihoods of the community,

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and alternatives were provided for the mangrove-dependent community. The assessment of changes in the land use and land cover between 2000 and 2020 showed an increase in the mangrove area from 13,105 to 15,953 ha indicating the impact of mangrove conservation efforts. MSSRF restored an area of about 175 ha of degraded mangroves between 1996 and 2008, while the state forest department has restored nearly 2500 ha between 1990 and 2020 jointly with the stakeholders. This paper deals the approaches, strategies and impacts of participatory mangrove management in the Godavari wetland.

Keywords Participatory · Mangrove · Management · Godavari wetland · Degradation · Restoration · Sylviculture · Community · Remote sensing · Land use and land cover

47.1 Introduction

Mangroves are one of the highly productive ecosystems which occur in the intertidal areas of tropical and subtropical coasts. Mangroves thrive in the intertidal areas through adaptations such as pneumatophores, stilt roots, viviparous seeds, salt glands, salt-excluding mechanisms, etc. Mangrove wetlands sustain more than 70 direct human activities, ranging from fuel wood to fisheries as the source of income for the local community (Dixon 1989; Lucy 2006). Mangrove wetlands ensure increased fish catch to the coastal communities as they act as spawning and nursery grounds for fishes, shellfishes, crustaceans and other invertebrates (Bennett and Reynolds 1993; Fromard et al. 1998; Ramasubramanian et al. 2006). High-value commercial products are obtained from the mangroves, and they are potential areas for tourism (Kathiresan and Bingham 2001). The mangrove ecosystems supply organic nutrients to the marine fishery resources (Hutchings and Saengar 1987). Mangroves play a significant role in reducing the impacts of natural disasters like cyclones and tsunami (Kathiresan and Rajendran 2005; Bahuguna et al. 2008). Though the mangrove ecosystem provides multiple ecosystem services, they are the most exploited ecosystems in the world undergoing widespread degradation due to a combination of physical, biological, anthropogenic and social factors. Asian countries such as India, Pakistan, the Philippines and Indonesia are now carrying out participatory mangrove conservation programmes successfully (Das Gupta and Shaw 2013). These countries are now adapting decentralization of forest management by involving the local community for forest conservation and management. Involvement of local communities along with other stakeholders in the forest management has been successful in different mangrove ecosystems in India (Agrawal and Gibson 1999; Badola et al. 2012; Datta et al. 2012). In Indian Sunderbans, Joint Forest Management Committees (JFMCs) were involved in restoring more than 17,000 ha of degraded mangroves and protecting 64,000 ha mangrove forests as well as the tigers from 1996 in 65 villages (Vyas and Sengupta 2012). The mangrove restoration gained momentum in India (Bhatt and Kathiresan, 2012; Vyas and Sengupta, 2012) as it is an economically appropriate option for coastal area protection during the natural disasters. Much attention has been paid after witnessing the role of mangroves in mitigating and saving the precious human lives during the Indian Ocean tsunami in 2004 (Kathiresan and Rajendran 2005). Datta et al. (2012) emphasized the importance of economic stake for the dependent community on the ecosystem for their active involvement in mangrove conservation and management.

The extent of mangroves in India is about 4975 km^2 (FSI 2019). Participatory mangrove conservation activities are being carried out in Tamil Nadu, Odisha, Andhra Pradesh, West Bengal and Gujarat (Das Gupta and Shaw 2013). Andhra Pradesh has 582 km^2 of mangrove wetlands representing about 12% of the total mangrove extent of the country. Extensive mangrove wetlands are present in the major deltas of Krishna and Godavari and are also found in minor estuaries in Visakhapatnam, West Godavari, Guntur, Prakasam and Nellore districts.

The extent of the degraded mangrove area was high when MSSRF initiated participatory mangrove conservation and management during 1996 in the Godavari mangrove wetland. The coastal community was using the mangrove resources for fuel wood, fodder, fencing material and timber for house construction. Extensive use of the mangrove resource for domestic needs was one of the causes for mangrove degradation along the fringe areas. However, the conversion of mangrove wetlands for other purposes such as aquaculture, agriculture, salt pans and industries was the other major cause for degradation. Felling of mangroves for fuel wood till 1990 is one of the reasons for mangrove degradation in the core areas. In addition to these factors, changes in the topography due to sediment deposition adjoining the creeks lead to formation of levees prevent free flow of tidal water into the mangrove wetlands leading to degradation of mangroves. Siltation of the natural creeks prevents proper tidal water supply inside the mangroves which also cause degradation.

MSSRF restored about 2500 ha of degraded mangroves in the state of Andhra Pradesh, Odisha and Tamil Nadu involving the stakeholders, and in Andhra Pradesh, about 900 ha of degraded mangroves were restored in Krishna and Godavari wetlands since 1996. The Andhra Pradesh Forest department has restored more than 5000 ha in Andhra Pradesh from 1990 to 2020 in both the deltas. This paper provides the methods and strategies followed in mangrove conservation and management in Godavari wetland which will help the planners for replication in other parts of the globe.

47.2 Study Area

The Godavari mangrove wetland is located in the Godavari river delta between 16° 30′–17° N and 82° 14′–82° 23′ E in the East Godavari district, Andhra Pradesh (Fig. 47.1). The extent of this wetland is about 33,263 ha (Rajesh Mittal 1993). The Coringa wildlife sanctuary is a part of the Godavari mangrove wetland which is about 23,570 ha located in the northern side of the delta. A sand spit of about 18 km long along the eastern side of the Kakinada Bay is protecting the mangroves from

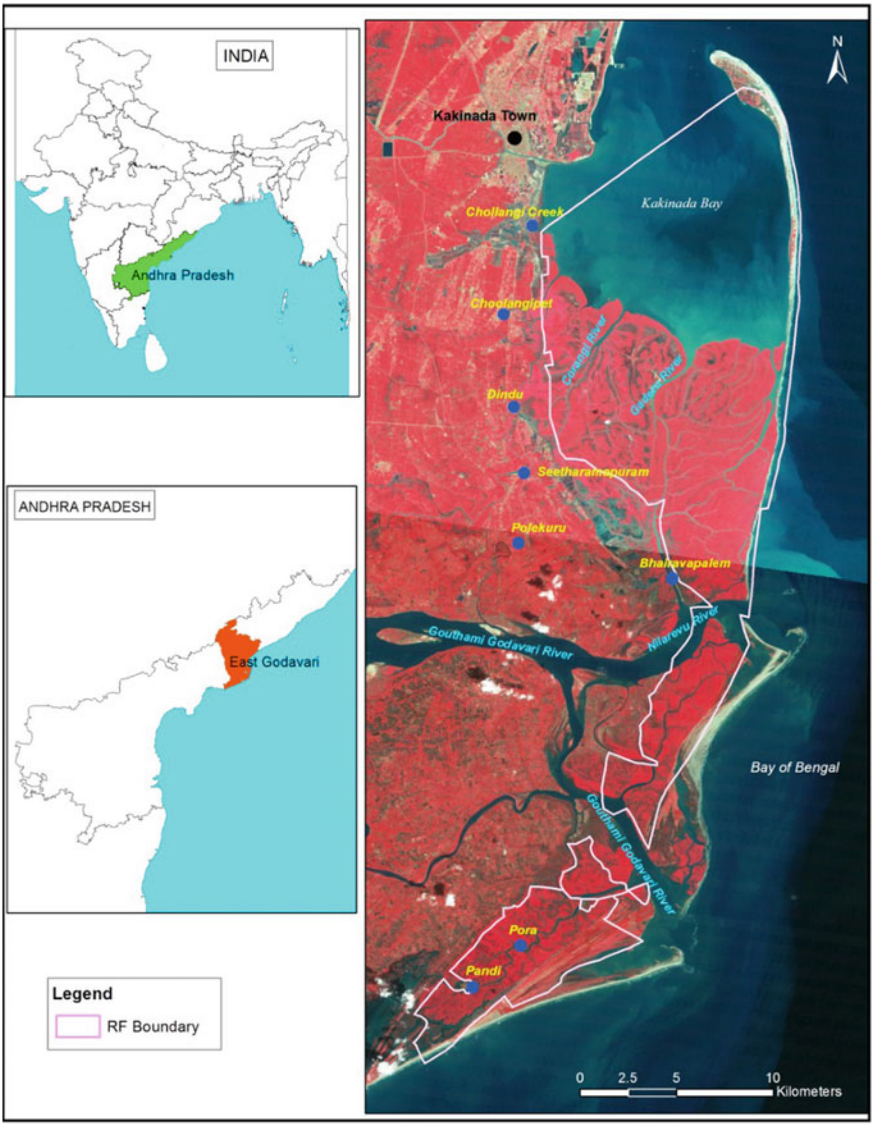

Fig. 47.1 Map showing the Godavari mangrove wetland

the high energy waves. Kakinada Bay is located in the northern side of the wetland which is shallow with an average depth of about 2 m. Two distributaries, namely Corangi and Gaderu, are branching-off from the River Godavari supply freshwater to the Coringa mangroves. Apart from these two major distributaries, a number of small creeks are interconnected forming a network of channels. Freshwater flows into the mangrove wetland for nearly six months in a year, and the peak flow normally occurs from July to September, coinciding with the southwest monsoon. Salinity is between 0 and 5 parts per thousand (ppt) during this period. The salinity level starts increasing from October through February and reaches its maximum during summer (March to May) when there is no freshwater discharge into the mangrove wetland. The drainage basin of the river Godavari occupies an area of 3.1×10^5 km^2, and the mean annual discharge is 1.05×10^{14} L (Alongi et al. 1992). The climate in this region is sub-humid, and the mean annual rainfall varies between 1200 and 1300 mm. The annual mean temperature is 28 °C. The area receives about 70% rainfall during the southwest monsoon and the remaining during northeast monsoon. The dry season extends for about six months, from December to May. The mean sea level in Godavari mangrove wetland is about 0.87 m, the maximum high tide is 1.54 m, and minimum high tide is 0.20 m (Upadhyay 1988). Fishing and farming communities living in 45 adjoining villages depend on mangroves for fish, fuel, fencing materials and fodder. Villages with dense mangrove forest cover were protected, and the villages with sparse mangrove cover were severely affected during November, 1996 cyclone.

47.3 Methodology

The participatory mangrove conservation is a community-centric program where the community and other stakeholders, namely the forest department and MSSRF, are involved in the process. Awareness on the importance of mangrove wetland for the livelihood and ecological security was explained through village-level meetings, workshops, folk media, audio-visuals and wall paintings. Entry point activities were carried out in the project villages to develop a better rapport with the community. The communities in the villages were mobilized and organized into a gender-balanced village-level institutions (VLIs) which have equal representation of both men and women in the general body as well as in the executive body. MSSRF implemented mangrove conservation program in six hamlets, namely Matlapalem, Dindu, Bhairavalanka, Gadimogga, Kobbarichettupeta and Chollangipet. The state forest department had established similar VLIs in 30 villages and implemented mangrove conservation activities. Participatory rural appraisal (PRA) was conducted in the project villages to identify the socioeconomic conditions, their dependency on mangroves, status of mangrove wetlands, availability of degraded area for mangrove restoration and also the nature of involvement of government departments in socioeconomic and mangrove development. Causes for mangrove degradation and the mangrove sylviculture practices were discussed in the PRA, and based on these discussions, microplans including the timeline and the budget were prepared jointly with the stakeholders. The microplan budget was deposited in a joint bank account which was operated jointly with the community. The degraded areas were identified with the help of bio-physical surveys, satellite imageries and through community interactions. Community members were trained in mangrove nursery, canal alignment, canal digging and planting of mangrove saplings. LPG gas stoves, chullahs and community wood lots were developed to reduce the mangrove dependency. The state forest department provided financial assistance to the farmers for withdrawing feral cattle from the forest. Both participatory monitoring and GIS-based monitoring of the areas were carried out to assess the progress.

47.3.1 Remote Sensing and GIS-Based Monitoring

The Landsat satellite image for the year 2000 was downloaded from USGS archives which have 30 m spatial resolution, and the Sentinel 2 satellite image was downloaded from ESA for the year 2020 which has 10 m spatial resolution used for assessment. The different bands from the satellite images were layer stacked, and the scenes were mosaiced and clipped for the study area using the ERDAS IMAGINE software. The pre-processing of the satellite images has been carried out for color correction and speckle removal. The supervised classification technique was used to classify the spectral values in the satellite image based on the spectral signatures using the ERDAS IMAGINE software. The training sets have been selected for each land use class, and the image has been trained to classify the satellite image for better accuracy. The Level 3 classification from FSI has been used to classify the land use with the focus on mangroves, mudflats and water bodies. In addition, the extensive ground truthing has been carried out to validate the classified land use using the handheld GPS. The post-processing has been carried out, and the classes have been validated for better accuracy. Finally, the layouts are prepared for the Godavari mangroves for the years 2000 and 2020 to assess the land use and land cover changes due to participatory mangrove conservation and management.

47.4 Results and Discussion

47.4.1 Community Mobilization and Organization

The community members were mobilized for participatory mangrove conservation which took considerable time as the approach was new then to all the stakeholders. Orientation on Joint Forest Management guidelines and the formation of VLIs with the equal representation of women in them were possible after many village-level meetings and consultations. Initially, it was a challenge which was overcome later due to entry point activities. The traditional panchayats dominated by men were sensitized for providing equal representation for women in the VLIs and involve them in the project activities. Gender-balanced VLIs were formed to plan, implement and monitor the project activities. The capacity building of the members of the VLIs were carried out on preparation of microplan, budget, minutes book, resolution books, maintaining account and other records including the bank pass books and transaction registers.

47.4.2 Restoration of Degraded Mangroves

Degraded areas suitable for mangrove restoration were identified through the PRA as well as using remote sensing images. Most of the local community visits the mangrove areas either for fishing or for grazing. The participatory methods such as focus group discussions with the elders of the villages provided the reasons for mangrove degradation. The identified area was assessed for its suitability based on the parameters such as soil salinity, soil texture, topography, suitable species to be planted based on zonation, tidal amplitude in the creeks, number of days of tidal inundation in a month and the depth of canals for proper tidal flushing. In the Godavari mangrove wetland, the degraded areas were not receiving tidal water inundation due to elevation beyond the high tide levels. The topographic survey in the degraded areas revealed that the areas were elevated between 30 and 40 cm above the high tide line due to levees. The canals were dug deeper in these elevated areas. Canals were dug with a depth ranging from 50 to 70 cm for facilitating tidal water flow inside the degraded area. Periodic tidal flushing, southwest monsoon and flood waters leached the salts in the soil. Soil salinity was reduced from 115 ppt in May to 60 ppt in August (90 days) after the area was opened for tidal water flushing (field observation). Mangrove nursery was established in the intertidal areas where the tidal water was used for raising the saplings. Growing the saplings in the saline environment helps better survival of saplings after transplantation in the degraded area. The rate of survival of planting of nursery raised mangrove saplings was higher than planting of seeds/propagules directly. Untawale (1996) and Snedaker and Biber (1996) reported the survival rate of nursery-raised saplings is more than direct sowing of mangrove seeds. Nursery-raised *Avicennia marina* and *Avicennia officinalis* were planted in the canals. These species have the ability to tolerate wide range of salinity. The local villagers were getting employment opportunities in the mangrove restoration works such as digging of canals, raising of mangrove nursery and planting of mangrove saplings. The involvement of the community in the restoration works ensured better monitoring of the plantation area, and also it indirectly triggering their close affinity and ownership of the restored patches.

Periodic monitoring of the growth and survival of mangrove saplings, desilting of canals for the tidal water flow during summer and casualty replacement were carried out in the first three years to get good survival rate of mangrove saplings. Remote sensing imageries were used for monitoring at a later stage. The Andhra Pradesh State Forest Department started mangrove restoration in the degraded areas in 1987 in an area of about 0.5 ha near Ramannapalem village in the Coringa Wildlife Sanctuary as a pilot and has improved the restoration practices gradually (Tulsi Rao 2013). MSSRF helped refining the restoration technique. MSSRF restored nearly 175 ha in Godavari mangrove wetland, and the APFD has restored 1634 ha between 1987 and 2015 in the Coringa Wildlife Sanctuary (Tulsi Rao 2013). The territorial division of the Godavari mangrove wetland also carried out large-scale mangrove plantation in their territory which is located in the southern part of the wetland.

47.4.3 Land Use and Land Cover Changes

The mangroves were felled till the Coringa Reserve Forest (RF) was declared as wildlife sanctuary in 1978 by the government, and the felling was continued till 1990 in the southern side of the wetland (territorial division). Repeated felling of mangroves on a rotational basis in the Godavari mangrove wetland between 1893 and 1990 resulted in poor regeneration of mangroves (Rajesh Mittal 1993). The restoration of degraded mangroves has been initiated by the forest department in 1989 and by MSSRF in 1996. MSSRF implemented India-Canada Environment Facility supported project on "Coastal Wetlands: Mangrove Conservation and Management", implemented between 1996 and 2003 and the Reliance Industries Limited supported project on "Mangrove restoration and afforestation of degraded mangroves in Godavari Estuary, Andhra Pradesh".

In addition to mangrove restoration, the dependency on mangroves by the coastal community has been reduced appreciably after 1996. The villagers started using LPG gas stoves and also constructed concrete houses after 1996 cyclone and 2004 *tsunami* with the support of the state and central government housing schemes. In 1996, more than 85% of the houses in the villages were huts built with mangrove wood. But now only less than 5% of the houses are huts. Similarly, the number of active fishers also came down as many left fishing due to less income. Many fishers are now working as masons, carpenters, auto drivers and labors in the industries. Earlier, fishers usually collect timber and fuel wood while fishing. They were selling them to the households, brick kilns and for tobacco curing. They were also using for smoking of fishes/shrimps. Since the number of boats and fishers in many villages has come down, their dependency for the above needs also comes down which is a positive factor for the mangrove cover increase. The state forest department, government welfare schemes and MSSRF-provided alternatives for the fuel wood to the dependent community reduced the mangrove usage. The land use and land cover classification of the degraded areas inside the reserve forest for the year 2000 and 2020 showed that the extent of the degraded area has come down drastically due to participatory mangrove conservation and management projects implemented by both APFD and MSSRF. The degraded area observed during 2000 was about 2657 ha, and in 2020, it was 129 ha only revealing the success of mangrove restoration efforts (Table 47.1, Figs. 47.2 and 47.3). Almost entire mangrove wetland inside the reserve forest has good mangrove cover now. Mangroves are also establishing naturally in the Kakinada Bay side due to extension of mudflats, while some of the mangroves were lost along the shore due to erosion. The sea level rise of 2–3 mm yr^{-1} is also contributing expansion of mangroves in the landward side as well as in the elevated degraded areas.

Table 47.1 Land use and land cover classification of mangroves in the reserve forests in Godavari mangrove wetland

S. No.	Land use/Land cover	Area in ha (2000)	Area in ha (2020)
1	Mangrove (dense and moderate)	13,105	15,953
2	Degraded mangrove (sparse)	2657	129
3	Mud flat	878	467
4	Other vegetation (*Casuarina*)	322	458
5	Sand	1299	1239
6	Water bodies	14,246	14,261
	Total	**32,507**	**32,507**

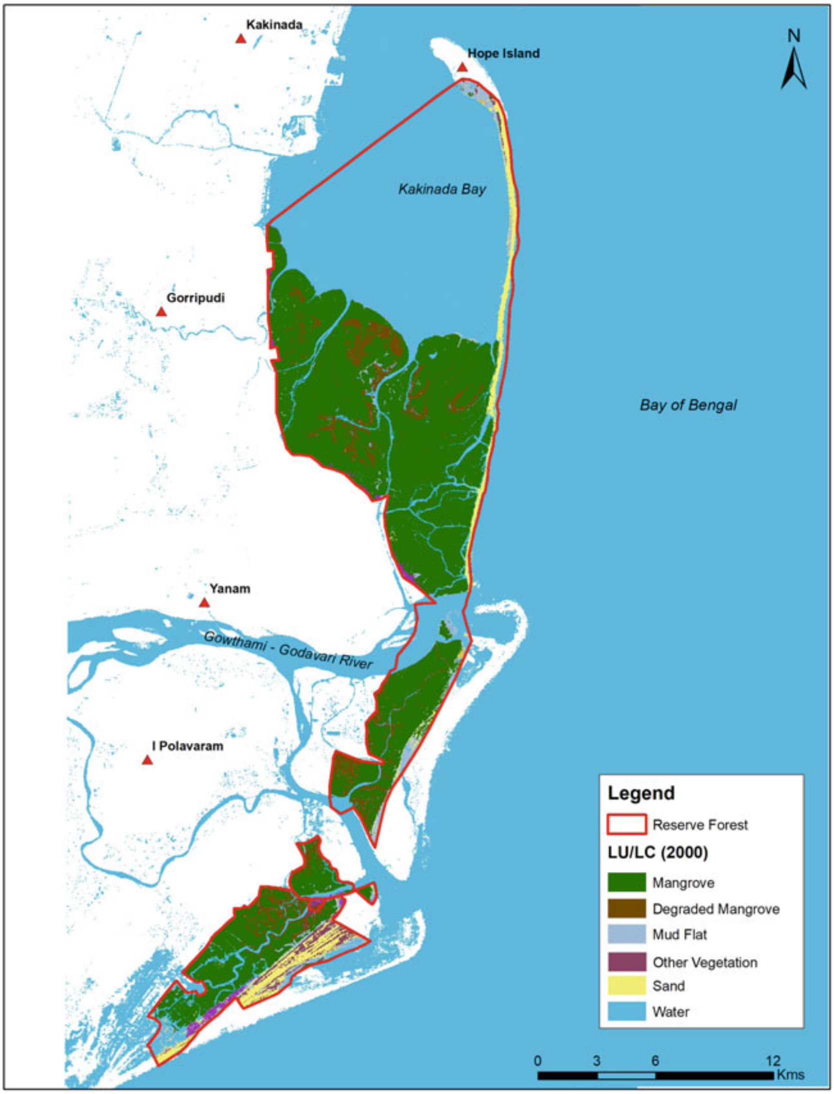

Fig. 47.2 Land use and land cover map showing the degraded mangrove areas in 2000

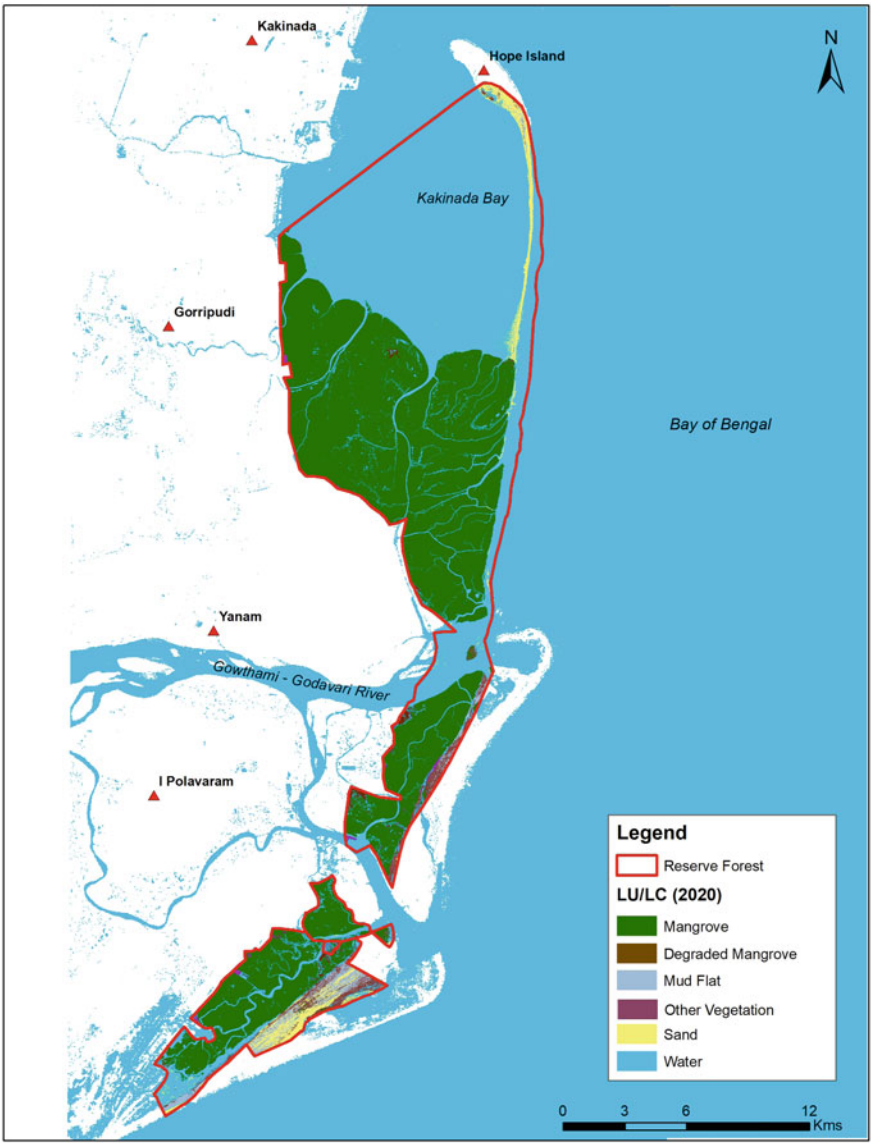

Fig. 47.3 Land use and land cover map showing the degraded mangrove areas in 2020

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References

Agrawal A, Gibson CC (1999) Enchantment and disenchantment: the role of community in natural resource conservation. World Dev 27(4):629–649

Alongi DM, Boto KG, Robertson AI (1992) Tropical mangrove ecosystem. In: Alongi DM, Robertson AI (eds) American Geophysical Union, Washington, DC, USA, pp 251–292

Badola R, Barthwal S, Hussain SA (2012) Attitudes of local communities towards conservation of mangrove forests: A case study from the east coast of India. Estuar Coast Shelf Sci 96:188–196

Bahuguna A, Nayak S, Roy D (2008) Impact of the tsunami and earthquake of 26th December 2004 on the vital coastal ecosystems of the Andaman and Nicobar Islands assessed using RESOURCESAT AWiFS data. Int J Appl Earth Obs 10:229–237

Bennett EL, Reynolds CJ (1993) The value of a mangrove area in Sarawak. Biodivers Conserv 2:359–375

Bhatt JR, Kathiresan K (2012) Valuation, carbon sequestration and restoration of mangrove ecosystems in India. In: Macintosh DJ, Mahindapala R, Markopoulos M (eds) Sharing lessons on mangrove restoration, Bangkok, Thailand: Mangroves for the future and gland. IUCN, Switzerland, pp 19–38

Das Gupta R, Shaw R (2013) Changing perspectives of mangrove management in India—an analytical overview. Ocean Coast Manage 80:107–118

Datta D, Chattopadhyay RN, Guha P (2012) Community based mangrove management: a review on status and sustainability. J Environ Manage 107:84–95

Dixon JA (l989) The value of mangrove ecosystems. Trop Coast Area Manage Newsl 4:5–8

Fromard F, Puig H, Mougin E, Marty G, Betoulle J, Cadamuro L (1998) Structure above-ground biomass and dynamics of mangrove ecosystems: new data from French Guiana. Oecologia 115:39–53

FSI (2019) The state of forest report. Ministry of Environment and Forest, Government of India

Hutchings P, Saengar P (1987) Ecology of mangroves. University of Queensland Press, St. Lucia, p 388

Kathiresan K, Bingham BL (2001) Biology of mangroves and mangrove ecosystems. Adv Mar Biol 40:81–251. https://doi.org/10.1016/S0065-2881(01)40003-4

Kathiresan K, Rajendran N (2005) Coastal mangrove forests mitigated tsunami. Estuar Coast Shelf Sci 74:601–606

Lucy E (2006) Counting mangrove ecosystems as economic components of Asia's coastal infrastructure. In: Proceedings of International conference and exhibition on mangroves of Indian and Western Pacific oceans (ICEMAN 2006), Aug 21–24 2006, Kuala Lumpur, pp 1–14

Rajesh M (1993) Management plan for Coringa wildlife sanctuary, Rajahmundry. Andhra Pradesh Forest Department, India

Ramasubramanian R, Gnanappazham L, Ravishankar T, Navamuniyammal M (2006) Mangroves of Godavari—analysis through remote sensing approach. Wetl Ecol Manag 14:29–37

Snedaker SC, Biber PD (1996) Restoration of mangroves in the United States of America: a case study in Florida. In: Field CD (ed) Restoration of mangrove ecosystems. International Society for Mangrove Ecosystem, Okinawa, Japan, pp 170–188

Tulsi Rao K (2013) Biodiversity management plan Coringa wildlife sanctuary—2013–2023, GoI-UNDP-GEF-GoAP Project on Mainstreaming Coastal and Marine Biodiversity Conservation (EGREE Foundation), p 283

Untawale AG (1996) Restoration of mangroves along the Central West coasts of India. In: Field CD (ed) Restoration of mangrove ecosystems. International Society for Mangrove Ecosystem, Okinawa, Japan, pp 111–125

Upadhyay S (1988) Physico-chemical characteristics of the Mahanadi estuarine ecosystem, eastcoast of India. Indian J Mar Sci 17:19–23

Vyas P, Sengupta K (2012) Mangrove conservation and restoration in the Indian Sundarban. In: Macintosh DJ, Mahindapala R, Markopoulos M (eds) Sharing lessons on mangrove restoration, IUCN, Gland, Switzerland and Mangroves for the Future, Bangkok Thailand, pp 93–101

Chapter 48
Unraveling the Potential of Belowground and Aboveground Biodiversity for Sustainable Management of the Health of Plantation Crop Soils in Coastal Agro-Ecosystem

George V. Thomas, P. Subramanian, Murali Gopal, Alka Gupta, and S. R. Prabhu

Abstract A range of plantation crops, viz., coconut palm, areca-nut palm, oil palm, cashew, cocoa, coffee, rubber and spices are cultivated in the tropical coastal agro-ecosystem to meet the needs of food, oil, beverage, industrial raw materials and fiber. Predominantly grown in small and marginal holdings, the sustainability of these crops is confronted with many challenges related to climate change and production base deterioration. In plantation crops, immense opportunities exist to enhance the aboveground biodiversity by introduction of compatible crops as inter/mixed crops, which in turn will determine belowground biodiversity that, in turn, influences soil health and crop growth. Agricultural technologies such as cover cropping and green manuring, recycling of lignin-rich crop residues, application of bio-fertilizers and bio-stimulants, cropping system approach—inter, mixed and high density multispecies cropping and mixed farming integrating animal husbandry have been reported to be effective in enhancing system productivity with significant benefits to soil biology and fertility. A cropping/farming system approach which can ensure optimum utilization of natural resources and simultaneously promote belowground and aboveground biodiversity and carbon sequestration will prove beneficial

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to achieve resilience in soil health and to address the challenges in the future scenarios of climate change.

Keywords Aboveground biodiversity · Belowground biodiversity · Coastal agro-ecosystem · Plantation crop soils · Sustainable health management

48.1 Introduction

Plantation crops, viz., coconut palm, areca-nut, oil palm, cashew, cocoa, coffee, rubber and spices cultivated in the coastal agro-ecosystem to meet the needs of food, oil, beverage, industrial raw materials and fiber, are the drivers of rural economy in the tropical regions of India. These crops sustain livelihood and play an important role in elevating the socio-economic status of millions who depend on these group of crops for cultivation, processing, value addition, marketing and export. Being perennial crops with long lifespan, these crops are also important in view of their role in ecosystem services and their impact on environment (Thomas 2009). Predominantly grown in small and marginal holdings, the sustainability of the agro-ecosystem of these crops is confronted with a number of challenges related to production base deterioration and climate change. Soil erosion, pollution, nutrient deficiencies, loss of soil organic carbon and soil biodiversity are serious impediments impacting the productivity and sustainability of these agro-ecosystems recently. In this context, viable and low-cost management technologies based on locally available resources that promote soil health and ecosystem functions are of vital importance to achieve sustainable production.

Several cropping/farming system models have been developed with the introduction of annual, biennial and perennial crops in the interspaces of plantation crops to utilize the resources effectively and to enhance the productivity on unit area, time and inputs and maximize the profitability of farming on a sustainable basis. In this paper, an attempt has been made to review the results of research carried out on enhancing aboveground diversity in plantation crops and its effects on belowground diversity and soil health improvement and the influence of soil health improvement and positive interaction effects on enhancing crop productivity on a sustainable basis.

48.2 Research Progress in Enhancing Aboveground Diversity in Plantation Crops

The research on enhancing aboveground diversity by way of developing appropriate cropping systems in plantation crops like coconut and areca nut is driven by the fact that these crops when cultivated as a monocrop utilize only a limited portion of the natural resources, particularly solar radiation, water, nutrients and land space available in the garden (Nelliat et al. 1974; Bavappa et al. 1986). In order to effectively utilize the natural resources and to meet the needs of farmers and to enhance the economic viability of farming, several cropping system models involving the cultivation of annuals, biennials and perennials in the interspaces of plantation crops have been developed (Nair 1977; Thomas et al. 2010). Cropping systems offer considerable scope for increasing productivity per unit area, time and inputs through efficient utilization of resources like sunlight, soil, water and labor. Growing annuals/biennials in the interspaces is referred as intercropping. A large variety of crops including tropical tuber crops, rhizome spice crops, cereals, vegetables, pulses, oil seeds, fruit crops, flower crops, medicinal and aromatic crops have been reported to be suitable for growing as intercrops. Cultivation of perennial crops with plantation crops is referred as mixed cropping. Perennials like cacao, clove, nutmeg, coffee, black pepper, cinnamon, cardamom, mango, papaya etc., can be successfully grown as mixed crops. High-density multispecies cropping system or multistoried cropping system involves growing of coconut or areca nut with a combination of annual and perennial crops of different heights, rooting characteristics and canopy patterns in the same garden so as to maximize utilization of solar radiation, nutrients and moisture (Bavappa et al. 1986). Mixed farming involves integration of other subsidiary enterprises such as livestock, poultry, rabbitry, pisciculture, sericulture and goat rearing along with the cultivation of fodder and pasture (Maheswarappa et al. 1998). Agroforestry is practiced in coconut involving cultivation of compatible fruit trees and multipurpose species for complimentary benefits and carbon sequestration potential (CPCRI 1989).

Agricultural technologies such as cover cropping and green manuring with leguminous crops possessing high N_2 fixation efficiency, recycling of lignin-rich crop residues and application of bio-fertilizers have been reported to be components for sustainable agriculture in plantation crops with significant benefits to soil biology and fertility.

48.3 Impact of Aboveground Diversity on Belowground Biodiversity

The technologies involved in enhancing the aboveground biodiversity in plantation crops by way of enhancement of crop diversity in plantations resulted in complementary and synergistic interactions between component crops in the system. There is scientific evidence that increased aboveground diversity can enhance belowground diversity as well. The factors which promote belowground diversity in a perennial garden with diversified crop combinations compared to a monocrop have been elucidated.

48.4 Root Exudates as Chemical Signals Driving Microbial Proliferation

Studies in the perennial crop-based cropping systems revealed that the component crops exerted influence on the microbial community structure and function through rhizospheric deposits, which act as chemical signals and source of nutrients for microbes. The roots of each crop in the cropping system exuded significant quantities of sugars, amino acids, organic acids, phenols and many other organic compounds into the rhizosphere, which influenced the number and diversity of microorganisms in the rhizosphere. A comparative study revealed distinct differences in the composition of root exudates from coconut palms under the monocropping and mixed cropping systems. Higher level of total sugar exudation by coconut palms in coconut-based mixed farming and multistoried cropping systems, when compared to monocrop of coconut, has been reported (Bopaiah et al. 1987).

48.5 Biological Indicators of Soil Health to Enhance Crop Diversity

The need to reduce the reliance on agrochemicals in view of its adverse effects on environment and the need to develop sustainable management practices make rhizosphere interactions' research a hotspot under the changing agricultural scenario (Zhang et al. 2017). The multitude of soil biological fertility parameters from plantation crop-based cropping/farming systems from different locations in coastal agro-ecosystems have clearly brought out the significant impact of increasing the above-ground diversity on a range of parameters contributing to belowground diversity, biological activities, soil health and fertility.

48.6 Soil Microbial Biomass as Sensitive Indicator of Soil Quality

The positive impact of introduction of various crops and animal husbandry components in a perennial stand of coconut and areca nut on soil quality was reflected on the soil microbial biomass. The influence on soil microbial carbon and nitrogen were prominent in root region of coconut and cocoa in a mixed stand than in coconut basin soils under monocrop (Bopaiah and Shetty 1991b). Introduction of animal husbandry components with significant addition of organic biomass had greater influence on soil microbial biomass carbon levels when compared to that in monocrop (Bopaiah and Shetty 1991a). Organic carbon inputs from crop roots, rhizosphere products and crop residues have significant effect on microbial biomass and its activity, which in turn, affect the ability of soil to supply nutrients to the plants through soil organic matter turnover.

48.7 Microbial Community Structure and Abundance

Several studies on plant beneficial microbial community in the perennial crop-based cropping/farming systems and the coconut stands without inter/mixed crops over the years revealed the profound influence of complementary and synergistic interactions in the cropping systems in augmenting plant beneficial microbial community in the soil, rhizosphere and internal tissues of crop plants (endophytes) of the main crop, irrespective of the crops which formed the components of the cropping systems (Nair and Subba Rao 1977; Potty et al. 1977; Rohini Iyer 1983; Bopaiah and Shetty 1991a, 1991b).

48.8 Function-Specific Microbial Communities

Function-specific microorganisms including biological nitrogen fixing bacteria, phosphate solubilizing bacteria and fungi, phosphate mobilizing fungi and plant growth promoting bacteria (PGPR) were reported to be present in higher numbers in root region, rhizosphere and endosphere of coconut under various cropping systems compared to that under monocropping systems (Nair and Subba Rao 1977; Bavappa et al.1986; Bopaiah et al. 1987; Thomas et al.1991). Mixed cropping of coconut with cocoa stimulated the population of function-specific microbes in the rhizosphere of coconut, particularly those involved in fixation of nitrogen (Nair and Subba Rao 1977). A study on 26 crops including plantation crops and intercrops in different cropping systems revealed the occurrence of *Azospirillum* in different levels in coconut-based farming systems (Ghai and Thomas 1989). The coconut harbored endophytic association of unique diazotrophs, viz., *Azoarcus* spp., *Burkholderia* spp., *Herbaspirillum frisingense* and *Arthrobactor* spp. with nitrogen fixation and plant growth promotion properties. Species diversity of *Azospirillum* included *A. lipoferum, A. brasilense, A. amazonense* in endorhizosphere and rhizosphere regions of coconut (Thomas and Prabhu 2003). A study on coconut and cocoa from different crop growing regions revealed the close association of bacteria possessing plant growth promoting (PGP) traits such as production of IAA, ACC deaminase, HCN, siderophore, chitinases and antibiotics, ammonification, ability to grow on N-free media and solubilization of phosphates (Litty et al. 2010; Priya et al. 2012).

48.9 Endophytic Association of Arbuscular Mycorrhizal Fungi

Plantation crops formed symbiotic association with arbuscular mycorrhizal fungi (AMF), the root inhabiting predominant microbiota which influence the health and productivity of plants. This symbiotic association, in addition to its role in suppressing root pathogens, helps plants in the absorption of phosphorus and other immobile elements, such as sulfur, calcium, zinc and copper, particularly from low-fertility soils. A study on diversity of arbuscular mycorrhizal (AM) fungi associated with coconut and areca nut intercropping systems of Kasaragod and Thiruvananthapuram districts of Kerala revealed that mycorrhizal parameters like spore density, root colonization, species richness and relative occurrence of species varied significantly among the cropping systems (Ambili et al. 2012). From the coconut palm cultivated in crop mixed system under rain-fed condition in a highly productive zone in Malappuram district of Kerala, India, forty AM species belonging to ten genera, viz., *Acaulospora*, *Claroideoglomus*, *Dentiscutata*, *Diversispora*, *Funneliformis*, *Gigaspora*, *Glomus*, *Redeckera*, *Scutellospora* and *Septoglomus* were recorded indicating high level of AM richness in coconut rhizosphere under intercropping (Rajesh et al. 2015).

48.10 Earthworm Community in Cropping Systems

In a study conducted in coconut plantations under different management practices, it was evident that earthworm community was completely absent in monocropped coconut gardens maintained with tillage and recommended dose of fertilizer inputs. But, the density and biomass of earthworm population were significantly high in high-density multispecies cropping system maintained with profuse aboveground diversity and integrated nutrient management with lower dose of chemical fertilizer inputs.

48.11 Increase in Arthropod Biodiversity

In alley cropping, where oil palm (*Elaeis guineensis*) was intercropped with pineapple, bamboo, black pepper, cacao and bactris palms, faunal biodiversity and related ecosystem services as well as productivity were significantly increased compared to monocrop (Ashraf et al. 2018). The number of arthropod orders, families and abundance were significantly greater in alley cropping/farming plots than those in monoculture plots. In addition, alley cropping treatments harbored larger numbers of predators and decomposers. The alley cropping system has been proved to be a key management strategy to improve biodiversity and ecosystem functions within oil palm production landscapes.

48.12 Soil Biological Activity as Evidenced by Enzyme Changes

Biological activity in the soil as evidenced by level of enzymes involved in nutrient cycling and microbial proliferation showed significant increase in cropping systems when compared to that in monocrop of coconut. The report of increase in activities of soil enzymes, viz., dehydrogenase, urease and phosphatase in integrated farming system of coconut were indicative of improved total biological activity in soil and enhanced transformations of urea and phosphate as a result of introduction of fodder grass and animal husbandry components and recycling of organic matter (Bopaiah and Shetty 1991a). In the high-density multispecies cropping system maintained with different fertilizer doses, soil enzymes, viz., dehydrogenase, phosphatase, aryl sulfatase and β-galactosidase, showed a general trend of increase in activities from unfertilized control to medium doses of fertilizers and a decline thereafter in higher doses. It was evident that recommended dose of fertilizers had adverse effect on soil enzymes and medium fertilizer inputs with organic recycling favored significantly higher enzyme activities (Kavitha 2009). Comparative analysis of data from different experiments revealed highest yield output in coconut and component crops in integrated nutrient management treatments while organic farming practices contributed to sustainable yield with greater beneficial effects on soil biological activity and soil health.

48.13 Mineralization of Nutrients

When carbon and nitrogen mineralization in root zone soils in coconut palm-based multistoried cropping system and monocrop of coconut were compared, the root zone soils of various intercrops had significantly greater levels of carbon and nitrogen mineralization, while the interspace soils had negligible mineralization (Bopaiah and Shetty 1991a). In the areca nut-based cropping system too, the rate of carbon mineralization was influenced by crops, nutrient management and the interaction of both. Among the nutrient levels evaluated, carbon mineralization increased significantly up to two-third recommended dose plus organic matter recycling, and there was reduction in mineralization rate at the full recommended dose (Bhat et al. 2008). Integrated nutrient management has been reported to provide highest yield output, while organic farming practices contributed to sustainable yield with greater beneficial effects on soil biological activity and soil health.

48.14 Carbon Sequestration Potential in the Aboveground and Belowground Biomass in Plantations

Carbon sequestration is a viable option to mitigate climate change as it enables to convert increased atmospheric CO_2 in atmosphere into long-lived wood biomass and soil carbon pool. The aboveground and belowground carbon sequestration potential of coconut-based vegetable intercropping system was brought out in a study by Kumar and Maheswarappa (2019). The incremental increase in the carbon sequestration by palms after two years was to the tune of 3.01 t ha^{-1} under intercropping compared to 2.31 t ha^{-1} in the monocropping system. The increase in soil carbon stock was significantly high reaching 21.16 Mg C ha^{-1} at 0–30 cm layer in the integrated nutrient treatment with FYM, vermicompost, composted coir pith, vermiwash spray and *Azotobacter* when compared to 17.94 Mg C ha^{-1} in inorganic fertilizer treatments. A study on carbon stocks in major cashew growing soils of coastal Karnataka by Srinivasan et al. (2019) revealed that cashew plantation under natural management had more SOC stock and high carbon sequestration potential than intensively managed cashew plantations with less aboveground diversity.

48.15 Ecosystem Services and Energy Use Efficiency

A study on areca nut palm-based cropping systems (ABCS) in farmers gardens in west coast of India indicated that ecosystem services and energy use efficiency were high in ABCS under organic farming (OF) practices followed by that in integrated nutrient management (INM) (Paramesh et al. 2019). The multiple benefits of organic farming include its effectiveness to improve system profitability, sustainable farm production, soil quality, energy efficiency and the environmental quality of areca nut-based cropping system in the west coast of India.

48.16 Interrelationships Between Belowground Diversity and Aboveground Diversity and Ecosystem Functioning

The beneficial effects of inter/mixed cropping in a perennial stand of plantation crops include availability of crop residues with varied chemical composition, increased availability of root surface area and resulting in increased quantity of root exudation for microbial use, improvement in soil fertility status and higher crop productivity in the system, which contributed to social and economic benefits. In-depth investigations in the system brought out the microbial processes and interactions leading to improvement in soil health and quality resulting in sustainable crop productivity. There are also reports on the significant contribution of diversity of microorganisms and animals that live belowground in shaping aboveground biodiversity and the functioning of terrestrial ecosystems (Bardgett and Putten 2014). Further evidence has also been collected by Gaba et al. (2015) on the greater role of soil biodiversity in determining the ecological and evolutionary responses of terrestrial ecosystems to current and future environmental change. Studies from different locations revealed that multiple cropping systems are drivers for providing multiple ecosystem services.

Better efficiency of ecosystem functioning in cropping systems with perennial plantation crops was evidenced from field experiments conducted over several decades in relation to increased yields of the main crop, overall productivity of the system, improved resource use efficiency, provision of ecosystem services and lower production risks. In intensive cropping, when crops are grown in association, interaction between different crops occur with increased efficiency of land use and yield gain of the main crop, which is attributed to the complementary effect. The beneficial effects include improvement in soil fertility status, enhanced biodiversity, higher biological activity, higher interception of light, better micro-climate and reduced weed growth which helped to achieve higher productivity. Evidences from cropping systems further revealed the vital importance of the complex underground root–soil–microbe interactions in determining the aboveground plant growth, health and fitness.

48.17 Future Thrust

The future research should focus on harnessing the potential of soil microbiome and agriculturally important functional genes from soil organisms to maximize soil health and crop productivity. Efforts are needed to sustainably manage soil biodiversity by identifying appropriate soil and crop husbandry practices. Lignin-rich biomass from plantation crops can itself form a solution to the issue of declining soil productivity by intelligent ways of recycling this biomass to sustainably maintain and improve soil health, soil biodiversity and crop productivity. Bio-stimulants (Rouphael and Colla 2020). produced from oil cakes from coconut and oil palm and fish wastes need to be explored for enhancing soil and crop health. A cropping/farming system approach with optimum utilization of natural resources with less reliance on agrochemicals and promoting higher level of belowground and aboveground biodiversity and carbon sequestration will prove beneficial to achieve resilience in soil health, which can help to address the challenges in the future scenarios of climate change. Of late, evidence is mounting on the vital role of microbiome in sustainable growth and productivity of plants. The plant microbiome comprising of a myriad of prokaryotic and eukaryotic organisms, including bacteria, archaea, viruses, fungi and protozoans, control the host functions such as metabolism, nutrition, physiology and immunology (Ottman et al. 2012). The insights gained in root–soil–rhizo-microbiome interactions, through the advances of omics and bioinformatics technologies, open up the immense opportunities to develop strategies to manage the complex rhizosphere interactions for enhancing crop production.

References

Ambili K, Thomas GV, Indu P et al (2012) Distribution of arbuscular mycorrhizae associated with coconut and arecanut based cropping systems. Agric Res 1(4):338–345

Ashraf M, Zulkifli R, Sanusi R et al (2018) Alley-cropping system can boost arthropod biodiversity and ecosystem functions in oil palm plantations. Agric Ecosyst Environ 260:19–26

Bardgett RD, Van der Putten WH (2014) Soil biodiversity and ecosystem functioning. Nature 515:505–511

Bavappa KVA, Kailasam C, Khader KBA et al (1986) Coconut and arecanut based high density multispecies cropping system. J Plantation Crops 14:74–87

Bhat R, Sujatha S, Thomas GV (2008) Soil microbiological and enzymological response to organic matter recycling and chemical fertilization in areca nut based cropping system. J Plantation Crops 36(3):281–289

Bopaiah BM, Shetty HS (1991a) Soil microflora and biological activities in the rhizosphere and root regions of coconut based multistoried cropping and monocropping systems. Soil Biol Biochem 23:89–94

Bopaiah BM, Shetty HS (1991b) Microbiology and fertility in coconut-based mixed farming and coconut monocropping systems. Trop Agric (Trinidad) 68(2):135–138

Bopaiah BM, Shetty HS, Nagaraja KV (1987) Biochemical characterization of root exudates of coconut palm. Curr Sci 56:832–833

CPCRI (1989) Annual report 1988. ICAR-Central Plantation Crops Research Institute (CPCRI), Kasaragod, Kerala, India, p 37

Gaba S, Lescourret F, Boudsocq S et al (2015) Multiple cropping systems as drivers for providing multiple ecosystem services: from concepts to design. Agron Sustain Dev 35(2):607–623

Ghai SK, Thomas GV (1989) Occurrence of *Azospirillum* spp. in coconut based farming systems. Plant Soil 114:235–241

Kavitha MS (2009) Soil microbial diversity and biological processes in high density multispecies cropping systems of coconut. Ph.D. Thesis. Mangalore University Karnataka, India, p 174

Kumar KS, Maheswarappa HP (2019) Carbon sequestration potential of coconut based cropping systems under integrated nutrient management practices. J Plantation Crops 47(2):107–114

Litty T, Gupta A, Gopal M et al (2010) Plant growth promoting potential of *Bacillus* spp. isolated from rhizosphere of cocoa (*Theobroma cacao* L.). J Plantation Crops 38(2):97–104

Maheswarappa HP, Hegde MR, Dhanapal R et al (1998) Mixed farming in coconut gardens: its impact on soil physical and chemical properties, coconut nutrition and yield. J Plantation Crops 26(2):139–143

Nair SK, Subba Rao NS (1977) Microbiology of root region of coconut and cocoa under mixed cropping. Plant Soil 46:511–516

Nair PKR (1977) Intensive multiple cropping with coconuts in India: principles, programs and prospects. Adv Agron Crop Sci 6, Verlag Paul Parey, West Berlin, p 147

Nelliat EV, Bavappa KVA, Nair PKR (1974) Multi-storied cropping- a new dimension in multiple cropping for plantations. World Crops 26(6):262–266

Ottman N, Smidt H, de Vos WM et al (2012) The function of our microbiota: who is out there and what do they do? Front Cell Infect Microbiol 2:104. https://doi.org/10.3389/fcimb.2012.00104

Paramesh V, Arunachalam V, Nath AJ (2019) Enhancing ecosystem services and energy use efficiency under organic and conventional nutrient management system to a sustainable arecanut based cropping system. Energy 187:1–10

Potty VP, George M, Jayasankar NP (1977) Effect of crop mixing on coconut rhizosphere. Indian Coconut J 8:1–2

Priya G, Gupta A, Gopal M et al (2012) Screening and *in vitro* evaluation of phosphate solubilising bacteria from rhizosphere and roots of coconut palms (*Cocos nucifera* L.) growing in different states of India. J Plantation Crops 40(1):61–64

Rajesh Kumar PP, Thomas, GV, Gupta A et al (2015) Diversity, richness and degree of colonization of arbuscular mycorrhizal fungi in coconut cultivated along with intercrops in high productive zone of Kerala, India. Symbiosis 65:125–141

Rohini lyer (1983) Rhizosphere microflora in crop mixed coconut soil. Philippine J Coconut Stud 6(2):42–45

Rouphael Y, Colla G (2020) Biostimulants in agriculture. Front Plant Sci 11:40. https://doi.org/10.3389/fpls.2020.00040

Srinivasan R, Natarajan A, Anil Kumar AS et al (2019) Carbon stocks in major cashew growing soils of coastal Karnataka, India. J Plantation Crops 47(1):55–61

Thomas GV (2009) New vistas in plantation crops research. J Plantation Crops 37(1):1–8

Thomas GV, Iyer R, Bopaiah BM (1991) Beneficial microbes in the nutrition of coconut. J Plantation Crops 19(2):127–138

Thomas GV, Prabhu SR (2003) Association of diazotrophic and plant growth promoting rhizobacteria with coconut palm (*Cocos nucifera* L.). In: Proceedings of 6th International PGPR workshop, IISR, Calicut, 5–10th October 2003, pp 20–26

Thomas GV, Krishnakumar V, Maheswarappa HP et al (2010) Coconut based cropping/farming systems. Central Plantation Crops Research Institute, Kasaragod, p 231

Zhang R, Vivanco JM, Shen Q (2017) The unseen rhizosphere root–soil–microbe interactions for crop production. Curr Opin Microbiol 37:8–14

Chapter 49
Nanofertilizers and Nanobioformulations: Blessings for Global Farming

J. C. Tarafdar

Abstract Nanofertilizers application in agriculture may serve as an opportunity to achieve sustainability towards global food production. Important benefits of nanofertilizers over conventional chemical fertilizers rely on nutrient delivery systems. For example, the nutrient can be released over 40–50 days in a slow-release fashion rather than 4–10 days by the conventional fertilizers. The nutrient use efficiency also improved by 3–20 times; therefore, nutrient requirements are less as well as reduces the need for transportation and application costs. Another advantage of using small quantities is that soil does not get loaded with salts that usually are prone to over application using conventional fertilizer. Nanofertilizers also can be used as nanobioformulations. The formulations containing one or more beneficial microorganisms after blending of required nanoparticles to enhance soil productivity. Nanobioformulations can be helpful to enhance the stability of biofertilizers with respect to desiccation, heat and UV inactivation. It can also solve some limitations of biofertilizers such as ease of handling, enhanced stability, protection against oxidation, retention of volatile ingredients, taste making and consecutive delivery of multiple active ingredients. In general, nanofertilizers mobilizes 30% more native nutrients than conventional fertilizer application. The average improvement of yield, irrespective of crops and soil types, varies between 24 and 32% as compared to 12–18% under chemical fertilizers. Nanofertilizers, with a particle size less than 100 nm, influence key life events of the plants that include seed germination, seedling vigour, root initiation, growth and photosynthesis to flowering. Additionally, nanofertilizers have been implicated in the protection of plants against oxidative stress as they mimic the role of anti-oxidative enzymes such as superoxide dismutase (SOD), catalase (CAT) and peroxidase (POX). But in spite of all these, nanofertilizers should be applied as recommended doses; because higher rate of application have been proved to cause phytotoxicity as they enhance the generation of reactive oxygen species (ROS). The elevated level of ROS may damage the cellular membranes, proteins and nucleic acids. The uptake rate of nanoparticles by plants also depends on their shape and sizes. In general, small sizes of nanoparticles can be penetrating through the cuticle while larger nanoparticles can penetrate through cuticle-free areas such

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as hydathodes, stigma of flowers and stomata. Nanofertilizers can be applied both on soils and on leaves as foliar. This can also be applied through drip, hydroponic, aqua and aeroponic. The properties of nanofertilizers depend upon a variety of parameters such as particle size, dispersity index, surface area, porosity, solubility, aggregation and zeta potential. With recommended doses of application, it can be envisaged to become a major economic driving force and benefit consumers and farmers with no detrimental effect on the ecosystem.

Keywords Crop yields · Ethical issues · Growth promoters · Nanofertilizers · Nanobioformulations · Nutrient use efficiency

49.1 Introduction

Agricultural production throughout the world is undergoing considerable challenges like stagnation in crop yields, low nutrient use potency, declining soil fertility, multi-nutrient deficiencies, shrinking of agricultural land, water accessibility and a dearth of labour due to evacuation of individuals from farming (Godfray et al. 2010; FAO 2017). Nanofertilizers and nanobioformulations show the light to solve these problems. Nanofertilizers, which are made with nano-size nutrient particles, can be delivered to the targeted sites to allow the release of active ingredients keeping the plant nutrient demand, reduce wastage of fertilization and be used to improve the fertility of the soil for a better yield, nutrient use efficiency and increased crop quality (Tarafdar et al. 2015). It may also protect the plants from different biotic and abiotic stresses (Burman et al. 2013). It has been reported that nanofertilizer can minimize soil toxicity and improve soil health (Kumar et al. 2014; Tarafdar 2021a). The main advantages of nanofertilizers are it has a high surface area and more reactivity, they can penetrate into the cell better, they can act as an effective catalyst for plant and microbial metabolism, and they have the potential to trigger the enzyme release.

Biofertilizer also can be integrated with nanonutrients particles in order to build on the better growth of the plants which can be termed as nanobioformulations. It may be containing one or more beneficial microorganisms enhancing soil productivity, that may be nitrogen fixers, P solubilizers/mobilizers and plant growth promoting stimulators. The major advantage of these types of formulations are the shelf life and delivery of biofertilizer may be improved, the active ingredient release can be controlled, the constraint of biofertilizers can be solved, the stability may be enhanced, the combination may protect against oxidation, and it may be possible for consecutive delivery of multiple active ingredients. There are many mutual benefits for the formulations to plants such as an increase in the plant photosynthetic rate, encourage plant growth, enhanced plant biomass, rise plant protein, increase in yield, bring down stress conditions, accumulation of proline, synthesis of plant hormones, more siderophore production as well as higher biological nitrogen fixation as well as phosphate solubilization and mineralization (Tarafdar 2021b).

All important and required plant nutrients can be prepared as nanoform after using physical, chemical, aerosol or biological techniques. However, nanobioformulations are more preferable as they are more environmentally friendly and stable. Nanonutrients are also the potential candidate as slow-release fertilizers due to their strong holding as they have higher surface tension than conventional surfaces (Tarafdar 2020). Individual nanoformulations may furnish a controlled-release system (Jamilek and Kralova 2017), and it also helps to reduce the doses. Moreover, nanoformulations safeguard the active ingredient against degradation and deactivation. Nanofertilizers and nanobioformulations may help in seed germination, microbial build up in rhizospheres, higher growth and yield of the applied crops, help to overcome the stress conditions faced by the plants, helps for more photosynthesis and native nutrient mobilization.

49.2 Prospects of Nanofertilizers and Nanobioformulations

Nanofertilizers are nothing but synthesized or altered form of fertilizer nutrient in nano size (1–100 nm); they are economically cheap as well as required relatively small amounts than chemical fertilizers. The most advantages of nanofertilizers are they can build up more carbon in the soil, can very well maintain the soil health like organic fertilizers, can maintain higher physiological activities of plants and microbes, help in enhancing enzyme release by the plants, cutting the pest and disease attack on plants, help in more moisture retention in the soil, encourage plants to tolerate stress conditions besides more nutrient use efficiency and higher yields. In general, the application of fertilizer in nano-size improves the efficiency of the elements, decreases their toxicity in the soil and minimizes their frequency of application. Due to their smaller requirement, the transport cost can be reduced considerably as well as the application may be easier. Nanofertilizers can balance the nutrient supply to the plants with restorative plant growth and quality improvement. They can very well regulate nutrient migration to the environment. They can help also in the accumulation of reactive oxygen species (ROS) by the plants. The major advantages of nanofertilizers over chemical fertilizers are presented in Table 49.1.

Moreover, the efficiency of nanofertilizers is higher in terms of nutrients absorption and utilization resulted from meagre losses of nutrients due to leaching and volatilization. They can also act as an effective catalyst for the plant and microbial metabolism. Their application guides to a gradual and controlled release of nutrients in the soil and prevent eutrophication and pollution of water resources.

Nanobioformulations has made significant attention due to their creation of a sustainable agricultural system. They are the integration of biofertilizers with the nanonutrients in order to improve the growth of the plants. The principal aspects in nanobioformulations are the interactions between the nanoparticles and the microorganisms, the shelf life of biofertilizers and their delivery. It is possible to make controlled-release environmental friendly smart fertilizers. There is no doubt that

Table 49.1 Edge of nanofertilizers over chemical fertilizers

Index	Nanofertilizers	Chemical fertilizers
Application rate	Low	30–100 times more than nanofertilizers
Nutrient use efficiency	Very high (60–85%)	2–20 times less than nanofertilizers
Solubility	High	Low
Dispersion of mineral nutrients	Improved dispersion of insoluble nutrients	Lower dispersion due to large particle size
Release of nutrients	Release rate and pattern is precisely controlled	Excess release leading to toxicity and soil imbalance
Loss rate	Reduced loss of fertilizer nutrients	High loss of nutrients due to leaching, drifting and run-off
Bioavailability	High	Low

nanotechnology has delivered the feasibility of exploiting nanoscale or nanostructure materials as fertilizer carriers or controlled-release vectors for the building of so-called smart fertilizer as new alternatives to enhance nutrient use efficiency and reduce the costs of environmental protection (Cui et al. 2010; Tarafdar et al. 2015). It has been found that nanoparticles have the enormous ability to deliver nutrients to particular sites in the living systems. It can be done by absorption, attachment or extracellular and intracellular mechanisms, encapsulation in polymeric shells and entrapment of polymeric nanoparticles.

49.3 Synthesis and Characterization

Nanofertilizer can be synthesized by using physical, chemical, aerosol (physicochemical) and biological techniques. The important trait is the preparation of the particles of required size, shape and stability. The important physical methods of synthesis are grinding, thermolysis, sputtering, pulsed laser deposition technique, condensation method and microwave-assisted synthesis. In the physical method, normally, solid precursors are used which can be straightway converted to nanosize by mechanically or vaporization technique. For instance, P nanofertilizer can be developed after purification of rock phosphate from the deposit and ground with the help of a ball mill or pot mill. Similarly, other metal nanofertilizers like Zn, Fe or Cu can also be manufactured from their mineral deposits.

The important chemical methods of synthesis are sol–gel technique, polyvinyl pyrrolidone (PVP) method, co-precipitation technique, micro-encapsulation method, sonochemistry, colloidal method, hydrothermal synthesis and micro-emulsions method. In general, the liquid and gas precursors are allowed to undergo a chemical reaction for achieving the supersaturation that is required to induce homogeneous nucleation of the particles. For example, ZnO nanofertilizer can be prepared by chemical sedimentation technique. The major advantage of chemical methods are: the variation of shapes and sizes of the particles is possible, the particles can be synthesized at low (< 350 °C) temperature, most of the techniques are very simple, huge quantities of material can be prepared within a very limited time, material although initially obtained as a liquid but can easily be converted into a dry powder or thin films, doping of foreign atoms (ions) is possible during synthesis, pattering is possible and inexpensive as well as less instrumentation is required as compared to the physical methods.

The aerosol technique of nanoparticle production is very handsome because of its ability to satisfy the demand for high product purity and scale-up potential. It is basically a metastable suspension of particles in a gas. Aerosol methods are very exciting due to their ability to satisfy the demands of high product purity, scale-up potential, improved control of phase identity, composition and small environmental footprint. The important aerosol techniques used for the preparation of nanofertilizers are furnace method, flame method, electrospray technique, chemical vapour deposition technique and physical vapour deposition technique. For example, Mg nanofertilizer can very well be prepared by aerosol technique and the shape and size of the nanoparticles can be changed by changing carrier gas flow, heater and diffusion dryer size. Aerosols can vary in size and composition.

Microorganisms and plants have vast potential for building nanofertilizers. They use different mechanisms for the synthesis of nanofertilizer particles. The important agents are fungi, bacteria, actinomycetes, yeast, algae and plants. After using the specific organisms and plants from simple bacteria or fungi to highly complex eukaryotes in the reaction mixture, the production of desired nanonutrients with shape and size can be obtained. For example, a large number of fungi can produce nanofertilizers like Zn, Mg, Fe, K, P, N, B, S, Mo, etc. from their respective salt solutions. The important methods used for nanobioformulations are electrospinning, electrospray and nanospray (Fig. 49.1). In the case of nanobioformulations, the bioactive may be confined in the cavity or it may disperse in the matrix. The major aspects of nanobioformulations are the interactions between nanoparticles and microorganisms, shelf life of biofertilizers and their delivery.

The manufactured nanofertilizer particles can be characterized for their size, shape, morphology, structure and concentration by using instruments like particle size analyser (PSA)/dynamic light scattering (DLS), scanning electron microscopy (SEM), transmission electron microscopy (TEM), atomic force microscopy (AFM), UV–VIS absorption spectroscopy, X-ray diffraction (XRD), Fourier transform infrared spectroscopy (FTIR), energy dispersive X-ray spectroscopy (EDS), lithography, inductively coupled plasma mass spectrophotometer (ICPMS) and inductively coupled plasma optical emission spectrophotometer (ICPOES). Nanofertilizer properties anticipate a diversity of parameters such as particle size, dispersity index, surface area, porosity, solubility, aggregation and zeta potential. Zeta potential is generally a measure of charge stability that controls all particle–particle interactions within a suspension. High level of zeta potential designates greater electrostatic repulsion among the particles, which minimizes aggregation/flocculation, increasing the

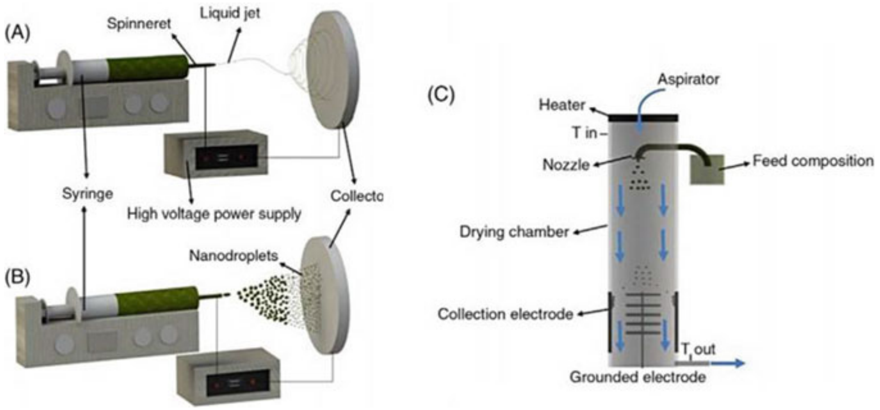

Fig. 49.1 Methods used for nanobioformulations **a** Electrospinning, **b** Electrospray and **c** Nanospray

stability of the particles. The magnitude of the zeta potential provides information about the particle stability, with higher magnitude potential exhibiting increased electrostatic repulsion and therefore increased stability. For example, if the zeta potential value is 0–5 mV, then the nanofertilizer particles tend to agglomerate or aggregate; if the value is increased to 5–20 mV, then the particles are minimally stable, while the values between 20 and 40 mV make the particles moderately stable, and the nanofertilizer particles are highly stable when the zeta potential value is above 40 mV. The magnitude of the charge on the surface of the nanoparticles depends on the solution pH. Practically, the surface charge can be reduced to zero at a specific pH referred to as the isoelectric point.

49.4 Application of Nanofertilizers and Nanobioformulations

Nanofertilizers and nanobioformulations can be applied mainly on the foliage of plants; they can also be applied directly on soils. It can also be applied through drip and sprinkler irrigation systems and in hydroponic and aeroponic systems. After being applied on plants, the particles can enter through plant shoots such as cuticle, epidermis, stomata, hydathodes and stigma or plant roots such as root tips, rhizodermis, lateral root junctions, wounding and cortex. The rate of uptake to the plants mainly depends on the size and the surface properties of the particles. It is noticed that smaller particles can move faster than the larger particles. For the application of nanofertilizers and nanobioformulations to plants, the use of an aerosol sprayer is much superior to a traditional sprayer. The use of lower concentrations promotes better absorption and penetration through plants. It is observed that up to 20 nm of nanonutrients size is better for the plants. Moreover, better penetration into plants and microorganisms was found with cube-shaped nanonutrients (Tarafdar et al. 2012). In general, the nanofertilizer concentration to spray depends on the type of nanonutrients as well as crops. For example, the optimum concentration of nanofertilizer K for cereals is 40 ppm, whereas for legumes, it is 20–30 ppm. In nanobioformulations, the bioavailability of nutrients is increased by their more surface area, their smaller size and high reactivity (Liu and Lal 2015). Nanofertilizer can trigger the plants to release more beneficial nutrients that result in more mobilization of native nutrients from the rhizospheres. The usefulness of nanobioformulations depends on the rate of uptake, distribution and accumulation of them to crops. The additional beneficial enzyme activity in the rhizospheres may increase up to 283%. Higher release was observed under legumes, followed by vegetables, cereals and oilseeds. The foliar application also improves the physiological and crop biochemical parameters.

Nanofertilizer application, especially the micronutrients through drip irrigation is an important method for nutrient feeding to crops. Many micronutrients are found to be not readily translocated within the plants, but they work well under drip irrigation. The doses should be minimized while using through drip. It is noted that the application of nanofertilizers through drips may enhance the yield of the crops by 30–70%. Nanofertilizers and nanobioformulations can also be applied through sprinkler irrigation, but the environmental losses are more. Sprinkler application is only suited for the row, field and tree crops, and water can be sprayed over or under the crop canopy. Nanofertilizer application in soil has many limitations due to the availability of nutrients to the plants. There is an enormous possibility of fixation of nutrients when directly applied to soils. The delivery of nanofertilizer to plants can be perceived through in vivo applications such as hydroponic or aeroponic. The principle of aeroponics involves continuously spraying a nano-nutrient solution on roots suspended in the air. It requires a high level of nutrients to sustain rapid plant growth, and therefore, its application is restricted. On the other hand, hydroponics is commonly known as solution culture as the plants are grown with their roots immersed in a solution without soil. Attention should be paid to the volume of nutrient solution as well as concentration, maintenance of oxygen demands and pH during using this method for delivery of nanonutrients and nanobioformulations. Overall, the efficiency of nanofertilizers and their impact on plant systems is influenced by their method of application.

49.5 Effect on Soil and Plants

Nanofertilizers and nanobioformulations are the nutrient carriers and are able to supply nutrients in the plant system for a long and extended time period without associated environmental threats. The stability of nanofertilizer particles in the soil depends on their surface energy. Nanofertilizer particles possessing low surface energy, in general, are more stable. The aggregate size in the solution of nanofertilizer particles depends on their initial particle size and concentration. Some of the

Table 49.2 A comparison of microbial population and activities between optimum doses of chemical fertilizer and nanofertilizer application in Aridisol

Properties	Improvement over chemical fertilizer (%)
Fungi population	23–56
Bacterial population	45–132
Actinobacteria population	18–66
Dehydrogenase activity	28–65
Esterase activity	27–86
Acid phosphatase activity	24–70
Alkaline phosphatase activity	29–105
Phytase activity	31–80
Nitrate reductase activity	17–45
Arylsulphatase activity	21–58

metal-based nanofertilizer particles are found to be thermodynamically unstable that result in chemical dissolution if kinetic restrictions are absent. Organic matter in the soil has the ability to stabilize the nanofertilizer particles. In general, the dissolved organic matter adheres to the surface of the nanofertilizer particles and modifies their surface physicochemical properties which enhances their stability. It has been found that soil pH has a role to accumulate the nanofertilizer particles, and it also guided the toxicity of nanofertilizer particles on the soil microorganisms and nematodes. In general, the application of nanofertilizers produces more humic acids during slow release which is the main source of carbon and nitrogen for the growth of microorganisms. Table 49.2 shows the major effect of the nanofertilizers on soil organisms and microbial activities.

In general, more soil microbial population and activities were observed with the application of nanofertilizers than chemical fertilizers. Nanofertilizer particles when exposed to the atmosphere are subjected to coagulation, surface coating through condensation of semi, volatile compounds and heterogeneous reactions with gaseous pollutants. The coagulation rate is low when the particles are of similar size but with differences in size, the rate increases in magnitude. The main effect of nanofertilizers is to minimize nutrient volatilization and leaching, improve soil quality and increase microbial activity and water holding capacity. Nanofertilizers also lead to an improvement in nutrient uptake.

The plant cell wall generally acts as a hurdle for easy entry of nanofertilizers or nanobioformulations. Only nanofertilizer aggregates with a diameter less than the pore diameter (5–20 nm) could easily pass through and get to the plasma membrane. There is also a possibility for enlargement of pores upon interaction with the nanofertilizer particles which results in enhanced entry of the nanofertilizer particles. The particles can also cross the membrane after getting embedded onto transport carrier proteins or through ion channels trichomes and afterwards get translocated to different tissues. The nanofertilizer particles may bind with various cytoplasmic organelles and interfere with the metabolic processes at that site. The accumulation of nanofertilizer particles on the photosynthetic surface causes foliar heating, alters gas exchange because of stomatal obstruction and brings out changes in various physiological and cellular functions of plants.

Nanofertilizers are adsorbed to plant surfaces and enter through different plant openings. The uptake rate depends on the shape and size of the nanofertilizer particles. Smaller size of nanofertilizer particles can penetrate through the cuticle, while larger particles may penetrate through cuticle-free areas. After entering inside, they move through the cell sap, may trigger the co-enzyme system, and thereafter, some particles may accumulate in the vacuoles. Some of the nanofertilizer particles may increase the permeability of plant cell walls under stress and then penetrate the cells. It is the possibility of enlargement of pores or installation of new cell wall pores due to interaction with nanofertilizer particles that results in more nanofertilizer uptake by the plants. Once inside the plant cells, the nanofertilizer particles can move through the plasmodesmata if the particle size is less than 40 nm. The nanofertilizer particles may also bind with different cytoplasmic organelles when they are in the cytoplasm and may dictate the metabolic processes at the site. Plant uptake can be a critical transport and exposure pathway of nanofertilizers in the environment.

With the application of recommended doses of nanofertilizers, an increase in the dry matter by 18–39% over chemical fertilizer application was recorded in arid crops. Higher dry matter production may be due to less exudation of carbon from the roots when nanofertilizer particles are applied as foliar spray. They can also increase the activities of various enzymes, helping the increase in chlorophyll content and root activity. It is now clear that some nanofertilizer particles influence crop improvement, plant advancement and yield, and a majority number of them are aggregated in various plant tissues, including the edible plant parts. It has been noticed that nanofertilizer particles in the detached chloroplast increased the photosynthetic activity multiple times higher than that of controls and improved electron transport rates.

49.6 Nutrient Use Efficiency

Nanofertilizers give an opportunity to the nutrients to be absorbed through the nanoscale plant pores. Due to their small size, more surface area and controlled rate of release, it is possible to facilitate the plants to take up most of the nutrients without much waste. The controlled nutrient release and increase water retention in the soil due to nanofertilizer application resulted in better nutrient use efficiency and yield of the plants. In general, nanofertilizers release the nutrient in a controlled manner concerning the reaction of different signals such as heat and moisture. Moreover, the increased mobility of the nanofertilizer particles leads to the transport of the nanoformulated nutrients to all the plant parts. The more surface area to volume ratio in the nanofertilizer makes them superior over any conventional fertilizers. Moreover, nutrient encapsulated in nanoparticles also increases the availability of nutrient elements

Table 49.3 A comparison of nutrient use efficiency

Nutrients	Nutrient use efficiency (NUE, %)		
	Chemical fertilizers	Nanofertilizers	Nanobioformulations
N	30–35	80–85	84–90
P	15–20	58–65	67–76
K	35–40	82–88	–
S	17–22	75–78	–
Fe	4–5	80–82	–
Zn	3–4	78–80	–
Cu	2–5	77–81	–

Modified from Tarafdar (2020)

for uptake to the plants. A comparison of nutrient use efficiency among the chemical fertilizers, nanofertilizers and nanobioformulations is presented in Table 49.3.

The higher nutrient use efficiency of nanofertilizers and nanobioformulations are due to their important properties such as more surface area that provides many sites to facilitate the different metabolic processes in the plant system resulting in more photosynthesis with the less consumption of the nutrient element; their high solubility in various solvents especially in water, smaller size (1–100 nm) of particles facilitates more penetration into the plant system; higher penetration in the plant system from applied surfaces strengthen uptake and nutrient use efficiency of the nanofertilizers and their formulations. The number of particles per unit area of fertilizer may provide more opportunity for contact and leads to more penetration and uptake (Tarafdar 2020). The significances of nanofertilizers are their penetration capacity, size and higher surface area which distinctly distinguishes them from the chemical fertilizers. The higher mobility of the nano-fertilizer particles leads to the transport of the nanoformulated nutrients to all parts of the plants. The betterment of nutrient use efficiency is an essential option for more crop production in marginal lands with low nutrient availability. Actually, any increase in use efficiency leads to a substantial cut in nutrient requirements that result in huge economic benefit in the cultivation.

49.7 Effect on Crop Yield

Nanofertilizers and nanobioformulations have an edge to improve the yield of the crops as compared to the other generations of fertilizers such as chemical fertilizers, organic fertilizers and growth stimulators. The average expected yield is much higher under nanofertilizer and its formulations. A comparison of the average yield increase is shown in Table 49.4.

Table 49.4 Average yield increase with different types of fertilizer

Type of fertilizer	Expected average increase in crop yield over control (%)
Chemical fertilizer	12–18
Organic fertilizer	8–12
Growth stimulator	5–10
Nanofertilizer	24–32
Nanobioformulations	26–35

Modified from Tarafdar (2021b)

In general, in nanomaterials, the size of the particles guides the success. For example, the maximum nanofertilizer effect on soybean was observed when the average particle size ranged between 15 and 20 nm. The effect was noted to be related to the synthesis of mitochondrial proteins. In most of the crops, it was revealed that nanofertilizer particle size less than 20 nm is most effective in plant growth and maturity. Moreover, it was perceived that nano fertilizers can act in a concentration-dependent manner. Except for a few cases, in most of the cases, higher concentrations have resulted in ill effects on plants. Generally, a lower concentration of nanofertilizer particles (5–15 ppm) was found to be very plant-friendly. Besides this, the exposure time is also important during the application of nanofertilizers. The most important aspect of nanobioformulations are interaction between nanoparticles and microorganisms, shelf life of biofertilizers and their dispatch. The use of nanobioformulations improves the stability of biofertilizers with respect to desiccation, heat and UV inactivation. Considerable improvement of root length, root area, dry biomass and nodulation was observed under different tested crops with the application of nanofertilizers or nanobioformulations. The improvement was more with the application of nano-P fertilizers.

The benefits of nanofertilizers and nanobioformulations on overall crop production may be due to an increase in gluten and starch content of applied plants, increased activation of catalase enzyme, accumulation of flavonoids and carotenoids, photosynthetic pigments and biomass accumulation under drought as well as decreased hydrogen peroxide (H_2O_2) and malondialdehyde (MDA) content. They also resulted in more stomatal opening and higher CO_2 assimilation. Under cold conditions, they enhanced the activities of antioxidant enzymes and decreased electrolyte leakage. Through improvement in root hydraulic conductance of plants, nanofertilizers and nanobioformulations can increase the water stress tolerance and more water uptake in plants. Moreover, they help to accumulate more osmolytes or osmoprotectants including amino acids such as proline, glycine and glutamine and sugars such as sucrose, trehalose, fructose and maltose. The formulations also influence different plant growth hormones such as indolebutyric acid (IBA), gibberellic acid (GA_3), abscisic acid (s-ABA), salicylic acid (SA), indole acetic acid (IAA) and N-acetyl thiazolidine 4-carboxylic acid (NATCA). The increase in growth hormones helps to achieve higher plant growth and yield.

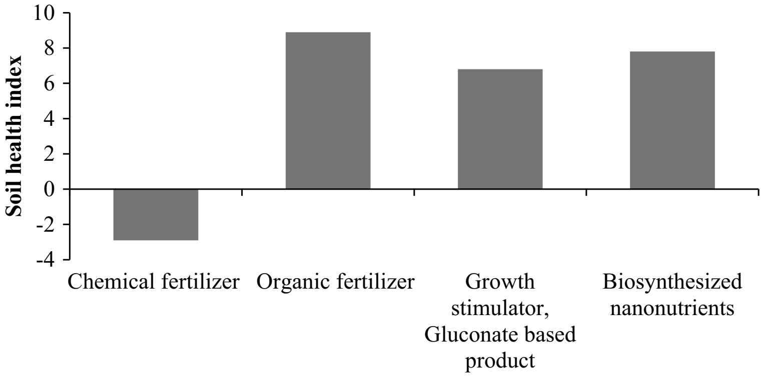

Fig. 49.2 Soil health index with the recommended doses of application for 5 years of different generations of fertilizer. Modified from Tarafdar (2021a)

Nanofertilizers reduce the nutrient loss problem and increase nutrient recovery in the applied plants. They also exhibit controlled discharge of agrochemical site-targeted delivery, resulted in a decline in poisonous quality and enhanced nutrient utilization of the applied fertilizers. This happens because of nanoparticles' high surface area to volume ratio, high solubility, small size, more versatility and targeted delivery. Nanofertilizers can directly or indirectly influence the plant physiological parameters by the alteration in the formation of reactive oxygen species, catalase, peroxidase, superoxide dismutase activities, chlorophyll, phenol and leaf protein content. It also helps to maintain the soil health where chemical fertilizers have failed. A comparison of soil health under different generations of fertilizer is presented in Fig. 49.2.

49.8 Future Prospects of Nanofertilizers and Nanobioformulations

Nanofertilizer and nanobioformulations implementation in agriculture may set out an opportunity to achieve sustainability towards global food production. The exact benefits of nanofertilizers over conventional chemical fertilizers rely on their nutrient deficiency system. Nanofertilizer regulates the nutrient availability in crops by way of a controlled-release mechanism. After taking advantage of this, slow nutrient delivery growers can enhance their crop growth because of consistently long-term delivery of nutrients to plants. For instance, the nutrients from nanofertilizers and their formulations can be released over 40–50 days in a slow-release fashion instead of only 4–10 days by the conventional chemical fertilizers. They also minimize the need for transportation and application costs. A further advantage of using smaller quantities in the case of nanoformulations is that soil does not get loaded with salts that is usually likely to happen due to over-application using conventional fertilizer on a short or long-term basis. Moreover, biosensors can be attached to new innovative formulations that control the delivery of nutrients according to soil nutrient status, crop growth period as well as environmental conditions.

It can very well be used for seed treatment which helps in increasing the moisture content of the seeds as well as act as protection in opposition to soil-borne diseases. Nanofertilizers also will help in seed germination. It may be used under precision farming. The nano-sensors might be distributed throughout the field where they monitor soil conditions and crop growth. It has been noticed that precision farming with the help of smart sensors will authorize more productivity in agriculture by providing more accurate information, thus helping farmers to take better decisions. Nano-sensors could also monitor crop health. Magnetic nanoparticles may help to remove soil contaminants. More researches are going on to developing biosensors based upon the surface plasmon resonance (SPR) by use of metal nanoparticles. Nano-based target-specific herbicide molecules encapsulated with nanoparticles for target weeds may also be synthesized. Once inside the root system, they are translocated to different parts and hinder glycolysis or other pathways of food reserve in the root system. This may result in the specific weed plant to starve for food and get killed. The important nanofertilizer particles used as herbicides are Ag, Cu, Fe, Zn, Mn, etc. Employment of nanofertilizer particles in plant protection and production of food is an under-explored area in future. Conceptualization of nano-encapsulated pesticides may lead to reduce the doses of pesticides, improve pesticide use efficiency which may be more eco-friendly for crop protection. A scale of formulations type has been suggested that includes nanoemulsions, nanopolymers and nanoclays. In general, large number of nanofertilizer particles can be used against plant pathogens. The most notable are Ag, Cu, S, Zn, TiO_2, etc. It is noted that the use of nanofertilizer particles in pest and plant disease management as pesticides, fungicides and herbicides is the fastest and cheapest way to control pests and diseases. Nano-based viral diagnostics have now taken momentum to detect the exact strain of the virus so that it is possible to stop the disease. Nanomaterials can very well use in water management such as efficient use of drinking water and wastewater treatment processes. Membranes can be designed with nanoscale pores that remove specific pollutants while allowing water molecules and important nutrients to pass through.

Nano-composite materials which are lightweight can reduce emissions in vehicles by reducing their weight, resulting in less fuel consumption. It has been estimated that a 10% reduction in the weight of the vehicle resulted in 10% less fuel consumption. Nanoparticle coatings are a good way in reducing emissions and maximizing clean energy production.

49.9 Ethical Issues

Numerous experiments showed that the recommended doses of application of nanofertilizer and nanobioformulations have no unfavourable effect on per cent seed germination, soluble seed protein content, body weight of mice fed with nanonutrients treated grain, grain consumption rate and blood pH of mice. The microbial population in the rhizospheres is rather enhanced when nutrients are delivered to plants as nanoformulations. It has been reported that plants grown with recommended doses of nanofertilizers did not cause any adverse effect in rats even after feeding more than two and half times the dose limit (Tarafdar 2021b). Histopathological studies indicate no toxicity on the liver, kidney and spleen with the continuous five years intake of recommended doses of nanofertilizer treated foods. Genetic and bioinformatics studies also reported no adverse unigenes behaviour with the application of recommended doses of nanoformulations to plants. Rather, the application of nanofertilizers promoted embryogenesis, seed germination, shoot growth, leaf formation, flower development and fruit ripening than chemical fertilizer application. They also had a positive effect on carbohydrate metabolism, lipid metabolism, nucleotide metabolism, amino acid metabolism and biosynthesis of secondary metabolites, etc. Nanoformulations also exhibit certain physicochemical properties, biokinetic behaviour, biological interactions and toxicological effects that are different from conventional fertilizers of the same ingredients.

There are questions about the accumulation of nanofertilizer particles in plants and their food parts. These turn on many factors but mainly on plant species, tissue/organ that will be used directly as food or for food processing as well as the nanofertilizer type and size of the particles. Because of the variability of interactions between the nanofertilizer particles and plants, nanoformulated materials may accumulate in plants, and in some cases, they may cause toxicity problems (Lowry et al. 2012; Zulfiqar et al. 2019). These problems can very well be avoided by applying the nanomaterials in recommended doses. It is certain that nanoformulations present a great opportunity in agriculture, but it is necessary to study in detail their accumulation and potential risk on human health and the environment when applied to different crops globally. There should also be a common consensus on the recommended safe dose for the individual crops. In-depth evaluation of various soil physico-chemical properties is also essential to recommend particular bioformulations to the specific crops and soil types. Certainly, nanofertilizers and nanobioformulations have the potential to achieve global sustainability in agriculture as well as soil health and the environment.

For testing the quality of nanofertilizers and their formulations, one must consider their solubility and dispersion, surface interactions, their carrier and encapsulated material, immunotoxicity, genotoxicity, carcinogenicity, reproductive toxicity, biodegradability, storage stability and safety.

49.10 Conclusions

Nanofertilizers and nanobioformulations have the potential to create a great moment for global agriculture by increasing plant productivity, nutrient use efficiency, stress tolerance and more native nutrient mobilization. It is cheaper and has future prospective to reduce leaching and volatilization which are well linked with conventional fertilizers. It can also assist in the maintenance of soil health and may very well drastically reduce the doses of application. They are also considered to be very safe with the use of recommended doses of application. These nanomaterials have boundless prospects to explore globally for sustainable crop production. Although, more research studies are still needed on environmental impact assessment on a long-term basis as well as determining the safe doses for each cultivated plant type. However, the results obtained so far has indicated that they are the best material to replace chemical fertilizer globally in future and prevail over the other generations of fertilizer.

References

Burman U, Tarafdar JC, Kaul RK et al (2013) Changes in carbon partitioning in pearl millet (*Pennisetum glaucum*) and clusterbean (*Cyamopsis tetragonoloba*) in response to ZnO nanoparticle application. Indian J Agric Sci 83:352–354

Cui HX, Sun CJ, Liu Q et al (2010) Applications of nanotechnology in agrochemical formulation, perspectives, challenges and strategies. In: International conference on food and agriculture applications of nanotechnologies, Sao Pedro, Brazil, 20–25 June 2010, pp 28–33

FAO (2017) The future of food and agriculture—trends and challenges. Food and Agriculture Organization, Rome

Godfray CHJ, Crute IR, Haddad L et al (2010) The future of the global food system. Philos Trans R Soc B 365:2769–2777

Jamilek J, Kralova K (2017) Application of nanobioformulations for controlled release and targeted biodistribution drugs. In: Sharma AK, Kesevani RK, Kesharwani RK (eds), Nanobiomaterials—application in drug delivery, 1st edn. Apple Academic Press, Boca Raton. https://doi.org/10.1201/9781315204918-5

Kumar R, Pandey DS, Vijay P et al (2014) Nanotechnology for better fertilizer use. Research bulletin no. 201. G.B. Pant University of Agriculture and Technology, Pantnagar, Uttarakhand, India

Liu R, Lal R (2015) Potentials of engineered nanoparticles as fertilizers for increasing agronomic productions. Sci Total Environ 514:131–139

Lowry GV, Kelvin GB, Simon AC et al (2012) Transformations of nanomaterials in the environment. Environ Sci Technol 46:6893–6899

Tarafdar JC (2020) Novel bioformulations for nano-phosphorus synthesis and its use efficiency. Indian J Fert 16(12):1278–1282

Tarafdar JC (2021a) Bionanofertilizer: a new invention for global farming. In: Rakshit A, Meena VS, Parihar M et al (eds) Biofertilizers—advances in bio-inoculants, vol 1. Woodhead Publishing, pp 347–358

Tarafdar JC (2021b) Nanofertilizer: challenges and prospects. Scientific Publishers, Jodhpur, Rajasthan, India, p 350

Tarafdar JC, Xiang Y, Wang WN et al (2012) Standardization of size, shape and concentration of nanoparticle for plant application. Appl Biol Res 14:138–144

Tarafdar JC, Rathore I, Thomas E (2015) Enhancing nutrient use efficiency through nanotechnological interventions. Indian J Fert 11(12):46–51

Zulfiqar F, Navarro M, Ashraf M et al (2019) Nanofertilizer use for sustainable agriculture: advantage and limitation. Plant Sci 289:110270. https://doi.org/10.1016/j.plantsci.2019.110270

Chapter 50
Carbon Dynamics and Greenhouse Gases Emissions in Coastal Agriculture: Mangrove-Rice Ecology in Sundarban, India

Pratap Bhattacharyya, S. R. Padhy, P. K. Dash, and H. Pathak

Abstract Mangrove systems act both as sink and source of GHGs including methane (CH_4), carbon dioxide (CO_2), and nitrous oxide (N_2O). Mainly, it acts as a sink for CO_2 because of its high biomass production. The higher source of organic carbon and rapid nutrient turnover are the key features of these systems. Mangrove systems facilitate methanogenesis and denitrification processes due to the dominance of anoxic conditions by frequent tidal water intrusions. Apart from these, mangroves provide significant ecological services including maintenance of biodiversity (mammals, birds, fish, algae, microbes), enhancing carbon (C) sequestration, protecting the coastal bank and sustaining economical profits. However, approximately, 40% of tropical mangrove forest was lost in the previous century primarily due to sea level rise, climate change and human-induced activities. About 10.5% of green was lost from Sundarban, India during 1930–2013. Major land use changes were from mangrove to rice and aquaculture-based agriculture. In last three decades, degraded mangrove, rice and aquaculture systems co-exists side by side and represent a typical ecology in Sundarban, India. This ecology has its unique carbon dynamics, GHGs emission pattern, microbial diversities and soil physiochemical dimensions. A distinct variations of the soil bacterial and archaeal diversities related to GHGs emissions and labile C-pools of degraded mangrove-rice system in wetland ecology exist. Soil physico-chemical properties (like high salinity, more available sulphur, sodium, iron) and the related microbial community (methanotrophs, methanogens, SRB) play an important role in carbon dynamics and to mitigate CH_4 emission in the mangrove-rice system. The ratios of methanotrophs: methanogens and sulphur reducing bacteria

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(SRB): methanogens are important indicators to net methane emission. Those are higher in mangrove mean the methane oxidation was dominant over methane production resulting less CH_4 emission from mangrove than rice. Similarly, continuous application of nitrogen fertilizer and more nitrifiers and denitrifiers community in rice, resulting in more N_2O emission as compared to degraded mangrove. Hence, the soil properties and the microbial community make mangrove a green production system as compared to the rice ecology in Sundarban, India. However, recent threats of climate change related issues like sea level rise, soil erosion and coastal bank degradation also make this mangrove-rice system vulnerable. So, soil conservation, mangrove restoration and regeneration and coastal bank protection of this system are the need of the hour.

Keywords Mangrove-rice system · Soil labile carbon pools · GHGs emission · Microbial diversity · Sundarban, India

50.1 Introduction

Mangroves in coastal wetlands are found in the subtropical and tropical region that provide a significant ecological service including maintenance of biodiversity (mammals, birds, fish, algae, microbes), enhancing carbon (C) sequestration, protecting coastal bank and sustaining economical profits (Ray et al. 2011; Chambers et al. 2014; Bhattacharyya et al. 2019). The highest area under mangrove is observed in Asia (42%), then in Africa, followed by North-Central America, Oceania and least in South America (20, 15, 12 and 11%, respectively) (Giri et al. 2011; Padhy et al. 2021). Globally, the characteristics of mangrove ecosystems are primarily driven by tidal behaviour, salinity and temperature. However, at regional level, the biomass and area of mangroves vary in relation to tidal intrusion, sea level rise, waves, rainfall, rivers-flow and anthropogenic activities. Specifically, the stability of mangrove ecosystem is considerably affected by the soil type, soil physico-chemical properties, nutrient status, predation and physiological tolerance to extreme environmental conditions like salinity, temperature and wind tidal intrusion. Mangroves play a key role in maintenance and establishment of coastlines and mediating the carbon (C) cycle and food chain (Marcial Gomes et al. 2008; Giri et al. 2011). However, sea level rise has strongly influenced the mangroves as well as mangrove-agriculture ecologies (Gilman et al. 2008; Day et al. 2008). Mangrove systems act both as sink and source of GHGs (Mukhopadhyay et al. 2002), including methane (CH_4), carbon dioxide (CO_2) and nitrous oxide (N_2O). The CH_4, N_2O and CO_2 contribute 20–25%, 5–10% and 40–50%, respectively, towards the warming of the globe. The recent rates of increase of these three GHGs per annum are 0.41, 0.25 and 0.42%, respectively (NOAA 2012; IPCC 2018). Tidal mangrove ecosystems are typical source of CH_4 and N_2O (Chauhan et al. 2008; Chen et al. 2010; Padhy et al. 2020, 2021). Mainly, it acts as a sink for CO_2 because of its high biomass production (Wang et al. 2016). The higher source of organic carbon and rapid nutrient turnover are the key features of these systems. Mangrove systems facilitate methanogenesis and denitrification processes due to the dominance of anoxic conditions by frequent tidal water intrusions (Rennenberg et al. 1992; Krithika et al. 2008; Bhattacharyya et al. 2020a; Padhy et al. 2021). So, eventually, the system function as a good source of N_2O and CH_4.

The world's biggest contiguous mangrove presents in Sundarban situated at the delta of three major rivers, namely the Ganga, Meghna and Brahmaputra. The total area under Sundarban-mangrove is around 10,000 km^2; out of which 38% present in India and the majority of 62% is in Bangladesh (Spalding et al. 2010). The major district in India is "South 24 Parganas" in the state, West Bengal. About 1678 km^2 area under "Reserve Forest" and 2585 km^2 under "Sundarban Tiger Reserve". Approximately, 40% of tropical mangrove forest was lost in previous century primarily due to sea level rise, climate change and human-induced activities. About 10.5% of green was lost from Sundarban, India, during 1930–2013. Major land use changes were from mangrove to rice and aquaculture (Chauhan et al. 2017). In last three decades, degraded mangrove, rice and aquaculture systems co-exist side by side and represent a typical ecology in Sundarban, India. This ecology has its unique carbon dynamics, GHGs emission pattern, microbial diversities and soil physiochemical dimensions. Recent threats of climate change-related issues like sea level rise, soil erosion and coastal-bank degradation also make this mangrove-rice system vulnerable. So, soil conservation, mangrove restoration and regeneration and coastal bank protection of this system are need of the hour.

50.2 Mangrove and Lowland Rice Paddy as an Effective Carbon Sink

Mangroves have higher C production and sequestration capacity (882,200 Mg C km^{-2}) as compared to other forest ecology (102,300 Mg C km^{-2}), globally (Bouillon et al. 2008; Donato et al. 2011). It acts as an effective C sink, thereby sequester higher amount of C (100 t CO_2 ha^{-1} ~ 27 t C ha^{-1}) and also reduce soil erosion. This is the most C-rich vegetation among coastal forests. Both above and below ground C storage capacity of mangroves are significantly higher than other forest in the tropics, hence could be considered as effective C sink. Wetting–drying conditions of the mangrove sediments favour the rapid litter decomposition rate which leads to rapid C influx to sediment and thereby enhancing soil C content. Soil organic C accounted for 49–98% of the total C storage and mostly found at the depth of 0.5 m to more than 3 m (Donato et al. 2011). However, mangrove deforestation emits 0.02–0.12 Pg C $year^{-1}$, which is around 10% of the total global C emissions (Donato et al. 2011). It has also been reported that lowland rice in tropics acts as C sink (0.93 t ha^{-1} $year^{-1}$) (Bhattacharyya et al. 2014), but much lesser quantity than that of pure mangrove ecosystem. Therefore, mangrove-agriculture (specifically rice) in coastal wetland have the potential to sink C provided managed properly.

50.2.1 Soil Labile Carbon Dynamics in Mangrove-Rice Systems

Large amount of soil organic carbon (SOC) is stored in mangrove soil due to higher litre deposition which subsequently sequestered in soil (Kauffman et al. 2013). Tidal pattern in mangrove system causes water stagnation, consequently lowering the rate of SOC decomposition that leads to less CO_2 production and higher C sequestration (Wang et al. 2016). But, small changes in the total organic carbon are difficult to detect as there are high background levels of total carbon in mangrove (Liang et al. 2012). Hence, the labile soil carbon pools are often selected as sensitive indicators to determine the C dynamics in degraded mangrove ecologies (Tian et al. 2013). We know that the labile C pools are significantly related to GHGs emission and nutrient dynamics in mangrove soils and a small change of which can be noticed precisely (Wohlfart et al. 2012). Similarly, in the rice rhizosphere, the soil labile fractions of C play a crucial role for regulating microbial metabolic activities. Soil labile C pools such as readily mineralizable C (RMC), microbial biomass C (MBC), water soluble carbon (WSC), potassium permanganate oxidizable C (KMnO4-C) and dissolved organic carbon (DOC) are considered as soil quality indicators in mangrove as well as rice ecologies (Wohlfart et al. 2012; Bhattacharyya et al. 2013; Padhy et al. 2020).

In a recent study, the soil labile C fractions of soils, viz., MBC, RMC and $KMnO_4$–C were recorded in mangrove-rice ecology, at three different sites (Sadhupur: 22.12 N, 88.86 E; Dayapur: 22.14 N, 88.84 E and Pakhiralaya: 22.14 N, 88.84 E) in Gosaba block of Sundarban, India during four seasons, i.e., winter, summer, pre-monsoon and monsoon. The labile carbon fractions were significantly higher during summer compared to other seasons. The RMC varied from 326.2 to 434.3; 307.0 to 446.6 and 333.3 to 409.3 μg carbon g^{-1} in soils at Pakhiralaya, Sadhupur and Dayapur, respectively (Table 50.1). The MBCs were also significantly higher in summer like RMC. The lowest MBC was found during monsoon (Table 50.1). Similar to RMC and MBC, the $KMnO_4$–C contents were also more in summer followed by winter, pre-monsoon and monsoon. Those were in the range of 795.8–1275.9; 847.9–1318.3 and 779.1–1263.8 μg C g^{-1} in soils at Pakhiralaya, Sadhupur and Dayapur, respectively (Table 50.1).

However, the labile C pools in rice soil were higher in monsoon season as compared to other seasons (Table 50.1). The RMC and MBC contents ranged from 255.8 to 316.4 μg C g^{-1} and 684.6 to 723.8 μg C g^{-1} during monsoon in all the sites (Table 50.1). Similarly, the $KMnO_4$–C was in the range of 1159.9–1308.0 μg C g^{-1} during monsoon which was higher followed by summer (1021.5–1234.7 μg C g^{-1}), winter (660.1–1197.0 μg C g^{-1}) and pre-monsoon (562.5–580.5 μg C g^{-1}), respectively (Table 50.1). So overall, the average labile C pools contents were higher in mangrove as compared to rice.

Table 50.1 Soil labile carbon pool dynamics mangrove-rice systems during four seasons in three locations of Sundarban, India

Location	Season	Readily mineralizable carbon (μg C g^{-1} soil)		Microbial biomass carbon (μg C g^{-1} soil)		$KMnO_4$ oxidizable Carbon (μg C g^{-1} soil)	
		Mangrove	Rice	Mangrove	Rice	Mangrove	Rice
Sadhupur	Winter	361.3 ± 16.3	171.9 ± 9.6	1051.6 ± 15.9	541.9 ± 17.7	1155.0 ± 12.5	916.3 ± 9.4
	Summer	444.6 ± 9.4	175.7 ± 11.8	1111.7 ± 20.6	387.4 ± 25.8	1318.3 ± 18.3	1066.7 ± 20.0
	Pre-monsoon	349.5 ± 9.7	126.4 ± 9.3	793.5 ± 18.2	223.2 ± 14.9	1013.1 ± 17.0	566.4 ± 15.5
	Monsoon	307.0 ± 9.3	255.8 ± 10.3	736.9 ± 17.4	723.8 ± 19.0	847.9 ± 16.5	1164.9 ± 18.5
Pakhiralaya	Winter	333.3 ± 11.7	139.3 ± 13.3	1165.1 ± 10.5	660.1 ± 19.8	1097.4 ± 15.8	660.1 ± 13.2
	Summer	434.3 ± 10.2	174.2 ± 11.4	1178.822.5	379.8 ± 24.6	1275.9 ± 14.2	1021.5 ± 12.9
	Pre-monsoon	348.4 ± 10.5	126.8 ± 9.6	774.7 ± 19.1	224.8 ± 15.3	939.4 ± 17.5	562.5 ± 33.0
	Monsoon	326.2 ± 10.5	286.6 ± 10.1	746.9 ± 17.0	705.6 ± 18.6	795.8 ± 19.6	1159.9 ± 20.0
Dayapur	Winter	266.0 ± 13.4	177.8 ± 13.9	979.2 ± 17.5	653.5 ± 9.4	1246.1 ± 12.5	1197.0 ± 12.6
	Summer	409.3 ± 9.3	172.4 ± 11.6	1027.4 ± 6.2	387.4 ± 19.4	1263.8 ± 18.9	1234.7 ± 18.2
	Pre-monsoon	329.8 ± 8.5	138.4 ± 8.1	785.0 ± 18.4	230.0 ± 17.9	896.6 ± 16.6	580.5 ± 18.9
	Monsoon	333.3 ± 11.0	316.4 ± 11.4	737.2 ± 27.7	684.6 ± 18.5	779.1 ± 22.7	1308.0 ± 20.6

Source Padhy et al. (2020)

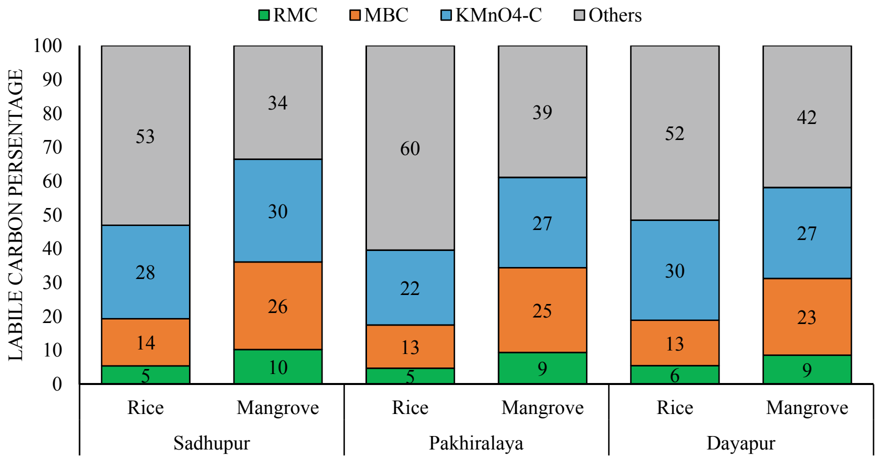

Fig. 50.1 Relative percent distribution of soil labile C pools under mangrove and adjacent rice ecology at three different sites of Sundarban, India. *Source* Dash et al. (2020)

50.2.2 Soil Labile Carbon Distribution in Mangrove-Rice Systems

The percentage of soil labile C pools distribution were estimated in mangrove and rice soil. Among the three labile C pools, $KMnO_4$–C percentage was higher (between 22 and 30%), followed by RMC and MBC (Fig. 50.1). The remaining portion of other labile C pools (considering 40% of TOC), which were not estimated in this study may include water-soluble C, dissolved organic C, etc. The $KMnO_4$ oxidizable carbon are labile in nature; this fraction also includes readily decomposable humic-material and few polysaccharides (Blair et al. 1995; Jiang and Xu 2006).

50.3 Greenhouse Gas Emission from Mangrove-Rice Systems

The GHGs emissions from sediments to the atmosphere in the mangrove ecology occur through three different pathways. Majority of emissions are taken place through the aerenchyma of mangrove-pneumatophores (it is the negatively geotropic breathing-roots of mangrove); diffusion through the sediments/soil by ebullition (as bubble, in soil water interphase) and exchanges through air–water interphases (as dissolved GHGs in stagnant or tidewater) in mangrove (Purvaja et al. 2004; Dutta et al. 2015). While, in rice ecology, emission takes place mainly through the aerenchyma of rice plant from soil to atmosphere and very negligible amount of gas emitted through other sources (10–15%) (Bhattacharyya et al. 2019, 2020b, 2020c).

50.3.1 Greenhouse Gases Fluxes from Sundarbans' Mangrove: Captured by Manual Chamber

The GHGs (CH_4, CO_2 and N_2O) fluxes were quantified in mangrove-rice system from soil to atmosphere by manual gas chamber method for four seasons in all the three sites. Seasonal methane flux was higher during monsoon (0.235 ± 0.04 mg m^{-2} h^{-1}), followed by pre-monsoon (0.089 ± 0.02 mg m^{-2} h^{-1}), summer and winter (Fig. 50.2a). During monsoon, CH_4 fluxes were higher in pneumatophore as compared to sediments that did not have pneumatophore (0.254 ± 0.05, 0.377 ± 0.04, 0.269 ± 0.07 mg m^{-2} h^{-1} and 0.164 ± 0.02, 0.120 ± 0.01, 0.228 ± 0.02 mg m^{-2} h^{-1} in pneumatophore and without pneumatophore at Sadhupur, Pakhiralaya and Dayapur, respectively). However, higher N_2O fluxes were observed during

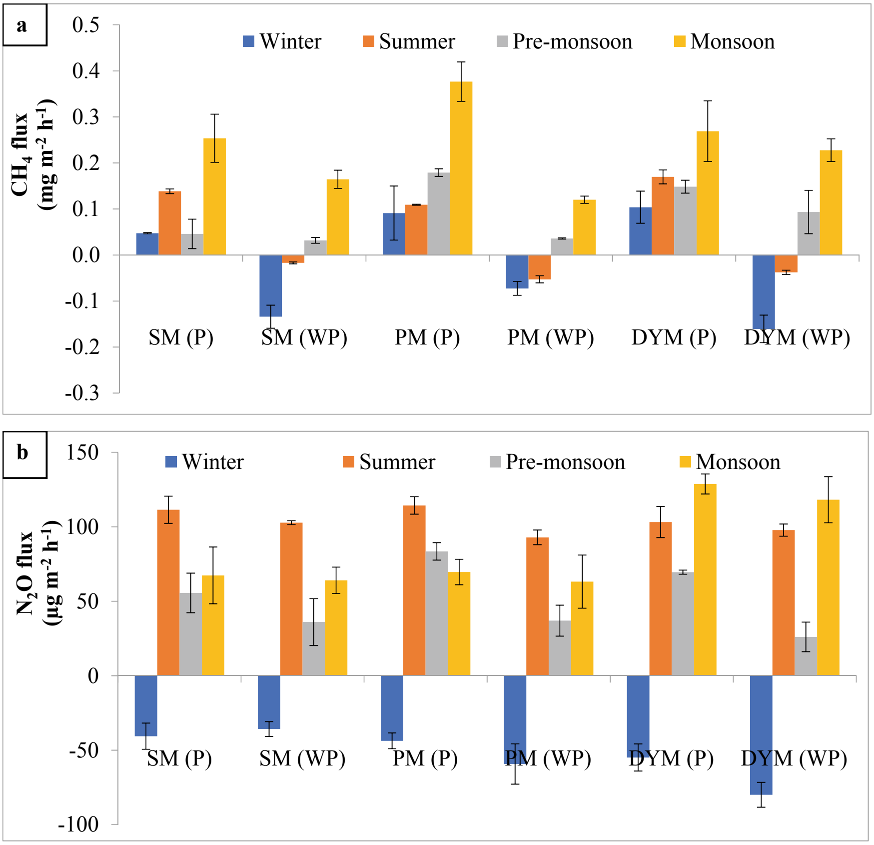

Fig. 50.2 (**a**) Methane and (**b**) Nitrous oxide fluxes estimation in three locations of mangrove (Sadhupur: SM; Pakhiralya: PM and Dayapur: DYM) during four seasons (winter, summer, pre-monsoon and monsoon) from mangrove sediments. P: in the presence of pneumatophore; WP: without pneumatophore. *Source* Padhy et al. (2020)

summer (103.7 ± 6.0 μg m^{-2} h^{-1}) followed by monsoon (85.2 ± 12.8 μg m^{-2} h^{-1}) and pre-monsoon (51.3 ± 9.4 μg m^{-2} h^{-1}) (Fig. 50.2b). In nut shell, higher GHGs fluxes were recorded in the presence of pneumatophore compared to without pneumatophore (Padhy et al. 2020).

50.3.2 GHGs Fluxes in Ebullition Process

The GHGs fluxes in ebullition were higher "during the time of tide" than "before tide" (Fig. 50.3a, b). The CH_4 and N_2O fluxes were ranged from 0.021 ± 0.005

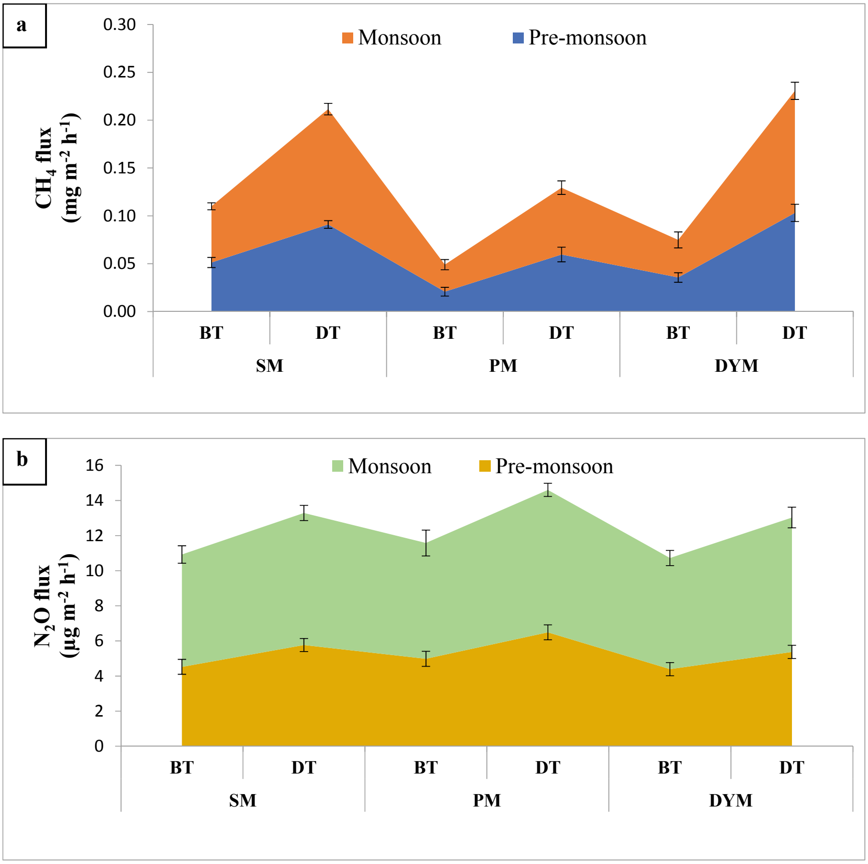

Fig. 50.3 (**a**) Methane and (**b**) Nitrous oxide emission through ebullition in three locations (Sadhupur: SM; Pakhiralya: PM and Dayapur:DYM) during two seasons (pre-monsoon and monsoon) from mangrove sediments. BT: before tide; DT: during tide. *Source* Padhy et al. (2020)

to 0.103 ± 0.009 mg m^{-2} h^{-1}, and 4.39 ± 0.37–6.49 ± 0.43 μg m^{-2} h^{-1} in pre-monsoon and 0.028 ± 0.005 to 0.128 ± 0.009 mg m^{-2} $h^{-1}$and 6.34 ± 0.43 to 8.12 ± 0.38 μg m^{-2} h^{-1} in monsoon at Sadhupur, Pakhiralaya and Dayapur, respectively (Padhy et al. 2020).

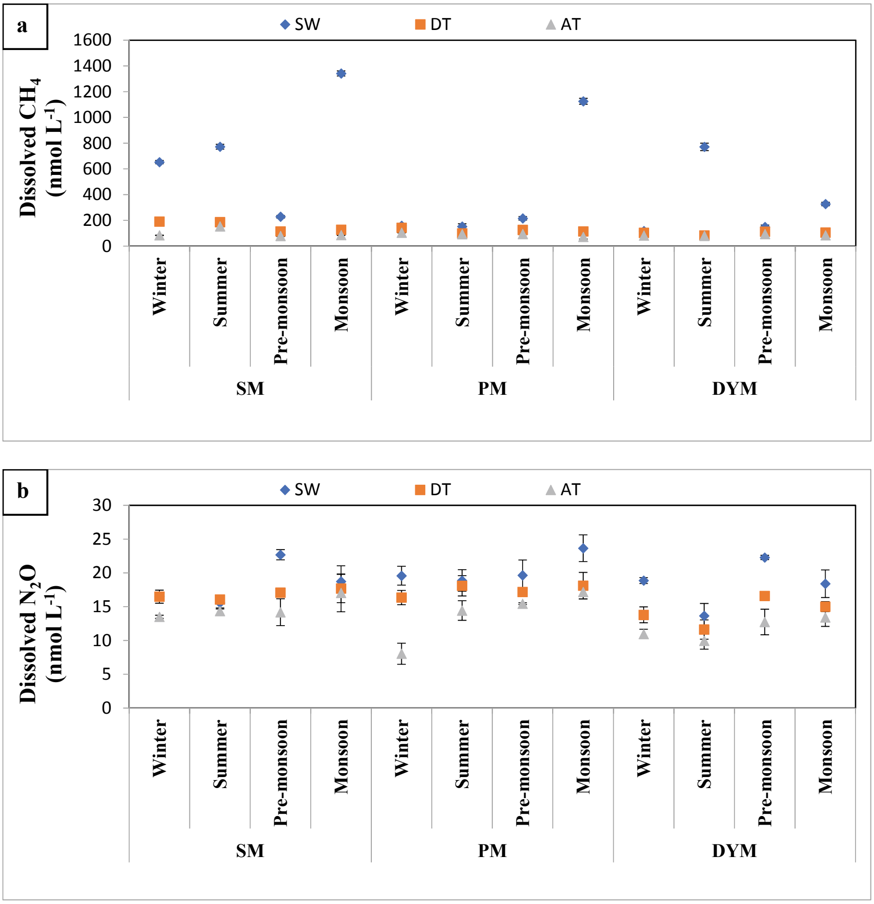

Fig. 50.4 (**a**) Methane and (**b**) Nitrous oxide concentration of surface water in three locations (Sadhupur: SM; Pakhiralya: PM and Dayapur: DYM) during four seasons (winter, summer, pre-monsoon and monsoon) from mangrove. SW: stagnant tide water; DT: during water and AT: after tide water. *Source* Padhy et al. (2020)

50.3.3 Dissolved GHGs Concentration in Surface Water in Mangrove

Tide plays the key role in regulating dissolved GHGs concentration in surface water. The dissolved GHGs concentrations were more in "stagnant-water" as compared to "during tide-water" and "after tide-water". Dissolved CH_4 concentration was more during monsoon than other season irrespective of sites and time of collection of surface water (Fig. 50.4a). Dissolved CH_4 concentrations were higher in "stagnant-water" (1341.2 ± 19.7, 1125.4 ± 23.0 and 327.2 ± 13.3 nmol L^{-1}) (nanomoles per litre) as compared to "during tide-water" (126.9 ± 12.1, 114.6 ± 5.5 and 105.7 ± 13.1 nmol L^{-1}) and "after tide-water" (85.7 ± 2.1, 71.7 ± 16.4 and 83.8 ± 3.9 nmol L^{-1}) during monsoon at Sadhupur, Pakhiralaya and Dayapur, respectively. However, the seasons had no significant effect on the dissolved N_2O concentration in surface water, and these were ranged from 8.0 ± 1.6 to 19.6 ± 1.4 nmol L^{-1}; 10.0 ± 1.3 to 18.9 ± 1.6 nmol L^{-1}; 12.7 ± 1.9 to 22.7 ± 0.8 nmol L^{-1} and 13.4 ± 1.3 to 23.6 ± 2.0 nmol L^{-1} during winter, summer, pre-monsoon and monsoon, respectively (Fig. 50.4b) (Padhy et al. 2020).

50.3.4 Greenhouse Gases Fluxes Through Rice Aerenchyma

The CH_4 and N_2O emission in rice was more during monsoon followed by summer, winter and pre-monsoon (Fig. 50.5a). In the monsoon season, CH_4 and N_2O fluxes were ranged from 0.313 to 0.663 mg m^{-2} h^{-1} and 103.0 to 134.7 μg m^{-2} h^{-1} in all the sites. Higher CH_4 and N_2O emission during monsoon and summer is due to the vegetative/flowering crop growth stages of rice.

50.4 Drivers of GHGs Emission from Mangrove-Rice System

50.4.1 Soil Physico-Chemical Properties

The bacterial and archaeal community structure responsible for GHGs production and emissions is primarily driven by the capability of microbes to withstand the prevalent environmental conditions like oxic/anoxic states of soil, soil texture, active salinity, nutrient dynamics and dominant plant type (Ikenaga et al. 2010; Padhy et al. 2020). The degraded mangrove and lowland rice situated side by side in Sundarban, India, representing a unique ecology with respect to salinity, nutrient dynamics, carbon pools, tidal pattern and oxic/anoxic conditions (Padhy et al. 2021). These

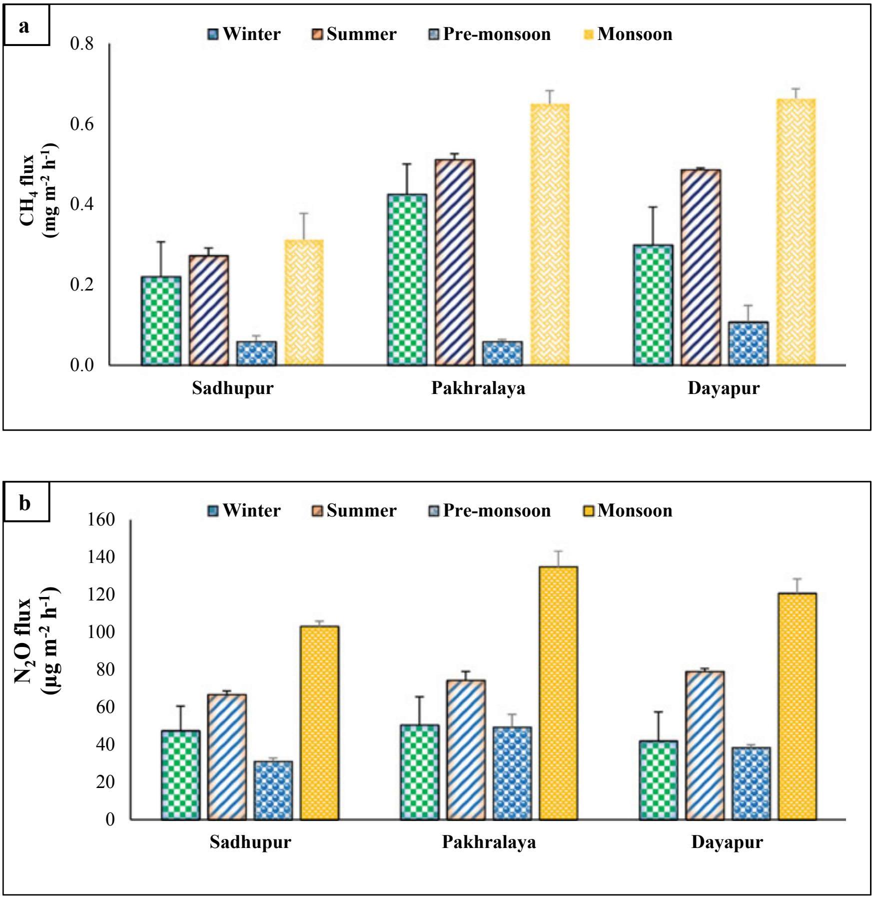

Fig. 50.5 (**a**) Methane and (**b**) Nitrous oxide fluxes estimation in three locations of rice system (Sadhupur: SM; Pakhiralya: PM and Dayapur: DYM) during four seasons (winter, summer, pre-monsoon and monsoon) in Sundarban, India

features have considerable impacts on the microbial community structures and functions. Lower CH_4 emission from mangrove than rice systems is generally due to higher salinity and greater availability of sulphate ions in the mangrove to that of rice (Padhy et al. 2021). While, higher N_2O emission was noticed from rice as compared to mangrove. In rice soils, the higher nitrogen substrate availability in the rhizosphere because of application of nitrogenous fertilizer can favours the N_2O emission. Also, the ammonium oxidizers, nitrifiers and denitrifiers abundance were higher in rice systems. Significant positive correlations existed among ammonium oxidizers, nitrifier and denitrifier that indicated that both nitrification and denitrification processes occurred simultaneously in degraded mangrove-rice ecology that triggers N_2O flux (Bhattacharyya et al. 2013; Padhy et al. 2021). However, Chauhan et al. (2017) reported that the average N_2O emission from the mangrove sediment was significantly higher than the rice paddy soil.

50.4.2 Methanotrophs, Methanogens and Sulphur Reducing Bacterial Community and Their Ratios

The relative methanogen population was found higher in rice compared to mangrove causing less CH_4 emission from mangrove. Further, in rice soil, *Methanosarcina* was identified as the dominant genus that is the specific methanogens which could produce CH_4 by all the three major metabolic pathways of methanogenesis (i.e., acetoclastic, hydrogenotrophic, methylotrophic) (Jing et al. 2016; Bhattacharyya et al. 2016, 2017). The ratios of methanotrophs: methanogens and sulphur reducing bacterial (SRB): methanogens were higher in degraded-mangroves that causes less CH_4 emission in mangrove. These two ratios were relatively less in rice, suggesting the methanogens were dominant over SRB and methanotrophs. Therefore, CH_4 emission was relatively more in rice compared to degraded mangrove in studied area of Sundarban. Sulphur reducing bacteria were predominant in mangrove. It plays a primary role in mineralization and decomposition of organic sulphur in mangrove ecology (Zhuang et al. 2020). The predominance of SRB in degraded mangrove suggested the potential resiliency and bioremediation of the system (Jing et al. 2016). Further, the AMO (ammonia monooxygenase) + nitrifier and denitrifiers ratio were higher in mangrove, resulting in less N_2O emission than that of rice. Though nitrifiers: denitrifiers ratios were higher in mangrove, but both the bacterial communities were significantly higher in rice compared to mangrove. This resulting in more nitrate production as well as higher N_2O emission from rice than that of mangrove.

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References

Bhattacharyya P, Roy KS, Neogi S et al (2013) Impact of elevated CO_2 and temperature on soil C and N dynamics in relation to CH_4 and N_2O emissions from tropical flooded rice (*Oryza sativa* L.). Sci Total Environ 461:601–611

Bhattacharyya P, Roy KS, Dash PK et al (2014) Effect of elevated carbon dioxide and temperature on phosphorus uptake in tropical flooded rice (*Oryza sativa* L.). Eur J Agron 53:28–37

Bhattacharyya P, Roy KS, Das M et al (2016) Elucidation of rice rhizosphere metagenome in relation to methane and nitrogen metabolism under elevated carbon dioxide and temperature using whole genome metagenomic approach. Sci Total Environ 542:886–898
Bhattacharyya P, Roy KS, Nayak AK et al (2017) Metagenomic assessment of methane production-oxidation and nitrogen metabolism of long-term manured systems in lowland rice paddy. Sci Total Environ 586:1245–1253
Bhattacharyya P, Dash PK, Swain CK et al (2019) Mechanism of plant mediated methane emission in tropical lowland rice. Sci Total Environ 651:84–92
Bhattacharyya P, Dash PK, Padhy SR et al (2020a) Estimation of greenhouse gas emission in mangrove-rice ecosystem. NRRI Research Bulletin 22, 20, ICAR-National Rice Research Institute, Cuttack, Odisha, India
Bhattacharyya P, Pathak H, Pal S (2020b) Climate smart agriculture: concepts, challenges, and opportunities. Springer Nature
Bhattacharyya P, Munda S, Dash PK (2020c) Climate change and greenhouse gas emission. New India Publishing Agency, New Delhi, India, 110088
Blair GJ, Lefroy RD, Lisle L (1995) Soil carbon fractions based on their degree of oxidation, and the development of a carbon management index for agricultural systems. Crop Pasture Sci 46(7):1459–1466
Bouillon S, Borges AV, Castañeda-Moya E et al (2008) Mangrove production and carbon sinks: a revision of global budget estimates. Glob Biogeochem Cycles 22(2)
Chambers LG, Davis SE, Troxler T et al (2014) Biogeochemical effects of simulated sea level rise on carbon loss in an Everglades mangrove peat soil. Hydrobiologia 726(1):195–211
Chauhan R, Ramanathan AL, Adhya TK (2008) Assessment of methane and nitrous oxide flux from mangroves along eastern coast of India. Geofluids 8(4):321–332
Chauhan R, Datta A, Ramanathan AL et al (2017) Whether conversion of mangrove forest to rice cropland is environmentally and economically viable? Agric Ecosyst Environ 246:38–47
Chen GC, Tam NFY, Ye Y (2010) Summer fluxes of atmospheric greenhouse gases N_2O, CH_4 and CO_2 from mangrove soil in South China. Sci Total Environ 408(13):2761–2767
Dash PK, Padhy SR, Bhattacharyya P (2020) Soil labile carbon distribution in degraded mangrove and adjacent rice ecology in Sundarban, India. In Williams S, Thanga S, Godson P. Proceedings of the International conference on conservation of mangrove ecosystem: synergies for fishery potential (CMESFP-2020) 19-21st November 2020: 46–55
Day JW, Christian RR, Boesch DM et al (2008) Consequences of climate change on the eco-geomorphology of coastal wetlands. Estuaries Coasts 31:477–491
Donato DC, Kauffman JB, Murdiyarso D et al (2011) Mangroves among the most carbon-rich forests in the tropics. Nat Geosci 4(5):293–297
Dutta MK, Mukherjee R, Jana TK et al (2015) Biogeochemical dynamics of exogenous methane in an estuary associated to a mangrove biosphere; the Sundarbans, NE coast of India. Marine Chem 170:1–10
Gilman EL, Ellison J, Duke NC et al (2008) Threats to mangroves from climate change and adaptation options, a review. Aquat Bot 89:237–250
Giri C, Ochieng E, Tieszen LL et al (2011) Status and distribution of mangrove forests of the world using earth observation satellite data. Glob Ecol Biogeogr 20(1):154–159
Ikenaga M, Guevara R, Dean AL et al (2010) Changes in community structure of sediment bacteria along the Florida coastal everglades marsh–mangrove–seagrass salinity gradient. Microb Ecol 59(2):284–295
IPCC (Intergovernmental Panel on Climate Change) (2018) Global warming of 1.5 °C: an IPCC special report on the impacts of global warming of 1.5 °C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty. Intergovernmental Panel on Climate Change
Jiang P, Xu Q (2006) Abundance and dynamics of soil labile carbon pools under different types of forest vegetation. Pedosphere 16(4):505–511

Jing H, Cheung S, Zhou Z et al (2016) Spatial variations of the methanogenic communities in the sediments of tropical mangroves. PLoS ONE 11(9):e0161065
Kauffman JB, Heider C, Norfolk J et al (2013) Carbon stocks of intact mangroves and carbon emissions arising from their conversion in the Dominican Republic. Ecol Appl 24(3):518–527
Krithika K, Purvaja R, Ramesh R (2008) Fluxes of methane and nitrous oxide from an Indian mangrove. Curr Sci 94:218–224
Liang Q, Chen H, Gong Y et al (2012) Effects of 15 years of manure and inorganic fertilizers on soil organic carbon fractions in a wheat-maize system in the North China plain. Nutr Cycl Agroecosys 92(1):21–33
Marcial Gomes NC, Borges LR, Paranhos R et al (2008) Exploring the diversity of bacterial communities in sediments of urban mangrove forests. FEMS Microbiol Ecol 66(1):96–109
Mukhopadhyay SK, Biswas H, De TK et al (2002) Impact of Sundarban mangrove biosphere on the carbon dioxide and methane mixing ratios at the NE coast of Bay of Bengal, India. Atmos Environ 36(4):629–638
NOAA/ESRL (2012) Available at. http://www.esrl.noaa.gov/gmd/ccgg/trends
Padhy SR, Bhattacharyya P, Dash PK et al (2020) Seasonal fluctuation in three mode of greenhouse gases emission in relation to soil labile carbon pools in degraded mangrove, Sundarban, India. Sci Total Environ 705:135909
Padhy SR, Bhattacharyya P, Nayak SK et al (2021) A unique bacterial and archaeal diversity make mangrove a green production system compared to rice in wetland ecology: a metagenomic approach. Sci Total Environ 781:146713
Purvaja R, Ramesh R, Frenzel P (2004) Plant-mediated methane emission from Indian mangroves. Glob Chang Biol 10(11):1825–1834
Ray R, Ganguly D, Chowdhury C et al (2011) Carbon sequestration and annual increase of carbon stock in a mangrove forest. Atmos Environ 45(28):5016–5024
Rennenberg H, Wassmann R, Papen H et al (1992) Trace gas exchange in rice cultivation. Ecol Bull 42:164–173
Spalding M, Kainuma M, Collins L (2010) World atlas of mangroves. Earthscan, London, UK, p 319
Tian J, Lu S, Fan M et al (2013) Labile soil organic matter fractions as influenced by non-flooded mulching cultivation and cropping season in rice-wheat rotation. Eur J Soil Biol 56:19–25
Wang H, Liao G, D'Souza M et al (2016) Temporal and spatial variations of greenhouse gas fluxes from a tidal mangrove wetland in Southeast China. Environ Sci Pollut Res 23(2):1873–1885
Wohlfart T, Exbrayat J, Schelde K et al (2012) Spatial distribution of soils determines export of nitrogen and dissolved organic carbon from an intensively managed agricultural landscape. Biogeosciences 9(11):4513–4525
Zhuang W, Yu X, Hu R et al (2020) Diversity, function and assembly of mangrove root-associated microbial communities at a continuous fine-scale. NPJ Biofilms Microbiomes 6(1):1–10

Chapter 51
Coastal Agriculture and Water Resources Management in Southern Italy

Marco Arcieri

Abstract Coastal agriculture is essential for Italian productions. Areas cultivated with high-income crops located in coastal zones account for almost half of the total irrigated area in the country. But often here, the primary sector has to compete with other more remunerative sectors operating in the same context such as tourism, commercial activities and industries. All of these are water consuming, moreover reaching their peaks of demand exactly in the same phase of the season when crops ask for their maximum irrigation requirements. A modern system of governance regarding water resources management, capable of taking into account demand coming from different sectors on the one hand, but also able to cope with potentially conflicting situations in service delivery between bordering regions, as a consequence of water scarcity periods deriving from extreme drought events, on the other, is a 'must have' condition to guarantee worthwhile results from the economic point of view for farmers. This paper discusses about the most important critical issues that coastal agriculture has to face in Basilicata, a region of Southern Italy peninsula, and the strategies adopted by the local Regional Government to deal with problems deriving from pressures exerted by various anthropic activities in the area, in order to maintain a viable equilibrium between the need to successfully yield cash crops and the necessity to protect and preserve coastal ecosystems.

Keywords Coastal agriculture · Water resources management · River basin · Coast protection

51.1 Coastal Agriculture in Basilicata Region: Physical and Climate Features

Basilicata region has an extension of about 10,000 km^2. It is placed in Southern Italy peninsula in the middle of the mountainous complex of the Apennines (Fig. 51.1).

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Fig. 51.1 Location of Basilicata Region in Southern Italy. *Source* Interregional River Basin Authority of Basilicata

The territory is mostly covered by mountains and hilly areas, whereas only 8% is interested by lowlands, located in the south of the region, along with some minor alluvial plains extending along the courses of main rivers and streams (Fig. 51.2).

As a matter of fact, the only significant plain is represented by the Metapontum area, which unfolds along the Ionian coast. Physical and environmental conditions

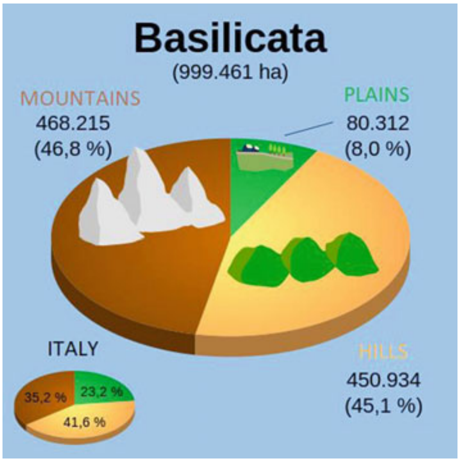

Fig. 51.2 Orography of Basilicata. *Source* Wikipedia (modified)

Fig. 51.3 Digital elevation model (DEM) with dams, weirs, rivers and rain gauges of Basilicata region. *Source* Interregional River Basin Authority of Basilicata

are some ways similar to most of the Mediterranean Countries, enjoying a varied climate depending on latitude and altitude (Fig. 51.3).

Mountains provide a typical continental climate, whilst coasts enjoy a Mediterranean one. The altitude pattern affects rainfall of course (Manfreda et al. 2002): on the southwest Apennines facing the Tyrrhenian Sea, a maximum annual rainfall of 1.500 mm is recorded, whilst south east Ionic coast-oriented basins of Bradano and Basento rivers reach levels of 600 mm per year (Fig. 51.4).

The main feature of the rainfall is the irregular distribution pattern, both in space and time. The region is rich in water resources, both rivers and surface streams, collected by means of several dams, barrages and weirs, conceived for water storage purposes connected through a complex system of aqueducts.

Agriculture is of course very important for the region's economy. In the flat areas and along the river valleys vegetables and fruits are grown, whilst olive trees, vines, durum wheat, barley and oats can be found on the inner hills. Animal breeding is also widespread, such as beef and dairy cattle, along with sheep and goats, mostly bred in the inland territories. But of course, agriculture with the highest added value in the region is provided by the intensive cultivation of high-income cash crops. The coastal plain of Metapontum area is scattered with modern peach and apricot orchards, orange and clementine groves, besides horticultural crops such as strawberries, lettuces, tomatoes, artichokes, cabbages and many others. All of these crops

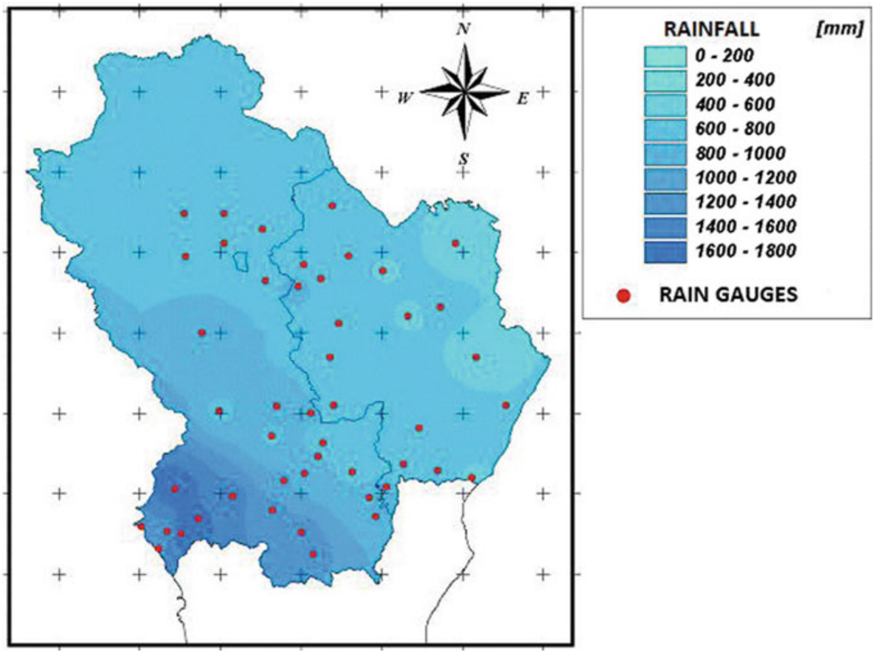

Fig. 51.4 Spatial distribution of rainfall in the study area and rain gauge network (•). *Source* Bove et al. (2004)

necessarily need irrigation, as the rainfall, temperature and evapotranspiration regime of the area is such that no yield could be obtained without water. The average annual values of minimum and maximum temperature are 10.2 and 21.4 °C, in January and July, respectively.

The coldest month is January, with an average minimum value of 3.1 °C, whereas the higher average values of the maximum temperatures (31.5 °C) are observed in July. The evaporative demand is lower during winter months, being January cumulative values equal to 43 mm on average; on the other hand, in the summer season, a cumulative value of 262 mm on average is reached in July (Fig. 51.5).

This abundance of both surface and groundwater resources enables large transfers towards neighbouring Apulia and Calabria regions, mainly for drinking and irrigation purposes but also for irrigation. Nevertheless, the region has been witnessing several drought events in recent years, besides alarming processes of land degradation and desertification. Reduction of rainfall, especially occurred in the recent past during the autumn and winter periods, has often hampered the exhaustive filling of reservoirs, diminished water storages and thus limited the possibility of irrigation in areas depending almost exclusively on the resource stored inside the artificial reservoirs.

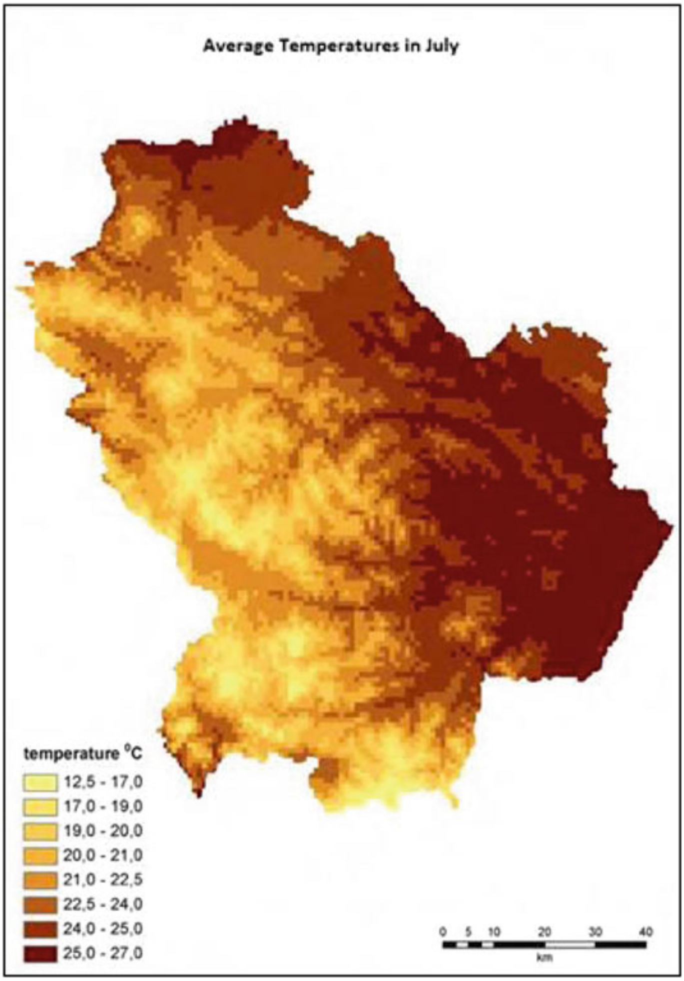

Fig. 51.5 Average temperatures in July of Basilicata region. *Source* Fiorenzo et al. (2008)

Particularly, severe has turned out to be water shortages during the irrigation seasons of 2001–2002, 2007–2008 and 2017 years of particularly severe drought which led the Italian Government to declare the status of emergency (Figs. 51.6 and 51.7).

These drought events and the subsequent water crises have led to remarkable economic losses for farmers, thus raising awareness that a proper management of the resource, when in such conditions, is to respond to new criteria. This is why in order to achieve a sound management of water resources and to prevent situations of water deficit, the Regional Government of Basilicata in the last 20 years has conceived, developed and enforced an innovative water resources governance system, also based on interregional cooperation.

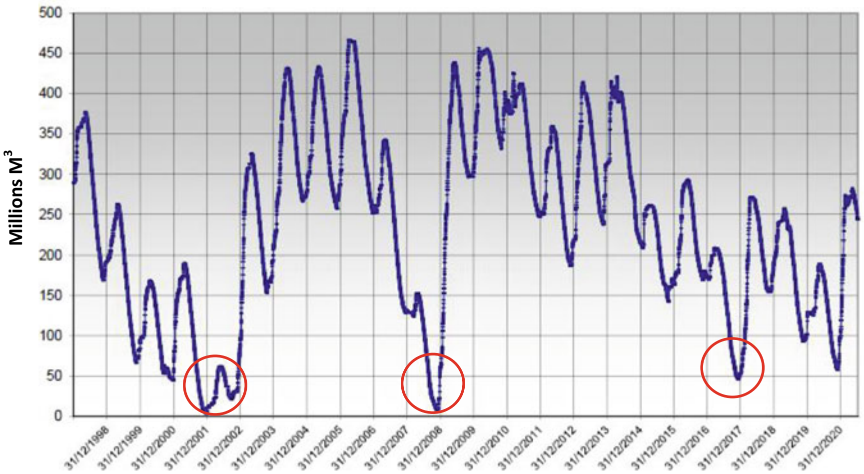

Fig. 51.6 Water resources (Mm^3) evolution in the Monte Cotugno Reservoir (Sinni river basin) during the 1998–2020 period. *Source* Interregional River Basin Authority of Basilicata

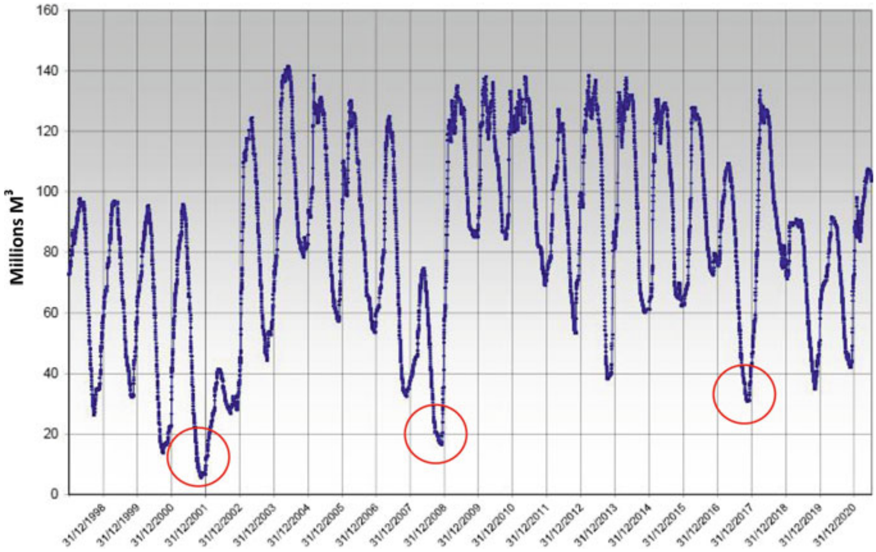

Fig. 51.7 Water resources (Mm^3) evolution in the Pertusillo Reservoir (Agri river basin) during the 1998–2020 period. Source: Interregional River Basin Authority of Basilicata

First step in this new approach has been the modernization of the hydraulic networks, in order to achieve a greater and more efficient transfer of water resources between different areas of the region and/or the bordering ones (Fig. 51.8).

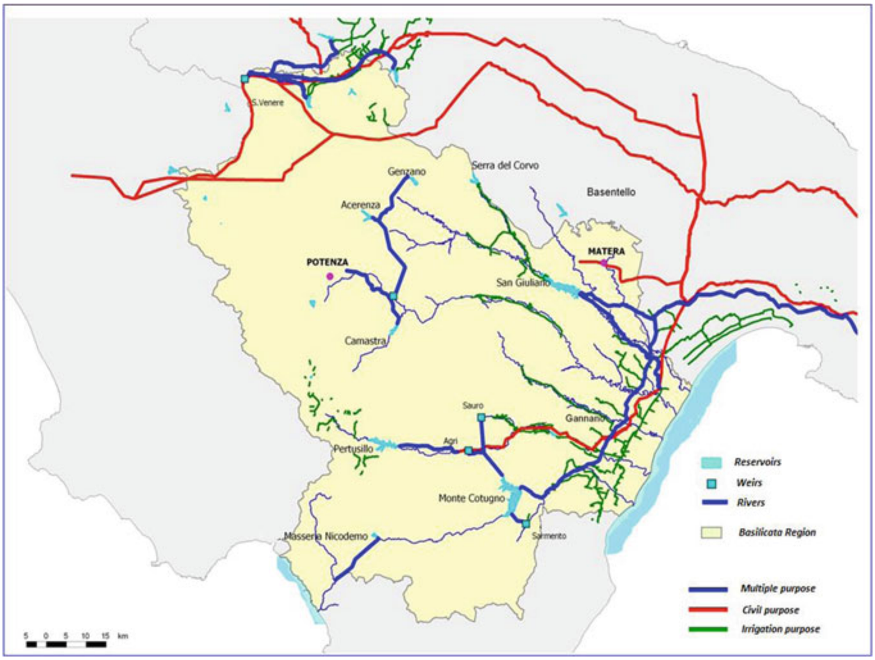

Fig. 51.8 Irrigation schemes and hydraulic infrastructures of Basilicata Region. *Source* Interregional River Basin Authority of Basilicata

On the other hand, new criteria such as *environmental tariffs* to be paid by main bodies for water delivery have been introduced, in order to compensate indirect negative effects on the territories interested by the creation of large hydraulic infrastructures (storage and transfer), such as those necessary to ensure water availability to the populations of Apulia and Calabria regions. But, also, to effectively take into account of the withdrawal of resources required to the social and economic development of the bordering territories. This new system of management has been primarily focussed on the establishment of a new Water Resources Authority Governance, chaired in turn by the Governors of the Regions involved, who take decisions regarding the implementation of plans and programmes for the utilization of water resource, in order to reduce the risk of shortages whilst ensuring a sustainably shared use. This new approach greatly helped in reducing contrast between the different categories of users within the region and outside of it, settling the existing conflicts arisen in the past between neighbouring territories and different stakeholders. This system, agreed upon and shared by all the institutional bodies operating in the water sector, allowed to correctly plan and manage infrastructures system and water distribution, taking into account resources and territorial needs, besides the proper requirements for the social and economic development processes of the regions.

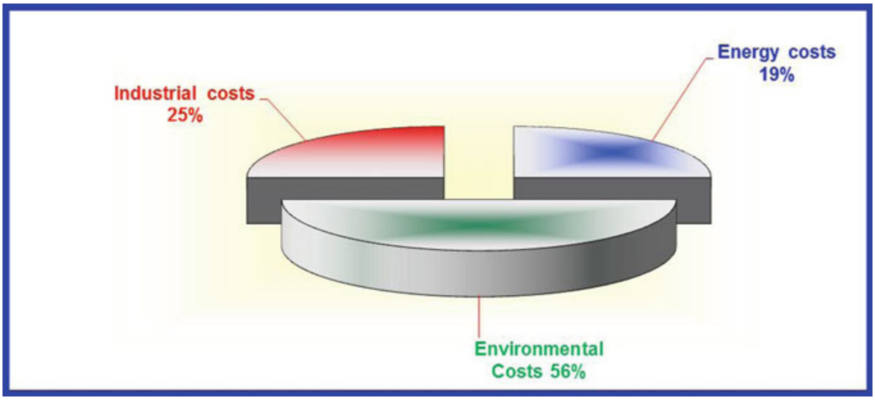

Fig. 51.9 Tariff system for water use adopted by Basilicata Region. Source: Interregional River Basin Authority of Basilicata

To do so, Government of Basilicata has implemented the following:

- A unitary supervision of the infrastructures and an organic planning of water distribution aimed to ensure an effective supply and the efficient transfer of resources from one end of the region to the other, especially in case of water shortage, as a result of a flexible system of delivery;
- elaboration of an advanced system of monitoring for the accountable use of water;
- proclamation of shared standards for the regulation of the withdrawal concessions within and amongst bordering regions;
- development of a new tariff system conceived to guarantee, on the one hand, water resources availability to all categories of users at an equitable price; on the other hand, to adequately take into account the environmental effects deriving from the realization of hydraulic infrastructures such as dams and weirs, allocating part of the tariff revenues into the exploitation of environmentally sound compensation activities (Fig. 51.9).

All of these measures have been combined into the so-called 'PROGRAMME AGREEMENT ON THE USE OF SHARED WATER RESOURCES', signed in August 1999 between the Italian Government (Ministry of Public Works), and Apulia, Calabria and Basilicata Regional Governments. This new governance system has proven to be of great benefit in enabling the full exploitation of water resources, especially as referring to an area characterized by different physical, social and economical aspects, often put under pressure by recurrent water crises periods due to extreme drought events. It can well be considered as a '*best practice*' and could be extended to other Countries of the Mediterranean, as well as to prone to drought countries suffering situations of water crisis where harsh situations of conflict, linked to the sharing of the resource, are recurrent. Under this perspective, Basilicata region water resources governance system is an outstanding case of study, also at the international level (Arcieri 2016).

51.2 The Ionian Coast of Basilicata Region: Features and Problems

The Metapontum plain is an alluvial complex formed by the gradation of rivers and minor waterways mouths flowing into the Ionian Sea. Here, the connected morphogenetic action of sea waves and rivers' streams has been deploying in time, giving birth to a complex physical context and generating an area of significant environmental, archaeological and economic interest, certainly a unique in Southern Italy: this is the home of ancient Magna Graecia and the area where famous mathematic Pythagoras used to lecture. The main rivers reaching here and flowing into the Ionian sea, moving from west to the east, are the river Sinni, Agri, Cavone, Basento and Bradano, whose basins altogether cover a total area of 8.697 km^2 (Table 51.1). Their watersheds are represented in Fig. 51.10.

The great amount of hydraulic works realized on almost all of the major rivers and streams of the region in the past decades, starting from the 50s, has had remarkable consequences on the environmental conditions of the coast: due to the decrease of rainfall witnessed starting from the 80's, and to the reduction of the streams' flow towards the sea, with the only exception of Cavone river which has never been interested by the construction of dams and/or weirs along its course, there has been a significant depletion in the average amount of sediments carried by rivers to sea, quantified as ranging between 15 and 20% of the previous. This has been of course a major concern in recent years, as well as the constant and progressive intrusion of saline water inside aquifers of the area, which as a consequence has greatly lowered and compromised water table, considerably affecting its present quality and for future utilizations.

Also, another important cause of alteration of the natural balance existing between rivers and coast has been the intense (and sometimes uncontrolled, especially in the past) extraction of sediments from the major river beds and alluvial streams, which resulted in the activation of significant coastal erosion processes, also due to the concomitant action of sea waves and to the hectic motion of currents existing. The representation of these processes along the coastal line and the average trend in time can be seen in Figs. 51.11 and 51.12.

Table 51.1 River basins area

Basin	Area (km^2)
Bradano	3.03661
Basentno	1.53459
Cavone	684,50
Agri	1.72345
Sinni	1.34468
Noce	373,54
Total	8.69738

Source Interregional River Basin Authority of Basilicata

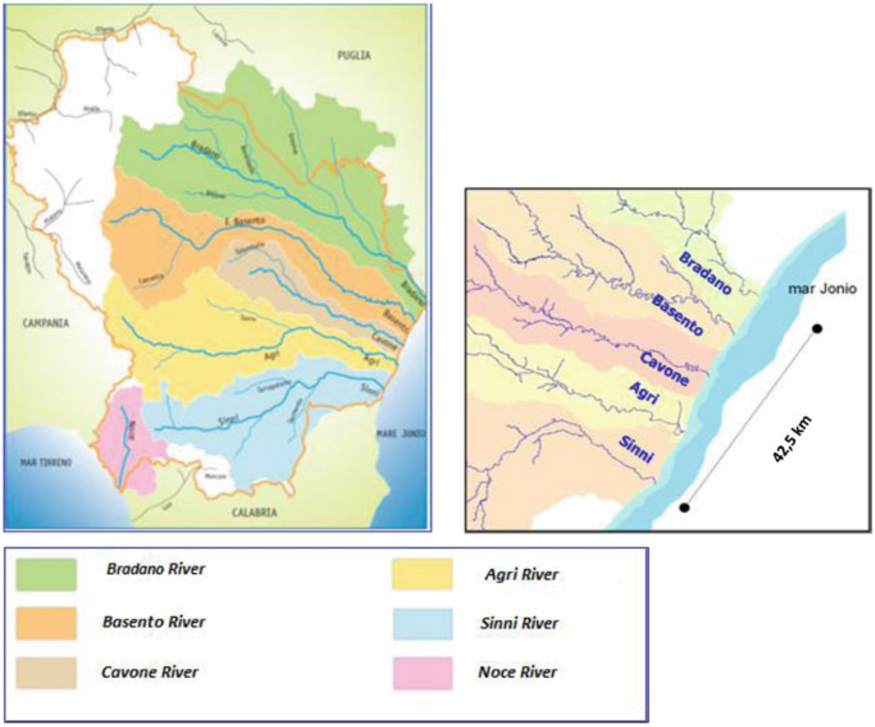

Fig. 51.10 Major river basins of Basilicata region with relative watersheds. *Source* Interregional River Basin Authority of Basilicata

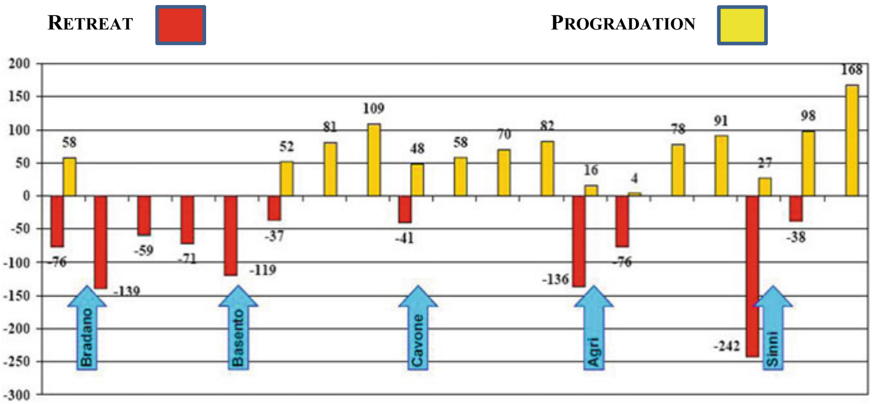

Fig. 51.11 Average trend in the shoreline retreat and progradation (metres) along the Ionic coast of Basilicata region during the 1949–2006 period. *Source* Interregional River Basin Authority of Basilicata

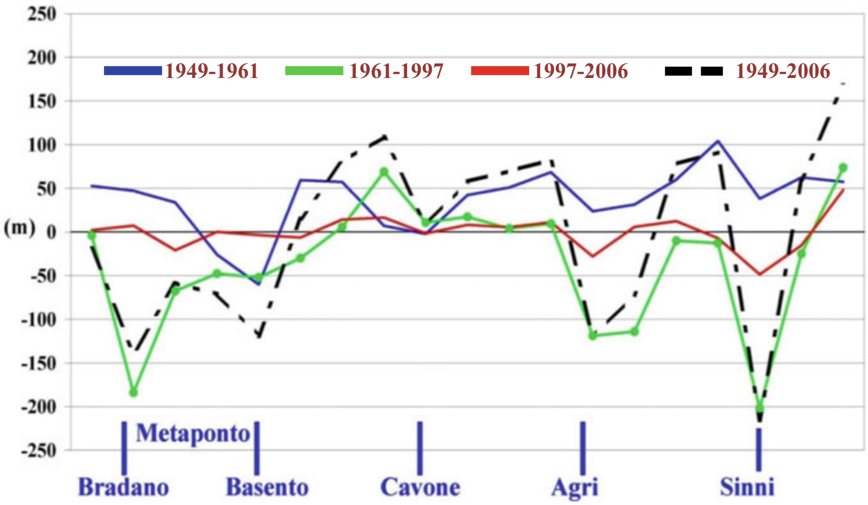

Fig. 51.12 Average variation (metres) of the Ionic coast line, as observed during the 1949–2006 period. *Source* Vita et al. (2008). Interregional River Basin Authority of Basilicata

So, even though the realization and implementation of this huge network of infrastructures on the one hand have allowed the possibility to dispose of important resources of water for irrigation during the dry season, on the other hand, it has given birth to environmental problems, such as the coastal erosion. Moreover, this consistent interception of sediments by dams and weirs has also raised some other major issues. Many of the most important reservoirs of the region after some 60–40 years of activity, depending on the time of their implementation, have been witnessing a significant reduction in their water storage capability, ranging between 30 and 40% of their total volume. Which accordingly brings along some other important problems. According to the experience that has been acknowledged in the past 60 years in Basilicata region, it is possible to say that the main problems connected to dams' management have been

- Reduction of reservoir storage capability.
- Breaking or forfeiture of hydraulic structures and bottom drains.
- Lesser capacity and control of water flow.
- Increased risk of flooding.

All of these problems require consistent financial resources to be dealt with, especially in the case of restoring the original storage capability as well as reestablishing the full efficiency of hydraulic structures, the main problem being the removal of sediments and the subsequent disposal which, still today, is very expensive and quite problematic (Fig. 51.13).

The use of hydrological and geomorphological models calibrated on the characteristics of the territory can help prevent soil erosion, reduce the sources and transport of sediments, potentially decreasing silting phenomena (Fig. 51.14). By means of

Fig. 51.13 Accumulation of sediments in reservoir. *Source* Interregional River Basin Authority of Basilicata

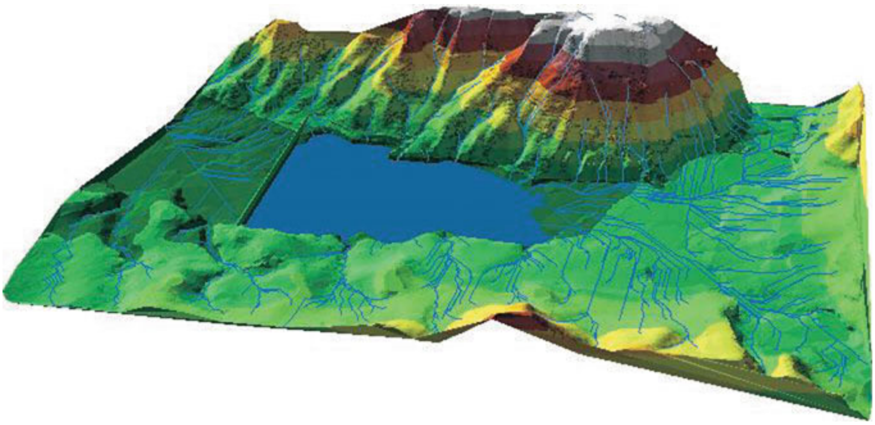

Fig. 51.14 Digital elevation model (DEM) of the river basin with its reservoir. *Source* Molino and Savastano (2004). Interregional River Basin Authority of Basilicata

some of the most advanced of these models, all principal factors affecting water flow can be properly evaluated, and a precise assessment of run off rates, distributed over the entire area under consideration, can be achieved. These information, coupled with data provided by geographical information systems (GISs), certainly render this approach a most valuable one, making it a very useful decision-making tool in the process of planning interventions aimed at the reduction of soil erosion and more generally, in the overall management process of the territory.

A significant reduction of sediment production within the hydrographic basin can be achieved through the increase of vegetation cover over the slopes. This has been accomplished by means of forestry interventions, woodland fences and/or shrub crops, in order to diminish run off (Fig. 51.15). The protection result carried out by the vegetation cover is mainly due to dissipation of the kinetic energy of rainfall, so that the impact on the ground of water drops, further dampened by litter, is significantly weakened.

Furthermore, the presence of very porous and permeable organic layers in the forestry covered soil absorbs and retains, for a certain period of time, large volumes of water. This water, rather than flowing freely along the slopes triggering dangerous processes, is partly used by plants and partly percolates through various strata of soil, to finally be disposed of in the collector bed of the basin. To increase the effectiveness of the process, various kinds of hydraulic manufacture works have also been implemented through the years (Fig. 51.16).

These kinds of structures have been conceived and realized with the main aim of aiding the vegetation cover in decreasing run off along hill slopes, especially in case of extreme meteorological events. The solid material flowing along the basin slopes and transported into the reservoir is intercepted by means of small diversion weirs, holding basins or storage tanks, located upstream of the reservoir. The coarser material is retained, but sedimentation of the finer material, transported by suspension, is only slightly contained (Fig. 51.17).

These soil erosion mitigation techniques can prove to be very effective, provided the periodic removal of the sediment material is frequent, as well as the inspection and maintenance of the structures are carried out with a regular cadence. This is also the main region why Basilicata Regional Government has been carrying out in time several interventions of meticulous inspection along the watersheds of major river basins, aimed at the safeguarding of hydraulic structures and the monitoring of critical situations along the most important water streams.

Through site-specific studies and field surveys, aimed at the recognition of conditions that might cause either actual or potential danger to people and/or existing assets, the most critical areas of the region watersheds have been identified. The activity has been systematic in time along all major water streams, as interventions for the most dangerous situations have been carried out in order to exert continuous surveillance and achieve an active prevention of flooding and/or landslides within the hydrographic basins (Fig. 51.18). The information acquired during the years has enabled the establishment of a very informative and dynamic database, referred to the operating conditions of works and settlements along the river beds, the either current or potential disorder of banks and embankments, as well as of any hindrances to the regular outflow of water. Monitoring has also been aimed at other critical conditions along water streams, such as the narrowing of the bed sections next to crossings of the river, structural issues due to the erosion of the bridge pillars, scouring of the foundations and so on.

Fig. 51.15 Forestry interventions to reduce soil erosion by means of vegetation cover and woodland fences. *Source* Interregional River Basin Authority of Basilicata

Fig. 51.16 Hydraulic works to reduce water velocity. *Source* Interregional River Basin Authority of Basilicata

Fig. 51.17 Hydraulic interventions to reduce soil erosion by means of small sedimentation weirs. *Source* Interregional River Basin Authority of Basilicata

All of these data gathered in time have been merged into the *River Basin Hydrogeological Management Plan*. This strategic planning document, based on the analysis of flooding hazard, specifies measures (works/actions) to be implemented in order to reduce the risk for people and assets, adopting site-specific strategies based on the recognition of well identified areas, classified according to probability of having floods with a return period of occurrence once in every 30 years (very high hydraulic risk areas), in every 200 years (high hydraulic risk areas) and in every 500 years (moderate hydraulic risk areas).

51.3 Prevention of Coastal Erosion

On the terminal end of the basin, i.e., the sea, Basilicata Regional Government has also deployed several measures to prevent and counter back the processes of retreat and progradation along the coastal line (Fig. 51.19). To prevent coastal erosion, two basic approaches have be carried out: soft interventions and hard works.

The strategy based on the approach with soft-type interventions foresees the stabilization of the coastline by means of artificial nourishment with granular material, whose characteristics are compatible with those of the native material. Significant

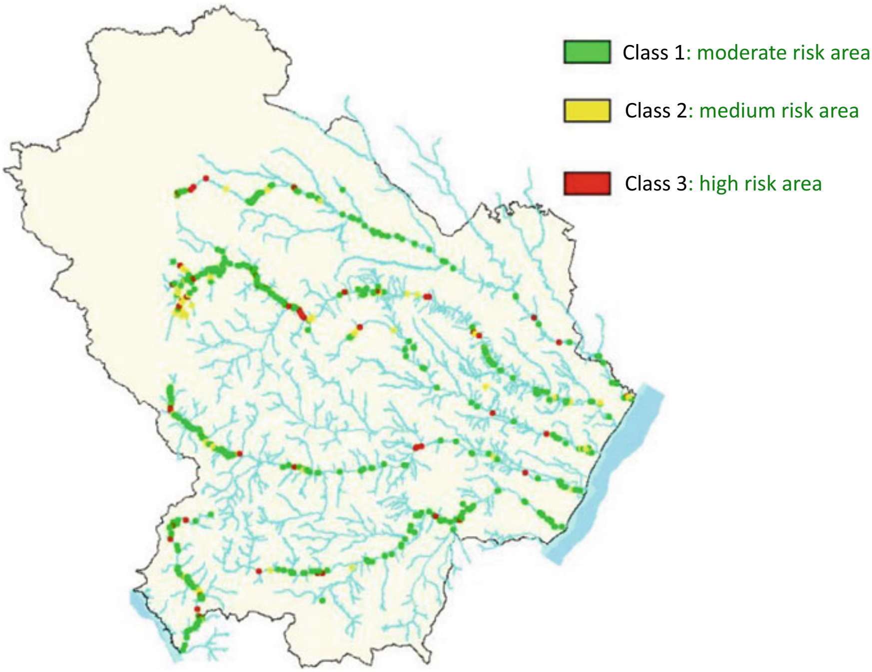

Fig. 51.18 Hydraulic safeguarding activity along major river and water streams of Basilicata Region. *Source* Interregional River Basin Authority of Basilicata

amounts of suitable sediments, of marine or terrestrial origin, are poured on the emerged and/or submerged beach. The material is moved to the ground and redistributed by the waves along the balance profile. With these kinds of nourishment interventions, the eroding beaches have been partially restored or stabilized in Basilicata region.

The approach based on rigid interventions instead can be carried out by means of works realized parallel to the shore line (longitudinal) and spaced from it works perpendicular to the coast (breakwaters), works parallel and adherent to the shore (grazing), T-shaped defence systems, protective walls and combinations of the above types. The scope of this kind of works is to reduce the powerful action of waves and to break their movement, creating an area of relative 'calmness' close to the coast and thus indirectly reducing the solid transport that might produce erosion.

However, aside from the kind of strategy adopted, defence interventions for coastal erosion in the medium and the long term need to be conceived within the context of an integrated action, in order to reduce *indirect effects* affecting resilience of the beaches and *direct effects* caused by coastal erosion and climate change processes. It is, therefore, necessary to consider these not solely as single mechanisms of protection, but as components of an integrated system which needs to be considered at the required physiographic unit scale. This is essential in order to reasonably take into

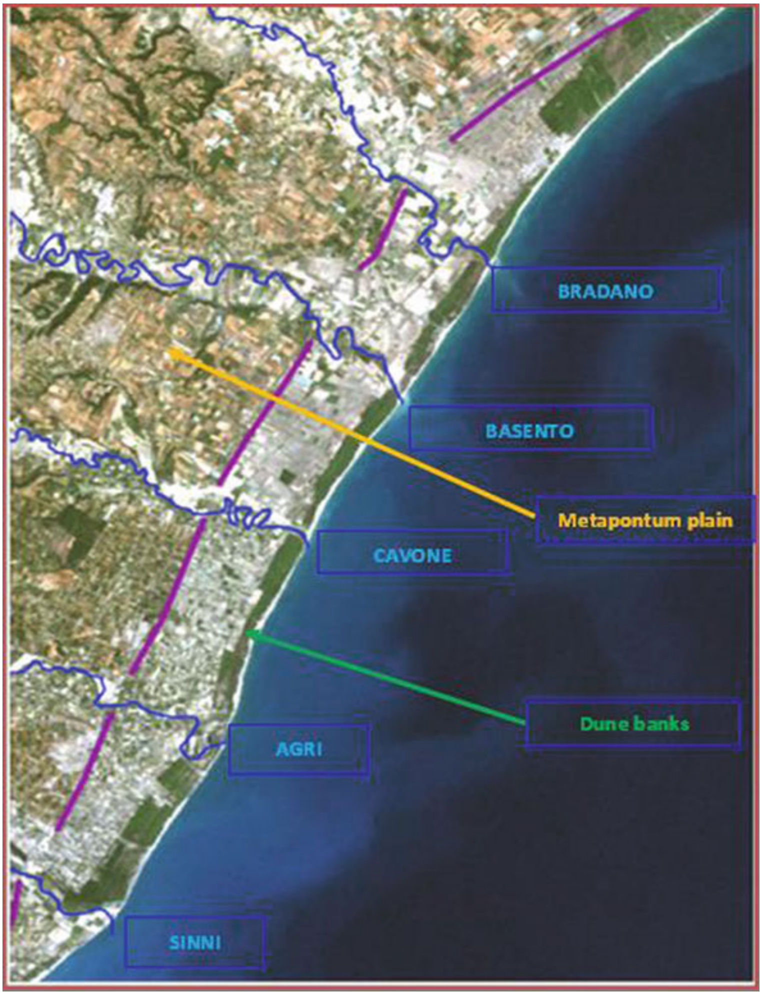

Fig. 51.19 The coastal line of Metapontum stretching along the Ionic Sea. *Source* Interregional River Basin Authority of Basilicata

account possible consequences on the coastal environment such as erosion, flooding, intrusion of the saline, alteration of pre-existing habitats and so on.

51.4 Conclusions

Water represents an essential resource for Italian agriculture. More than two thirds of the Italian agricultural production value inside GNP come from irrigated crops;

and within these coastal zones account for almost half of the irrigated areas. It is also worthwhile mentioning that coastal agriculture and associated sceneries are the pillars of the so-called *made in Italy*, which attracts every year a large number of tourists coming to the country. The excellence of Italian products, such as wine, olive oil, fruit, vegetables and cheese, make Italian agricultural industry very competitive on the world market, because of the intrinsic value deriving from its typical origin, which cannot be replicated or cloned (Arcieri 2016): irrigation makes it possible to obtain this authentic genuine Italian value. Thus, proper water resources management appears to be a strategic issue, with respect to these considerations. This is especially true in areas such as the coastal zones of Southern Italy, where along with agriculture necessarily need to cohabit other sectors such as tourism, commerce and industry, all of them extremely important for Italian economy but also extremely water demanding, moreover in the same period of the year when cash crops need to be provided with their highest water requirements. This is why new innovative forms of governance regarding water resources management are way more needed today, in order to face the new challenges deriving from the alarming climate change scenarios appearing on the horizon, which seem to depict more intense episodes of drought, likely to happen with increasing frequency and growing strength. But, also, to deal successfully with the escalation of social conflicts potentially likely to arise between bordering communities (or even cross borders), as a consequence of these extreme climatic events. This is what Regional Government of Basilicata has been implementing during the last 20 years, in such a way that the 'PROGRAMME AGREEMENT ON THE USE OF SHARED WATER RESOURCES', signed in August 1999 between the Italian Government (Ministry of Public Works), Apulia, Calabria and Basilicata Regional Governments has become a case study and a virtuous example for the whole Country. But even in presence of such ad advanced institutional form of agreement regarding new forms of governance on water, somehow the full exploitation of intensive systems of coastal agriculture is hampered here by two major concerns: first one is the large amount of increasingly skilled labour force requested to gain economically viable productive and commercial results, besides the need of a continuous presence of farmers 'in the field' to keep these contexts in harmony between production and environmental safeguard. In order to fulfil these challenges, the involvement of young farmers will become more and more essential in the future, as well as the introduction and dissemination of technological innovations, capable of optimizing yields whilst respecting and preserving the environment. Unfortunately, in recent, the fraction of people involved in agriculture seems to be progressively reducing, as economic restraints and new social models of life are pushing youngsters towards sectors other than agriculture and especially along the coast urban settlements. Second one is the continuous and at the same time, extremely alarming intrusion of saline water inside the main aquifers of the coastal plain. This is primarily a significant consequence of the reduced amount of water flow towards the sea, as a result of the interception actuated by dams and weirs located along major river and streams, which slowly tends to deplete the more superficial water table existing downstream. Moreover, the negative effects due to this condition are way more amplified by the sometimes uncontrolled and unregulated exploitation of ground water exerted by local farmers.

This has been especially occurring during some of the recent water crisis periods, as water service and delivery could not be provided by the operating irrigation and land reclamation consortium, because of drought. This true environmental emergency poses very dire threats over the full economic and sustainable exploitation of coastal agriculture of this area, essentially based on cash crops, but also severely menaces the fragile ecosystem of the area, especially as a perspective.

Nevertheless, because of its crucial importance for the things so far said, coastal agriculture in this area will continue to play a fundamental role inside economic processes of the region. Many positive examples of possible coexistence between different sectors stand in front of us, also worldwide: in Vietnam for instance, a country where farmers are very often involved in fishery, new forms of multiactivity have been boosting local farmers' economy, so that, nowadays, this country is the fourth most important exporter of shrimps to EU.

Coastal agriculture, thus, should be reconsidered and thought of inside of a new, holistic vision, capable to cope with both sustainable and economic development, taking also into account environment protection criteria such as the conservation of dune ecosystems, the arrest of saline intrusion and the prevention of coastal erosion, the back bone of an effective defence strategy to reduce the risk of floods. Soil erosion and reduced solid transportation processes, very much linked to human activities and variations in land use, are the main sources of sediments accumulation inside the reservoirs, as we know. But effective forestry measures and shrubs cover can ensure soil protection over the basin, reduce erosion and landslides insurgence; these can be aided by hydraulic structures conceived with the aim of decreasing water velocity and thus solid transportation within the reservoirs, hence exploiting a balancing action over the hydrogeological *land to sea* cycle. On the other hand, in order to preserve and protect coastal ecosystems, necessary measures of interventions aimed at the reduction of the concomitant action of sea currents and waves, should also be considered. In order to do this, a thorough scientific study of the Ionian Sea should be carried out, enabling decision-makers to choose the most appropriate typology of defence interventions according to features and characteristics of both the coastal line and sea currents dynamics.

References

Arcieri M (2016) Water resources and soil management in Italy. Irrig and Drain 65(2):165–181. https://doi.org/10.1002/ird.1985

Bove B, Brindisi P, Glisci C et al (2004) Climatic indicators of desertification in Basilicata, Italy. Forest@ 2:74–84. https://doi.org/10.3832/efor0265-0020074

Fiorenzo F, Mancino G, Borghetti M et al (2008) Metodi per l'interpolazione delle precipitazioni e delle temperature mensili della Basilicata. Forest@ 5:337–350. https://doi.org/10.3832/efor0550-0050337

Manfreda S, Di Santo G, Iacobellis V et al (2002) A regional analysis of rainfall pattern in Southern Italy. Proceedings of the 4th EGS Plinius Conference, Mallorca, Spain, 2002

Molino B, Savastano L (2004) Approccio distribuito per la stima dell’erosione idrica superficiale di un bacino idrografico. In: Il processo di interrimento degli invasi: genesi, effetti ed interventi per la tutela dell’ambiente, Autorità di Bacino della Basilicata - Studi e ricerche, vol 4, pp 83–84
Vita M, Bulfaro M, Cavuoti C et al (2008) Interazione Bacino–Costa: cause e mitigazioni della vulnerabilità. Il caso del litorale jonico lucano. In: Atti del Convegno di Maratea Prevenire, programmare, pianificare, Maratea, Italia 15–17 maggio 2008. Autorità di Bacino della Basilicata - Studi e ricerche, vol 8, pp 29–43

Chapter 52
Groundwater Salinity—Impacts and Possible Remedial Measures and Management Solutions

Gopal Krishan, Jay Prakash, Purnabha Dasgupta, Andrew Mackenzie, and Thiyam Tamphasana Devi

Abstract Groundwater, the largest freshwater resource, is used for drinking, irrigation, and industrial uses worldwide. Ever-increasing demands have accelerated the consumption of groundwater resources leading to its exploitation which has undesirable effects such as declining water levels, land degradation, and water pollution. In coastal, arid, and semi-arid areas, groundwater salinization has been observed at local or regional scales due to saltwater intrusion, caused naturally by geological formations and also by human activities. Its occurrence is controlled by factors such as hydraulic aquifer characteristics, distribution, rate of groundwater recharge, residence time, flow velocities, and nature of discharge areas. Therefore, for its remediation and management solutions, understanding of aquifers and groundwater movements is very crucial.

Keywords Groundwater · Salinity · Impacts · Remediation and management solutions

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52.1 Introduction

Salinity is a global issue due to its occurrence under all climate conditions found to affect soil and water resources, agriculture, and may disrupt the natural ecosystem. Salinity processes can be naturally linked with landscape and various processes of soil formation. Gradually with the time, increase in groundwater salinity is related to high concentrations of elements like sodium, chloride, sulfate, boron, fluoride, arsenic, and high radioactivity. Groundwater salinity is generally of three types (1) primary/natural salinity—result of dissolution of minerals from bedrocks or accumulation of salts from rainfall built up over time ranging from thousands to millions of years, (2) secondary/dry land salinity—result of accumulation of salts on the surface as a result of increasing water levels and these salts are percolated down in high rainfall areas, but they stay on the surface in arid and semi-arid areas, and iii) tertiary/irrigated salinity—result of a number of irrigations of water where salts remain after evaporation and accumulate over time (Krishan 2019). Salinity may be of (1) marine origin, (2) terrestrial origin—natural sources, (3) terrestrial origin—anthropogenic contaminations, and (4) mixed origin—combined effect of marine/terrestrial (Krishan 2019).

Expansion of groundwater salinity has also been reported in several instances in areas with excessive groundwater extraction leading to lowering of groundwater level and creating a stress in freshwater zones leading to the movement of saline water (Krishan et al. 2020, 2021a, 2021b, 2021c, 2021d, 2021e). There may be several factors responsible for movement of saline water such as: aquifer type—its geometry and geology; irrigation and agricultural practices; intensity and frequency of rainfall; total rate of groundwater withdrawals to the rate of recharge; presence of freshwater drainage canals with no salinity control structures; distance between stress points, such as wells and drainage canals, and the source of saline water intrusion; length of time required to reduce aquifer levels; long-term changes in sea level caused by tidal fluctuations; variations in groundwater recharge and evapo-transpiration rates on a seasonal and annual basis. However, existence of confining units may be geologic structures that can prevent saltwater intrusion.

In India, many states have been affected by groundwater salinity, but the area of influence may differ. Severely affected states in coastal areas are West Bengal, Orissa, Andhra Pradesh, Tamil Nadu, Gujarat, Maharashtra, Goa, and Kerala (CWC 2020); and in inland areas are Karnataka, Uttar Pradesh, and states of north-west India such as Haryana, Punjab, Rajasthan, and Delhi (CGWB 2007, 2019). However, groundwater salinity in all the states is critical, but in Indian Sundarban area of West Bengal, it is peculiar, and a study was carried out under India UK Water Centre sponsored pump priming project (NIH 2020). In the present study, groundwater salinity in Sunderban area of West Bengal is discussed along with possible remediation and management solutions.

52.2 Study Area

For study, the Indian Sundarbans area was selected where majority of the population live in acute poverty (Dasgupta et al. 2019; Kibria et al. 2019). By adopting suitable development framework with consideration of the hydrologic and socio-economic these can provide a sustainable solution to the problems. Groundwater level in Indian Sundarbans is shallow and is saline in nature which rises to double or more than double in summer months than that of monsoon season. In this article, salinity measurements were carried out and suggest few demonstrative schemes as resilience building measures.

52.3 Salinity Measurements

For measuring the salinity in the region, the samples were collected from the deep (5-7 m amsl) and shallow (9–11 m amsl) wells in the months of June, July, August, September, and October of year 2019 from the 12 selected sites. Salinity was measured using handheld Eutech EC meter.

Figure 52.1 depicts variations in salinity, as well as changes in salinity in terms of PSU with months. Some sources now express salinity values in practical salinity units (PSU), with 1 PSU equaling 1 ppt (parts per thousand). The third aquifer (deep) is represented by blue color, while the first aquifer (shallow) by orange color. A significant difference in salinity between the two depths third to first aquifer was found over five months. The results presented in Fig. 52.1 also show that in shallow aquifer, the salinity decreased by ~6 PSU from June 2019 to October 2019 while almost constant salinity was observed in deep or third aquifer. There is a need of detailed study to find the source of salinity, its mechanism, and movement of groundwater as reported for other areas by Krishan et al. (2021a) using stable isotopes and environmental tritium (^{3}H) to distinguish recharge and discharge zones (Krishan et al. 2021e).

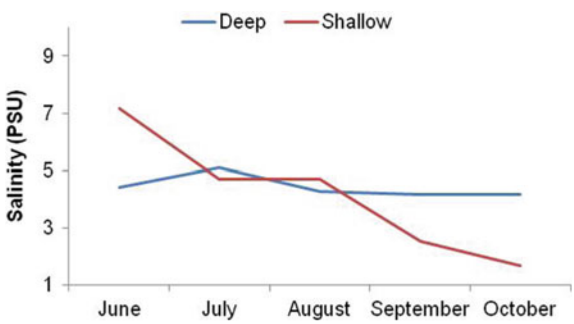

Fig. 52.1 Salinity variations (June, 2019–October, 2019) in Sundarbans, West Bengal

52.4 Impacts of Salinity

The data on salinity implies that the water available from majority of the sources are higher than the permissible limits for drinking as well as cultivation and long-term exposure from these water sources may have detrimental health effects.

52.5 Management and Remedial Measures

Continuous monitoring of the saline water interface is required to calculate the most effective management technique. The following possible remedial measures of saline water are suggested:

1. Maintaining a high basin water level.
2. Creating a freshwater bubble in a saline aquifer.
3. Constructing a pumping trough or an extraction barrier trough.
4. Construction of artificial subsurface barriers.
5. Using rainwater harvesting technology and artificial recharging structures.

The most efficient designs and implementation of measures for control of groundwater salinity are very much dependent on the local context. Among the hydraulic measures to be considered are the optimization of the pattern and intensity of groundwater abstractions and the development of hydraulic barriers with injected water to reduce and check further saline water intrusions. Furthermore, strategic freshwater reserves, both surface and subsurface, are being created through rainwater harvesting and managed aquifer recharge (MAR), by combining surface and brackish water and by desalinizing inland brackish groundwater for drinking water. To develop optimal solutions for managing the groundwater salinity, specific information about the climate, topography, and hydrogeology of the region, the origin of groundwater salinity, available water resources, land use, etc., are required. Groundwater salinity management strategies can be generally placed in the three categories with the ultimate goal of preserving groundwater resources for current and future use (Bear 1979, 2004; Bear et al. 1999; ACASA 2011; Sharma and Kumar 2013): (1) scientific monitoring, assessment and modeling, (2) behavioral and institutional approaches, and (3) engineering measures.

52.5.1 Scientific Monitoring, Assessment and Modeling

Specific aquifer dynamics can vary with the locations; therefore, scientific monitoring and assessment are the critical steps toward effective saline water intrusion management by providing decision-makers an in-depth, localized understanding of their freshwater resources and enabling them to make sound and informed decisions.

Data collection and monitoring is very important for groundwater studies. These data types required for groundwater studies where saltwater intrusion plays a role relate to records of (1) well logs, geophysical surveys, and hydro-geological parameters, (2) climate data and natural recharge, (3) water levels (water table and piezometric levels, surface water levels, (4) groundwater quality (chemical and isotopic composition, particularly salinity, and sources of groundwater pollution), (5) surface water (natural outflow, availability, and quality of surface water for artificial recharge), (6) present and past abstractions of groundwater, present and past artificial recharge, (7) water demands, at present the time and estimates for the future uses. Observation-well networks to monitor groundwater levels and quality are essential for monitoring the saltwater freshwater interface, where the warning signals can be raised on detection of any intrusion of saltwater in subsurface. Such monitoring and assessment contributes to a thorough understanding of existing conditions in these aquifers and constitutes a necessary step for comprehending human impact on water and ecological resources. Modeling is a numerical way of conceptualizing the physical processes by which groundwater flow and solute transport occur in the groundwater system. Modeling helps identify the different factors such as recharge the groundwater that influence groundwater movement.

52.5.2 Behavioral and Institutional Approaches

Behavioral and institutional approaches are aimed toward ensuring sustained water quality and quantity over the long term by taking care of water supply and demand management, usage of fresh and saline blended water using institutional instruments, raising salt-tolerant crops, implementation of suitable policy, and plan development.

52.5.3 Engineering Measures

These aquifer management strategies consist of use of various engineering measures which can be employed to prevent salt water intrusion and also as control measures in those places where groundwater withdrawals in fresh water aquifers have caused water levels in the aquifers to fall significantly below the water table. These techniques can be used in assuring control of groundwater exploitation. After salinity assessment, the suitable management and remedial measures such as aquifer storage and recovery (ASR) or managed aquifer recharge (MAR), groundwater abstraction optimization, raising salt-tolerant species, diversion of saline water to evaporation basins, developing habitats for halophiles, use for health and wellness (thermos mineralized groundwater), and salt production can be suggested. Some of the engineered techniques include the construction of barriers/impermeable screens to prevent salt movement, reducing waterlogging-induced salinization by raising groundwater level depth or increasing discharge or lowering water consumption,

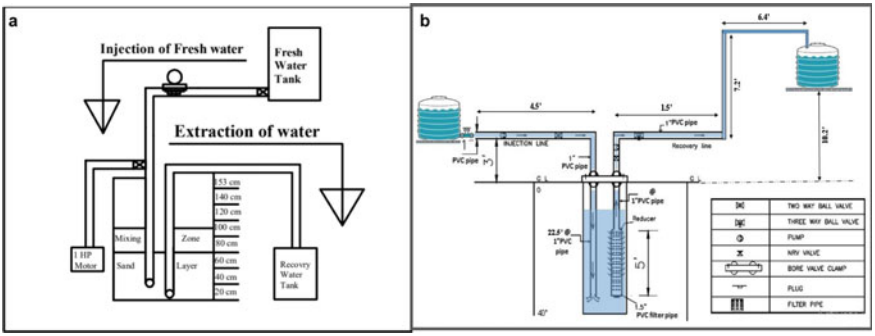

Fig. 52.2 Aquifer storage and recovery experiment setup **a** controlled conditions, **b** field conditions

lowering evaporation rates, drainage (subsoil drains, ditches, lowering of water levels in surface water bodies), or biological drainage by planting large plants such as eucalyptus and acacia. Desalination of saline water through phase-change membrane processes is another technique that could be used. The techniques for controlling by recharging and management/land reclamation can also be practiced as suitable measures. One of the most important options is the conjunctive use of surface water and groundwater such as aquifer storage and recovery (ASR) and is being discussed here.

52.5.3.1 Aquifer Storage and Recovery Experiment

Experiments on aquifer storage and recovery (ASR) were set up in the controlled and field conditions under World Bank funded, Mewat Purpose Driven Study (PDS) under National Hydrology Project with an aim to develop a freshwater bubble in the saline water (Fig. 52.2). The first part of the experiment was conducted in an experimental model fabricated at National Institute of Hydrology, Roorkee. In the experiment, freshwater bubble was developed, and 63% of the freshwater with EC $< 1000\ \mu S\ cm^{-1}$ after 29 h of experiment was recovered from saline water (Kaushal et al. 2020). After this, the same experiment was conducted under field conditions where an ASR well was developed at a depth of 40 feet in Karhera area of district Mewat. Freshwater was injected into saline aquifer with the help of inlet tank, and simultaneously a recovery pipe line was connected to the outlet tank. At different time periods, freshwater with EC ~ $1000\ \mu S\ cm^{-1}$ was recovered from the saline aquifer with EC $> 20{,}000\ \mu S\ cm^{-1}$ with the recovery efficiency rates varying from 40 to 60%. Retention time was increased from hours to days. ASR is a useful technique which can be used in saline aquifers of coastal as well as inland aquifers to get the water during the lean period.

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References

ACASA (2011) Saltwater intrusion and climate change. Atlantic Climate Adaptation Solutions Association, Prince Edward Island Department of Environment, Labour and Justice, Charlottetown, Canada

Bear J (1979) Hydraulics of groundwater, McGraw-Hill International Book Co

Bear J (2004) Management of a coastal aquifer (editorial). Ground Water 42:316–317

Bear J, Cheng AHD, Sorek S et al (1999). Seawater intrusion in coastal aquifers: concepts, methods and practices. Kluwer, Dordrecht

CWC (2020) Guidelines for preparation of detailed project report (DPR) for salinity ingress management projects in coastal areas. Coastal Management Directorate, New Delhi

CGWB (2007) Manual on artificial recharge of ground water. Central Ground Water Board, Ministry of Jal Shakti, Department of Water Resources, River Development and Ganga Rejuvenation, GoI, New Delhi

CGWB (2019) Groundwater year book. Central Ground Water Board, Ministry of Jal Shakti, Department of Water Resources, River Development and Ganga Rejuvenation, GoI, New Delhi

Dasgupta R, Hashimoto S, Okuro T et al (2019) Scenario-based land change modelling in the Indian Sundarban delta: an exploratory analysis of plausible alternative regional futures. Sustain Sci 14(1):221–240

Kibria AS, Costanza R, Groves C et al (2019) Does higher access ensure greater wellbeing?-In the perspective of forest ecosystem services of the Sundarbans mangrove forest, Bangladesh. Ocean Coast Manage 177:22–30

Kaushal AA, Krishan G, Pandey G (2020) Recovery efficiency of an aquifer storage and recovery (ASR) experiment from saline aquifer under controlled conditions. Curr World Environ 15(3):441–445

Krishan G (2019) Groundwater salinity. Curr World Environ 14(2):186–188

Krishan G, Ghosh NC, Kumar CP et al (2020) Understanding stable isotope systematics of salinity affected groundwater in Mewat, Haryana, India. J Earth Syst Sci 129:109. https://doi.org/10.1007/s12040-020-1380-6

Krishan G, Prasad G, Anjali K et al (2021a) Identifying the seasonal variability in source of groundwater salinization using deuterium excess—A case study from Mewat, Haryana, India. J Hydrol Reg Stud 31:100724. https://doi.org/10.1016/j.ejrh.2020.100724

Krishan G, Vashisth R, Sudersan N et al (2021b) Groundwater salinity and isotope characterization: a case study from south-west Punjab, India. Environl Earth Sci 80:169. https://doi.org/10.1007/s12665-021-09419-7

Krishan G, Sejwal P, Bhagwat A et al (2021c) Role of ion chemistry and hydro-geochemical processes in aquifer salinization—A case study from a semi-arid region of Haryana, India. Water 13(5):617. https://doi.org/10.3390/w13050617

Krishan G, Sudersan N, Sidhu BS et al (2021d) Impact of lockdown due to COVID 19 pandemic on groundwater salinity in Punjab, India: some hydrogeoethics issues. Sustain Water Resour Manag 7:27. https://doi.org/10.1007/s40899-021-00510-2

Krishan G, Kumar B, Sudarsan N et al (2021e) Isotopes (δ18O, δD and 3H) variations in groundwater with emphasis on salinization in the State of Punjab, India. Sci Total Environ 789:148051. https://doi.org/10.1016/j.scitotenv.2021.148051

National Institute of Hydrology, Roorkee (2020). Improving our understanding aquifer systems of Sunderban. Report on the Pump Priming Project sponsored by The India-UK Water Centre; Centre for Ecology & Hydrology, Wallingford and Indian Institute of Tropical Meteorology, Pune. http://nihroorkee.gov.in/sites/default/files/Final_Report.pdf

Sharma A, Kumar CP (2013) Coastal aquifer management including use of hydraulic barriers for control of seawater ingress. In: Base Paper submitted to DoWR,RD&GR, GoI

Chapter 53
Importance of Monitoring by Application of GALDIT Method for the Sustainable Management of Salinity in the Coastal Aquifers of the Bengal Basin, Bangladesh

Anwar Zahid, M. Muhyminul Islam, and Ibrahim Rashiq Shams

Abstract The coastal population of Bangladesh has already been suffering from the salinity encroachment both in groundwater and surface water regime. Reduced river discharge, coastal surges, shrimp farming and lowering of groundwater table due to dry season irrigation in a large part of the country accelerate the rate of saline water distribution. In addition, sea level rise, due to the impact of climate change, may contribute to salinity encroachment on coastal freshwater resources, particularly in the shallow alluvial aquifers. The obvious pressure, therefore, is transferred to deeper aquifer. For the last decades, this deep aquifers are exploited in the coastal parts and therefore facing vulnerability to multiple contamination. Problems are also due to unplanned development and management, wasteful use and inadequate governance actions. To sustain groundwater use in stressed aquifers, interventions need to be developed. In the present study, the GALDIT index methodology was applied to the coastal alluvial aquifers of southern Bengal Basin, Bangladesh to assess the magnitude and extent of vulnerability of these aquifers to seawater encroachment. The GALDIT method shows that the coastal aquifer is highly susceptible to seawater intrusion, which is coherent with the characteristics of the aquifer. This method would help the decision-makers towards sustainable development and management of the limited fresh water resources by identifying the vulnerable zones and protect the aquifers from further degradation in the coastal region of Bangladesh.

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Keywords Groundwater · Salinity distribution · Aquifer vulnerability · GALDIT · Sustainable management

53.1 Introduction

Increased anthropogenic activities related to household, agriculture, tourism and industry led to raise the demand for freshwater in many folds in the coastal areas of Bangladesh in the recent years. Besides, urban development limits the rainfall recharge whereas sea level rise pose a continuous threat of increased seawater intrusion into the coastal aquifers of the Southern Bengal Basin, Bangladesh (Ayers et al. 2016; Vengadesan and Lakshmanan 2018). Thus, dependence as well as the possibility of contamination of groundwater by seawater due to overexploitation has increased in this area (Shamsudduha et al. 2011; Fatema et al. 2018; Zahid et al. 2018). Globally, this is also the key problem in most of the coastal parts (Pedreira et al. 2015; Bouderbala et al. 2016; Gnanachandrasamy et al. 2019). Along with seawater intrusion, the coastal aquifers are vulnerable to multiple contaminations which indicate the sensitivity of the groundwater quality to any contaminant (Lobo-Ferreira et al., 2003). The intrinsic properties of the aquifer that controls this characteristics are subject to change with change of natural and anthropogenic factors or activities. Therefore, identification of the vulnerable aquifers and assessment of their nature and extent is necessary for the sustainable coastal groundwater management.

Bangladesh is an agrarian country, and agriculture is the single largest user of ground water. With the introduction of high-yielding *Boro* rice variety in 1970, groundwater-fed irrigation became popular in the country (Shamsudduha et al. 2011). Over the country 90% of the total abstracted groundwater is used for irrigation and the rest is used for domestic and industrial purposes. Government or privately owned shallow wells installed within <150 m below sea level (bsl) provides groundwater to these sectors. It is estimated that, about 98% of drinking and 80% of dry season irrigation water demand is fulfilled by groundwater withdrawn from shallow aquifers (<150 m bsl) (Shamsudduha et al. 2019). However, these wells are widely affected by arsenic contamination (46% of the wells exceed the World Health Organization guideline value of 10 $\mu g\ L^{-1}$) and in the coastal parts largely by the invasion of sea water. Hence, there are pressures for abstracting groundwater from deeper aquifers (>150 m bsl) as a safer and cost-effective source of freshwater for irrigation and drinking water supply (Burgess et al. 2010; Shamsudduha et al. 2018).

In the southern coastal belt, though the groundwater quality is controlled by multiple stressors, the seawater intrusion poses the major threat above all (Bahar and Reza 2010; Ayers et al. 2016). The occurrence of brackish and saline water in the coastal aquifers of Bangladesh does not follow any regular pattern spatially or vertically (Naus et al. 2019b; Zahid et al. 2016). It was studied that even a mixing of 1% of seawater (containing 250 mgl^{-1} chloride) to the freshwater aquifers can degrade the portability of the freshwater (Werner et al. 2013). The upper aquifer units occurring within 150 m bsl of the coastal region are mostly brackish to saline and do not produce safe drinking water. However, the leaky to confined main and deep aquifer units that appears mostly below150 m bsl are considered as potential formation for limited scale groundwater abstraction in the coastal area of Bangladesh. Therefore, deep aquifer units of the southern Bengal Basin are selected for vulnerability assessment. This has been a subject of intensive research during the past years and a number of numerical or statistical methods, e.g. DRASTIC, SINTACS, PESTICIDE, GOD and AVI have been developed or applied to find specific vulnerable zones in different countries around the world (Bouderbala et al. 2016; Kardan Moghaddam et al. 2017; Gnanachandrasamy et al. 2019). Amongst the methods, GALDIT index is the most suitable and useful tool to predict and identify the coastal groundwater vulnerability zones highlighting seawater intrusion (Ferreira et al. 2007; Pedreira et al. 2015; Bouderbala et al. 2016; Trabelsi et al. 2016). The GALDIT index model incorporates multiple geo-environmental parameters that control the hydrodynamic processes related to direct or passive seawater intrusion in the coastal aquifers (Chachadi and Lobo-Ferreira 2001; Eminoglou et al. 2017). According to the hydrogeological conditions of an area, weights and rating of degree of vulnerability magnitude are assigned to these factors for the mapping and identification of potential vulnerable zones that are susceptible to contamination by seawater intrusion (Sophiya and Syed 2013; Eminoglou et al. 2017; Seenipandi et al. 2019). Therefore, in the present study, the GALDIT index methodology was applied to the coastal alluvial aquifers of southern Bengal Basin, Bangladesh to assess the magnitude and extent of vulnerability of these aquifers to seawater encroachment. This would help the decision-makers towards sustainable development and management of the limited fresh water resources by identifying the vulnerable zones and protect the aquifers from further degradation in the coastal region of Bangladesh.

53.2 Materials and Method

53.2.1 Study Area

The study area encompasses the southern part of Bengal Basin and comprises of 19 coastal districts, namely Bagerhat, Barguna, Barisal, Bhola, Chandpur, Chittagong, Cox's Bazar, Feni, Gopalganj, Jessore, Jhalokati, Khulna, Lakshmipur, Narail, Noakhali, Pirojpur, Satkhira and Shariatpurof Bangladesh (Fig. 53.1). This covers about 32% landmass of the country and lies between 21 23" N and 89 93" E. Ganges Tidal Floodplains and Ganges River Floodplains in the south-west, Meghna Estuarine Floodplains in the south-central and Chittagong Coastal Plains in the south-east of the Bengal Basin dominate the study area (Fig. 53.2). The flat deltaic lands in the coast are interlaced by an intricate river and tidal channel system which cuts the land into numerous areas. The narrow strip of the Chittagong Coastal Plains is characterized by piedmont plains adjoining hills and meander floodplains adjoining rivers (Brammer 2012). Elevation of this area ranges between 1.2 and 4.5 m above

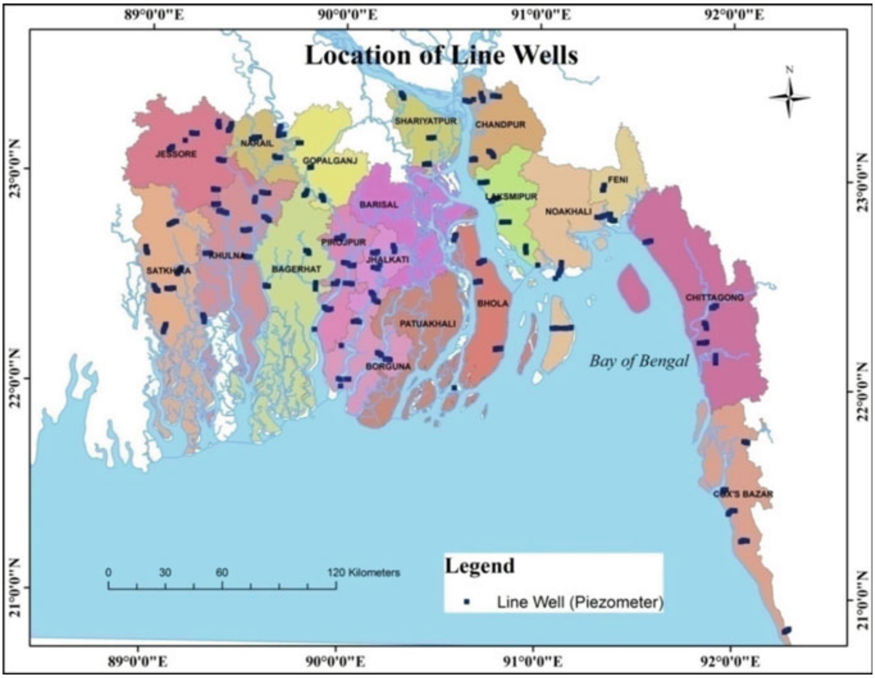

Fig. 53.1 Location of the study area

mean sea level and has a low lying feature with gentle slope from north to the south (Uddin et al. 2019).

The subtropical monsoon climatic environment characterized by varying amount of seasonal rainfall, moderate warm temperature and high humidity prevails in the study area. The average annual rainfall ranges between 2000 and 3000 mm in the coast and more than 71% of it occurs in the monsoon (June to September) over the Bengal Basin (Hossain et al. 2014; Khatun et al. 2016; Sarker et al. 2018). Variability in the onset and other characteristics of the monsoon highly influences the water resources, livelihoods and ecosystems of the coastal Bangladesh (Khatun et al. 2016).

Due to its geographical position, the coastal part of the Bengal Basin is known as zone of vulnerabilities. Natural disasters like cyclone, storm surge and flood are prevalent in the study area. Anthropogenic activities like agriculture, aquaculture, harbour, etc., are also prominent in the coastal districts of Bangladesh. Both of such natural and man-made activities/ events directly influence the quality and quantity of the water resources of this region.

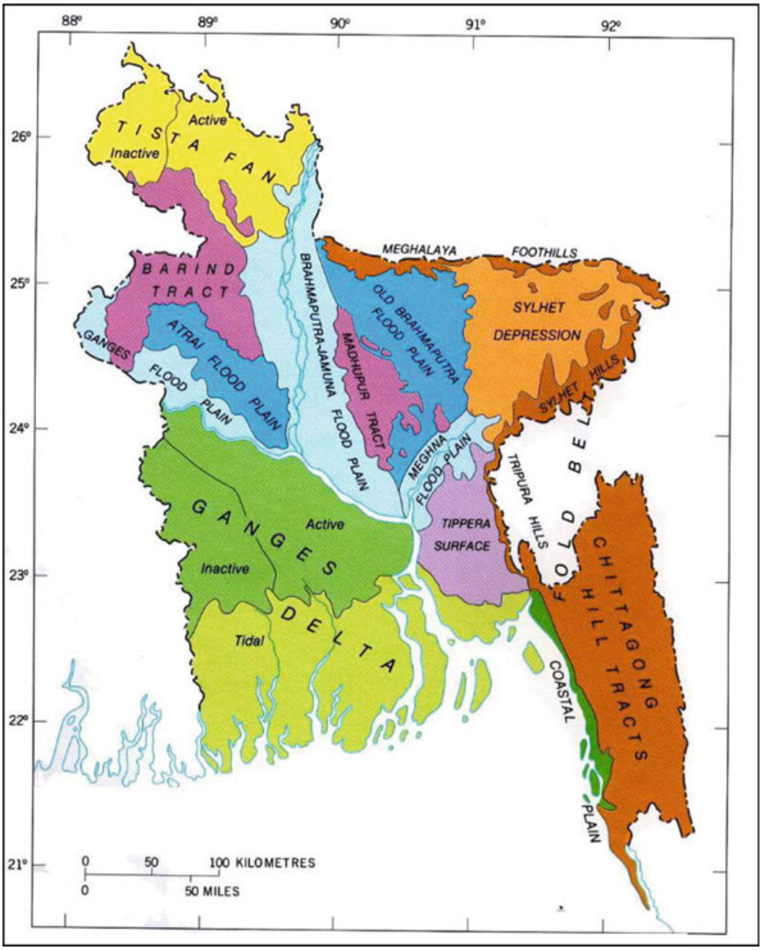

Fig. 53.2 Physiographic map of Bangladesh (Alam et al. 1990)

53.2.2 Hydrogeology

The mainland coast of the Bengal Basin occupies the Holocene coastal plain deposit. The tidal deltaic sediment and marshy peat overlying by thick silty clay deposits covers this coastal plain. During the late quaternary period, the unconsolidated sand, silt and clay carried and deposited by the Ganges-Brahmaputra-Meghna (GBM) River system developed this region (Goodbred and Kuehl 2000; Islam et al. 2020). The deposition of these sediments has produced a variable and multilayered aquifer system in the coastal region of Bangladesh (Ravenscroft et al. 2013; Zahid et al. 2018). Alteration of aquifer-aquitard is highly variable within a very short distance of this region, and the appearance of clay or silty clay aquitards is discontinuous till to depth of 350 m. Therefore, the aquifers occurring down to the depth of 350 m are likely to be hydraulically connected in places despite the impact of mechanical loading and are in threat of possible contamination by natural or anthropogenic influence (Zahid et al. 2018). Considering the groundwater investigation and hydrogeological research by different studies, the coastal aquifer system of the Bengal Basin is generally categorized into three major aquifer systems and is published elsewhere (BWDB-UNDP 1982; Ravenscroft and McArthur 2004; Naus et al. 2019a).

In the present study, the multilayer aquifer system of the coastal Bengal Basin is identified as below: The first aquifer is the upper Holocene aquifer. Locally, this is known as the shallow aquifer and appears at a depth of 50 m to more than 100 m in places. Fine to very fine sand with presence of clay lenses composes this aquifer in this coastal region (Ayers et al. 2016; Zahid et al. 2018). In places, a considerable thick layer of silt or clay overlies this aquifer (Zahid et al. 2018). However, groundwater of this aquifer in the coastal parts is mostly saline with occasional fresh water pockets (Ayers et al. 2016; Hoque et al. 2017). The second aquifer is the mid-Holocene aquifer (lower shallow aquifer) and extends down to depth of 250 to 350 m. This water-bearing zone is composed of fine to very fine sand and is generally underlain and overlain by silty clay layers (Zahid et al. 2018; Islam et al. 2020). This serves as the main aquifer to the most of the coastal communities of Bengal Basin. It is either semi-confined to leaky in nature or consists of stratified interconnected, water-bearing formations (Zahid et al. 2018). The third one is the deep aquifer and is Late Pleistocene-early Holocene type aquifer. In the coastal belt, for potable water supply, deep aquifers are exploited to depth of 300–350 m. This has become the main source of municipal and industrial water supply in this coastal region with the increased use of motorized deep tube well (Ravenscroft et al. 2018). Grey to dark grey fine sand interceded by occasional silty clay or clay lenses composes this aquifer. Generally, a clay or silty clay aquitard overlies this aquifer which is very insignificant in some places of the coastal region of Bangladesh till to the depth of 350 m (Zahid et al. 2018).

53.2.3 Hydrochemistry: Scenario of Salinity Hazard

Salinity is the major constraint in the investigated aquifers of the southern coastal areas of Bangladesh. All the different depth levels of aquifer system down to the investigated depths of 350 m have been affected by salinity in many areas (Zahid et al. 2013). Groundwater chloride concentrations at different depth levels of coastal aquifers show that salinity ($Cl > 600$ mg l^{-1}) occurs in the shallow aquifers of Shariatpur, Chandpur, Feni, Laksmipur, Noakhali, Cox's Bazar, Barguna, Barishal, Bhola, Pirojpur, Gopalganj and Jhalokathi district areas. Fresh water occurs in the main aquifers of Chandpur, Feni, Laksmipur, Cox's Bazar, Barguna, Patuakhali, Barishal, Bhola, Satkhira and Jessore district areas. In the deep aquifer, fresh water occurs in Chandpur, Feni, Laksmipur, Chittagong, Cox's Bazar, Barguna, Patuakhali, Barishal, Bhola, Satkhira, Jessore and Narail districts. However, salinity affects the aquifers of Shariatpur, Barguna, Gopalganj, Khulna and Cox's Bazar district.

Groundwater chloride values vary from 9 to 13,000 and 11.5 to 13,800 mg l^{-1} in dry and wet seasons, respectively, in the 1st aquifer or shallow aquifer. The maximum chloride value of dry and wet seasons was measured 13,000 and 13,800 mg l^{-1}, respectively, at Patharghata, Barguna. In the 2nd aquifer, it ranges from 92.5 to 11,200 mg l^{-1} in dry season and in wet season 33 to 10,200 mgl^{-1}. Maximum chloride values of dry season and wet season were detected 11,190 and 10,230 mg l^{-1} at Patharghata. The deep or 3rd aquifer shows groundwater chloride values between 69 and 11,100 mg l^{-1} in dry season and 21.5 and 3100 mg l^{-1} in wet season. Maximum chloride value of 11,100 mg l^{-1} was observed in dry season at Kalapara, Patuakhali, and maximum value of 3100 mg l^{-1} was observed in wet season at Bhandaria, Pirojpur.

53.2.4 Methodology

For the evaluation of the proposed sites, hydrogeological, morphological and hydrochemical characteristics have been analyzed. The current status of the aquifer systems under investigation is then evaluated using these relevant parameters that are rated and weighted according to their importance. To calculate the index knowledge using GALDIT method, six different parameters are required which are (1) groundwater occurrence (G): In natural aquifer groundwater-bearing layers may be confined, unconfined, semi-confined and/or leaky confined. In natural condition, unconfined and semi-confined aquifers are more prone to seawater intrusion than the other aquifer types; (2) aquifer hydraulic conductivity (A): This parameter indicates how easy water can flow through the pore spaces of the aquifers; (3) depth to groundwater level (L): This is a very important parameter as it determines the hydraulic pressure to encroach the saltwater; (4) distance from shore (D): The impact of seawater intrusion decreases with increasing distance from the shore; (5) impact of the existing status of seawater intrusion (I): This can be determined based on the measured electric conductivity or salinity (ppt) level and (6) thickness of the aquifer (T): This parameter plays an essential role to store water as well as in preventing intrusion of saltwater into an aquifer (Chachadi and Lobo-Ferreira 2001; Santha Sophiya and Syed 2013; Trabelsi et al. 2016). Project generated, but limited, data have been used for this assessment.

The G, A, D and T parameters are static and usually do not change much over time whereas the depth to groundwater and saline water encroachment may significantly fluctuate, influencing the hydraulic regime in the region. The most important factors have weights of 4 whereas a weight of 1 is assigned to the less important factors related to seawater intrusion and aquifer potential. Parameters and their weight used for this study are listed in Table 53.1.

The GALDIT vulnerability index (GVI) is calculated by multiplying the rating of each parameter by its relative weight and finally by summing up all weights based

Table 53.1 GALDIT parameters used in the study and their ranks based on the range (modified from Chachadi and Lobo-Ferreira 2001)

G: Groundwater occurrence		A: Aquifer hydraulic conductivity (m day^{-1})		L: Height/elevation (m) of groundwater level (asl)	
Aquifer type	Ranking	Range	Ranking	Range	Ranking
Unconfined	10	>10	10	<2	10
Semi-confined	7.5	8.1–10	7.5	2.1–4	7.5
Leaky confined	5.0	6.1–8	5	4.1–6	5
Confined	2.5	<6	2.5	>6.1	2.5
D: Distance from the shore (km)		I: Impact of existing status of seawater intrusion ($ClHCO_3^{-1}$)		T: Thickness of the aquifer (m)	
Range	Ranking	Range	Ranking	Range	Ranking
<1	10	>2.1	10	>80	10
1.1–5	7.5	1.6–2.0	7.5	60.1–80	7.5
5.1–10	5.0	1.1–1.5	5.0	40.1–60	5
>10.1	2.5	<1.0	2.5	<40	2.5

on the following equation (Lobo-Ferreira et al. 2007; Chachadi and Lobo-Ferreira 2001).

$$\text{GALDIT Index} = \sum_{i=1}^{6}(W_i)R_i \Big/ \sum_{i=1}^{6}(W_i) = (2 \times G + 3 \times A + 3 \times L + 4 \times D + 2 \times I + 1 \times T)/15 \quad (53.1)$$

where W_i is the weight of the i-th indicator and R_i is the significance rating of the i-th indictor. G, A, L, D, I and T are the rating factors of the parameters in the GALDIT index method. The numerical values are the weights that are set for these six indicators.

The GALDIT vulnerability index usually provides a relative assessment of the area and the higher the index, the greater the seawater intrusion vulnerability of the coastal aquifers of interest. Computed results are then evaluated based on vulnerability index classes (Table 53.2) (Chachadi and Lobo-Ferreira 2001; Ferreira et al. 2007). The GALDIT parameters for the investigated wells are listed in Table 53.3. The ranking of sites according to their suitability potential is shown in Table 53.4.

Table 53.2 Index of vulnerability to seawater intrusion

GALDIT vulnerability index (GVI) Range	Vulnerability class
>7.5	Highly vulnerable
6.1–7.5	Moderately high vulnerable
5–6	Moderately vulnerable
<5	Low vulnerable

53.3 Results and Discussion

53.3.1 Results of the Study

The coastal area of Bangladesh covers an area of 47,201 km^2 and contains the longest, i.e., 710 km of coastline in the world (Ahmad 2019). The alluvial aquifers occurring in the coastal belts are facing over exploitation due to unplanned aquifer development and management process (Zahid et al. 2008; Shamsudduha et al. 2011, 2018). Mainly, three major types of aquifers generate at different depths in the coastal parts of the Bengal Basin (Zahid et al. 2008; Islam et al. 2019b). The unconfined shallow aquifers get recharged by direct infiltration, and the recharge zone of the deep aquifers is elsewhere in the GBM basin (Rahman et al. 2011; Shamsudduha et al. 2011; Sarker et al. 2018). Regionally, the groundwater flow follows a general direction from north to the south following the local topography (Sarker et al. 2018). In the eastern coastal plain, where the local topography is influenced by the presence of Neogene, low hill ranges the regional groundwater flows from east or northeast to west and south-west (Fatema et al. 2018). In this study, the aquifer characteristics of the study area were carried out by examining exploratory data of 33 wells. Six GALDIT index parameters related to properties, lithology, hydrology and hydrochemistry of the aquifer were studied to determine the vulnerability of the coastal aquifers to sea water intrusion (Table 53.3). Acquired data were then combined into the GALDIT equation that the shows vulnerability class (Table 53.4) of the studied aquifers.

Groundwater occurrence (G) manifests the aquifer characteristic or type of the study area. Unconsolidated deltaic deposits of silt, silty clay, fine and very fine sand dominate the alluvial aquifer system of the coastal Bangladesh. Clay or silty clay layers of variable thickness act as the aquitards that separate the aquifers into multiple aquifer system (Figs. 53.3, 53.4 and 53.5). However, as the aquitards do not appear continuously over the region, it gives the underlying 2nd or 3rd aquifers a semi-confined to confined (leaky) character (Sarker et al. 2018; Zahid et al. 2018; Islam et al. 2019b). In Cox's Bazar of the Chittagong Coastal Plain, mostly the sandy aquifers (fine to coarse sands) interceded by silt or clay are predominant and are assumed to be hydraulically connected as examined in different studies (Fatema et al. 2018). The confined parts do not occur continuously and exist dispersedly in all of tidal, estuarine or coastal plain parts of the Bengal Basin. According to the

Table 53.3 GALDIT parameters of investigated sites used for vulnerability analysis

S. No.	Location: District (Upazila)	Groundwater occurrence (G): aquifer type (deep aquifer)	Aquifer hydraulic conductivity (A) in m day^{-1}	Height of groundwater level (L) (minimum) in m	Distance from the shore (D) in km	Impact of seawater intrusion (I) ($ClHCO_3^{-1}$)	Thickness of aquifer (T) in m
	Tidal delta						
1	Patharghata, Borguna	Confined	7.35	−0.68	5.0	11.45	30 (270–300)
2	BorgunaSadar	Confined	1.9	−7.8	20.0	0.07	30 (250–280)
3	Amtoli, Borguna	Confined (leaky)	6.02	−0.5	30.0	0.03	20+ (320–340+)
4	Kolapara, Patuakhali	Confined (leaky)	4.04	2.26	6.0	0.61	60 (210–270)
5	Galachipa, Patuakhali	Confined	7.35	−0.8	24.0	0.03	40+ (290–330+)
6	Dumki, Patuakhali	Confined (leaky)	5.45	−0.3	60.0	0.06	30 (290–320)
7	Shyamnagar, Satkhira	Confined (leaky)	2.22	−0.56	46.0	2.43	30 (170–200)
8	Khulna Sadar	Confined (leaky)	7.35	−4.0	92.0	3.09	120 (150–270)
9	Rupsha, Khulna	Semi-confined	7.35	−1.4	91.0	6.28	200 (80–280)
10	Bagerhat Sadar	Confined (leaky)	7.35	0.1	76.0	1.39	80 (220–300)
11	Bhandaria, Pirojpur	Confined (leaky)	7.35	−1.16	50.0	16.37	60 (280–340)
12	Jhalokathi Sadar	Confined	7.35	−1.3	86.0	0.21	90+ (250–340+)
13	Barisal Sadar	Confined (leaky)	7.35	−4.1	45.0	0.87	40 (240–280)
14	Lalmohon, Bhola	Confined	4.04	−1.22	10.0	0.58	35 (265–300)

(continued)

Table 53.3 (continued)

S. No.	Location: District (Upazila)	Groundwater occurrence (G): aquifer type (deep aquifer)	Aquifer hydraulic conductivity (A) in m day^{-1}	Height of groundwater level (L) (minimum) in m	Distance from the shore (D) in km	Impact of seawater intrusion (I) ($ClHCO_3^{-1}$)	Thickness of aquifer (T) in m
15	Laksmipur Sadar	Confined (leaky)	9.92	2.3	25.0	0.20	40 (270–310)
	Inactive delta						
16	Bagharpara, Jashore	Unconfined	7.35	−1.33	140.0	0.65	320 (0–320)
17	Keshobpur, Jashore	Confined	0.37	−1.5	105.0	0.09	20 (280–300)
18	Narail Sadar	Confined	7.4	−1.3	128.0	0.90	75 (235–310)
	Active delta						
19	Moksedpur, Gopalganj	Confined	9.9	1.07	135.0	1.52	170+ (150–320+)
20	Muladi, Barisal	Confined	7.4	0.2	45.0	1.93	30+ (290–320+)
21	Naria, Shariatpur	Confined (leaky)	9.9		70.0	1.90	90 (210–300)
22	N. Matlab, Chandpur	Confined (leaky)	0.67	0.1	104.0	2.10	90+ (230–320+)
23	Sandwip, Chattogram	Confined (leaky)	3.0	2.4	4.0	0.83	40 (250–290)
	Tippera surface						
24	Kachua, Chandpur	Confined	3.0	−2.72	88.0	1.14	30 (310–340)
25	Shahrasti, Chandpur	Semi-confined	3.0	−3.0	60.0	1.99	315+ (05–320+)
26	Kabirhat, Noakhali	Confined (leaky)	2.0	1.5	18.0	1.42	40 (250–290)

(continued)

Table 53.3 (continued)

S. No.	Location: District (Upazila)	Groundwater occurrence (G): aquifer type (deep aquifer)	Aquifer hydraulic conductivity (A) in m day^{-1}	Height of groundwater level (L) (minimum) in m	Distance from the shore (D) in km	Impact of seawater intrusion (I) ($ClHCO_3^{-1}$)	Thickness of aquifer (T) in m
27	Laskarhat, Feni	Confined (leaky)	3.0	3.8	22.0	0.11	30 (230–260)
	Coastal plain						
28	Sitakundo, Chattogram	Confined (leaky)	0.44	−2.51	3.0	0.23	90 (170–260)
29	Bohoddarhat, Chattogram	Confined (leaky)	7.56	−10.7	4.0	0.25	50 (220–270)
30	Anowara, Chattogram	Confined	1.65	1.46	3.0	0.27	15 (285–300)
31	Chokoria, Cox's Bazar	Confined (leaky)	Artesian	3.15+	14.0	0.20	80 (220–300)
32	Ramu, Cox's Bazar	Confined (leaky)	Artesian	2.32+	16.0	0.17	5 (280–285)
33	Cox's Bazar Sadar	Semi-confined	3.06	−2.5	1.0	0.28	90 (110–200)

Table 53.4 Vulnerability ranking/class of investigated sites using GALDIT method

S. No.	Location: District (Upazila)	Groundwater occurrence (G)	Aquifer hydraulic conductivity (A)	Height of groundwater level (L)	Distance from the shore (D)	Impact of seawater intrusion (I)	Thickness of aquifer (T)	GALDIT vulnerability index (GVI)	Vulnerability class	Rank
	Tidal delta									
1	Patharghata, Borguna	2.5	5.0	10.0	7.5	10.0	2.5	6.8	Moderately high	
2	Borguna Sadar	2.5	2.5	10.0	2.5	2.5	2.5	4.0	Low	
3	Amtoli, Borguna	5.0	5.0	10.0	2.5	2.5	2.5	4.8	Moderate	
4	Kolapara, Patuakhali	5.0	2.5	7.5	5.0	2.5	5.0	4.7	Low	
5	Galachipa, Patuakhali	2.5	5.0	10.0	2.5	2.5	5.0	4.7	Low	
6	Dumki, Patuakhali	5.0	2.5	10.0	2.5	2.5	2.5	4.3	Low	
7	Shyamnagar, Satkhira	5.0	2.5	10.0	2.5	10.0	2.5	5.3	Moderate	
8	Khulna Sadar	5.0	5.0	10.0	2.5	10.0	10.0	6.3	Moderately high	
9	Rupsha, Khulna	7.5	5.0	10.0	2.5	10.0	10.0	6.7	Moderately high	
10	Bagerhat Sadar	5.0	5.0	10.0	2.5	5.0	7.5	5.5	Moderate	
11	Bhandaria, Pirojpur	5.0	5.0	10.0	2.5	10.0	5.0	6.0	Moderate	

(continued)

Table 53.4 (continued)

S. No.	Location: District (Upazila)	Groundwater occurrence (G)	Aquifer hydraulic conductivity (A)	Height of groundwater level (L)	Distance from the shore (D)	Impact of seawater intrusion (I)	Thickness of aquifer (T)	GALDIT vulnerability index (GVI)	Vulnerability class	Rank
12	Jhalokathi Sadar	2.5	5.0	10.0	2.5	2.5	10.0	5.0	Moderate	
13	Barisal Sadar	5.0	5.0	10.0	2.5	2.5	2.5	4.8	Low	
14	Lalmohon, Bhola	2.5	2.5	10.0	5.0	2.5	2.5	4.7	Low	
15	Laksmipur Sadar	5.0	7.5	7.5	2.5	2.5	2.5	4.8	Low	
	Inactive delta									
16	Bagharpara, Jashore	10.0	5.0	10.0	2.5	2.5	10.0	6.0	Moderate	
17	Keshobpur, Jashore	2.5	2.5	10.0	2.5	2.5	2.5	4.0	Low	
18	Narail Sadar	2.5	5.0	10.0	2.5	2.5	7.5	4.8	Low	
	Active delta									
19	Moksedpur, Gopalganj	2.5	7.5	10.0	2.5	5.0	10.0	5.8	Moderate	
20	Muladi, Barisal	2.5	5.0	10.0	2.5	7.5	2.5	5.2	Moderate	
21	Naria, Shariatpur	5.0	7.5	10.0	2.5	7.5	10.0	6.5	Moderately high	

(continued)

Table 53.4 (continued)

S. No.	Location: District (Upazila)	Groundwater occurrence (G)	Aquifer hydraulic conductivity (A)	Height of groundwater level (L)	Distance from the shore (D)	Impact of seawater intrusion (I)	Thickness of aquifer (T)	GALDIT vulnerability index (GVI)	Vulnerability class	Rank
22	N. Matlab, Chandpur	5.0	2.5	10.0	2.5	10.0	10.0	5.8	Moderate	
23	Sandwip, Chattogram	5.0	2.5	7.5	7.5	2.5	2.5	5.2	Moderate	
	Tippera surface									
24	Kachua, Chandpur	2.5	2.5	10.0	2.5	5.0	2.5	4.3	Low	
25	Shahrasti, Chandpur	7.5	2.5	10.0	2.5	7.5	10.0	5.8	Moderate	
26	Kabirhat, Noakhali	5.0	2.5	10.0	2.5	5.0	2.5	4.7	Low	
27	Laskarhat, Feni	5.0	2.5	7.5	2.5	2.5	2.5	3.8	Low	
	Coastal plain									
28	Sitakundo, Chattogram	5.0	2.5	10.0	7.5	2.5	10.0	6.2	Moderately high	
29	Bohoddarhat, Chattogram	5.0	5.0	10.0	7.5	2.5	5.0	6.3	Moderately high	
30	Anowara, Chattogram	2.5	2.5	10.0	7.5	2.5	2.5	5.3	Moderate	
31	Chokoria, Cox's Bazar	5.0	2.5	7.5	2.5	2.5	7.5	4.2	Low	

(continued)

Table 53.4 (continued)

S. No.	Location: District (Upazila)	Groundwater occurrence (G)	Aquifer hydraulic conductivity (A)	Height of groundwater level (L)	Distance from the shore (D)	Impact of seawater intrusion (I)	Thickness of aquifer (T)	GALDIT vulnerability index (GVI)	Vulnerability class	Rank
32	Ramu, Cox's Bazar	5.0	5.0	7.5	2.5	2.5	2.5	4.3	Low	
33	Cox's Bazar Sadar	7.5	2.5	10.0	10.0	2.5	10.0	7.2	Moderately high	

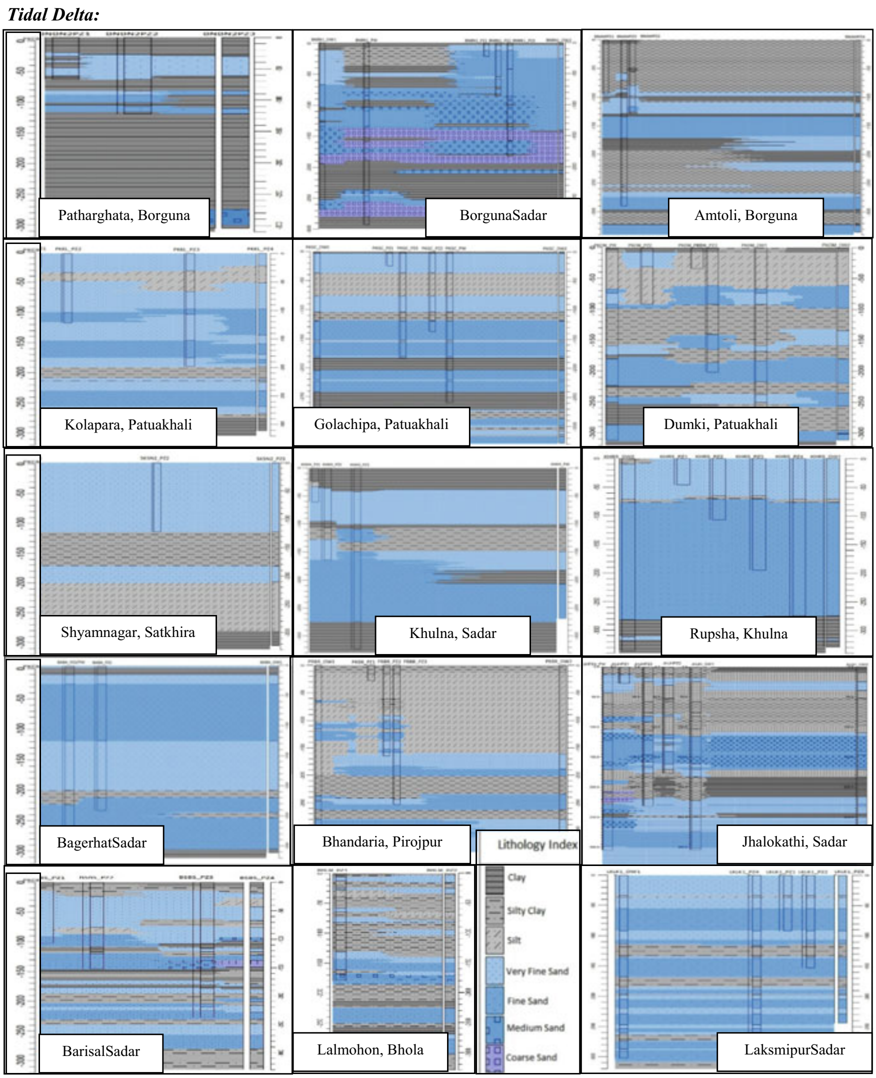

Fig. 53.3 Lithological cross-sections of aquifer sediments at tidal deltaic part of the Bengal Basin (Zahid et al. 2021)

GALDIT methodology, all the aquifers parameters are rated from 2.5 to 10 denoting the minimum to maximum vulnerability, respectively. As the regional coastal aquifers face overexploitation, this creates a large cone of depression around the impacted well and makes it more prone to seawater intrusion (Chachadi 2005). In the study area, the unconfined aquifers are heavily abstracted for irrigation and are overlain by very thin layer of silty clay aquitard. Instead, the confined aquifers occur generally below 150 m and are overlain by single or multiple layers of aquitards of variable

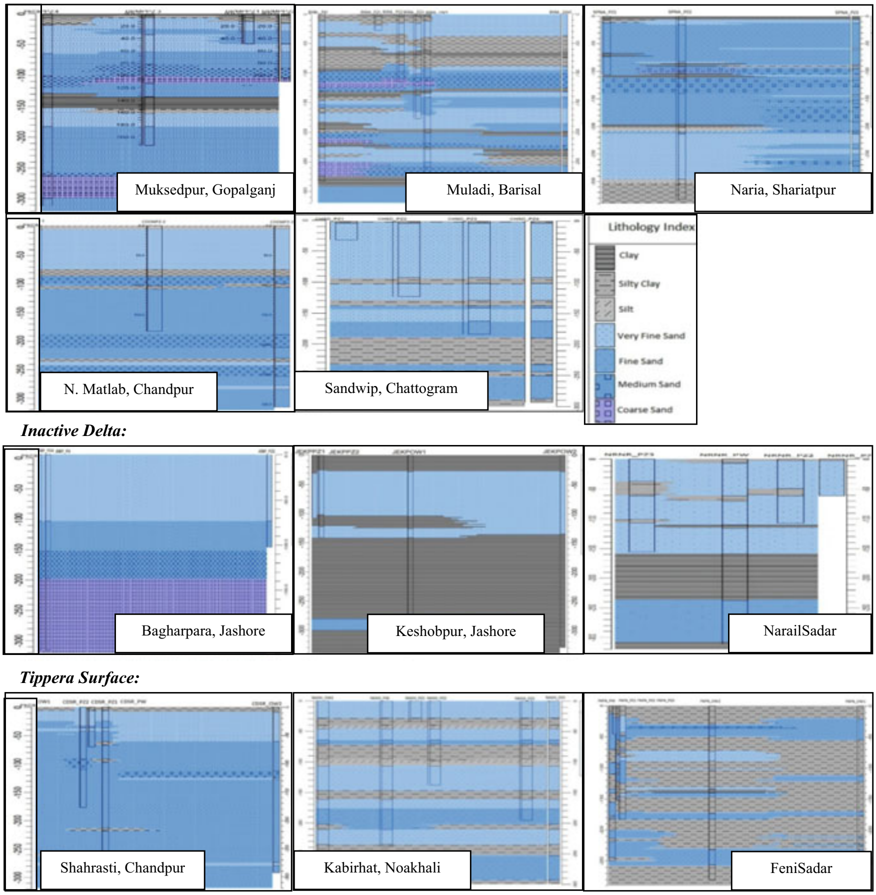

Fig. 53.4 Lithological cross-sections of the aquifer sediments at active, inactive deltaic part and Tippera surface of the Bengal Basin (Zahid et al. 2021)

thickness. Therefore, modifying the ranking values as suggested by Chachadi (2005), the investigated wells developed within the unconfined aquifer system of the studied coastal region are assigned with a rating value of 10 and confined aquifers are assigned with rating value of 2.5. However, amongst 33 wells from the study area, only 3 wells were found to be leaky confined in nature (Table 53.3) and hence the rating value for this type of aquifer is assigned as 7.5 whereas semi-confined and unconfined are attributed to 5 and 2.5, respectively (Table 53.4).

Hydraulic conductivity (HC) values estimated by conducting slug tests range up to 9.92 m/day in the main and the deep aquifers of the southern coastal Bangladesh (Table 53.3). Aquifers originating in the tidal, inactive and active deltas show higher values of hydraulic conductivity, whilst lower hydraulic conductivity values are observed in the main and deep aquifers of Tippera Surface and Chittagong Coastal Plains of the Bengal Basin. The reported maximum hydraulic conductivity of third

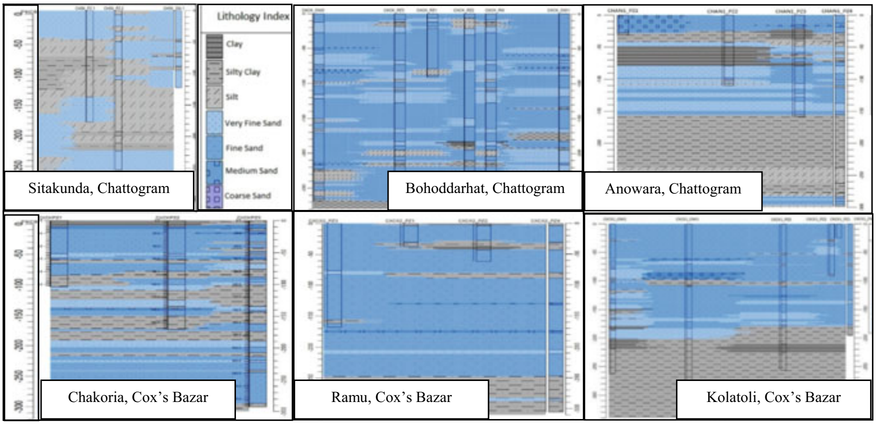

Fig. 53.5 Lithological cross-sections of the aquifer sediments at Chattogram-Cox's Bazar Coastal Plain of the Bengal Basin (Zahid et al. 2021)

aquifer is 9.92 m day^{-1} at Laskimur Sadar, and the minimum is 0.37 m day^{-1} at Keshobpur, Jessore of Tidal Delta. According to the Table 53.1, the hydraulic conductivity is classified into four classes and the recorded values are assigned to rating value ranging between 2.5 and 10 according to their observed classes (Table 53.4).

Height of groundwater level above mean sea level (msl) was calculated from 33 wells over the coastal region (Table 53.3). More than 60% of the investigated wells have a piezo metric level below the mean sea level where the local elevation ranges from1.2 to 4.5 m above msl. As such low height of the groundwater level indicates the impact of over exploitation and likelihood of additional pressure from the sweater to interfere the equilibrium interface lying between the fresh and saltwater (Ghyben 1889; Herzberg 1901; Chachadi 2005), the rating for the parameter L to the observed wells is assigned to 10 to refer the maximum vulnerability impact. Hence, the sampling well located in Bohoddarhat, Chattogram is rated as 10 in respect to the recoded groundwater level of −10.4 m bsl (Table 53.4). The maximum height was recorded in Feni of Tippera Surface, located in the upper part of the study area. The higher height gives the aquifer more hydraulic pressure to retreat the seawater coming inward, and therefore, the rating value is assigned to 2.5 to this well. Thus, all the wells are rated between 2.5 to 10 (Table 53.4) based on their height of groundwater level above mean sea level (msl) as per the GALDIT index method and are listed in Table 53.1.

According to the GALDIT index method, the maximum distance to the coast is set as 1000 m. However, the southern coastal parts of the Bengal Basin are crisscrossed by numerous tidal rivers and witness two cycles of tide (flood tide and ebb tide) everyday (Talchabhadel et al. 2017). The rivers are highly impacted by the inward encroachment of the seawater (Bhuiyan and Dutta 2012; Islam et al. 2016) and likely to affect the coastal aquifers by natural river bank infiltration process during the dry seasons (Hoque et al. 2014; Sarker et al. 2018). Therefore, in the present study, the parameter 'distance from the shore' has been modified from the GALDIT index method and classified into four 3 classes as 1, 1.1–5, 5.1–10 and >10 km (Table 53.3). Since, at the closest proximity to the coast the impact is high, rating for the parameter D is set between 2.5 to 10 representing the minimum and maximum impacts for the distance value of 10 km and 1 km, respectively. The calculated results are shown in Table 53.4.

The existing imbalance in sweater-freshwater interface has been appointed by calculating the Cl/HCO_3^- ratio. Cl/HCO_3^- ratio of the investigated wells is incorporated in Table 53.3. For assessing the parameter I, GALDIT index divides the Cl/HCO_3 ionic ratio into four classes and rates within the range between 2.5 to 10 to appoint the least to maximum vulnerability impact, respectively (Table 53.1). In the present study, rating value of 10 is assigned to the wells with Cl/HCO_3^- ratio of 2 and above. Rest of the values are rated also according to Table 53.1.

Saturated thickness of the aquifer is one of the determining factors that control sea water intrusion into the aquifer and is classified into four classes (ranging from < 40 m to > 80 m) for this deltaic coastal region (Table 53.1). The recorded maximum saturated thickness of the unconfined aquifer of the study area was found 320 m and is located in the interior part of the coast. In other aquifer types, thickness exceeded mostly 20 m within the study area (Table 53.3). As the greater thickness of aquifer represents higher potentiality of seawater intrusion, they (>80 m) are assigned with rating value of 10 whilst the least (<40 m) is rated as 2.5 indicating lowest vulnerability to sea water intrusion. About 30% of the investigated wells are marked with rating value of 10 whilst rest of wells are assigned between 7.5 and 2.5 according to their respective thickness classes (Table 53.4).

53.3.2 Discussion

53.3.2.1 Vulnerability Assessment

Using the six parameters described in Eq. 53.1, the GALDIT index for vulnerability of seawater intrusion has been estimated (Table 53.4). The higher index represents the greater vulnerability for seawater intrusion. This categorizes the study area into different vulnerability classes. The range of the index scores is graded into four classes likely <5, 5–6, 6.1–7.5 and >7.5 corresponding to the low, moderate, moderately high and high vulnerable classes, respectively (Tables 53.2 and 53.4). Thereafter, using GIS tool, the spatial distribution of GALDIT index representing the vulnerability class of the southern Bengal Basin, Bangladesh was produced (Fig. 53.6). The GALDIT vulnerability index (GVI) map in Fig. 53.6 shows that three classes of vulnerability, namely low, moderate and moderately high vulnerability prevail in the study area. The central part of the study area and most of the part of Tippera surface have GVI values below 5 which denotes low vulnerability to sea water intrusion. In this part of the coastal belt, the aquifer system is more

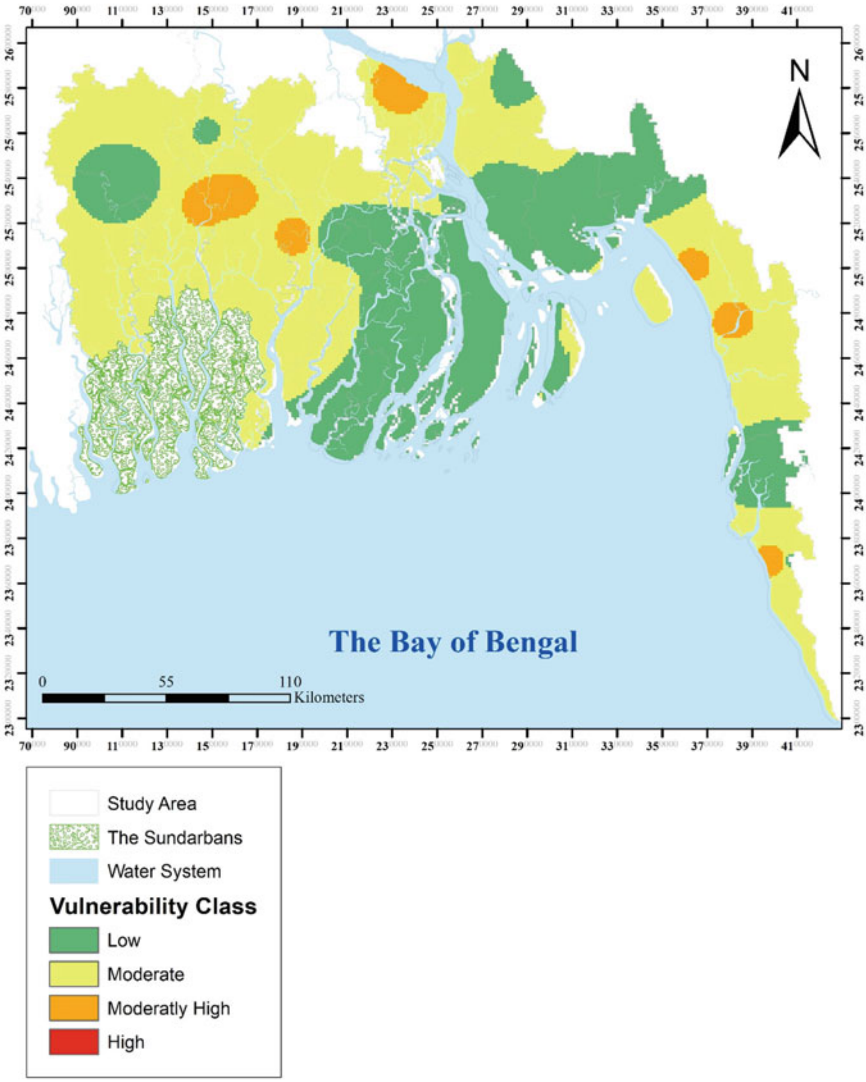

Fig. 53.6 Aquifer vulnerability index map of the study area

complex and consists of four aquifer units within 330 m from the surface. The silty clay and clay aquitards separate the water-bearing layers and the deep aquifer exists between depths of 285 m to 330 m (Figs. 53.4 and 53.5). Therefore, the main and deep aquifers of these areas are well protected against contamination from sea water intrusion through up coning or vertical infiltration from the upper saline aquifer.

The GVI map (Fig. 53.6) also depicts that south-west and south-east parts of the Bengal Basin comprising of Satkhira, Khulna, Bagerhat, Patuakhali and Chittagong districts of Bangladesh have vulnerability values ranging between 5 and 6, implying the moderate vulnerability to seawater intrusion. This indicates moderate exploitation of the main or deep aquifers and spatially accounts approximately 54.54% of the study area. Physiographically, this falls mostly within the Ganges deltaic plain (tidal, active, inactive deltaic zones) and Chittagong Coastal Plains of the Bengal Basin (Fig. 53.2). Lithological data (Fig. 53.3) show that in the south-western part of the basin, in Khulna, down to depth of 325 m two aquifers are available which are separated by 10 to 50 m thick clay and silty clay aquitard.

In Satkhira, two aquifer system prevails and a 60 m thick grey silty clay aquitard overlies the main or 2nd aquifer situating between 170 to 200 m below the surface. The upper aquifer is consisted of grey fine sand and layer of very fine sand forms the main aquifer (Fig. 53.3). In this part of the Bengal delta, the upper aquifer has lost its appeal as freshwater source due to the presence of high salinity and Arsenic in the groundwater (Bahar and Reza 2010; Burgess et al. 2010; Shamsudduha et al. 2018). Moreover, salt water shrimp farming and recurrent tropical cyclones led to inundate the embanked lands (polder) of the coastal area for longer period that caused to enhance the groundwater salinity in many folds (Islam et al. 2019a, 2019b).Therefore, the obvious pressure has been extended to the deeper aquifer which as the only available source of non-saline water provides fresh water to this coastal community for drinking, agriculture, industrial and other domestic purposes. It is likely that the incessant over-extraction of deep groundwater may have an impact on the vulnerability of the main and deep aquifers due to invasion of salinity (Burgess et al. 2010). The moderate hydraulic conductivity rate (6.1–8.0 m day^{-1}), leaky nature of the aquifer and improper development of wells also may have contribution to this main or deep aquifer salinization process (Shamsudduha et al. 2019).

In Patuakhali, a three layer aquifer system separated by clay or silty clay aquitards is also impacted by the seawater. The 2nd or main aquifer of this area encounters at depth of 265 to 295 m and is overlain by 100 m thick silty clay aquitard. The 3rd or deep water-bearing zone is separated from the main aquifer by a 27 m thick silty clay or clay layer and generally occurs at depths of 325–335 m below the surface (Fig. 53.3). These confining aquitards protect the underlying main and deep aquifers from possible contamination through direct recharge or saltwater intrusion. However, the thickness varies regionally. Presence of a thin confining layer or semi-confined to leaky type aquifer would allow contaminants to penetrate into the main or deeper layer from the upper layers due to the prevailing hydraulic connections. This may make the aquifer vulnerable to contamination which is reflected in the GALDIT vulnerability index map (Fig. 53.6).

A similar scenario is evident from Fig. 53.6 in small part of the Tippera surface and in Chittagong coastal plains where the confining clay or silty clay layer protects the main and underlying deep aquifer from possible contamination (Fig. 53.5). Regionally, the upper aquifer is heavily exploited for irrigation. The main aquifer serves the freshwater demand for municipal water supply (Zahid et al. 2008). Lithological cross section (Fig. 53.5) of the area shows that the thickness of the confining layer varies considerably and sometimes ranges only from 2 to 5 m. In part of the Tippera surface at Chandpur, only a 5 m thick silty clay aquitard overlies the aquifer that extends down to depth of 320 m, and in Chittagong city area of the Chittagong Coastal Plain, a 2 to 5 m thick silt and silty clay layer divide the upper and main aquifer at about depth of 220 m. Therefore, in presence of excessive abstraction, the underlying deeper aquifer may experience a direct impact of up coning and resulting sea water invasion. Probable mixing of saline water from the upper aquifer through vertical infiltration also poses a threat to the deeper aquifer which together makes this aquifer moderately vulnerable to sea water intrusion as depicted in Fig. 53.6. The interference of the seawater to the coastal alluvial aquifer of Cox's Bazar was already reported in the previous study (Fatema et al. 2018). The aquifer system of this area is highly dynamic and experiencing a declining hydraulic head due to unsustainable abstraction. Therefore, a moderate vulnerability (Fig. 53.6) persists in this touristic district of Bangladesh. Figure 53.6 demonstrates that a very few localized zones of Khulna and Bagerhat in the south-west, Pirojpur and Shariatpur in the south-central, and Chattogram and Cox's Bazar region in the south-east have GVI values ranging between 6.1 to 7.5. This denotes the moderately high vulnerability of the aquifers to sea water intrusion and higher exploitation characteristics of the main or deep aquifer dominated by heavy anthropogenic activities. Constant over-extraction may generate a permanent loss of water table and cause to intrude salt water into the coastal aquifers from the surrounding tidal rivers or the sea. Special attention and immediate measures should to be taken to protect this aquifers from further exploitation.

53.3.2.2 Validation of Groundwater Vulnerability Map

It is important to validate the result of a model to avoid drawing a wrong conclusion that would badly affect the groundwater assessment process. As no single variable can absolutely identify the sea water intrusion, use of different applications/analyzes can help appointing the mixing of fresh and sea water event (Trabelsi et al. 2016). In the present study, to assess the validity of the GALDIT vulnerability map, a comparison with hydrochemical analyzes (i.e., Br^-/Cl^- ratio) was performed.

Both of the chloride and bromide ions are chemically conservative in aqueous system and the $Br^-:Cl^-$ ratio can be used as indicator of sea or brackish water intrusion into groundwater as they do not take part in redox reaction, neither sorbed on to the mineral/organic matter's surface or form any insoluble precipitates (Fetter 1993). A similar $Br^-:Cl^-$ ratio to seawater indicates salt water invasion at tributing the chloride enrichment process to the marine intrusion. Cl^- ion is also attributed to anthropogenic pollution like industrial effluents, municipal sewages, fertilizers, etc., as indicated by dissimilar $Br^-:Cl^-$ ratio to seawater (Andreasen and Fleck 1997). The $Br^-:Cl^-$ ratios and corresponding chloride concentration are plotted in Fig. 53.7. A trend line depicting the theoretical $Br^-:Cl^-$ ratio equivalent to the $Br^-:Cl^-$ ratio in seawater (Hem 1985) is drawn to indicate the marine origin of the Cl^- ion.

Figure 53.7 shows that the deep groundwater samples of the tidal, active and inactive deltas occurring in the south-west, and a few samples of the Chattogram coastal plain have similar $Br^-:Cl^-$ ratios to the Bay water ratio (i.e. 0.0033–0.0037). This indicates that seawater is the primary source of the chloride in the groundwater

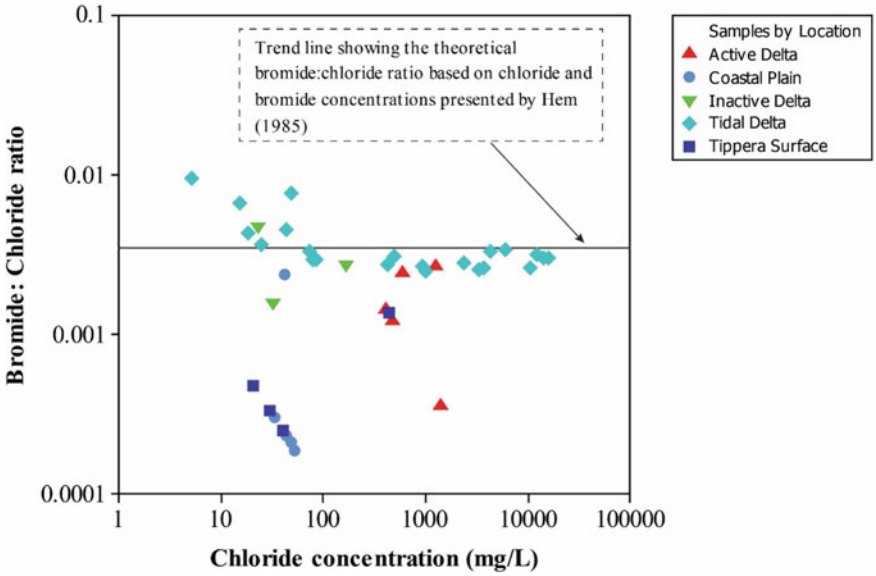

Fig. 53.7 Bromide: chloride ratios related to chloride concentrations (mgl^{-1}) in groundwater of the deep coastal aquifers of the Bengal Basin, Bangladesh

(Andreasen and Fleck 1997). However, this cannot ascertain the impact of the recent ingression or mixing event with relict sea water and requires more intensive research. Nevertheless, this implies the vulnerability of the respective aquifers to salt water mixing as depicted in the GALDIT vulnerability map in the present study (Fig. 53.6). Groundwater occurring from the multilayer aquifers (>150 m bgl) of Barguna, Patuakhaliin the south-central (active delta) and of Noakhali, Feni (Tippera surface) in the south-east part of Bangladesh has Br^-:Cl^- ratios ranging from 0.00025 to 0.009615. These ratios are dissimilar from that of Bay water, and the samples are low in nitrate concentrations (<3.0 mg l^{-1}), therefore, indicating the fresh water characteristics (Andreasen and Fleck 1997). The GALDIT vulnerability indices map also identified these zones as low vulnerable area and thus it validates the present study (Fig. 53.6).

53.3.2.3 GALDIT as a Decision-making Tool for Groundwater Management

Groundwater has become the primal entity of living for the coastal community of southern Bangladesh. Not only for drinking, this is also the major source of freshwater for irrigation and municipal water supply (Zahid et al. 2008; Ravenscroft et al. 2013). But the upper shallow aquifer of the coastal Bengal Delta is already affected by the saline/brackish water (Halim et al. 2009; Bahar and Reza 2010; Zahid et al. 2013; Islam et al. 2019b), and the surface water quality of this region is beyond the threshold of drinking water quality standard (e.g., for salinity, bacteria) or requires pre-treatment that amplifies the cost for living (Benneyworth et al. 2016; Mahtab and Zahid 2018). Inevitably, the deeper aquifer has become the main source of freshwater in this region and is experiencing heavy exploitation (Burgess et al. 2010; Ravenscroft et al. 2013; Hasan et al. 2018). In places, the deeper aquifer of the region also contains relict sea water (Rahman et al. 2011; Khan and Michael 2015; Islam et al. 2019b) and the heavy withdrawal of fresh water from this layer may lead to mixing of the saline water with the fresh water. Thus, salinization in the upper aquifer and subsequent dependency on the deeper aquifer is putting an extravagant stress on this only available fresh water resource in the coastal Bengal Basin. This is also making the deeper aquifer more vulnerable to contamination which is already reflected in the current study. GALDIT index method is a very efficient tool to identify the aquifers those are vulnerable to saltwater contamination. In the coastal zone of Bangladesh, low to moderately high level of vulnerability due to salt water intrusion was documented in the present study. Moderate vulnerability was observed in the eastern and western parts of the Bengal Basin, where the main and deeper aquifers are getting negatively impacted by mixing of saltwater. The central parts of the study area and the Tippera surface of the Bengal Basin are in the less vulnerable zone whilst moderately high vulnerability prevails dispersedly all over the study area (Fig. 53.6). Thus, GALDIT index method helps identifying the vulnerable aquifers of the coastal Bengal Basin and provides an insight into the particular vulnerable zone that would support designing the sustainable management scheme for the impacted area or region. The Bangladesh Water Act 2013 of Bangladesh also put emphasis on demarcating the stressed aquifers of a region or of the country and defining a safe yield level for the vulnerable aquifers to ensure sustainable abstraction (Goverment of Bangladesh 2013). As GALDIT vulnerability map has identified the vulnerable aquifers of the study area, taking certain measures the vulnerable water-bearing zones of the coastal belt could be protected from further contamination as well as the non-vulnerable aquifers could be preserved for sustainable abstraction. Drawing the limit of abstraction or the safe yield value based on the extent of the vulnerability of the particular main and deep aquifers would be a possible solution to control the magnitude and spatial extent of the vulnerability in an area. A buffer zone could be established around the vulnerable zones based on its extent, where the range of anthropogenic activities should be administered and unplanned well development should be regulated under rigorous monitoring scheme. Moderately high vulnerable aquifers should be addressed with high precision, and special measure should be taken immediately to lessen the vulnerability. Recharge with harvested rainwater or non-saline surface water would be a possible strategy to fight against this situation. Besides, based on the vulnerability classes, different groundwater surveillance teams could be formed to consistently monitor and asses the groundwater quality of the area. The team would also help in regulating the human activities and contribute to achieving the sustainability in the groundwater management sector of the country. A continual assessment of the aquifers using GALDIT vulnerability index method would help the management authorities assessing the updated vulnerability status of the area and develop the appropriate monitoring scheme. Thus, the GALDIT vulnerability indices map would act as the cornerstone in developing the sustainable groundwater management plan for the coastal part of Bengal Basin, Bangladesh.

53.3.2.4 Sustainable Management of Groundwater Resources

Bangladesh is an agricultural country and its costal parts are not different. Though rainfed agriculture is primarily practiced, this last only through the monsoon or post-monsoon. Rest of the year, irrigation supports the agriculture and surface water is the key source of the irrigation water. However, in the coastal parts, the river water becomes saline in the end of post-monsoon and hinders the irrigation over the dry season (Islam et al. 2016; Mahtab and Zahid 2018). During prolonged dry period, the situation becomes worse and affects the interior coastal districts also with the progressive encroachment of sea water towards the inland. Therefore, irrigation becomes dependent on the groundwater sources and it is estimated that about 78% of the irrigation in the coastal parts of Bangladesh is dependent on groundwater (Shamsudduha et al. 2018). Over the country, primarily, shallow aquifers are exploited for irrigation and as it is mentioned in the earlier section that saline water intrusion in the upper aquifer has deteriorated the quality of the water for irrigation. In such cases, artificial recharge with fresh water from pond or harvested rainwater could support refreshing process in the upper aquifer. As the main and deeper aquifer of the region are leaky to semi-confined type, freshening of the upper shallow would help reducing the vulnerability of these aquifers beneath. As well, sustainable abstraction goal for the deeper aquifer could be achieved. Besides, to lessen the burden of irrigation water from the subsurface water, monsoonal precipitation could be stored in existing or excavated canals which could be used for irrigation afterwards during the prolonged summer period. If continuous monitoring could be established, surface water from the coastal rivers could also be ingressed into the canals with prior assessment of the water quality and stored for irrigation during the dry period. Adapting with the water stressed environment by changing the cropping pattern or cultivating saline tolerant species would curtail the high demand of freshwater in the coastal region. Drip irrigation would also be a possible alternative for tackling the higher demand for irrigation water during the summer. In the western part of the study area, where enhanced salinization is observed due to intensive shrimp farming, changing into this practice to freshwater agricultural farming, e.g., rainfed rice cultivation would help reducing the groundwater salinity in the upper aquifer and contribute lessening the groundwater vulnerability of the area. However, a holistic approach should be required to monitor the surface water salinity in the coastal rivers and groundwater quality of the area. GALDIT index method would play the central role by detecting the spatial extent of the vulnerability and help the decision-makers to take appropriate actions to ensure sustainability of the multilayer aquifers of the coastal Bengal Basin, Bangladesh.

53.4 Conclusions

Seawater intrusion is a major environmental threat for groundwater resources, and since a large portion of the global population is located within the coastal zone, this phenomenon has also social and economic dimensions. Bangladesh is a deltaic country, and its southern coastal part is low lying with general elevation of 1.2–4.5 m. Groundwater is the primary fresh water resource in this area, and shallow aquifers are exploited heavily for agriculture, domestic and other purposes. However, in many parts of the coast, the upper aquifer is highly saline and is unsuitable for drinking or irrigation. The obvious pressure, therefore, is transferred to deeper aquifer. For the last decades, these deep aquifers are exploited in the coastal parts and therefore facing vulnerability to multiple contamination. The GALDIT method shows that the coastal aquifer is highly susceptible to seawater intrusion, which is coherent with the characteristics of the aquifer. The vulnerability potential to seawater intrusion was assessed taking into consideration various influencing factors such as groundwater occurrence, hydraulic conductivity of the aquifer, thickness of the aquifer, the groundwater level under mean sea level, the distance from the shore and the exploitation of groundwater. According to GALDIT method, the aquifer is moderately vulnerable in the eastern and western part of the country. In the east, the heavy urbanization and closer proximity of the coast or estuaries have influenced the intrusion potential. South-western region is impacted mostly by tropical cyclones, and land is characterized by shrimp farming within a poldered environment. These adversely affected the groundwater system of the area also and the aquifers are experiencing moderate to moderately high vulnerability. To protect the groundwater resources of the coast and to bring sustainability which is also one of the agenda of the sustainable development goals (SDG), the managing authorities should establish rigorous monitoring scheme. GALDIT index method would be a very efficient tool for this purpose and contribute to achieving sustainable groundwater management in the coastal part of the Bengal Basin, Bangladesh.

References

Ahmad H (2019) Coastal zone management Bangladesh coastal zone management status and future trends. J Coast Zo Manag 22:466. https://doi.org/10.24105/2473-3350.22.466

Alam MK, Hasan AKMS, Khan MR et al (1990) Geological map of Bangladesh. Dhaka, Bangladesh

Andreasen DC, Fleck WB (1997) Use of bromide: chloride ratios to differentiate potential sources of chloride in a shallow, unconfined aquifer affected by brackish-water intrusion. Hydrogeol J 5:17–26

Ayers JC, Goodbred S, George G et al (2016) Sources of salinity and arsenic in groundwater in southwest Bangladesh. Geochem Trans 17:4. https://doi.org/10.1186/s12932-016-0036-6

Bahar MM, Reza MS (2010) Hydrochemical characteristics and quality assessment of shallow groundwater in a coastal area of southwest Bangladesh. Environ Earth Sci 61:1065–1073. https://doi.org/10.1007/s12665-009-0427-4

Benneyworth L, Gilligan J, Ayers JC et al (2016) Drinking water insecurity: water quality and access in coastal south-western Bangladesh. Int J Environ Health Res 26:508–524
Bhuiyan MJAN, Dutta D (2012) Assessing impacts of sea level rise on river salinity in the Gorai river network, Bangladesh. Estuar Coast Shelf Sci 96:219–227. https://doi.org/10.1016/j.ecss.2011.11.005
Bouderbala A, Remini B, Saaed Hamoudi A et al (2016) Assessment of groundwater vulnerability and quality in coastal aquifers: a case study (Tipaza, North Algeria). Arab J Geosci 9. https://doi.org/10.1007/s12517-015-2151-6
Brammer H (2012) The physical geography of Bangladesh. The University Press Ltd., Dhaka, Bangladesh
Burgess WG, Hoque MA, Michael HA et al (2010) Vulnerability of deep groundwater in the Bengal Aquifer System to contamination by arsenic. Nat Geosci 3:83–87. https://doi.org/10.1038/ngeo750
BWDB-UNDP (1982) Groundwater survey: the hydrological conditions of Bangladesh. New York
Chachadi AG (2005) Seawater intrusion mapping using modified GALDIT indicator model: a case study in Goa
Chachadi AG, Lobo-Ferreira JP (2001) Sea water intrusion vulnerability mapping of aquifers using GALDIT method. Coastin (coast Policy Res Newslett) 4:7–9
Eminoglou G, Gkiougkis I, Kallioras A et al (2017) Updated groundwater vulnerability evaluation at a coastal aquifer system in NE Greece. Eur Water 57:423–428
Fatema S, Marandi A, Zahid A et al (2018) Seawater intrusion caused by unmanaged groundwater uses in a coastal tourist area, Cox's Bazar, Bangladesh. Environ Earth Sci 77:1–13. https://doi.org/10.1007/s12665-018-7260-6
Ferreira JPL, Chachadi AG, Diamantino C et al (2007) Assessing aquifer vulnerability to seawater intrusion using the GALDIT method: Part 1-application to the Portuguese Monte Gordo aquifer. In: Ferreira JPL, Vieira JMP (eds) IAHS-AISH Publication. IAHS Press, Wallingford, UK, pp 161–171
Fetter CW (1993) Contaminant hydrogeology. Macmillan Publishing Company, New York, USA
Ghyben WB (1889) Nota in verband met de voorgenomen putboring nabil Amsterdam [Memorandum related to planned well drilling near Amsterdam]. Tijdschr Koninhitk Inst Ing 9:8–22
Gnanachandrasamy G, Ramkumar T, Chen JY et al (2019) Evaluation of vulnerability zone of a coastal aquifer through GALDIT GIS index techniques. GIS Geostat Tech Groundw Sci 209–221. https://doi.org/10.1016/B978-0-12-815413-7.00015-8
Goodbred SL, Kuehl SA (2000) The significance of large sediment supply, active tectonism, and eustasy on margin sequence development: late quaternary stratigraphy and evolution of the Ganges-Brahmaputra delta. Sediment Geol 133:227–248. https://doi.org/10.1016/S0037-0738(00)00041-5
Goverment of Bangladesh (2013) Bangladesh water act, 2013. Bangladesh
Halim MA, Majumder RK, Nessa SA et al (2009) Hydrogeochemistry and arsenic contamination of groundwater in the Ganges Delta Plain, Bangladesh. J Hazard Mater 164:1335–1345. https://doi.org/10.1016/j.jhazmat.2008.09.046
Hasan MM, Ahmed KM, Sultana S et al (2018) Investigations on groundwater buffering in Khulna-Satkhira Coastal Belt using managed aquifer recharge. In: Mukherjee A (ed) Groundwater of South Asia. Springer, Singapore, pp 453–462
Hem JD (1985) Study and interpretation of the chemical characteristics of natural water. US Geol Surv Water-Supply Pap 2254
Herzberg A (1901) Die wasserversorgung einiger Nordseebader [the water supply of the North Sea coast in Germany]. Z Gasbeleucht Wasserversorg 44:815–819
Hoque MA, Burgess WG, Ahmed KM (2017) Integration of aquifer geology, groundwater flow and arsenic distribution in deltaic aquifers—a unifying concept. Hydrol Process n/a–n/a. https://doi.org/10.1002/hyp.11181

Hoque MA, McArthur JM, Sikdar PK et al (2014) Tracing recharge to aquifers beneath an Asian megacity with Cl/Br and stable isotopes: the example of Dhaka, Bangladesh. Hydrogeol J 22:1549–1560

Hossain MS, Roy K, Datta DK (2014) Spatial and temporal variability of rainfall over the south-west coast of Bangladesh. Climate 2:28–46

Islam ARMT, Siddiqua MT, Zahid A et al (2020) Drinking appraisal of coastal groundwater in Bangladesh: an approach of multi-hazards towards water security and health safety. Chemosphere 255. https://doi.org/10.1016/j.chemosphere.2020.126933

Islam MA, Hoque MA, Ahmed KM et al (2019) Impact of climate change and land use on groundwater salinization in Southern Bangladesh—Implications for other Asian Deltas. Environ Manage 64:640–649. https://doi.org/10.1007/s00267-019-01220-4

Islam MM, Azad AK, Ara MH et al (2016) Environmental Study on a coastal river of Bangladesh with reference to irrigation water quality assessment: a case study on Shailmari River, Khulna. J Geosci Environ Prot 04:41–64. https://doi.org/10.4236/gep.2016.410003

Islam MM, Marandi A, Fatema S et al (2019) The evolution of the groundwater quality in the alluvial aquifers of the south-western part of Bengal Basin, Bangladesh. Environ Earth Sci 78:1–20. https://doi.org/10.1007/s12665-019-8714-1

Kardan Moghaddam H, Jafari F, Javadi S (2017) Vulnerability evaluation of a coastal aquifer via GALDIT model and comparison with DRASTIC index using quality parameters. Hydrol Sci J 62:137–146. https://doi.org/10.1080/02626667.2015.1080827

Khan MR, Michael HA (2015) Vulnerability of deep groundwater in the Bengal Basin to contamination: the role of physical and chemical aquifer heterogeneity and pumping. In: AGU fall meeting abstracts

Khatun MA, Rashid MB, Hygen HO (2016) Climate of Bangladesh. Dhaka, Bangladesh

Lobo-Ferreira JP, Diamantino C, Leitão TE et al (2003) Projecto FCT Valorização e Protecção da Zona Costeira Portuguesa: avaliação e estudo da vulnerabilidade de sistemas aquíferos costeiros (Componente 11)

Mahtab MH, Zahid A (2018) Coastal surface water suitability analysis for irrigation in Bangladesh. Appl Water Sci 8:1–12. https://doi.org/10.1007/s13201-018-0650-9

Naus FL, Schot P, Ahmed KM et al (2019a) Influence of landscape features on the large variation of shallow groundwater salinity in southwestern Bangladesh. J Hydrol X 5. https://doi.org/10.1016/j.hydroa.2019.100043

Naus FL, Schot P, Groen K et al (2019b) Groundwater salinity variation in Upazila Assasuni (southwestern Bangladesh), as steered by surface clay layer thickness, relative elevation and present-day land use. Hydrol Earth Syst Sci 23:1431–1451. https://doi.org/10.5194/hess-23-1431-2019

Pedreira R, Kallioras A, Pliakas F et al (2015) Groundwater vulnerability assessment of a coastal aquifer system at River Nestos eastern Delta, Greece. Environ Earth Sci 73:6387–6415

Rahman MATMT, Majumder RK, Rahman SH et al (2011) Sources of deep groundwater salinity in the southwestern zone of Bangladesh. Environ Earth Sci 63:363–373. https://doi.org/10.1007/s12665-010-0707-z

Ravenscroft P, McArthur JM (2004) Mechanism of regional enrichment of groundwater by boron: the examples of Bangladesh and Michigan, USA. Appl Geochemistry 19:1413–1430. https://doi.org/10.1016/j.apgeochem.2003.10.014

Ravenscroft P, McArthur JM, Hoque MA (2013) Stable groundwater quality in deep aquifers of Southern Bangladesh: the case against sustainable abstraction. Sci Total Environ 454:627–638

Ravenscroft P, McArthur JM, Rahman MS (2018) Identifying multiple deep aquifers in the Bengal Basin: implications for resource management. Hydrol Process 32:3615–3632. https://doi.org/10.1002/hyp.13267

Santha Sophiya M, Syed TH (2013) Assessment of vulnerability to seawater intrusion and potential remediation measures for coastal aquifers: a case study from eastern India. Environ Earth Sci 70:1197–1209. https://doi.org/10.1007/s12665-012-2206-x

Sarker MMR, Van Camp M, Islam M et al (2018) Hydrochemistry in coastal aquifer of southwest Bangladesh: origin of salinity. Environ Earth Sci 77:1–20. https://doi.org/10.1007/s12665-017-7196-2

Seenipandi K, Nainarpandian C, Kandathil RK et al (2019) Seawater intrusion vulnerability in the coastal aquifers of southern India—an appraisal of the GALDIT model, parameters' sensitivity, and hydrochemical indicators. Environ Sci Pollut Res 26:9755–9784. https://doi.org/10.1007/s11356-019-04401-0

Shamsudduha M, Joseph G, Haque SS et al (2019) Multi-hazard groundwater risks to water supply from shallow depths: challenges to achieving the sustainable development goals in Bangladesh. Expo Heal. https://doi.org/10.1007/s12403-019-00325-9

Shamsudduha M, Taylor RG, Ahmed KM et al (2011) The impact of intensive groundwater abstraction on recharge to a shallow regional aquifer system: evidence from Bangladesh. Hydrogeol J 19:901–916. https://doi.org/10.1007/s10040-011-0723-4

Shamsudduha M, Zahid A, Burgess WG (2018) Security of deep groundwater against arsenic contamination in the Bengal aquifer system: a numerical modeling study in southeast Bangladesh. Sustain Water Resour Manag 5:1073–1087. https://doi.org/10.1007/s40899-018-0275-z

Sophiya MS, Syed TH (2013) Assessment of vulnerability to seawater intrusion and potential remediation measures for coastal aquifers: a case study from eastern India. Environ Earth Sci 70:1197–1209

Talchabhadel R, Nakagawa H, Kawaike K et al (2017) Experimental investigation on opening size of tidal basin management: a case study in Southwestern Bangladesh. J Japan Soc Civ Eng Ser B1 (Hydraulic Eng 73:I_781–I_786). https://doi.org/10.2208/jscejhe.73.i_781

Trabelsi N, Triki I, Hentati I et al (2016) Aquifer vulnerability and seawater intrusion risk using GALDIT, GQISWI and GIS: case of a coastal aquifer in Tunisia. Environ Earth Sci 75. https://doi.org/10.1007/s12665-016-5459-y

Uddin MN, Saiful Islam AKM, Bala SK et al (2019) Mapping of climate vulnerability of the coastal region of Bangladesh using principal component analysis. Appl Geogr 102:47–57. https://doi.org/10.1016/j.apgeog.2018.12.011

Vengadesan M, Lakshmanan E (2018) Management of coastal groundwater resources. Elsevier Inc.

Werner AD, Bakker M, Post VEA et al (2013) Seawater intrusion processes, investigation and management: recent advances and future challenges. Adv Water Resour 51:3–26. https://doi.org/10.1016/j.advwatres.2012.03.004

Zahid A, Afzal Hossain AFM, Hazrat Ali M et al (2018) Monitoring the coastal groundwater of Bangladesh. In: Mukherjee A (ed) Groundwater of South Asia. Springer, Singapore, pp 431–451

Zahid A, Hassan MQ, Balke K-D et al (2008) Groundwater chemistry and occurrence of arsenic in the Meghna floodplain aquifer, southeastern Bangladesh. Environ Geol 54:1247–1260. https://doi.org/10.1007/s00254-007-0907-3

Zahid A, Jahan K, Ali MH et al (2013) Distribution of groundwater salinity and its seasonal variability in the coastal aquifers of Bengal Delta. In: Zahid A, Hassan MQ, Islam R et al (eds) Impact of climate change on socio-economic conditions of Bangladesh. German Academic Exchange Service (DAAD), German Development Cooperation (GIZ), Alexander von Humboldt (AvH) Foundation and Alumni Association of German Universities in Bangladesh (AAGUB), pp 170–193

Zahid A, Rahman A, Ali MH et al (2016) Determining sources of groundwater salinity in the multi-layered aquifer system of the Bengal Delta, Bangladesh. BRAC Univ J (Sci Eng)XI (2):37–52

Zahid A, Nowreen S, Islam MK et al (2021) Assessment of hydraulic conductivity in the multi-layered aquifer system of the Bengal Basin, Bangladesh by performing slug tests. Bull Eng Geol Environ 8

Chapter 54
A Remote Sensing Assessment of Spatio-Temporal Dynamics of Coastal Ecosystem: Evidence from Indian Sundarbans

Uttam Kumar Mandal and Dibyendu Bikas Nayak

Abstract The Sundarbans is the largest contiguous mangrove ecosystem in the world located in the southern part of West Bengal, India and Bangladesh, and lies on the delta of the Ganges, Brahmaputra and Meghna rivers in the Bay of Bengal. Owing to its unique geographical location, this world heritage site is highly vulnerable to climate change. Despite the value and vulnerability of the coastal delta, very little data exist on the spatio-temporal dynamics of the land and the impacts of anthropogenic and natural disturbances of the ecosystem. Under the global climate change and the related sea level rise, we explored the spatio-temporal dynamics of the changing coastline and assess the vulnerability of the region. Multi-temporal Landsat imagery was used for studying land use/land cover dynamics and shoreline changes in Sundarbans. Out of the total 7300 km^2 study area of the Indian Sundarbans, total erosion and accretion was 163 km^2 and 149 km^2, respectively, from 1975 to 2015 and net change was an erosion of 14 km^2. The land use–land cover dynamics indicated that in Sundarbans, mangrove forest remained more or less stable since 1975, whereas the aquaculture and cropped area during rabi season increased considerably and fallow area decreased. The salinity map indicated that there was shifting in soil salinity from west to east during 1973–2015 because of increased rabi cultivation in the western part of Sundarbans, whereas increased brackish water aquaculture in the eastern part increased salinity in the region. The village-level climate change vulnerability in the agricultural sector of the Indian Sundarbans region was estimated using spatially aggregated biophysical and socio-economic parameters by applying the equal weight method. The results indicated that the villages in Sandeshkhali-I and II and Minakhan of North 24 Parganas was under the highly vulnerable zone. Out of 1074 villages in the Sundarbans, 139 villages covering an area of 587 km^2 with a population of 5.64 lakhs were found to be highly vulnerable to climate change.

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Keywords Climate vulnerability · Coastal erosion · Land use land cover dynamics · Soil salinity · Sundarbans

54.1 Introduction

Coastal land use across the globe has experienced remarkable rapid changes over the recent decades because of extraordinary anthropogenic pressure and climate variability and change (Islam et al. 2016). The coastal region has experienced land use changes probably because of economic opportunities, attracting a growing population. Despite some social and economic benefits of land use land cover (LULC) change, the increasing anthropogenic pressure on the coastal resources and conversion of LULC are often causing ecosystem degradation of the region. This is exacerbated by climate-change-induced rise in sea level, increase in soil salinity and increase in the incidence and severity of cyclones.

Coastal land use is highly diverse and competitive. Urbanization and industrialization, population growth, trade and tourism are exerting continuous stress on the resources of the coastal region, thereby exposing people to coastal hazards (Jangir et al. 2016). Hydrodynamics, geomorphic, tectonic and climate forces induce shoreline changes, thus making the coastal zone a vulnerable region. Shoreline is one of the most important terrain features of the coastal zone and is defined as the line of contact between land and sea. Although it is easy to define shoreline, it is difficult to capture, as it has never been stable in either long-term or short-term positions. Processes, such as tidal flooding, sea level rise, winds, erosion–deposition, land subsidence, regular wave action and periodic storm surges, are mainly responsible for gradual as well as abrupt changes in the coastal region. Further, natural hazards like tsunami and periodic cyclones along the Indian coast have resulted in geomorphological and shoreline changes. An ever-increasing coastal population and thereby the demand for quantitative information on the coastal hazards necessitate regular shoreline mapping for effective coastal zone management. Therefore, land use change detection on a spatial basis would be a critical requirement for developing effective land management and planning strategies in coastal areas.

Agricultural development in the coast is mostly constrained by dry season soil salinity, poor soil fertility, heavy soil texture, short winter season and poor embankment management. Hence, cropping intensity and production levels are much lower in the region compared with other parts of the country. Because of non-remunerative agriculture in the region, many farmers have switched over to modern commercially oriented, high output-intensive brackish water farming from traditional agriculture, allowing entry of saltwater in the crop field which poses severe environmental threats to the region. Coastal embankments provide an opportunity for intensive shrimp farming in cropland and mangroves areas. On the other hand, the breakage of coastal embankments in search of seawater has led to increased salinity in cropland, resulting in decreased crop productivity.

The coastal ecosystems are important dynamic environments that are constantly reshaped and reformed. Relative sea/land level changes are fundamental to people living on the coast. The lands in the West Bengal coast are highly vulnerable due to the constant threat of powerful nor'westers, bay cyclones, tidal surges and constant changes of courses by the numerous distributaries of the river Ganges in the active part of the delta. The Sundarbans, the largest contiguous mangrove ecosystem in the world, occupy the major part of the West Bengal coast. Despite the value and vulnerability of the coastal delta, very little data exist on the spatio-temporal dynamics of the land and the impacts of anthropogenic and natural disturbances of the ecosystem. There is a need for appropriate water and land care system for the coastal areas to make this fragile ecosystem climatically more resilient. Cyclone Alia in 2009 and the recent cyclones Bulbul, Amphan and Yaas further exposed the climatic vulnerability in the Sundarbans.

On this background, multispectral images acquired periodically by satellite sensors have a powerful capability to discriminate and quantify the land surface changes in space and time. Systematic analysis of multispectral images by integrating satellite remote sensing and Geographic Information System (GIS) techniques provides an important source of information on accurate, quantitative and up-to-date spatial patterns of land use change. As large areas of Sundarbans are inaccessible and declared natural forest reserve by the government, remote sensing is useful for monitoring the changes taking place in and around the Sundarbans ecosystem. Remote sensing can also offer an exceptional opportunity to complete and update existing mapped areas in a given location (Quader et al. 2017).

Therefore, the objectives of this study were to: (i) quantify the long-term changes in LULC using satellite images and (ii) discuss the impact of land use changes in the specific coastal zones of West Bengal.

54.2 Study Area: Indian Sundarbans

Sundarbans delta in India is comprised of 102 islands, demarcated by the river Hooghly on the west, the Bay of Bengal on the south, the Ichamati-Kalindi-Raimangal rivers on the east and the Dampier-Hodges line on the north. The Sundarbans is spread over 19 administrative blocks of South and North 24 Parganas districts of West Bengal, India. The blocks in South 24 Parganas are Sagar, Namkhana, Kakdwip, Patharpratima, Kultali, Canning I and II, Basanti, Gosaba, Mathurapur I and II and Jaynagar I and II. The blocks in North 24 Parganas are Haroa, Sandeshkhali I and II, Hingalganj, Hasnabad and Minakhan. The total area of the Sundarbans region in India is 9600 km^2, which constitutes the Sundarbans Biosphere Reserve. In 1970, the Ministry of Environment and Forests, Government of India, declared the entire 9630 km^2 of the Sundarbans as the Sundarbans Biosphere Reserve. This includes approximately 4260 km^2 of reserve forests, of which around 40% has been declared protected areas, including about 1330 km^2 as a national park and around 406 km^2

as wildlife sanctuaries. The land is split by numerous rivers and water channels all emptying into the Bay of Bengal.

54.3 Trend of Sea Level Rise in West Bengal Coast

We analysed the sea level rise trends in the estuaries of the West Bengal coast and compare them with other coastal regions of India, based on estimates derived from tide-gauge data. The PSMSL (Permanent Service for mean sea level) tide data have been examined to detect the changes of sea level trend using Mann-Kendall non-parametric test, and the magnitudes of such trends have been estimated using Sen's slope (Mandal et al. 2018). Among the data of 27 Indian stations available at the PSMSL, only nine stations (Chennai, Cochin, Mumbai, Visakhapatnam, Sagar, Tribeni, Haldia, Diamond Harbour, Garden Reach) have 40 or more years of usable records. There are eight PSMSL sites in West Bengal, and they all are located by the Hugli from its confluence near Sagar to 208 km upstream (Tribeni). Data from all of these stations are not usable for time series analysis; however, four stations, Sagar, Gangra, Haldia and Diamond Harbour, are relatively free from the influence of upstream discharge and possess quality data of sufficient duration without unexplained datum shifts or anomalous values and were used for this study. The results affirmed that the rate of sea level changes for four stations, Garden Reach, Diamond Harbour, Haldia and Gangra in West Bengal coast, are found to be + 7.48, + 4.27, + 3.24 and + 2.06 mm year^{-1} (Table 54.1, Fig. 54.1), whereas for the stations Mumbai and Cochin in west coast, the rate of changes were 0.78 and 2.07 mm year^{-1}, and for Chennai and Vishakhapatnam in the east coast, the rate of changes were 1.06 and 1.00 mm year^{-1}. The rise in sea level in the West Bengal coast was more in the last ten years (2005–2014), and it increased by 1.65% of the long term average in the region.

54.4 Satellite Images and Processing for Spatio-Temporal Dynamics in Sundarbans

Landsat images were used to analyse the LULC in the study area during the 1973–2015 periods (Table 54.2). Cloud cover is a consistent problem in all tropical regions. Because this study aimed to delineate the shoreline changes, land use land cover changes and salt-affected areas images need to be totally cloudless over the area of interest. These images were downloaded from the United States Geological Survey (USGS) earth explorer website where archived satellite image data are available. The images were georeferenced. USGS supplies Landsat images with basic georeferencing, and the district boundary map (georeferenced from the topo-sheet) was used

Table 54.1 Trend analysis of long-period tide gauge data at Hugli estuary in Sundarbans along with East and West coast of India

Station	Minimum	Maximum	Mean	C.V	Kendall's tau	P-value	Sen's slope	Slope of linear regression line
Haldia	6918 (1972)	7150 (2013)	7055.69	0.72	0.530	< 0.0001	3.24	2.80
Diamond Harbour	6883 (1963)	7230 (2013)	7056.98	1.30	0.659	< 0.0001	4.27	3.96
Garden Reach	6750 (1951)	7457 (1999)	7071.58	2.56	0.614	< 0.0001	7.48	6.70
Gangra	6874 (1997)	7039 (2000)	6973.19	0.57	0.277	0.049	2.06	1.19
Sagar	6641 (1968)	6998 (1956)	6850.06	1.48	−0.319	0.0016	−3.69	−2.98
Mumbai	6937 (1905)	7156 (2008)	7016.91	0.53	0.563	< 0.0001	0.78	0.80
Cochin	6843 (1945)	7022 (2007)	6934.70	0.64	0.521	< 0.0001	2.07	1.52
Chennai	6926 (1982)	7067 (2010)	6993.10	0.49	0.292	0.004	1.06	0.57
Visakhapatnam	6990 (1961)	7172 (2013)	7075.81	0.56	0.286	0.002	1.00	0.92

for further georeferencing the image and extracting the study area. Absolute radiometric calibration was carried out for multi-temporal studies to reduce the effects due to changes in the sensor characteristics, atmospheric condition, solar angle and sensor view angle. These corrections involve the conversion of the digital number (DN) to the top of atmosphere reflectance that helps in the temporal analysis. The DN of all the images was converted to at-satellite spectral reflectance (Chander et al. 2009).

Delineation of shoreline and mapping was carried out based on the Survey of India toposheet of 1972 and Landsat images in the GIS environment. Temporal changes in the shoreline were identified using overlay analysis. Boundaries were delineated by on-screen visual interpretation and digitization in the GIS platform. Since the goal of the image interpretation steps was to distinguish between land and water in each image, the combination of the green, red and near-infrared bands of the images was used to create false colour images. All vegetated areas in these false colour images showed different hues of red; bare soils were coloured in shades of brown, and mudflats or sandy beaches were coloured in shades of white. Water bodies were either in shades of blue or black since water absorbs infrared radiation. Some muddy water showed a brownish hue, but from the morphological structure of the river mouths and the bay, it could be clearly identified as water and not soil. Normalized difference vegetation index (NDVI) images were also created using the red (R) and

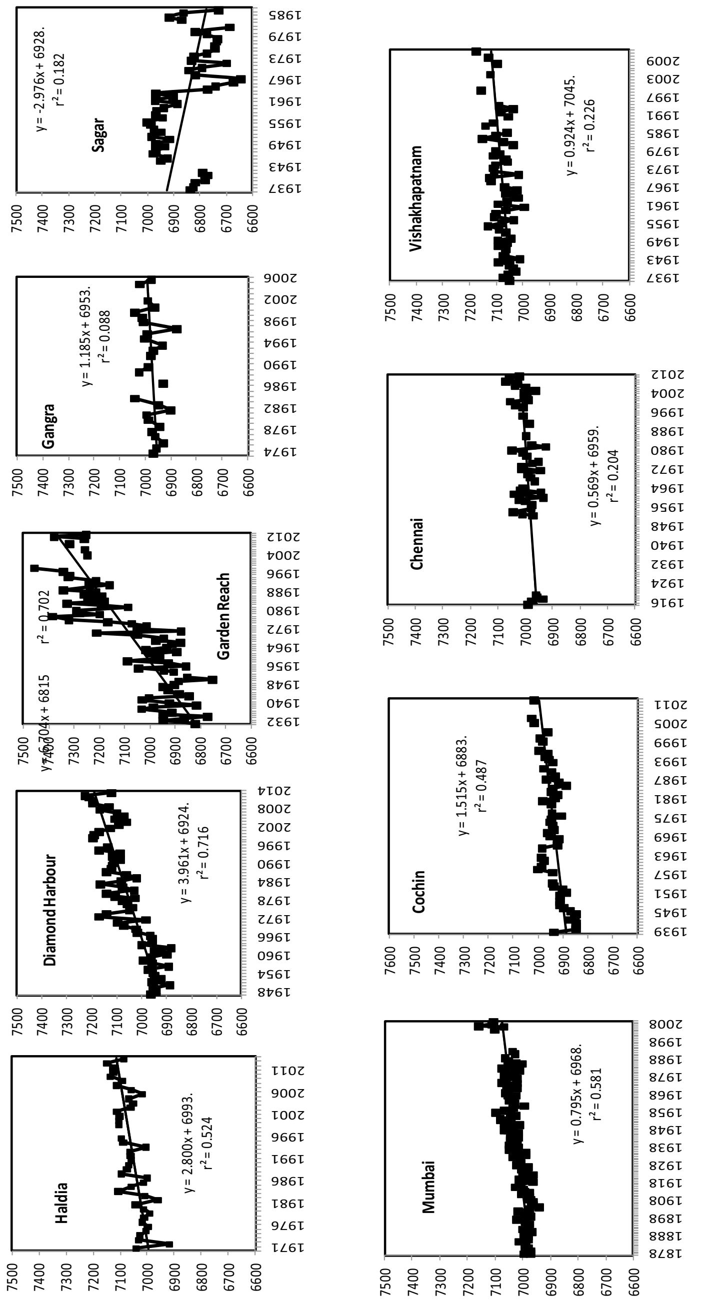


Fig. 54.1 Changes in annual sea level at tidal observations

Table 54.2 Landsat scenes used for spatio-temporal study in Sundarbans

Date of acquisition	Satellite data	Sensor	Path and row	Remarks
February 21, 1973	Landsat-1	MSS	P-148, R-045	Good quality
December 5, 1975	Landsat-2	MSS	P-148, R-045	Good quality
January 19, 1989	Landsat-4	TM	P-138, R-045	Good quality
November 15, 1999	Landsat-7	ETM+	P-138, R-045	Good quality
April 13, 2002	Landsat-7	ETM+	P-138, R-045	Good quality
November 4, 2004	Landsat-5	TM	P-138, R-045	Good quality
January 13, 2007	Landsat-5	TM	P-138, R-045	Good quality
November 8, 2011	Landsat-5	TM	P-138, R-045	Good quality
March 8, 2015	Landsat-8	OLI-TIRS	P-138, R-045	Good quality

near-infrared (IR) bands to verify the land–water boundary since the NDVI values of water are negative, and those of dry terrestrial surface is positive (Rahman et al. 2011). NDVI values show this characteristic (negative for water and positive for terrestrial surfaces) irrespective of whether radiance or reflectance values of R and NIR are used in its calculation. We used these NDVI and false colour images to classify land and water.

Images were classified using unsupervised classification in ERDAS software. Initially, images were classified into 150 classes and then recoded to broad 5–6 land use classes and Google Earth was used for ground truthing purpose. The bare soils and agricultural land were extracted from each classified image to delineate the salt-affected area. Three indices Normalized Difference Vegetation Index (NDVI), Salinity Index (SI) and Canopy Response Salinity Index (CRSI) were used for our study.

$$\mathbf{NDVI} = \frac{(NIR-R)}{(NIR+R)}$$

$$\textbf{Salinity Index} = \sqrt{G \times R}$$

$$\textbf{Canopy Response Salinity Index} = \sqrt{\frac{(NIR\times R)-(G\times B)}{(NIR\times R)+(G\times B)}}$$

where B stands for blue, G for green, R for red and NIR for near-infrared corresponding to Band 2, 3, 4 and 5 of Landsat-8 OLI. We used the squared value of CRSI for the calculation.

54.4.1 Spatio-Temporal Dynamics of Sundarbans

Out of the total 7300 km^2 study area of Indian Sundarbans, total erosion and accretion was 163 km^2 and 149 km^2, respectively, during 1975–2015 (Fig. 54.2 and Table 54.3). Changes in land surface area of few Sundarbans Islands are presented in Table 54.4. The net change was erosion of 14 km^2. The land use land cover dynamics indicated that in Sundarbans, mangrove forest remained more or less stable since 1975 because the area is under reserved forest, whereas the aquaculture and cropped area during rabi season increased considerably and fallow area decreased (Fig. 54.3). The salinity map indicated that there was shifting in soil salinity from west to east during 1973–2015 because of increased rabi cultivation in the western part of Sundarbans, whereas increased aquaculture more specifically brackish water aquaculture in the eastern part increased salinity in the region (Fig. 54.4).

Accretion zone (Red) between 1975 to 2015 based on Landsat imagery in Sundarbans	**Erosion zone (other than green) between 1975 to 2015 based on Landsat imagery in Sundarbans**

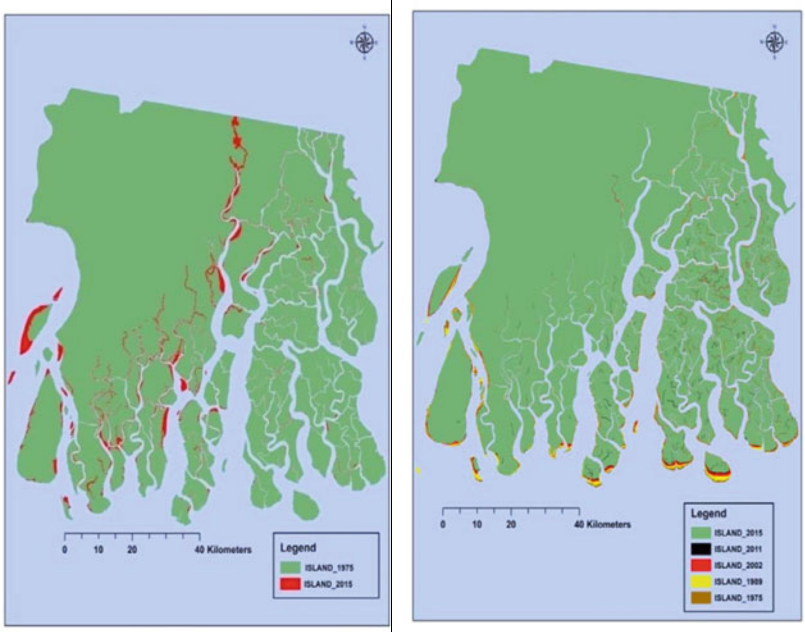


Fig. 54.2 Erosion and accretion zone of the Indian Sundarbans analysed using multi-temporal Landsat imagery

Table 54.3 Net erosion and accretion in Sundarbans (km^2)

	2015–2011	2011–2002	2002–1989	1989–1975	2015–1975
Erosion	− 33.69	− 36.63	− 81.80	− 63.13	− 163.37
Accretion	19.39	49.61	50.60	81.45	148.86
Net change	− 14.30	+ 12.98	− 31.20	+ 18.32	− 14.51

Table 54.4 Year-wise land surface area of few Indian Sundarbans Islands

Island name	Area (km^2)						Population (2011)
	1975	1989	2002	2011	2015	2015–1975	
Sagar	236.59	238.20	23,438	234.44	235.15	−1.44	212,037
Ghoramara	7.20	6.13	4.65	4.30	4.15	−3.04	5193
Jambudwip	6.78	7.67	4.24	4.20	3.91	−2.86	No habitation
Mousuni	30.83	30.74	27.69	27.76	27.10	−3.72	22,073
Lothian	33.95	34.49	33.44	34.46	34.33	0.38	Reserved forest
Bulcheri	28.71	27.46	20.49	21.76	20.74	−7.97	Reserved forest
Dalhousie	76.13	70.86	63.34	59.76	57.28	−18.86	Reserved forest
Bangaduni	41.70	37.97	29.68	24.72	22.72	−18.98	Reserved forest
Nayachar	30.04	41.04	47.55	44.82	47.35	17.31	2500
Nayachar1		0.54	0.50	3.25	3.04	3.04	Not available
Badford Dwip	3.56	1.33				−3.56	

54.5 Coastal Land Dynamics and Its Implications

In the Sundarbans region, both erosion and accretion are pragmatic because of the huge sedimentation by the Ganges–Brahmaputra–Meghna river system. The area undergoes rapid morphological changes because of the dynamics of water and sediment movement. These driving forces are responsible for the rate of land erosion and accretion. However, the rate of erosion and accretion varies significantly over time. This study reveals that the accretion process was dominating during the period 1975–1989 and 2002–2011, but from 1989–2002 to 2011–2015, more land has been lost than recreated because of riverbank erosion. A large-scale land accretion and consolidation with the mainland have been observed in the study area, although a large land has been eroded in the seaward side under mangrove forest. However, the value of the lost land is generally higher than that of newly accreted land.

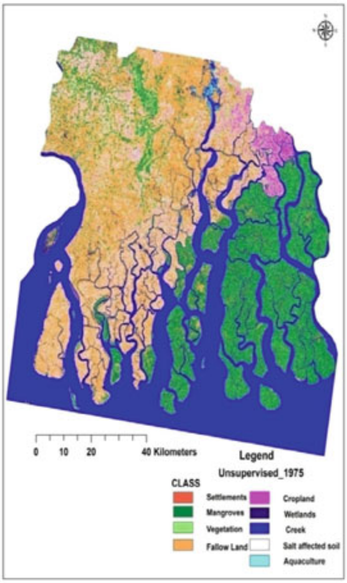
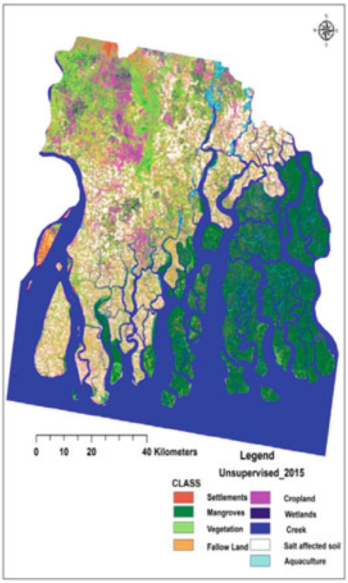
LULC class during 1975	LULC class during 2015
	
Aquaculture 129 km^2,Salt affected soils 764 km^2 Cropland 224 km^2, Settlement 24 km^2 Fallow 3049 km^2, Vegetation 581 km^2 Mangroves 1991 km^2, Wetland 274 km^2	Aquaculture 217 km^2, Salt affected soils 1050 km^2 Cropland 679 km^2, Settlement 301 km^2 Fallow 1240 km^2 Vegetation 1238 km^2 Mangroves 1962 km^2, Wetland 128 km^2

Fig. 54.3 Land use land cover (LULC) change during 1975 and 2015 in Indian Sundarbans analysed using multi-temporal Landsat imagery

The settlement area has consistently increased in the study region. Between 1991 and 2011, the population of the Indian Sundarbans increased from 3.15 million to 4.43 million (Samanta 2018). This created extra pressure on land use with respect to settling people. The results from this study also suggest that dynamic change of LULC has been occurring, and that it may be closely linked with the productivity and sustainability of agriculture and/or aquaculture, that is, food production in each ecological zone. The area with high risks and/or vulnerability in food production can be mapped clearly at high spatial resolution. Local and governmental policy making should be based on timely and high-resolution land use maps derived from satellite images to reduce the possible risks in threatening food production and to design better land use scenarios for the future.

Brackish water aquaculture has developed as a strong industry in Asia. Scientific brackish water aquaculture started in India with tiger shrimp (*Penaeus monodon*) farming initiated during the early 1990*s*. With the introduction of Pacific white shrimp (*Penaeus vannamei*) in 2009, the Indian aquaculture industry has grown rapidly. India produced 4.88 million tonnes of aquatic animals through aquaculture during

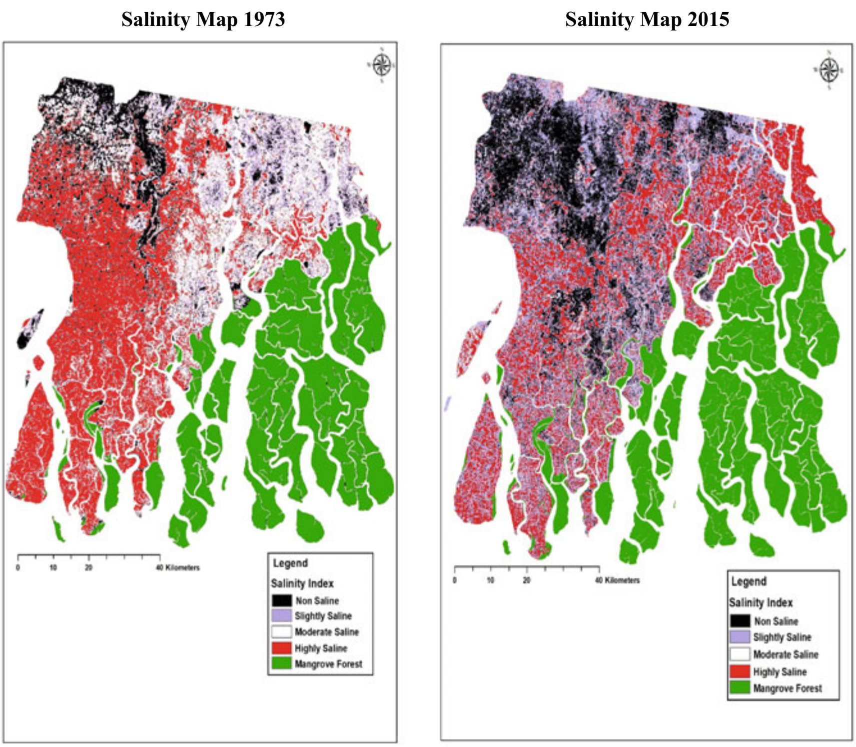


Fig. 54.4 Change in soil salinity during 1973 and 2015 in Indian Sundarbans analysed using multi-temporal Landsat imagery

2014, ranking second in the world only after China, while total fisheries production was 9.6 million tonnes (FAO 2016). This change towards shrimp cultivation has made socio-environmental impacts including loss of cropland, marginalization, rural unemployment, social unrest and conflicts, mangrove degradation, loss of biodiversity, sedimentation, saltwater intrusion and pollution and disease outbreaks. The majority of the shrimp area has gained from single cropland followed by double cropland. A gradual transformation of cropland into shrimp farming has been occurring from small-scale farmers to larger private shrimp farming in the coastal area since 1990.

The productivity of rice declined as encroachment of shrimp farming has led to saltwater intrusion in rice fields through seepage or breaching the embankment. Prolonged shrimp farming had increased soil salinity, acidity and depleted soil Ca, K, Mg and organic C to variable degrees; these have caused soil degradation that has reduced rice yield considerably (Ali 2006). High tides and rise in sea level would certainly threaten shrimp cultivation both inside and outside embankments. The issues of shrimp farming and associated land use changes with respect to competitiveness with rice cultivation and encroachment of mangrove areas, ecological changes and social contestation have been considered as a challenge for decision-making and policy formulation. Therefore, shrimp farming needs a holistic management scheme and has to be developed as part of a comprehensive integrated coastal zone management plan in the country (Afroz and Alam 2013).

For long-term planning, understanding the rate and spatial pattern of emerging new land and sustainable use of this land for agriculture, forestry, livestock and fisheries is indispensable. Here, the accreted lands were found to transform into single and double croplands or under aquaculture. The newly accreted soils are rich in nutrients, but the damage of ripened crops and loss of lives and properties from cyclonic storms are not uncommon. Under such situations, several measures have been suggested including plugging of the breaches and strengthening of the dykes along the coastal belt to arrest erosion and accelerate accretion and developing of tools of predicting morphological changes in response to the relative sea level rise.

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References

Afroz T, Alam S (2013) Sustainable shrimp farming in Bangladesh: a quest for an integrated coastal zone management. Ocean Coast Manag 71:275–283. https://doi.org/10.1016/j.ocecoaman.2012.10.006

Ali AMS (2006) Rice to shrimp: land use/land cover changes and soil degradation in Southwestern Bangladesh. Land Use Policy 23:421–435. https://doi.org/10.1016/j.landusepol.2005.02.001

Chander G, Markham BL, Helder DL (2009) Summary of current radiometric calibration coefficients for landsat MSS, TM, ETM+ and EO-1 ALI sensors. Remote Sens Environ 113:893–903

FAO (2016) The state of world fisheries and aquaculture 2016. Contributing to food security and nutrition for all. Food and Agriculture Organization, Rome

Islam RM, Miah MG, Inoue Y (2016) Analysis of land use and land cover changes in the coastal area of Bangladesh using landsat imagery. Land Degrad Dev 27:899–909

Jangir B, Satyanarayana ANV, Swati S et al (2016) Delineation of spatio-temporal changes of shoreline and geomorphological features of Odisha coast of India using remote sensing and GIS techniques. Nat Hazards 82:1437–1455

Mandal UK, Nayak DB, Samui A et al (2018) Trend of sea-level-rise in West Bengal coast. J Indian Soc Coastal Agric Res 36(2):64–73

Quader MA, Agrawal S, Kervyn M (2017) Multi-decadal land cover evolution in the Sundarban, the largest mangrove forest in the world. Ocean Coast Manag 139:113–124

Rahman AF, Dragoni D, El-Masri B (2011) Response of the Sundarbans coastline to sea level rise and decreased sediment flow: a remote sensing assessment. Remote Sens Environ 115:3121–3128

Samanta B (2018) Population growth in Sundarban region-a spatio-temporal analysis. Scholars J Arts Humanit Soc Sci 6(4):877–883

Chapter 55
Application of Geotextiles for Protection Against Coastal Erosion

Tapobrata Sanyal

Abstract Protection of the coast against erosion is an important component of coastland management. Waves, littoral drift, storm surges and sea-level rise coupled with anthropogenic activities near-shore such as dredging are the main causes of coastal erosion. Geotextiles (GTs) made from thermoplastics (synthetic) belong to the group of planar textile fabrics used usually in or on the soil to improve its engineering performance. Synthetic geotextiles have been in use to protect coasts for the last 5/6 decades effectively in developed countries. The USP of synthetic geotextiles is its long-term durability, high tensile strength and felicity in making customized fabric and economy. For geotextiles to perform efficiently, they must satisfy site-specific mechanical, hydraulic and durability requirements. The long-term behavior of geotextiles against mechanical stresses in a site-specific hydraulic environment can be pre-assessed in the laboratory. Synthetic geotextiles singly may not, however, protect a coast subject to severe erosion for which offshore structural intervention in addition to robust on-coast geotextile protection may be necessary. Innovative forms of geotextiles such as geo-tubes/geo-containers are also used in appropriate cases in place of simple geotextile fabrics. Eco-concordance of polymer-based geotextiles is not, however, without question. It is worth exploring if mangroves can be nurtured along coasts concurrently with synthetic GTs to protect coastland against erosion. Mangroves with their stilt roots can hold coastal soil, can induce accretion of silt over coasts when silt-laden seawater passes through their root system and can attenuate wave impact.

Keywords Coastal erosion · Coastal protection · Geosynthetics · Geotextiles · Mangroves · Soil stability

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55.1 Introduction

55.1.1 Coastal Erosion and Its Causes

Protection of the coast against erosion is an important component of coastland management. Man has been trying to protect the coast since ages against ravages caused by sea-borne erosive forces with the help of available natural resources. Attempts to protect the coast by using natural implements in the past, however, did not sustain as such measures were more instinctive in nature and empirical than scientific. On top of it, processes of erosion in sea-coast and the behavior of coastal soil against such erosive forces of nature were not precisely known in the past. Waves driven by wind and propelled by the movement of ships veering past the coast, the orientation of oceanic currents—principally littoral (along-shore) currents, and occasional storm surges resulting from tectonic disturbances such as tsunami are palpable causes behind erosion in the coast. Sea-level fluctuation due to diurnal/semi-diurnal tides caused as a result of global warming disquiets coastal equilibrium. The development of high pore-water pressure within coastal soil also affects coast-soil stability.

Oceanic environment being highly dynamic warrants careful observation over a sufficient period of time for identification and estimation of the erosive forces responsible for coastal erosion at a particular site. On coasts verdant with aquatic vegetation such as mangroves, the problem of erosion is markedly less. Besides attenuation of wave impact, root-webs of mangroves facilitate part of sea-borne sediment to accrete over shore when silt-laden brackish water flows through them, largely compensating soil loss caused as a result of erosion. Additionally, anthropogenic interventions may affect coastal stability. Offshore structures help re-orient wave and current behavior of the coast. Deepened sea-bed profile caused by dredging near-shore could also affect the impact of waves and current on the coast.

55.1.2 Remediation of Coastal Erosion by Use of Geotextiles

Over the years man has gained precise knowledge about the nature and intensity of sea-borne erosive forces and the behavior of varying kinds of coastal soil against them. It now stands established that the best approach to control coastal erosion should be two-pronged-first, to adopt measures to lessen the effects of such erosive forces on the coast by structural interventions and secondly, to devise contrivances for retention of coastal materials in place and to dissipate pore-water pressure developed within coastal soil that could disquiet its stability. The development and application of geotextiles address these dual objectives.

In this paper, an attempt has been made to present the basic design approach underlying use of geotextiles in combating coastal erosion without going into engineering design intricacies considering the fact that the target readership comprises mostly agricultural scientists/researchers and fiber technologists.

55.2 Geotextiles

Geotextiles are basically breathable fabrics made of either artificial fibers or natural fibers. This discussion is confined to artificial geotextiles made from thermoplastics such as polyamide, polyester, polyethylene, polypropylene, commonly known as 'synthetic geotextiles' or 'geosynthetics' in view of the fact that natural geotextiles made usually of jute or coir fibers degrade quickly especially when exposed more so in saline ambience and are far less durable than their synthetic counterpart in general. Moreover, most of the natural fibers are too coarse to make fabrics that conform to the precise design pore size (AOS, i.e., apparent opening size) and strength. In this paper, the term 'geotextiles' has been used to denote polymer-based synthetic geotextiles only.

It needs mention that any geotextile fabric, natural or polymeric, has three constructional variants, viz., woven, non-woven, and open-weaved (knitted). Woven geotextiles are the strongest and most durable of the three variants. Considering the intensity of erosive forces (also called loads) in the coast, woven geotextiles are invariably used as a protective cover over eroded/erosion-prone coast.

Three criteria are critical in the design of geotextiles. These are durability, tensile strength and the desired pore size. The principal functions of a geotextile are separation, filtration, drainage and reinforcement. Fabric-permeability is a critical criterion in the design of a site-specific geotextile for the proper performance of filtration function.

Filtration is the most important function of geotextiles. This implies that the fabric is supposed to retain coastal materials in place on the one hand and on the other has to facilitate dissipation of pore-water pressure generated within the coastal soil under protection. Prima facie, the aforesaid two functions, may appear to be in contrast in as much as retention of coastal materials calls for smaller fabric pore size in keeping with an average grain size diameter of coastal soil whereas pore-water dissipation requires bigger fabric-openings for release of excess pore-water pressure from coastal soil. Rigorous research in the field has led to the development of valid test-procedures to satisfy both the criteria with optimized porometric features of geotextile fabric in relation to the average grain size diameter of coast-soil particles and estimated pore-water pressure, besides conforming to the criterion of strength and allied properties.

Woven geotextiles possess higher abrasive, puncture and tearing resistance and tensile strength than the non-woven type. Non-woven type, however, being more permeable than the woven variant possesses higher filtration efficiency. It is for this reason, sometimes, both types are used in conjunction in cases where both strength and more efficient filtering capability of a geotextile are simultaneously required.

Basically, geotextiles are used in or on the soil to improve its engineering performance. Improved engineering performance implies enhanced capacity of soil to remain stable under the impact of different kinds of pre-estimated imposed loads. Fundamentally, the role of geotextiles is that of a change agent that helps in building up 'effective stress' in the soil to be protected. Effective stress is a condition of the soil that maximizes its resistivity against the impact of loads. Simply stated, it is a factor of compactness of soil particles that can be attained by ensuring adequate filtration. Proper filtration removes inter-particulate voids between soil particles, thus making it compact with soil particles touching each other and thus generating effective stress within the soil mass.

To ensure efficient performance by a geotextile, in-situ mechanical, hydraulic and durability criteria must be known and addressed (Van Zanten 1986). The long-term behavior of geotextiles against mechanical stresses in a site-specific hydraulic environment is pre-assessed in the laboratory.

However, it should be noted that geotextiles singly may not always protect a coast subjected to severe erosion. In moderate cases of coastal erosion, the fabric is overlain by revetment (also called 'riprap' or 'armor') made of stone boulders/concrete blocks to withstand the initial impact of the imposed forces such as current and waves and to prevent washing away of coast-soil and resist uplift caused by seepage flow. Stones of high specific gravity and individual weight are recommended for constructing revetments. In extremely severe cases, protective structures such as offshore break-waters and spurs may have to be built for repulsion of currents away from the coast or for diverting current to a safer direction. Geotextiles are sometimes put to use in such structures appropriately for strengthening them.

Two mechanical criteria for geotextile fabric overlain by riprap deserve consideration (Lawson 1992). These are mass per unit area and trapezoidal tear resistance. ASTM standards exist for these two criteria. For hydraulic criteria, the orientation of flow and wave activity at the site is to be considered. In the event where varying hydraulic flow patterns are to be encountered, selection of a geotextile should be done on a conservative basis keeping higher tolerance limits for deciding its specification. The fundamental design principle is that the geotextile should be able to resist the maximum estimated imposed loads including chemical and biological loads during its design service life. In other words, the strength of the chosen geotextile should remain higher than the estimated occurring loads. Additionally, care must be taken to ensure that the geotextile does not turn out to be a plane of sliding.

To pre-estimate, the occurring loads, the oceanic environment at the site should be assessed properly. Data on waves and currents, especially wave heights, current orientation and its celerity, sea-level fluctuations vis-à-vis mutating ground-water level over a period of time, sub-soil characteristics such as plasticity, cohesiveness, permeability, angle of internal friction and grain size diameter, must be considered by the designer. On top of these, at sites where ship movements induce considerable waves, data on ship traffic, ship velocity and ship size may be necessary. The specifications of geotextiles to be used for coastal protection should be selected taking into account its strength, durability and filtration efficiency against occurring loads. Understandably, the design of geotextiles in a dynamic coastal environment demands specialized engineering knowledge and experience.

Selection of anappropriate geotextile product for a specific application should be matched by strict quality control over the manufacture of the recommended geotextile in the factory as well as work execution at the site. For coastal application, comparatively heavy types of geotextiles with high tensile strength and adequate resistance against puncture and abrasion are usually recommended. As already indicated, in cases where woven geotextiles do not singly meet the filtration requirements, the non-woven variety of appropriate specifications should be used in conjunction with its woven counterpart.

Apart from the design criteria stated above, two other probable pos-application conditions of geotextile fabric that deserve attention are 'clogging' and 'blocking'. Clogging is caused by extraneous deposits within the fabric-thickness, while blocking is blockade caused by the accumulation of extraneous particles on the fabric surface. Clogging and blocking of any woven geotextile fabric understandably affect filtration efficiency. Susceptibility of a woven geotextile to clogging and blocking can be predicted by conducting gradient ratio test (ASTM D 5101)/hydraulic conductivity ratio test (ASTM D 5567) prior to application.

As indicated, the use of geotextiles in tackling coastal erosion is not always confined to their use singly as fabric with only revetment (riprap) overlying it for preventing their displacement against various erosive agents and seepage uplifts. Various innovative forms of geotextiles have been developed over the years that can be put to use effectively to control severe coastal erosion if the situation so demands.

55.3 Innovative Forms of Geotextiles

Several innovative forms of geotextiles have since been developed beyond its conventional form as fabric. Mention may be made of sand-filled geo-tubes, geotextile containers, poly-felts (multi-layered filters), rope-gabions, etc., as tools against severe erosion. In cases where the use of geotextile as the fabric is not considered sufficient, these innovative variants are sometimes used considering the extent of the severity of coastal erosion. Geo-tubes filled with suitable granular materials are used as scour apron on sea-bed and as ingredients for constructing dykes/spurs. Geo-tubes are sometimes filled by pumping dredge-spoils directly from a dredging site if it is close to the coast. Large-volume geo-containers are sometimes used as components of offshore structures in cases of severe coastal erosion. Precise placement of geo-tubes/geo-containers on the coast or for building offshore constructions calls for support of appropriate constructional facilitators. For the construction of some types of offshore structures, geo-bags containing suitable granular materials are stacked in convenient geometric shapes by placing them one above the other as is done in the case of stacking of cement/grain-filled bags. In India, such innovative forms of geotextiles have been sparingly used so far. Details of such innovative variants and their specific applications have been avoided for the space-limitation of this paper.

55.4 First Trial with Geotextiles

The first physical trial with geotextiles was undertaken in the Netherlands in the 1950s to protect the coast against massive erosive forces of the North Sea. This gigantic project was a concerted effort of hydraulic engineers, researchers, fabric engineers and construction experts of the country. The success of this application led other developed countries to try the product. In fact, global interest in geotextiles ensued after the success of the trial leading to increased activity in research, innovation and application of geotextiles in various fields of civil engineering where soil poses problems.

The use of geotextile mattresses on riverbed in the Hugli estuary opposite Haldia for construction of a 2.8 km long massive guide-wall at the northern tip of Nayachar island (opposite Haldia docks) was successfully carried out by the Kolkata Port Trust with technical support from the Dutch Government for the first time in the country in the late 1980s. The mobile riverbed was found destabilizing the massive wall being built over it, and the geotextile mattresses were used to stabilize it (Sanyal 1991a).

55.5 Eco-Compatibility of Geotextiles

Geosynthetics, however, do not possess full-proof eco-concordance which has led to increasing adoption of natural geotextiles (usually made of jute and coir) in areas calling for less severe technical requirements. Questions have been raised by environmentalists about the behavior of polymeric-derivatives staying within or on soil for years. Doubts remain to be cleared convincingly so far.

55.6 Mangroves and Coastal Erosion

Mangroves deserve consideration by experts for coastal protection in the context of environmental preservation. The ability of mangroves to protect coastland stands substantiated by studies. It is worth exploring if mangroves can be nurtured along coasts concurrently with geotextiles to protect coastland against erosion. Mangroves with their stilt (knee) roots can hold coastal soil and at the same time can induce accretion of silt over coasts when silt-laden seawater passes through their rootsystem. Mangroves can attenuate wave impact to a good degree. There are about 64 varieties of mangroves with varying degrees of salt tolerance and growth rate. It is advisable to consult agriculture experts to decide on the choice of the right type of mangrove species for a particular site (Sanyal 1991b).

Mangroves thrive in coastal swamps and inter-tidal brackish water zones, especially along sea-coasts and estuarine reaches where the coast is alternated by wetting during tides and drying during ebbs at a regular periodicity. The plant has special characteristics inherent in them to sustain and grow in such an environment. There are other factors that determine the expanse of a mangrove forest such as inter-tidal reach, soil substrata, extent of salinity of soil and water and period of inundation. It has been noticed in initial studies that mangroves can dissipate wave energy by about 40%.

55.7 Conjunctive Use of Geotextiles and Mangroves

It is worthwhile to explore if mangroves can be grown on the coasts in association with geotextiles. The bio-engineering approach could compensate to a good extent the eco-discordance caused by geotextiles. To ensure conjunctive use of mangroves and geotextiles, perforations may be made in the geotextile fabric to plant mangrove-saplings through them following a pattern and spacing that will allow uninhibited growth of each plant. The resultant effect of the combination demands careful in-situ study and subsequent refinement of the plantation technique. The author advocates a physical trial and study with these two anti-erosion tools, one natural (mangroves) and the other artificial (geotextiles) under the close technical surveillance of a competent research outfit.

55.8 Conclusions

Till such time a fully eco-compatible solution is found, and geotextiles with their variants remain to be the only plausible answer to the problem of coastal erosion. Despite questions about doubtful eco-concordance of geotextiles, their effectiveness in addressing geotechnical problems of various natures and degree stands established beyond question due to validation by physical applications, intensive study and continuing research. Besides, the aspect of the economy and easy availability cannot also be ignored. Conjunctive use of geosynthetics and mangroves, if successful in controlling coastal erosion, will dispel reservations about the man-made product's eco-incompatibility and promote its wider acceptability.

References

Lawson CR (1992) Geotextile revetment filters. Geotext Geomembr 11:431–448

Sanyal T (1991a) Laying of geomattresses for bed-protection in the river Hugli—a case study. Geotext Geomembr 10(4):357–377. https://doi.org/10.1016/0266-1144(91)90011-K

Sanyal T (1991b) Mangroves in control of bank-erosion—a pilot scheme in Nayachar island. In: Proceedings of the national seminar on conservation and management of mangrove ecosystems with special reference to Sundarbans, Bidhan Chandra Krishi Viswavidyalaya, Mohanpur, West Bengal, India, 6–8 Dec 1991

Van Zanten VR (ed) (1986) Geotextiles and geomembranes in civil engineering. Wiley, New York, p 658

Chapter 56
Efficacy of Jute Geotextiles in Mitigating Soil-Related Problems Along with a Few Case Studies

P. K. Choudhury and Koushik Das

Abstract The environment around the globe is governed by three main basic elements, viz., soil, water and air. The natural environment is progressively transformed by human beings with indiscriminate deforestation, ever-expanding urbanization, building large industrial projects, use of non-biodegradable materials, etc. In order to combat the situation for restoration of environmental ecosystem through application of bio-engineering approach is a proven cost-effective method and can conveniently be adopted as remedial measures. With the growing awareness for the protection of environment, the scientists and technologists have developed new products which are eco-compatible and biodegradable. In this respect, use of jute geotextile (JGT), made out of 100% natural jute fibres, has been found to be quite effective for protection of surface soil erosion, stabilization of earthen slope and overburden dumps, road construction, river bank protection including growth of seedling/sapling in forest and other nurseries. The products have been standardized by BIS and application guidelines have also been published by the competent authorities of state and central government departments. Many departments have included JGT as an item of work in their schedule of rates. Total number of successful field applications as of date is more than 800 in India. The products so long were found to be highly effective in normal soil and climatic condition. Interesting, JGT was also found equally effective in difficult soil with high salinity in and around Sunderbans area in coastal region of West Bengal where the materials were used for construction of *Aila*-affected flood embankment, road construction in Patharpratima and elsewhere, river bank protection in Kakdwip, growth of mangrove seedling/sapling at Canning, Basanti and Gosoba, construction of rainwater harvesting tank at Sagar Island, etc. JGT is one of the low-cost technologies for protection of environment in mitigating soil-related problems. Properties of jute, JGT and method of application along with its effect substantiated with some case studies have been discussed in this paper.

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Keywords Jute geotextile · CBR · Mangrove · Sapling · Erosion · Sub-grade · Eco-friendly

56.1 Introduction

Restoration of environmental ecosystem, particularly in the field of geotechnical engineering, is a matter of utmost importance in the context of present stint. In order to mitigate the problems, both synthetic and natural geotextiles are widely used worldwide. The synthetic geotextiles owe their origin to natural components like tree-shreds, reeds that were used to combat soil erosion in earlier days. The Netherlands pioneered the use of polymers in making of synthetic geotextiles way back in 1953. Research, studies and field application of man-made geotextiles developed for a variety of geotechnical applications have paved the way for development and standardization of the products and their ultimate acceptability to the engineers using them. However, durability of synthetic geotextiles and their probable immiscibility with soil on which they are laid leaves room for doubt about their eco-compatibility. It is this aspect that bestows preponderance on jute geotextile (JGT) over its artificial counterpart. The intrinsic properties like flexibility, drapability, high initial strength, low extensibility, etc., of 100% natural jute fibre-made jute geotextile an ideal alternative to synthetic geotextiles in addressing majority of geotechnical applications. Extensive studies on development and application of jute geotextile were taken up since mid-1980s. The products are eco-compatible as well as biodegradable and have been found to be quite effective in mitigating host of soil-related and alike problems for protection of surface soil erosion (Rickson 1988), stabilization of earthen slope and overburden dumps through bio-engineering technique (Howell et al. 2006), road construction, river bank protection including growth of seedling/sapling in forest nurseries and many more. Efficacy of JGT has been well established from the encouraging results of field applications. The products are standardized by Bureau of Indian Standards (BIS 2001) and application guidelines have also been published by the competent authorities of state and central government departments. Number of departments has also included JGT as an item of work in their schedule of rates. Total number of successful field applications as of date is more than 800 in India. So long, JGT was found to be highly effective in normal soil and climatic condition. But it was also found to be equally effective in difficult soil having moderate salinity (15–25 ppt) in and around Sunderban areas in coastal region of West Bengal where the materials were used for construction of *Aila*-affected flood embankment, road construction in Patharpratima and elsewhere, river bank protection in Kakdwip, growth of mangrove seedling/sapling at Canning, Basanti and Gosoba, construction of rainwater harvesting tank at Sagar Island, etc. JGT is one of the low-cost technologies for protection of environment in mitigating soil-related problems (National Jute Board 2015). The properties of jute and JGT, its method of application along with effect have been discussed in this paper substantiated with some case studies.

Table 56.1 Chemical composition of jute fibre

Constituents	%
Cellulose	60–62
Hemicellulose	22–24
Lignin	12–14
Others	1–2

Table 56.2 Properties of jute fibre

Physical properties	Values
Specific gravity (g cc^{-1})	1.48
Swelling in water (area wise)	40%
Water retention	70%
Specific heat (Cal g^{-1} $°C^{-1}$)	0.324
Thermal conductivity (Cal s^{-1} cm^2 $°C^{-1}$ cm^{-1})	0.91×10^{-4}
Ignition temperature (°C)	193

56.2 Chemical Composition and Properties of Jute Fibre

Jute is a natural ligno-cellulosic bast fibre grown abundantly in eastern India, Bangladesh, China, Burma, Thailand, etc. The matured jute plant with a height of about 3 m is cut and sun-dried in the field. The plants with shaded leaves are tied in bundles and immersed in mild flow water for about 2 weeks for retting. The fibres are extracted from the plant, washed in clean water and sun-dried to make it ready for use. Jute cultivation has an additional advantage. Study reveals that during 100 days of jute cultivation, 1 hectare of jute plant can absorb about 15 MT of CO_2 and liberate about 11 MT of O_2. The fibres are then mechanically processed in jute mills to manufacture fabric (JGT) having specific physical, mechanical and hydraulic properties suitable for use in geotechnical field of engineering. The constituents of jute fibre are mainly cellulose, hemicellulose and lignin. The chemical composition of jute fibre and their properties are shown in Tables 56.1 and 56.2. The jute fibre would be suitable for manufacturing geotextiles when it possesses suitable mechanical and hydraulic properties. Unique features of jute enabled to design and manufacture right type of JGT suitable for mitigating soil-related problems naturally. The comparative properties of different fibres are given in Table 56.3.

56.3 Jute Geotextiles (JGT)

JGT is a permeable textile fabric available in woven, non-woven and open-weave forms used in or on soil to improve its engineering performance. Woven JGT performs the functions of separation, filtration, initial re-enforcement and drainage when used

Table 56.3 Comparative properties of different fibres

Type of fibre	Tenacity N/tex	Extension at break (%)	Initial modulus N/tex	Volume swelling %	Moisture regain %	Lignin content %
Jute	0.3–0.9	1–1.8	17–19	44.3	12–14	12–14
Coir	0.18	41–45	4.22	–	10	30
Sisal	0.37–4.7	1.9–4.5	25–26	39.5	11–14	9.9
Polyester	0.3–0.8	15–55	6–12	–	0.4–0.6	Nil
Polypropylene	0.3–0.8	15–35	2–9	–	< 0.1	Nil

in the interface of road sub-grade and sub-base, thereby helps soil consolidation and increases the California Bearing Ratio (CBR) value. Properly designed woven JGT with appropriate porometry (O95) treated with suitable additives is used as filter material in river bank protection. Open-weave JGT when laid on the denuded surface of vulnerable slopes arrests dislodged soil particles to flow downward during runoff and finally helps quick grow of vegetation and stabilize the slope with bio-engineering intervention. Jute sapling bags, as an alternative to synthetic poly bags, are tailor-made products used to grow saplings in the nurseries. Growth and survival rate of sapling in jute bags are higher than poly bag. On transplantation of saplings in jute bags on to the ground, jute degrades and mixes with soil leaving no hazardous item causing pollution to the environment.

56.3.1 Types of Jute Geotextiles and Their Specifications

JGT is a tailor-made product. Site-specific products can be manufactured depending upon end-use requirements. Woven JGT like 627gsm of 20 kN m^{-1} and 724 gsm of 25 kN m^{-1} are in use for river bank protection work and road construction work, respectively, which are cost-effective and technically suitable for their specific uses. Open-weave JGT of three types, viz., 730 gsm, 500 gsm and 292 gsm are used for erosion control and slope protection purpose depending upon gradient of slope and soil properties. The specifications of woven JGT and open-weave JGT are given in Tables 56.4 and 56.5.

56.3.2 Technical Function of JGT

It is well known that any geotextile performs four basic functions, viz., separation, filtration, drainage and initial reinforcement. The right porometry of the fabric in commensurate with the average particle size distribution of soil and initial strength to withstand hydraulic and mechanical loads are the basic requirements of a geotextile

Table 56.4 Woven jute geotextiles

Nomenclature	Woven JGT 20 kN m^{-1}	Woven JGT 25 kN m^{-1}
Construction	DW plain weave	DW plain weave
Weight (gsm)	627	724
Width (cm)	100	100
Ends × picks (dm^{-1})	85 × 32	94 × 39
Thickness (mm at 2 kPa)	1.7	1.85
Tensile strength (kN m^{-1}) (MD × CD)	20 × 20	25 × 25
Elongation at break (%) (MD × CD)	8 × 8	10 × 10
Puncture resistance (kN)	0.400	0.500
Burst strength (kPa)	3100	3500
Permittivity at 50 mm constant head (s^{-1})	350×10^{-3}	350×10^{-3}
A O S (μ) O_{95}	150–400	150–400

Table 56.5 Open-weave jute geotextiles

Properties	Type 1	Type 2	Type 3
Weight (g m^{-2})	730	500	292
Threads/dm (MD × CD)	7 × 7	6.5 × 4.5	12 × 12
Thickness (mm)	7	5	3
Width (cm)	122	122	122
Open area (%)	40	50	60
Strength (kN m^{-1}) (MD × CD)	12 × 12	10 × 7.5	10 × 10
Water holding capacity on dry weight (%)	500	500	400

that facilitates performance of the four functions as indicated. Jute geotextile, like its man-made counterpart, can be tailor-made. The apprehension frequently expressed by engineers is about performance of jute geotextile beyond its effective life, i.e., after its bio-degradation. Case studies have confirmed findings in laboratories about catalytic function of jute geotextile and, for that matter, any geotextile in effecting improvement of engineering properties of soil for an initial period not exceeding two season cycles according to our experience. Soil gains strength in two ways basically—through separation and retention of fines on the one hand and drainage efficiency facilitated by geotextile on the other. It is an accepted understanding that riddance of water from soil imparts strength to it. It does not take more than six to seven months to optimize moisture content in soil as has been found in laboratories. In fields, the process may take a slightly longer time, but not more than two season cycles in any case. The accepted procedure in soil compaction is to ensure optimum moisture content (OMC) in soil first to achieve maximum dry density in it. It is worth mentioning here that the ingredients of jute geotextile increases permeability of soil after coalescing with it. This is a special feature of jute geotextile unmatched by other geotextile types made of other fibres—natural and man-made. We feel prompted to make mention of some important research findings of in this regard. According to the findings of Ramaswamy and Aziz (1989) soil treated with jute geotextile becomes less and less dependent on the fabric with the passage of time. Secondly, the loss in strength of jute geotextile with time is compensated by corresponding gain in strength of soil under the same time frame. Studies in Jadavpur University, India, also confirm the aforesaid findings of Ramaswamy and Aziz. Further, JGT is a highly hydrophilic and most able among all other geotextile fabrics which establish its uniqueness for surficial soil erosion and establishment of vegetation on the slope of hills and embankments.

56.4 Case Studies

56.4.1 Case Study 1

Reconstruction of 6 m high with angle of slope of 2:1 and slope length of 12 m and about 980 km long flood embankment damaged by severe cyclone *Aila* in 2009 with the use of 500 gsm open-weave jute geotextile followed by grass turfing for stabilization of slopes of earthen embankments.

Location: Janagar, Kakdwip, Gosoba, Basanti, Sonakhaliand Blocks and adjoining areas in South and North 24 Parganas Districts of West Bengal.

Description of work and impacts: The slope surface was dressed and levelled. JGT was laid side by side on the surface with an overlap of 10 cm and fixed on to the ground with bamboo peg/iron nails. The properties of JGT used for reconstruction of the earthen embankment are given in Table 56.6. Top and bottom ends were anchored in the trench (20 cm × 10 cm) dug at top and bottom line of the slope. Grass sods/seeds was spread followed by occasional watering.

At the end of six months on application of JGT, the slopes of the embankment were found to be sufficiently stable, and the entire surface was covered with vegetation (Fig. 56.1). Similar process was adopted to restore the entire flood embankment

Table 56.6 Properties of jute geotextile used

Properties/type	Type 2
Weight (g m^{-2})	500
Threads/dm (MD × CD)	6.5 × 4.5
Thickness (mm)	5
Width (cm)	122
Open area (%)	50
Strength (kN m^{-1}) (MD × CD)	10 × 7.5
Water holding capacity on dry weight (%)	500

Before use of JGT | Laying of JGT | Stabilized slope

Fig. 56.1 The jute geotextile for reconstruction of embankment damaged by cyclone

in phases. Based on encouraging results observed, Irrigation and Waterways Department of Government of West Bengal has decided to use of JGT for reconstruction of 320 km long earthen embankment damaged by another super cyclone *Amphan* in Sunderban and adjoining areas in coastal West Bengal.

56.4.2 Case Study 2

Strengthening weak road sub-grade with the use of woven jute geotextile.

Location: Jainagar, Kakdwip, Gosoba, Basanti blocks of South & North 24 Parganas Districts in coastal West Bengal.

Description of work and impacts: The pre-work sub-grade conditions indicated presence of inorganic silty clay and inorganic clay. Optimum moisture content (OMC) and maximum dry density (MDD) were 18.7% and 1.68 gm cc^{-1}, respectively. Plasticity index varied between 18.36 and 19.36, while CBR value showed an average value of 3.3%. The existing bricklayer was removed from the unpaved road surface and compacted with a power roller of 8–10 tonnes capacity after filling with local soil. JGT was laid on the compacted sub-grade longitudinally with a sideway overlap of 10 cm overlain with thin cushion of sand of 25 mm thickness. Granular subbase (GSB) I and II layers were also laid prior to applying water-bound macadam (WBM) layer. Finally, it is to be finished with 20 mm thick premixed carpeting followed by 6 mm thick bituminous seal coat (wearing course). The properties of woven jute geotextile used for strengthening weak road sub-grade are given in Table 56.7.

Post-work study was conducted by the engineers of West Bengal State Rural Development Agency (WBSRDA) when no distress of the treated road was noticed. The top surface was perfectly smooth (Fig. 56.2). Excavation is scheduled to make near the edge of the pavement for collecting soil sample from the sub-grade below the JGT layer for testing at the laboratory. The average CBR value of the sub-grade before application of JGT was 3.5%. The sub-grade is supposed to gain strength significantly (Farooq and Goyal 2017) as were found in more than 200 cases in India by application of JGT (IRC 2019). Photographs of the application are shown in Fig. 56.2.

Table 56.7 Properties of woven jute geotextile used

Properties	Value
Weight (g m^{-2}) at 20% M.R	724
Threads/dm (MD × CD)	94 × 39
Thickness (mm)	1.85
Width (cm)	100
Strength (kN m^{-1}) (MD × CD)	25 × 25
Elongation at break (%) (MD × CD)	10 × 10
Pore size (090) (μ)	300
Permittivity at 50 mm constant head (s^{-1})	350×10^{-3}
Puncture resistance (N cm^{-2})	0.500

Prepared sub-grade **JGT laid on sub-grade** **GSB laid on JGT** **WBM laid on GSB**

Fig. 56.2 The woven jute geotextile for strengthening weak road sub-grade

56.4.3 Case Study 3

Restoration work of severely eroded right bank of river using treated JGT as filter fabric.

Location: Severely eroded right bank of river Jagatdal at Uttarsurendraganj village in Patharpratima Block in South 24 Pargans District of West Bengal.

Description of work and impacts: The vulnerable bank of the river Jagatdal was about 400 m in length located at about 15 km away from Bay of Bengal. The river was tidal in nature and the bank soil was mostly clayey silt. Due to drawdown effect during recession of both high and low tides, the bank soil naturally tends to flow down to the river, causing severe erosion. The impact of wave that hugs to the bank soil was also another cause of erosion. Salinity of river water varies from 7 ppt to 20 ppt.

In order to prevent migration of soil particles from the river bank and also for providing escape routes to the confined water to neutralize the differential over pressure, jute geotextile treated with bitumen was used as filter fabric on the prepared bank-slope. JGT was covered with brick blocks as armour. The properties of jute geotextile used are given in Table 56.8.

Table 56.8 Properties of jute geotextile used

Properties	Value
Weight (g m^{-2}) at 20% M.R	760
Threads/dm (MD × CD)	102 × 39
Thickness (mm)	2.20
Width (cm)	200
Strength (kN m^{-1}) (MD × CD)	21 × 21
Elongation at break (%) (MD × CD)	10 × 10
Pore size (090) (μ)	300
Permittivity at 50 mm constant head (s^{-1})	350×10^{-3}
Puncture resistance (N cm^{-2})	0.500

No subsidence or disturbance of the protected stretch has taken place after completion of one year. There appeared to be no adverse effects on the JGT-treated bank slope. The average siltation over this period has been estimated to be around 20 cm over the armour. Site inspection was again carried out after an elapse of two years in November, 2012. No subsidence and disturbance of the armour layer were observed. Most of the treated area was covered with vegetation which ensured stabilization of bank with use of JGT (Fig. 56.3). Use of JGT in river bank protection proved to be an effective alternative to conventional methods in respect of capital investment and recurring maintenance cost. The undisturbed bank after 2 years implies that JGT performed its designated functions and helped in natural consolidation of the bank soil. Durability of JGT beyond one and half years, even under persistent flow adversities, proved to be redundant due to catalytic function of JGT.

Eroded river bank **JGT laid on sub-grade** **Stabilized slope with vegetation**

Fig. 56.3 The treated JGT for restoration of severely eroded bank of river

56.4.4 Case Study 4

Application of JGT for slope stabilization of newly constructed rain water harvesting tanks (RWHT); slope stabilization of road of embankment and growth of sapling using jute sapling bag.

Location: RWHT at Benuban, road from Chamuguri Jetty Ghat to Benuban and jute sapling bag within the premises of Gangasagar Bakkhali Development Authority (GBDA) at Sagar Island in Sagar Block of South 24 Parganas district in West Bengal.

Description of work and impacts: The dimension of RWHT was L 200 m × W 27 m × D 2 m with angle of slope of 2:1. The length of road was 800 m with a slope of 2:1. The JGT having 500 gsm and Type-2 with other specifications as shown in case study 1 was used both for stabilization of RWHT and road.

After digging the pond as per specified dimensions, the slopes of all the four sides as well as both the inners and outer side slopes were dressed, levelled and slope angle was brought to 2:1 keeping a provision of benching to retard intensity of runoff. Benching in the slope of road was not provided due to its low height. JGT was then laid along the length of the slope surface with an overlap of 10 cm and fixed on to the ground with bamboo peg/iron nails. Top and bottom ends were anchored in the trench (20 cm × 10 cm) dug at top and bottom lines of the slope. Vetiver grass was planted on the slope through the openings of JGT considering the salinity of soil for quick growth and survival, and watering was done occasionally for better effect.

About 2000 pieces of eco-friendly jute sapling bag of size 7 inches × 5 inches were used for raising sapling of Lambu (local name) plant. After filling the bags with soil, saplings were planted followed by watering once daily prior to grown up sapling to the desired height within a period of about 6 months. The saplings were then transplanted directly on to the designated ground.

Within a period of four months, after application of JGT, the slopes of the embankments were found to be sufficiently stable, and the entire surface was covered with vegetation at both the sites (Figs. 56.4 and 56.5). The performance of jute sapling bags was also found quite satisfactory in respect of growth and survival rate of the seedlings as well as saplings (Fig. 56.6). The grown up saplings were then trans-

Preparation of slope | Laying of JGT | Stabilized slope

Fig. 56.4 Application of JGT for slope stabilization of newly constructed rain water harvesting tanks (RWHT)

Eroded slope JGT laid on prepared slope Stabilized slope

Fig. 56.5 Application of JGT for slope stabilization of road of embankment

Seedling inserted Growth of sapling Grownup sapling Transplanted sapling

Fig. 56.6 Growing sapling using jute sapling bag

planted directly on to the ground without removing the biodegradable jute bag after a period of about six months.

56.4.5 Case Study 5

Use of eco-friendly and biodegradable jute sapling bag for growth of mangrove saplings under Mahatma Gandhi National Rural Employment Generation Scheme (MGNREGS) by Government of West Bengal.

Location: Canning-I, Basanti and Gosoba Blocks in Sunderbans, South 24 Parganas District, West Bengal.

Description of work and impacts: Soil of project sites at Canning, Basanti and Gosoba is generally saline in nature, having the salinity level between 25 and 30 ppt. Soil texture is mostly clayey and being saline hinders the normal growth of saplings. Jute 47 × 47 ends × picks/dm-272 gsm plain weave grey hessian fabric was used to manufacture sapling bag stitched with lock stitch industrial model sewing machine. As desired by the Department, out of total number of 13 lakhs bags, 5 lakhs bags were prepared with grey fabric having dimension of 9″ × 6″, while the remaining 8 lakhs bags were prepared with rot resistant treated fabric having dimension of 5″ × 7″. After filling the bags with soil, seeds of mangrove collected from river was inserted in it and kept for growing the seedlings and also to grow saplings. Within a period of about

Fig. 56.7 Growing mangrove sapling using jute sapling bag

four months, growth of seedlings and saplings was observed to be very satisfactory in respect of growth and survival rate. The grown up saplings were then transplanted directly on to the ground in the coastal area without removing the biodegradable jute bag (Fig. 56.7). Based on successful field trial, the MGNREGS authority decided to manufacture jute sapling bags locally to ensure employment generation for the poorer sector of the society with the technical support and guidance of National Jute Board.

References

BIS (2001) Guidelines for application of jute geotextile for rainwater erosion control in road and railway embankments and hill slopes (IS-14986)

Farooq A, Goyal R (2017) Stabilization of soil by use of geo-jute as soil stabilizer. Int Res J Eng Technol 4(8):1654–1665

Howell JH, Sandhu SC, Vyas N et al (2006) Introducing bio-engineering to the road network of Himachal Pradesh. J Indian Roads Congr 67:3

IRC (2019) Guidelines for the design and construction of low volume rural roads using jute geotextiles, Indian Roads Congress, India (IRC: SP:126-2019)

National Jute Board (2015) Case studies with jute geotextiles (JET) in rural road, river bank erosion control & hill slope management. Saraswaty Press Ltd., India

Ramaswamy SD, Aziz MA (1989) Jute geotextile for roads. In: Proceedings of international workshop on geotextiles, Bangalore, India, 22–29 Nov 1989

Rickson RJ (1988) The use of jute geotextiles in soil erosion control. In: Proceedings of fifth international soil consolidation conference, Bangkok, vol V, pp 627–633

Chapter 57
Carbon Dynamics as Influenced by Biochar Application in Ultisols (*Typic Plinthustults*) of Kerala

R. Rajakumar, S. Jayasree Sankar, and U. Bagavathi Ammal

Abstract To study the dynamics of C in lateritic soils of Kerala, an incubation experiment was conducted with three levels of biochar (5, 7.5, 10 t ha^{-1}), FYM @ 10 t ha^{-1}, soil test-based nutrient application + biochar @ 10 t ha^{-1} and soil test-based nutrient application as treatments. The treatments were imposed on the soil contained in plastic pots and incubated at field capacity moisture content for 15 months. The C fractions were determined on destructive samples at 0, 3, 6, 9, 12 and 15 months after incubation. Water-soluble carbon (WSC) and microbial biomass carbon (MBC) content increased up to 6 months of incubation and decreased thereafter. With the advancement of the incubation period, there was a decline in the organic carbon content. In the case of permanganate oxidizable carbon (POXC) and hot-water-soluble carbon (HWSC), a decreasing trend was noticed. While the highest value of WSC and HWSC were recorded with the application of FYM @ 10 t ha^{-1}, all other fractions were higher in the treatments of soil test-based nutrient application + biochar @ 10 t ha^{-1} and biochar application @ 10 t ha^{-1}. With an increase in levels of biochar, POXC and MBC contents increased. The labile C fractions were in the order POXC > HWSC > MBC = WSC. The rate of decrease in organic carbon was computed using regression analysis and found to be highest in soil test-based nutrient application. With an increase in the biochar levels, a sharp reduction was noticed in the rate of decrease. However, the application of biochar together with inorganic fertilizer sources increased the reduction in organic carbon. The study indicated that biochar application by reducing labile carbon pools and promoting the accumulation of soil organic carbon (SOC) could contribute to the sequestration of carbon in the soil. Furthermore, as an amendment, biochar is highly resistant to decomposition and

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with full of recalcitrant carbon, it can serve as a viable proposition for C sequestration in soils of the tropics.

Keywords Biochar · Lateritic soils · Carbon dynamics · Labile carbon · Carbon fractions

57.1 Introduction

Laterite and lateritic soils, classified under order Ultisols, cover nearly 65% of the total geographical area of Kerala, occupying the midland and mid upland regions. These soils are generally acidic, low in cation exchange capacity (CEC) and base saturation percentage (BSP), poor in inherent fertility and high in P fixation. The compact B horizon that inhibits root penetration, reduced soil volume, low soil organic matter (SOM) and decreased moisture retention are the major constraints to crop production which can be overcome through the application of manures, fertilizers and liming materials. Soil compaction and the high rate of mineralization under tropical situations necessitate the continuous application of organic manures and amendments. It is in this context that 'biochar' which is an amendment highly resistant to decomposition serves as a viable proposition. Biochar is defined as a C-rich product derived from the slow pyrolysis of organic material at relatively low temperatures (<700 °C) (Lehmann 2007). It possesses the ability to store C for a longer period as it is more stable in soil chemically and biologically than the source material (Lehmann et al. 2006). Production of biochar and its storage in soils has been suggested as one of the possible means of reducing atmospheric CO_2 (Clough et al. 2010; Dainy 2015; Rajakumar and Sankar 2016). Biochar's climate mitigation potential stems primarily from its highly recalcitrant nature which reduces the rate at which photosynthetically fixed C is returned to the atmosphere. Considering the possible strategies to remove atmospheric CO_2, biochar is notable, if not unique, in this regard for sequestering carbon in the soil thus mitigating climate change effects and global warming (Huang et al. 2018).

Soil organic carbon (SOC) is the largest pool of terrestrial carbon, with an average content of 1550 Pg up to 1 m depth (Batjes 1996), which is twice the amount of atmospheric pool and thrice the biotic pool (IPCC WGI 2001). Even a small manipulation in the SOC stock could significantly affect the atmospheric CO_2 concentration. Therefore, knowledge about the mechanisms of storage and organic carbon stability in soil gains greater importance. SOM contributes to the supply of nutrients, soil physical properties improvement and protection from erosion, and thus, there would be a positive correlation between SOC content and soil quality. The SOC content is strongly influenced by environmental conditions and agricultural management practices. In particular, many field experiments have shown that the management-induced changes in SOC occur more rapidly in the labile pools than in the passive pool (Graham et al. 2002). Thus, the labile carbon pools can be used as early indicators of changes in total organic matter that will become more obvious in the longer term (Gregorich et al. 1994; Bolinder et al. 1999; Paul et al. 2001; Ghani et al. 2003; Banger et al. 2010). In addition, the labile fraction has a disproportionately large effect on nutrient supplying power and structural stability of soils.

The carbon contained in biochar is by and large stable and aromatic which makes it unavailable to the microbes. But it is revealed that the metabolizable fraction of C present even in minute quantities would alter the nutrient transformation process which necessitates studying the C dynamics in soils added with biochar. While many scientists have shown interest in using biochar as an amendment in the tropical acidic lateritic soils (Dainy 2015; Rajalekshmi 2018), there is hardly any study that makes a comparative evaluation of biochar on SOC fractions in the lateritic soils. In this background, the research was undertaken to study the dynamics of carbon fractions in lateritic soil applied with different levels of biochar, with time.

57.2 Materials and Methods

57.2.1 Site Characteristics

For conducting the incubation experiment, unfertilized surface soil (0–15 cm) was collected from F block, Agricultural Research Station, Mannuthy, located in Thrissur district of Kerala state, India. The farm is located in the Agro Climatic Zone-II (Midland laterites), Agro-ecological Unit-10 (Northcentral laterites) of Kerala at 10° 32′ N latitude and 76° 10′ E longitude, at an altitude of 22.5 m above MSL. The state has a humid tropical climate with two predominant rainy seasons caused by southwest and northeast monsoon. The mean annual rainfall is 3000 mm. The annual average ambient temperature is 27.5 °C, and the relative humidity varies from 70 to 95%.

Initial characterization of the experimental soil was done by adopting the standard procedures, and the results are presented in Table 57.1. Particle size distribution was determined by the international pipette method, and the parameters like bulk density, particle density and porosity were determined by following the methods as outlined by Piper (1966). Soil pH and electrical conductivity (EC) was measured in a 1:2.5 soil–water suspension by using pH and EC meter, respectively (Jackson 1973). Cation exchange capacity of the soil was determined by the summation method given by Hendershot and Duquette (1986). Soil organic carbon was determined by the chromic acid wet digestion method as outlined by Walkley and Black (1934) and the available N was estimated by the alkaline permanganate method as per Subbiah and Asija (1956). Available P was extracted by using Bray No. 1 extractant and estimated colorimetrically by reduced molybdate ascorbic acid blue colour method (Bray and Kurtz 1945). Extraction of available K, Ca and Mg was done by using neutral normal ammonium acetate solution (Jackson 1973) and estimated by using inductively coupled plasma optical emission spectrometer (ICP-OES). Available S was extracted using 0.15% $CaCl_2$ solution and estimated turbidimetrically (Piper

Table 57.1 Initial characteristics of the experimental soil

S. No.	Properties	Values
A. Physical properties		
1	Textural class	Sandy clay loam
2	Bulk density (Mg m^{-3})	1.23
3	Particle density (Mg m^{-3})	2.27
4	Porosity (%)	47.64
B. Electro-chemical properties		
1	pH	5.24
2	Electrical conductivity (dS m^{-1})	0.053
3	Cation exchange capacity (cmol [+] kg^{-1})	3.72
C. Chemical properties		
1	Organic carbon (%)	1.55
2	$KMnO_4$–N (kg ha^{-1})	213.25
3	Bray-P (kg ha^{-1})	27.08
4	NH_4OAc–K (kg ha^{-1})	374.9
5	NH_4OAc–Ca (mg kg^{-1})	304.4
6	NH_4OAc–Mg (mg kg^{-1})	59.56
7	$CaCl_2$–S (mg kg^{-1})	12.19
8	HCl–Fe (mg kg^{-1})	17.59
9	HCl–Mn (mg kg^{-1})	46.61
10	HCl–Zn (mg kg^{-1})	4.67
11	HCl–Cu (mg kg^{-1})	2.29
12	Hot-water-soluble B (mg kg^{-1})	0.104

1966). Extraction of plant available micronutrients, viz., Fe, Mn, Zn and Cu was done by using 0.1 N HCl (Sims and Johnson 1991) and estimated by feeding the extract to ICP-OES.

The soil used in the study was sandy clay loam in texture, belonging to Velappaya series which belongs to fine loamy kaolinitic, isohyperthermic, *Typic Plinthustults* as per USDA classification. The bulk density of soil was 1.23 Mg m^{-3}, and the pore space was 47.64% pointing out the free draining nature. With respect to the pH and EC, the soil was strongly acidic and non-saline. The organic carbon content was 1.55% and the CEC was 3.72 cmol (+) kg^{-1}, which showed the dominance of kaolinite. The soil was found to be low in $KMnO_4$–N, medium in Bray-P and high in NH_4OAc–K. Among the secondary nutrients, Ca and S were found to be in the sufficient range, whereas the element Mg was deficient in the experimental soil. All the micronutrients tested, except boron were in the sufficient range (Table 57.1).

57.2.2 Biochar Used and Its Properties

Biochar used in the present study was prepared from the pyrolysis of materials with biological origin, viz., coconut shell and husk in 1:1 ratio. Characterization of biochar was done by adopting standard procedures. pH and EC of biochar were estimated using a modified dilution of 1:10 (biochar: de-ionized water) following the procedure suggested by Rajkovich et al. (2012). Analysis of C, H, N and S was carried out using a CHNS analyser (Model: Elementar Vario EL Cube). A quantity of 0.2 g sample was weighed and digested with concentrated HNO_3 in a microwave digestion system (Model: MARSX 250/40) and made up to 100 ml with double-distilled water. The acid extract was fed to ICP-OES (Model: Optima® 8 × 00) for estimating nutrient content. The cation exchange capacity of the biochar was determined using a combination of the modified ammonium acetate displacement method (Sumner and Miller 1996) and the rapid saturation diffusion method (Mulvaney et al. 2004). Bulk density, particle density and porosity of biochar was determined as per the standard method (Piper 1966). The physical, electro-chemical and chemical properties of biochar are presented in Table 57.2. The bulk density and particle density were 0.128 Mg m^{-3} and 0.833 Mg m^{-3}, respectively. The porosity value of 84.63% reflected the biochar was highly porous in nature. Regarding electro-chemical properties, pH was 10.01 revealing the alkaline nature, electrical conductivity was 3.42 dS m^{-1} and CEC 15.78 cmol (+) kg^{-1}, with K^+ and Ca^{2+} as the dominant cations. Another noticeable feature of biochar was the high content of carbon, 64.14%. Hydrogen was present in the biochar up to 2.08%. In respect of total macronutrients, biochar contained 0.567% N, 0.982% P, 4.175% K, 1.190% Ca, 0.456% Mg and 0.244% S. The material had a C: N ratio of 113:1. It also contained a significant amount of micronutrients, viz., Fe (1535 mg kg^{-1}), Mn (83.9 mg kg^{-1}), Zn (53.9 mg kg^{-1}), Cu (35.5 mg kg^{-1}) and B (55.0 mg kg^{-1}). Basicity and acidity of biochar were worked out to be 2.02 and 0.08 mmol g^{-1}, respectively.

57.2.3 Experiment Details

A laboratory incubation experiment was conducted in the Department of Soil Science and Agricultural Chemistry, College of Agriculture, Vellanikkara, Kerala Agricultural University, India, during June 2017 to August 2018. The treatments were as follows: T_1—absolute control; T_2—FYM @ 10 t ha^{-1}; T_3—biochar @ 5 t ha^{-1}; T_4—biochar @ 7.5 t ha^{-1}; T_5—biochar @ 10 t ha^{-1}; T_6—soil test-based nutrient application + biochar 10 t ha^{-1}; T_7—soil test-based nutrient application (soil test-based nutrient application consisted of 54.6, 22.2, 37 kg N, P_2O_5 and K_2O ha^{-1} and FYM 10 t ha^{-1}).

The treatments were imposed in the soil (1 kg) kept in plastic pots and after application as per the treatments, nutrients and biochar were mixed thoroughly in the soil. Distilled water was added to bring the gravimetric water content of the soil

Table 57.2 Physical, electro-chemical and chemical properties of biochar

S. No.	Properties	Values
A. Physical properties		
1	Bulk density (Mg m^{-3})	0.128
2	Particle density (Mg m^{-3})	0.833
3	Pore space (%)	84.63
B. Electro-chemical properties		
1	pH	10.01
2	Electrical conductivity (dS m^{-1})	3.42
3	CEC (cmol (+) kg^{-1})	15.78
C. Chemical properties		
1	C (%)	64.14
2	H (%)	2.088
3	C:N ratio	113: 1
4	N (%)	0.567
5	P (%)	0.982
6	K (%)	4.175
7	Ca (%)	1.190
8	Mg (%)	0.456
9	S (%)	0.244
10	Fe (mg kg^{-1})	1535
11	Mn (mg kg^{-1})	83.9
12	Zn (mg kg^{-1})	53.9
13	Cu (mg kg^{-1})	35.5
14	B (mg kg^{-1})	55.0

to field capacity, and the moisture content was maintained uniformly throughout the incubation period. The soil samples with different treatments in triplicate following a completely randomized design were maintained separately at room temperature for 15 months. Sampling was done at 0, 3, 6, 9, 12 and 15 months after incubation and analysed for C fractions. Moisture factor was computed and applied to express the results on an oven-dry basis. Labile pools of soil carbon were estimated by adopting standard procedure, which is briefed hereunder.

57.2.4 Determination of Soil Organic Carbon Fractions

Total carbon content in the soil samples was determined by dry combustion method (Lettens et al. 2007), using an elemental analyser (Model: Multi EA 4000). Water-soluble carbon (WSC) and hot-water-soluble carbon (HWSC) were estimated as described by Ghani et al. (2003). Soil samples were weighed into 100 ml polypropylene centrifuge tubes and were extracted with 30 ml of distilled water for one hour in a rotary shaker, centrifuged for 30 min at 10,000 rpm and filtered. From this, 5 ml of supernatant was pipetted into a conical flask and treated with 5 ml 0.07 N $K_2Cr_2O_7$, 10 ml concentrated H_2SO_4 and 5 ml H_3PO_4. The sample was digested at 150 °C for 30 min using a water bath; the contents were cooled by adding 200 ml of distilled water and titrated against 0.035 *N* ferrous ammonium sulphate using diphenylamine indicator. This fraction of the SOC was classified as 'WSC'. Further, 30 ml of distilled water was added to the sediments in the same centrifuge tubes and shaken on a rotary shaker for 1 min to suspend the soil in water. The tubes were capped and treated for 16 h in a hot water bath at 80 °C. At the end of the extraction period, tubes were shaken to ensure that HWSC released from the SOM was fully suspended in the extraction medium. These tubes were centrifuged for 30 min, filtered, and the carbon content was determined as in the case of WSC and classified as 'HWSC'.

Permanganate oxidizable carbon (POXC) was estimated as described by Blair et al. (1995). Finely ground samples (2 g) were taken in centrifuge tubes and oxidized with 25 ml 333 mM $KmnO_4$ by shaking for 1 h. The tubes were centrifuged for 5 min at 4000 rpm, and 0.1 ml of supernatant was diluted to 25 ml with double-distilled water; the concentration of $KMnO_4$ was measured at 565 nm wavelength using a spectrophotometer. The change in concentration of $KMnO_4$ was used to estimate the amount of organic carbon oxidized assuming that 1.0 mM of MnO_4 was consumed ($Mn^{7+} - Mn^{4+}$) in the oxidation of 0.75 mM (9.0 mg) of carbon.

Microbial biomass carbon (MBC) was measured by the chloroform fumigation extraction method as suggested by Jenkinson and Powlson (1976). Briefly, three sets of 10 g soil for each sample was weighed, of which one was used to determine the moisture content, another for immediate extraction with 0.5 M K_2SO_4 and the third one for fumigation. A beaker containing the soil sample was placed in the vacuum desiccators, the inner surface of which was lined with moist filter paper. Also, placed in the desiccators was 250 ml ethanol-free chloroform with some glass beads. The lid joint was sealed with high-density vacuum grease and the vacuum pump was run. Closed the outlet and kept the desiccators in darkness overnight at 25 °C. On the next day, the beaker containing chloroform and filter paper was removed after releasing the vacuum slowly. Back suction was given for five minutes to remove the adhered chloroform and then released the vacuum slowly. Fumigated samples were extracted with 25 ml of 0.5 M K_2SO_4 for 30 min and filtered. The supernatant collected for both fumigated and non-fumigated samples were estimated for their carbon content, and the difference in carbon content was classified as MBC.

57.2.5 Statistical Analysis

The analytical data were subjected to statistical scrutiny following the procedure outlined by Gomez and Gomez (1976), using the Web-based agricultural statistics software package (WASP) package. Correlation and regression analysis were carried out using the SPSS package. The data on labile carbon fractions were statistically analysed using analysis of variance (ANOVA) in a completely randomized design and compared by critical difference at the 5% significance level. Pearson's coefficient analysis was used for correlation.

57.3 Results and Discussion

57.3.1 Water-Soluble Carbon

WSC, the product of SOM decomposition which is sorbed on soil or sediment particles or dissolved in soil water, serve as a main energy source for the soil biota in addition to providing nutrients like N, P and S in the mineralizable form and influencing the availability of metal ions in soil by forming soluble complexes (Stevenson 1994). WSC content ranged from 92.61 to 111.5 mg kg^{-1} with the treatment FYM 10 t ha^{-1} recording the highest. Over the period of incubation, it showed an increase only up to the first 6 months which was significant, whereas the reduction noticed in the last two phases of incubation was only marginal. Irrespective of stages, the higher WSC was recorded in FYM 10 t ha^{-1}, and it was also significant (Table 57.3).

The rate of decomposition of the material determines the amount of WSC in the system. On comparing the efficacy of FYM which registered the highest value of 111.5 mg kg^{-1} with biochar, the statement gets substantiated further. The initial increase noticed for up to 6 months of incubation may be due to the increased rate of decomposition of added organic sources, and the reduction towards the fag end of incubation is directly ascribed to the reduction in the mineralization rate and also the increased consumption of WSC as an energy source by the microorganisms involved. The positive correlation observed between WSC and POXC (0.476^{**}), MBC (0.296^{**}) further supports the more intense activity of microorganisms and, thus, more decomposition of SOM and labile organic carbon (Table 57.4). Such a positive correlation of WSC with MBC has also been reported by Demise et al. (2014) and Sparling et al. (1998). Demise et al. (2014) stated that the proportion of WSC accounting for total organic carbon is lower than the other labile carbon fractions, indicating that it had been consumed by the microorganisms earlier. Moreover, in the later phases of incubation, WSC content was found to be lower in biochar-applied treatments, which can be attributed to the recalcitrant nature of biochar carbon as reported by Laird et al. (2010), Dainy (2015), Rajakumar and Sankar (2016), Rajakumar and Sankar (2019).

Table 57.3 Changes in the water-soluble and hot-water-soluble carbon content (mg kg^{-1}) of soil at different stages of incubation

Treatments	Water-soluble carbon							Hot-water-soluble carbon						
	Incubation period (months)						Treatment (T) mean	Incubation period (months)						Treatment (T) mean
	0	3	6	9	12	15		0	3	6	9	12	15	
T_1	101.8	118.4	129.6	87.27	73.53	100.5	**101.8**	439.6	296.5	308.2	184.1	219.9	302.3	**291.8**
T_2	104.0	105.6	164.3	106.2	65.06	123.7	**111.5**	506.8	434.3	360.3	177.5	281.0	376.8	**356.1**
T_3	100.3	82.46	131.4	99.10	55.58	87.76	**92.77**	470.1	288.5	332.3	236.6	263.8	254.5	**307.6**
T_4	97.41	113.8	155.1	126.3	72.86	54.19	**103.3**	479.8	282.1	322.2	236.7	301.2	356.2	**329.7**
T_5	91.89	148.0	131.6	106.9	92.38	47.24	**103.0**	502.7	282.3	348.8	250.3	155.1	265.3	**300.8**
T_6	88.56	156.0	142.6	107.5	87.14	37.40	**103.2**	523.6	280.5	354.9	299.4	216.3	318.2	**332.2**
T_7	86.61	141.0	134.5	88.91	60.67	43.94	**92.61**	417.9	367.1	322.2	230.1	178.5	345.6	**310.2**
Stage (S) mean	**95.80**	**123.6**	**141.3**	**103.1**	**72.46**	**70.66**		**477.2**	**318.8**	**335.6**	**230.7**	**230.8**	**317.0**	
	S	**T**	**T × S**					**S**	**T**	**T × S**				
CD (0.05)	4.68	5.05	12.38					13.2	14.3	35.0				

Table 57.4 Correlation between the fractions of carbon during incubation ($n = 124$)

	WSC	HWSC	POXC	MBC	OC	TC
WSC	1.000					
HWSC	0.127^{NS}	1.000				
POXC	0.476^{**}	0.471^{**}	1.000			
MBC	0.296^{**}	-0.179^{*}	0.007^{NS}	1.000		
OC	0.419^{**}	0.340^{**}	0.720^{**}	0.252^{**}	1.000	
TC	0.097^{NS}	0.298^{**}	0.425^{**}	0.006^{NS}	0.530^{**}	1.000

* Significant at 5% level of significance; ** Significant at 1% level of significance

57.3.2 Hot-Water-Soluble Carbon

HWSC is a sensitive indicator of ecosystem changes. Being a component of the labile SOM and also being closely related to soil microbial biomass and micro aggregation, it can be used as one of the soil quality indicators in the soil plant continuum. This fraction extracted after WSC, using hot distilled water, extracts soil microbial biomass, simple organic compounds and compounds which are hydrolysable under the given extraction conditions (Weigel et al. 2011). Plenty of literature designates its extraction as near to natural conditions of the ongoing mineralization process. Here also, the treatment FYM 10 t ha^{-1} registered the highest value for HWSC as in the case of WSC. The lowest HWSC was registered in control (291.8 mg kg^{-1}), which was on par with biochar 10 t ha^{-1}. However, the treatments and days of incubation had a strong effect on its content as evidenced by a decline noticed over the incubation period (Table 57.3). Considering the trends in changes in the contents of WSC and HWSC on incubation, it can be said that the HWSC which constitutes the soil microbial biomass, simple organic compounds and easily hydrolysable carbon might have decomposed and converted into WSC. This may be the reason for the decline in HWSC carbon over incubation and the corresponding increase in the WSC. Similarly, Demise et al. (2014), Sandhu et al. (2017) and John (2019) also suggested that the decline in the HWSC with the advancement of incubation can be related to the increase in the WSC content. The results of correlation analysis revealed a positive relationship between the hot-water-soluble carbon and organic carbon (0.340^{**}), total carbon (0.298^{**}), NH_4-N (0.303^{**}) and total N (0.292^{**}), which showed its influence on the process of mineralization and capacity as a tool for determining the easily available pool of mineralizable N. This is in agreement with the findings of John (2019), wherein a positive correlation was obtained between the HWSC and organic carbon, total carbon, NH_4-N and total N.

Both the WSC and HWSC were found to be higher with the application of FYM 10 t ha^{-1}, which indicated the rapid decomposition of FYM as compared to biochar-treated soil. Comparatively, a lower amount of WSC and HWSC in the biochar treatments shows the accumulation of organic carbon with the biochar application. Jiang et al. (2006), Demise et al. (2014) have described that the high proportion of labile organic carbon accounting for TOC would be detrimental to soil quality to some degree. This statement promotes biochar as a suitable amendment for the accumulation of organic carbon in tropical soils, wherein the decomposition is very high.

57.3.3 Permanganate Oxidizable Carbon

The next in the series of labile carbon fractionated was the POXC, which encompasses all readily oxidizable organic components including humic materials and polysaccharides, which generally accounts for 5–30% of SOC (Blair et al. 1995; Blair 2000; Gragham et al. 2002). This is usually extracted using a weak $KMnO_4$ solution (333 mM). Culman et al. (2012) stated that the POXC was closely related with the smaller and heavier particulate organic carbon, indicating that POXC reflects a relatively stabilized pool of active soil carbon. From the results given in Table 57.5, it could be inferred that the POXC content showed a significant decrease with the advancement of incubation, where it reduced to 890.2 from 1549.8 mg kg^{-1} recorded at the start of incubation, irrespective of treatments. The POXC content registered was comparable in respect of soil test-based nutrient application, soil test-based nutrient application + biochar 10 t ha^{-1} and biochar 10 t ha^{-1}. The soil alone treatment, i.e., the control, registered the lowest value for POXC. An increase in biochar level brought about an increase in the content of POXC also. Unlike WSC and HWSC, a continuous reduction was noticed in the content of POXC during incubation. The decrease was significant at every stage of incubation in the case of biochar 10 t ha^{-1}, soil test-based nutrient application + biochar and soil test-based nutrient application treatments.

Though there was a declining trend in the concentration of POXC, the application of biochar at higher doses recorded higher POXC values in all the stages of incubation, followed by FYM application. This is because of relatively higher labile carbon inputs associated with these organic manures. Demise et al. (2014) reported that the higher labile carbon input associated with biochar application resulted in a higher lability index, indicating that POXC is a sensitive indicator in soil quality for soil management. Higher POXC content recorded with biochar application in this experiment confirmed the positive effect of biochar on soil quality.

To ascertain the effect of the incubation period over the POXC content, a simple regression analysis was carried out, which revealed that in all the treatments, the days of incubation had a significant effect on the POXC content (Table 57.6). On comparing the treatments, the control recorded the maximum rate of decrease, whereas the minimum rate of decrease of 0.993 mg kg^{-1} day^{-1} was associated with soil test-based nutrient application. With an increase in biochar levels, the rate of decrease in POXC got reduced. It was further noticed that when the biochar and FYM were applied along with NPK fertilizer, there was a sharp reduction in the rate of decrease as compared to their sole application. For example, when the soil was treated with biochar 10 t ha^{-1}, the rate of decrease was 1.293 mg kg^{-1} day^{-1},

Table 57.5 Changes in the permanganate oxidizable carbon (POXC) and microbial biomass carbon content (mg kg^{-1}) of soil at different stages of incubation

Treatments	Permanganate oxidizable C							Microbial biomass carbon						
	Incubation period (months)						Treatment (T) mean	Incubation period (months)						Treatment (T) mean
	0	3	6	9	12	15		0	3	6	9	12	15	
T_1	1449.4	1400.5	1350.8	826.8	647.1	760.6	**1072.5**	64.82	77.21	103.77	92.95	79.61	64.02	**80.40**
T_2	1520.1	1507.5	1421.5	1221.5	876.8	849.2	**1232.8**	68.60	98.51	172.95	93.67	104.22	96.07	**105.67**
T_3	1538.0	1436.8	1452.5	949.3	868.6	825.6	**1178.5**	69.30	78.36	129.57	120.34	92.53	144.54	**105.77**
T_4	1568.2	1561.1	1399.9	1103.1	1084.3	820.9	**1256.3**	67.36	87.27	126.16	117.27	105.18	169.87	**112.19**
T_5	1591.1	1429.8	1414.6	1442.3	1316.3	857.7	**1342.0**	73.00	115.79	228.34	105.48	150.55	125.86	**133.17**
T_6	1626.2	1478.2	1445.2	1187.6	1315.6	1086.6	**1356.6**	78.05	113.79	187.44	100.96	115.08	113.53	**118.14**
T_7	1555.5	1448.5	1444.5	1387.0	1299.4	1030.8	**1360.9**	72.68	137.13	285.46	108.53	104.20	109.35	**136.22**
Stage (S) mean	**1549.8**	**1466.1**	**1418.4**	**1159.7**	**1058.3**	**890.2**		**70.54**	**101.15**	**176.24**	**105.60**	**107.34**	**117.61**	
	S	**T**	**T x S**					**S**	**T**	**T x S**				
CD (0.05)	29.6	32.0	78.4					6.15	6.65	16.28				

Table 57.6 Simple regression analysis between POXC (Y) and days of incubation (X)

Treatments	R^2	a (intercept)	Rate of change (mg kg^{-1} day^{-1})
Control	0.822**	1517.4	– 1.977
FYM 10 t ha^{-1}	0.897**	1621.8	– 1.729
Biochar 5 t ha^{-1}	0.871**	1590.6	– 1.832
Biochar 7.5 t ha^{-1}	0.930**	1646.5	– 1.735
Biochar 10 t ha^{-1}	0.681**	1626.3	– 1.263
Soil test-based nutrient application + biochar 10 t ha^{-1}	0.790**	1602.5	– 1.093
Soil test-based nutrient application	0.768**	1584.4	– 0.993

** Significant at 1% level of significance

which got reduced to 1.093 mg kg^{-1} day^{-1} when the biochar was applied with soil test-based nutrient application. This is in agreement with the findings of Manna et al. (2007), who reported a sharp decrease in POXC content when inorganic N was combined with carbon-rich material. The addition of carbon-rich material together with easily available inorganic N sources would have helped in the proliferation of soil microorganisms, resulting in faster depletion of labile carbon pool. The result was further confirmed by obtaining a significant and positive correlation with all the carbon fractions studied, namely WSC, HWSC, organic carbon and total carbon and also with nitrogen fractions.

57.3.4 Microbial Biomass Carbon

In any soil, the microbial biomass is a key component because it defines the functional component of the soil biota which are primarily responsible for decomposition, SOM turnover and nutrient transformations (Smith and Paul 1990; Witter 1996). According to Gil-Sotres et al. (2005), MBC can be used as an approach to evaluate soil quality. Microbial biomass also is a transformation matrix for all natural organic materials in the soil and act as a labile reservoir of plant-available nutrients (Jenkinson and Ladd 1981). MBC is a measure of carbon contained within the living component of SOM, consists of bacteria and fungi and makes up about 1–5% of the total SOC. From the results (Table 26.5), it could be inferred that MBC was lowest in soil alone treatment, whereas it was highest in soil applied with soil test-based nutrient application and biochar at 10 t ha^{-1}. Similar positive effects of biochar application on MBC was observed by Kolb et al. (2008), O'Neill et al. (2009), Liang et al. (2010) and Lehmann et al. (2011).

Another noticeable feature was the increase in MBC content with an increase in the biochar levels. Such a positive relationship between MBC and biochar application rate was also observed by Steiner et al. (2008) in a similar highly weathered soil. The porous nature of biochar, its high surface area, ability to adsorb soluble organic matter and inorganic nutrients would have provided a suitable niche for the microbes which conforms to the findings of Thies and Rillig (2009), Shenbagavalli and Mahimairaja (2012). The improvement in soil physical and chemical environment thus providing a favourable habitat has also been pointed out by Lehmann et al. (2011), Jien and Wang (2013) as the favourable after effect of biochar application.

On analysing the effect of the incubation period on MBC, it was seen that the content got increased and reached a maximum at 6 months and declined thereafter. The treatment effect was significant only up to 9 months of incubation. In addition, a significant difference was also noticed in considering the interaction of the incubation period with treatments. MBC was the lowest in the control at all stages of incubation, and also, in all the treatments except control, the lowest MBC was registered during the 0^{th} month of incubation.

The increasing trend in MBC content noticed during the first six months and its decline thereafter are attributable to the content of WSC which also showed a similar trend for the first six months of incubation. This can further be explained by the fact that it is the WSC that serves as the immediate source of energy for soil microorganisms, and a reduction in which will reflect negatively on the microbial activity. The positive and significant correlation obtained between MBC and WSC matches well with the explanation. Such a positive correlation of MBC with WSC has also been observed by Sparling et al. (1998), Demise et al. (2014).

57.3.5 Organic Carbon

Soil test-based nutrient application + biochar 10 t ha^{-1} recorded the highest organic carbon content throughout the incubation period, whereas the control recorded the lowest. As in the case of total carbon, it is the carbonaceous nature of biochar that has brought about the increase in organic carbon content. Only a marginal increase could be noticed in the organic carbon content with an increase in biochar levels, as against that in total carbon (Table 57.7). This can be related to the low amount of chromic acid extractable carbon in the biochar. It was observed that with the advancement of the incubation period, there was a decline in the organic carbon content, which was similar in all the treatments. Similar observation on the decline in the organic carbon with the advancement of the incubation period was also reported by Rajakumar and Ammal (2016), and they have attributed this decline to the decomposition of added organic sources.

In order to quantify the rate of decrease, simple regression analysis was resorted to (Table 57.8). Here, the highest rate of reduction was noticed in soil test-based nutrient application (4.177 mg kg^{-1} day^{-1}), which consisted of inorganic NPK and FYM application. The addition of labile carbon-rich FYM together with easily available inorganic N source would have helped in the proliferation of soil microorganisms, resulting in faster depletion of organic carbon in this treatment as suggested by Demise et al. (2014), Rajakumar and Ammal (2016).

Table 57.7 Changes in the organic carbon and total carbon content (%) of soil at different stages of incubation

Treatments	Organic carbon							Total carbon						
	Incubation period (months)						Treatment (T) mean	Incubation period (months)						Treatment (T) mean
	0	3	6	9	12	15		0	3	6	9	12	15	
T_1	2.031	2.006	1.980	1.933	1.870	1.891	**1.952**	2.070	1.990	2.057	1.933	1.893	1.957	**1.983**
T_2	2.105	2.138	2.141	2.114	2.078	1.969	**2.091**	2.270	2.077	2.157	2.108	2.087	2.064	**2.127**
T_3	2.021	2.114	2.121	1.993	1.951	1.914	**2.019**	2.310	2.120	2.080	2.248	2.162	2.160	**2.180**
T_4	2.079	2.119	2.138	1.953	1.957	1.980	**2.038**	2.373	2.123	2.330	2.265	2.175	2.216	**2.247**
T_5	2.121	2.092	2.137	2.132	1.988	2.006	**2.079**	2.437	2.383	2.290	2.437	2.262	2.178	**2.331**
T_6	2.199	2.127	2.175	2.108	2.094	2.048	**2.125**	2.727	2.340	2.280	2.538	2.437	2.313	**2.439**
T_7	2.124	2.126	2.187	2.127	1.986	1.957	**2.084**	2.313	2.053	2.130	2.236	2.048	1.983	**2.127**
Stage (S) mean	**2.097**	**2.103**	**2.126**	**2.051**	**1.989**	**1.966**		**2.357**	**2.155**	**2.189**	**2.252**	**2.152**	**2.124**	
	S	**T**	**T x S**					**S**	**T**	**T x S**				
CD (0.05)	0.025	0.027	0.065					0.045	0.049	0.119				

Table 57.8 Simple regression analysis between organic carbon (Y) and days of incubation (X)

Treatments	R^2	a (intercept)	Rate of change (mg kg^{-1} day^{-1})
Control	0.697**	20,339.7	− 3.657
FYM 10 t ha^{-1}	0.446**	21,544.9	− 2.817
Biochar 5 t ha^{-1}	0.501**	21,011.7	− 3.642
Biochar 7.5 t ha − 1	0.483**	21,207.2	− 3.689
Biochar 10 t ha − 1	0.457**	21,433.9	− 2.845
Soil test-based nutrient application + biochar 10 t ha^{-1}	0.552**	21,908.6	− 2.915
Soil test-based nutrient application	0.422**	21,783.9	− 4.177

** Significant at 1% level of significance

With an increase in the biochar levels, a sharp reduction was noticed in the rate of decrease in organic carbon content. As far as laterite soils are concerned, continuous application of organic manures and amendments is highly essential because of soil compaction and the high rate of mineralization associated with tropical conditions. Moreover, faster depletion of soil organic carbon is not a good index of soil quality. Overall, the sharp reduction in the rate of decrease in organic carbon content brings out the biochar as a suitable organic amendment for the tropics. The positive impact of biochar on carbon sequestration in tropical soils was also observed by Dainy (2015), Rajalekshmi (2018), Rajakumar (2019). It was also noticed that the application of biochar together with inorganic fertilizer sources increased the rate of reduction in SOC. This suggests that we should not depend completely on the inorganic sources, rather we should explore the organic sources for meeting the plant nutrient demand.

57.3.6 Total Carbon

The information on total carbon which is the summation of three carbon forms, namely organic, elemental (which is insignificant in most soils) and inorganic (usually carbonates and bicarbonates) is essential for understanding the different components of SOM. Generally, in lateritic soils, the content of total carbon almost equates with the organic carbon content.

A perusal of total carbon values in the incubation experiment showed that the content decreased initially, followed by an increase up to six months of incubation, after which it decreased further. Considering the treatment effect, it was seen that the soil test-based nutrient application + biochar registered a significantly higher value followed by biochar 10 t ha^{-1}. Control recorded the lowest value for the total carbon (1.983%) (Table 57.7). Increasing the quantity of biochar led to an increase in the total carbon level, which was also statistically significant. The interaction of the incubation period with treatments made a significant effect on total carbon content. However, soil alone treatment registered the lowest value at all the stages of incubation. Throughout the incubation period, the highest value of total carbon was associated with the treatment biochar 10 t ha^{-1} and soil test-based nutrient application + biochar, which were comparable statistically as well. The highly carbonaceous nature of biochar (64.14%) is directly responsible for the improvement in total carbon, on incubation.

57.4 Conclusions

The present study conducted in the lateritic soils (Ultisols) of Kerala demonstrated the distinct effect of biochar on soil carbon fractions. The highest value of WSC and HWSC was recorded in FYM 10 t ha^{-1}, whereas all other C fractions were higher in the treatments of soil test-based nutrient application + biochar 10 t ha^{-1} and biochar 10 t ha^{-1}. With an increase in biochar levels, there was an increase in the concentration of POXC and MBC. Higher WSC and HWSC content recorded with the FYM application indicated that organic manures like FYM with more lability decomposes much faster than biochar. Higher POXC recorded with biochar application in this experiment has confirmed the positive effect of biochar on soil quality. With the sole application of biochar, a sharp reduction was noticed in the rate of decrease in organic carbon during incubation, whereas application of biochar together with inorganic fertilizer sources increased the reduction in organic carbon. As far as laterite soils are concerned, continuous application of organic manures is highly essential because of the high rate of mineralization associated with the tropical conditions.

Taking into the consideration that high mineralization rates are good only for soil quality in the short term and the stable carbon fractions are the one which is important for soil quality in the long term, it can be concluded that biochar with less lability but more SOC accumulation could contribute to sequestration of carbon in soil and sustain the soil quality in the long term. Furthermore, as an amendment highly resistant to decomposition and full of recalcitrant carbon, biochar serves as a viable proposition for C sequestration in tropical soils. However, concerted long-term and large-scale field experiments are required to assess the benefit over time and to quantify the amount of recalcitrant carbon supplied and sequestered.

References

Banger K, Toor GS, Biswas A et al (2010) Soil organic carbon fractions after 16-years of applications of fertilizers and organic manure in a Typic Rhodalfs in semi-arid tropics. Nutr Cycling Agroecosyst 86:391–399

Batjes NH (1996) Total carbon and nitrogen in the soils of the world. Eur J Soil Sci 47:151–163

Blair N (2000) Impact of cultivation and sugar-cane green trash management on carbon fractions and aggregate stability for a Chromic Luvisol in Queensland, Australia. Soil till Res 55:183–191

Blair GJ, Lefroy RD, Lisle L (1995) Soil carbon fractions based on their degree of oxidation, and the development of a carbon management index for agricultural systems. Aust J Agric Res 46:1459–1466

Bolinder MA, Angers DA, Gregorich EG et al (1999) The response of soil quality indicators to conservation management. Can J Soil Sci 79:37–45

Bray RH, Kurtz LT (1945) Determination of total, organic, and available forms of phosphorus in soils. Soil Sci 59:39–46

Clough TJ, Bertram JE, Ray JL et al (2010) Unweathered wood biochar impact on nitrous oxide emissions from a bovine-urine-amended pasture soil. Soil Sci Soc Am J 74:852–860

Culman SW, Snapp SS, Freeman MA et al (2012) Permanganate oxidizable carbon reflects a processed soil fraction that is sensitive to management. Soil Sci Soc Am J 76:494–504

Dainy MS (2015) Investigations on the efficacy of biochar from tender coconut husk for enhanced crop production. Ph.D. (Ag) Thesis, Kerala Agricultural University, Thrissur, Kerala, India

Demise W, Liu Z, Chang M (2014) Effect of biochar on carbon fractions and enzyme activity of red soil. CATENA 121:214–221

Ghani A, Dexter M, Perrott KW (2003) Hot-water extractable carbon in soils: a sensitive measurement for determining impacts of fertilisation, grazing and cultivation. Soil Biol Biochem 35:1231–1243

Gil-Sotres F, Trasar-Cepeda C, Leirós MC et al (2005) Different approaches to evaluating soil quality using biochemical properties. Soil Biol Biochem 37:877–887

Gomez KA, Gomez AA (1976) Statistical procedures for agricultural research with emphasis on rice. IRRI, Los Banos, Manila, Philippines

Graham MH, Haynes RJ, Meyer JH (2002) Soil organic matter content and quality: effects of fertilizer applications, burning and trash retention on a long-term sugarcane experiment in South Africa. Soil Biol Biochem 34:93–102

Gregorich EG, Carter MR, Angers DA et al (1994) Towards a minimum data set to assess soil organic matter quality in agricultural soils. Can J Soil Sci 74:367–385

Hendershot WH, Duquette M (1986) A simple barium chloride method for determining cation exchange capacity and exchangeable cations. Soil Sci Soc Am J 50:605–608

Huang R, Tian D, Liu J et al (2018) Responses of soil carbon pool and soil aggregates associated organic carbon to straw and straw-derived biochar addition in a dryland cropping mesocosm system. Agric Ecosyst Environ 265:576–586

IPCC WGI (2001) Climate change: the scientific basis. Cambridge University Press, Cambridge, UK

Jackson ML (1973) Soil chemical analysis. Prentice Hall of India (Pvt.) Ltd., New Delhi, India, p 498

Jenkinson DS, Ladd JN (1981) Microbial biomass in soil: measurement and turnover. Soil Biochem 5:415–471

Jenkinson DS, Powlson DS (1976) The effects of biocidal treatments on metabolism in soil—V. A method for measuring soil biomass. Soil Biol Biochem 8:209–213

Jiang PK, Xu QF, Xu ZH et al (2006) Seasonal changes in soil labile organic carbon pools within a *Phyllostachys praecox* stand under high rate fertilization and winter mulch in subtropical China. For Ecol Manag 236:30–36

Jien SH, Wang CS (2013) Effects of biochar on soil properties and erosion potential in a highly weathered soil. CATENA 110:225–233

John IE (2019) Carbon: nitrogen dynamics in acid sulphate and acid saline rice soils of Kerala. Ph.D. (Ag) Thesis, Kerala Agricultural University, Thrissur, Kerala, India

Kolb SE, Fermanich KJ, Dornbush ME (2008) Effect of charcoal quantity on microbial biomass and activity in temperate soils. Soil Sci Soc Am J 73:1173–1181

Laird DA, Fleming P, Davis DD et al (2010) Impact of biochar amendments on the quality of a typical Midwestern agricultural soil. Geoderma 158:443–449

Lehmann J (2007) A handful of carbon. Nature 447:143–144

Lehmann J, Gaunt J, Rondon M (2006) Bio-char sequestration in terrestrial ecosystems—a review. Mitig Adapt Strateg Glob Chang 11:403–427

Lehmann J, Rillig MC, Thies J et al (2011) Biochar effects on soil biota—a review. Soil Biol and Biochem 43:1812–1836

Lettens S, DeVos B, Quataert P et al (2007) Variable carbon recovery of Walkley-Black analysis and implications for national soil organic carbon accounting. Eur J Soil Sci 58:1244–1253
Liang B, Lehmann J, Sohi SP et al (2010) Black carbon affects the cycling of non-black carbon in soil. Org Geochem 41:206–213
Manna MC, Swarup A, Wanjari RH et al (2007) Long-term fertilization, manure and liming effects on soil organic matter and crop yields. Soil till Res 94:397–409
Mulvaney RL, Yaremych SA, Khan SA et al (2004) Use of diffusion to determine soil cation-exchange capacity by ammonium saturation. Commun Soil Sci Plant Anal 35:51–67
O'Neill B, Grossman J, Tsai MT et al (2009) Bacterial community composition in Brazilian Anthrosols and adjacent soils characterized using culturing and molecular identification. Microb Ecol 58:23–35
Paul EA, Collins HP, Leavitt SW (2001) Dynamics of resistant soil carbon of Midwestern agricultural soils measured by naturally occurring ^{14}C abundance. Geoderma 104:239–256
Piper CS (1966) Soil and plant analysis. Hans Publishers, Bombay, India, p 368
Rajakumar R, Ammal UB (2016) Quantification of nutrient release pattern of soil enriched with tank silt and organic manures. Madras Agric J 103(7–9):213–218
Rajakumar R, Sankar SJ (2016) Biochar for sustainable agriculture—a review. Int J Appl Pure Sci Agric 2(9):173–184
Rajakumar R, Sankar SJ (2019) Effect of biochar on improving soil properties of Ultisols (*Typic plinthustults*). Environ Ecol 37(4):1336–1342
Rajakumar R (2019) Aggrading lateritic soils (Ultisol) using biochar. Ph.D. (Ag) Thesis, Kerala Agricultural University, Thrissur, Kerala, India
Rajalekshmi K (2018) Carbon sequestration and soil health under different organic sources in wetland rice. Ph.D. (Ag) Thesis, Kerala Agricultural University, Thrissur, Kerala, India
Rajkovich S, Enders A, Hanley K et al (2012) Corn growth and nitrogen nutrition after additions of biochars with varying properties to a temperate soil. Biol Fert Soils 48:271–284
Sandhu SS, Ussiri DAN, Kumar S et al (2017) Analyzing the impacts of three types of biochar on soil carbon fractions and physiochemical properties in a corn-soybean rotation. Chemosphere 184:473–481
Shenbagavalli S, Mahimairaja S (2012) Production and characterization of biochar from different biological wastes. Int J Plant Anim Environ Sci 1:197–201
Sims JR, Johnson GV (1991) Micronutrient soil tests. In: Mortvedt JJ, Cox FR, Shuman LM et al (eds) Micronutrients in agriculture, 2nd edn. Soil Science Society of America, Madison, USA, pp 427–476
Smith JL, Paul EA (1990) The significance of soil biomass estimations. In: Bollag JM, Stotzky G (eds) Soil Biochemistry. Marcel Dekker, New York, pp 357–396
Sparling G, Vojvodić-Vuković M, Schipper LA (1998) Hot-water-soluble C as a simple measure of labile soil organic matter: the relationship with microbial biomass C. Soil Biol Biochem 30:1469–1472
Steiner C, Das KC, Garcia M et al (2008) Charcoal and smoke extract stimulate the soil microbial community in a highly weathered xanthic Ferralsol. Pedobiologia 51:359–366
Stevenson FJ (1994) Humus chemistry: genesis, composition, reactions, 2nd edn. Wiley, New York, p 497
Subbiah BW, Asija GL (1956) A rapid procedure for the estimation of available micronutrient in soils. Curr Sci 25:259–260
Sumner ME, Miller WP (1996) Cation exchange capacity and exchange coefficients. In: Sparks DL, Page AL, Helmke PA et al (eds) Methods of soil analysis, part 3. Chemical methods. American Society of Agronomy and Soil Science Society of America, Madison, Wisconsin, pp 1201–1229
Thies JE, Rillig MC (2009) Characteristics of biochar—biological properties. In: Lehmann J, Joseph S (eds) Biochar for environmental management: science and technology. Earthscan, London, p 85

Walkley A, Black IA (1934) An examination of the wet acid method for determining soil organic matter and a proposed modification of the chromic acid titration method. Soil Sci 37:29–38
Weigel A, Eustice T, vanAntwerpen R et al (2011) Soil organic carbon (SOC) changes indicated by hot water extractable carbon (HWEC). Proc South Afr Sugar Technol Assoc 84:210–222
Witter E (1996) Soil C balance in a long-term field experiment in relation to the size of the microbial biomass. Biol Fertil Soils 23:33–37

Chapter 58
Spatio-Temporal Change in Salinity Dynamics in Different Land-Use Systems of Climatically Vulnerable Indian Sundarbans

Sourav Mullick, Uttam Kumar Mandal, and Rambilash Mallick

Abstract Sundarbans in West Bengal, India, located in the eastern coast of the Bay of Bengal is one of the vulnerable islands subjected to abrupt climate change. The consequence of climate change is of particular importance because of its closeness to sea leading to sea water intrusion. Sea water intrusion not only affects the soil salinity and groundwater quality but also changes the salt dynamics of the region, hampering crop yield due to accumulation of salt in the root zone. The present study assessed the spatio-temporal changes in salinity of soil for the major land-use systems, namely rice–rice (RR), rice–fallow (RF), rice–vegetable (RV), rice–pulse (RP) and vegetable–vegetable (VV) in Basanti, one of the islands in Sundarbans delta. Spatial map was generated using ArcGIS for pictorial view of the analyzed data using Kriging interpolation technique. Top soil salinity (0–20 cm) varied from 1.55 to 3.82 dS m^{-1} for winter season and from 3.55 to 9.77 dS m^{-1} for summer season. The average increase of soil ECe for summer season was 63%, 156%, 97%, 153% and 38% over that of winter season for the above land-use systems, respectively.

Keywords Coastal soils · Spatio-temporal change · Kriging

58.1 Introduction

The largest contiguous mangrove ecosystem is located in the southern part of West Bengal, India and Bangladesh, which lies on the delta of the Ganges, Brahmaputra and Meghna rivers in the Bay of Bengal, which is the Sundarbans. For its inimitable

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geographical location, it is under constant threat of powerful nor'westers, cyclones, tidal surges and many more catastrophic events. Thus, the lands in these regions are extremely degraded due to phenomena like saline water intrusion following storm and brackish groundwater table close to the soil surface due to the influence of sea or saline river water. Although the region receives a very high rainfall, which is mainly concentrated only over a few monsoon months, so most of the precipitation goes to waste as runoff, thus creating widespread water logging of the low-lying agricultural fields (Mandal et al. 2019). Traditionally, farmers cultivate low-yielding local rice varieties under rainfed conditions in the wet season (Sarangi et al. 2014). The degraded soil and water quality, lack of irrigation water in non-monsoon months and drainage congestion in monsoon months; besides, climatic adversities contribute to low agricultural productivity and poor livelihood security in the region. The effect of high tides on the sea would increase the hydrostatic pressure of the sea water which will facilitate for its ingress into the inland fresh water system. Consequently, sea water intrusion along with the saline backwater effect would lead to a devastating effect on the coastal ecosystem. There is need for appropriate water and land care system for coastal area to make this fragile ecosystem into climatically more resilient. Soil salinity is the most frequently cited soil and agricultural utilization problem for farmers in salt-affected coastal farming areas. Salt accumulation takes place at the root zone if the upward salt movement caused by evaporation exceeds the downward gravitational movement. Most of the crops are susceptible to salinity it suffer salt injury at concentration equivalent of electrical conductivity of the soil saturation extract (ECe) of 4 dS m^{-1} or higher. At such a level of salinity, plant growth is restricted even though enough water may be present in the root zone (American Society of Civil Engineers 1990; Karim et al. 1990). In the coastal region of Sundarbans, considerable amounts of salt accumulate on the soil surface by evaporation, particularly in presence of a shallow saline water table during the dry period. Thus, salt-affected soils represent an opportunity that can be used to increase agricultural production and productivity to ensure national food and nutritional security. Monitoring and spatial mapping for assessing temporal change in soil salinity in the near surface soil of a delta will definitely focus the entire problem of the region for higher and sustainable productivity in agriculture and aquaculture for vulnerable coastal delta. The recent advances in technologies such as Global Positioning Systems (GPSs) and Geographic Information Systems (GIS) have brought to the forefront tools that can be used for the analysis of the spatial variation in soil properties, topography and other factors. Geostatistical methods in GIS are being used to describe the spatial dependence structure of soil properties, providing a greater precision as well as errors of estimation (Webster and Oliver 2001) that allow accurate description of the spatial distribution of soil properties within an island system. These techniques allow the user to integrate the databases generated from various sources on a single platform and analyze them efficiently in a spatial–temporal domain.

Therefore, understanding the spatio-temporal change of coastal soil is a prerequisite for devising appropriate management strategies to improve land productivity of the coastal regions. In the light of the above background, the present study was aimed to assess the change of salinity in different land-use systems and to identify factors responsible for the soil salinity and maintaining productivity of degraded coastal saline soils of Sundarbans.

58.2 Materials and Methods

58.2.1 Study Area: The Coastal Region of West Bengal (Sundarbans)

The coastal region of West Bengal, (*Sundarbans*), situated (21°32′ and 22°40′ N latitude and 88°05′ and 89°00′ E longitude) in the delta of the river Ganga–Brahmaputra–Meghna is the largest delta system in the World. The *Sundarbans* is a UNESCO World Heritage Site covering its two-third in Bangladesh while rest one-third in India. The Indian Sundarbans has 102 numbers of islands including parts of main land; out of these, 54 islands are inhabited and the rests are under the mangrove forest. The main focus was given on one of the islands (i.e., Basanti, Fig. 58.1a) in Indian Sundarbans which consists of all the major land -use systems including mangrove forest and aquaculture locally called bhery.

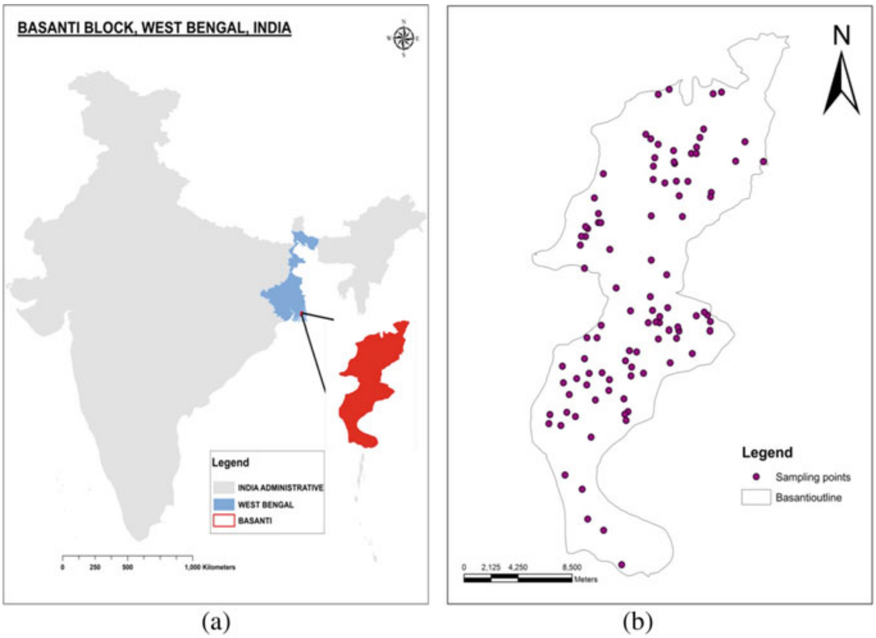


Fig. 58.1 **a** Study area and **b** sampling points

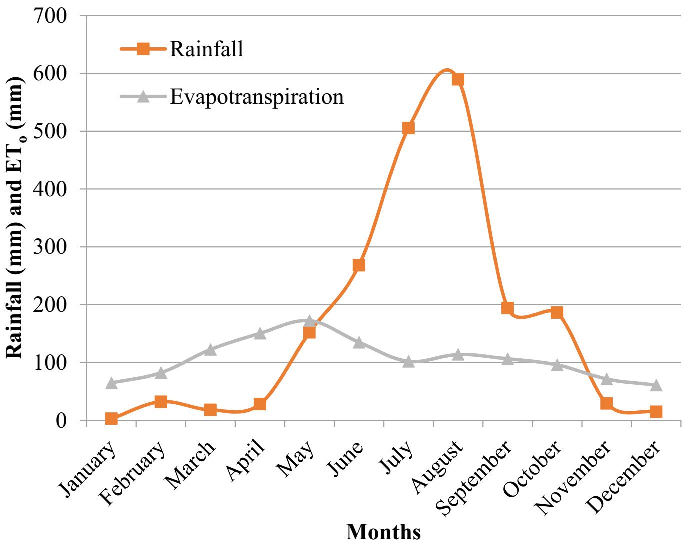


Fig. 58.2 Relationship between rainfall and evapotranspiration

The climate of the region is typically hot humid with three distinct seasons in a year: summer (March–May), monsoon (rainy) (June–September) and winter (October–February). The mean annual temperature is 26.4 °C with a minimum of 12.5 °C (January) and maximum of 34.7 °C (May). The average maximum relative humidity reaches to 91% during September and the minimum 49% during December and January. Reference Evapotranspiration (ET_0) ranged from 62.7 mm permonth during wet season to 143.25 mm permonth in dry season. There was 56.23% increase in ET_0 in dry seasons than that of wet seasons (Fig. 58.2).

58.2.2 Land-Use Systems Taken for the Study

Different types of land-use systems were taken under consideration for understanding salinity dynamics so that a proper view can be established for livelihood and environmental security for farmers in future. The dominant land -use systems used under study were rice–rice (RR), rice–fallow (RF), rice–vegetable (RV), rice–pulse (RP) and vegetable–vegetable (VV).

58.2.3 Rainfall and Evaporation

Rainfall data were obtained from the automatic weather station installed in the ICAR-Central Soil Salinity Research Institute, Regional Research Station, Canning Town, around 10 km away from the study area.

58.2.4 Sampling/Data Collection for Impact Assessment

Soils were collected to a depth of 0–20 cm from different land-use systems throughout the Basanti Block from 114 points as shown in the Fig. 58.1b.

58.2.4.1 Soil Analysis

From each sampling points, around 500 g soil was collected, which were dried and sieved for the physical and chemical analyses. For estimation of bulk density, core samples were collected along with original samples. Soil samples were analyzed using standard protocol, i.e., pH (1:2.5, soil: water ratio), organic carbon by Walkley–Black method (Jackson 1973). Core method was used for measurement of bulk density (Blake and Hartge 1986). Bouyoucos hydrometer method was used for estimation of soil texture (Gee and Bauder 1986).

For estimation of soil salinity and soluble ions present, saturation extract was used. Soil electrical conductivity was estimated by following the method described by Rhodes et al. (1999). Among the cations, Na^+ and K^+ were determined by emission spectrometry, whereas Ca^{2+} and Mg^{2+} were estimated by Versenate method, i.e., by EDTA titration. For the anions, Cl^- was estimated by titration with $AgNO_3$, HCO_3^- by alkalinity and SO_4^{2-} by turbidimetric methods. Total soluble cation and anion was calculated by summation of the content of soluble Na^+, K^+, Ca^{2+} and Mg^{2+} for cation and Cl^-, HCO_3^-, and SO_4^{2-} for anion. Moreover, total soluble salt content was also calculated by the addition of soluble cations and anions. SAR was also calculated as ratio of Na^+ concentration to square root of half of the total concentration of Ca^{2+} and Mg^{2+}.

58.2.5 Statistical Analysis

Statistical analysis was done with the help of SPSS software version 21.0 and Microsoft Excel, 2007.

Table 58.1 Particle distribution of different cropping systems

Land-use systems	% Silt	% Clay	% Sand	Textural class
Rice–rice	39.64	41.64	18.72	Clay
Rice–fallow	35.64	41.64	22.72	Clay loam
Veg–veg	23.64	41.64	34.72	Clay loam
Rice–veg	31.64	41.64	26.72	Clay
Rice–pulse	31.64	46.00	22.36	Clay

58.3 Results and Discussion

58.3.1 Site Characteristics

58.3.1.1 Soil Texture

The soils of all the sites were generally fine in texture, with poor internal drainability. RF and VV had clay loam texture, whereas RR, RV and RP were observed to have clayey texture of soil. (Table 58.1).

58.3.2 Assessing Soil Properties

Soil salinity under different land-use systems showed seasonal variability (Table 58.2). Soil salinity of the saturation paste extract (EC_e) was less than 4 dS m^{-1} in all the systems during winter season where EC_e ranged from 1.55 dS m^{-1} in RP system to 3.82 dS m^{-1} in RF system. Salinity increased in all the land-use systems as the time progressed, and in summer season, it ranged between 3.92 and 9.77 dS m^{-1}. This can be explained mainly due to upward rise of saline groundwater present at shallow depth (<2 m during dry season) by capillary action due to evaporative loss of soil moisture from its surface which resulted in gradual accumulation of salts on the surface (Mandal et al. 2019). The spatial change in soil salinity is depicted in Fig. 58.3a, b.

Seasonal effect on soluble ionic composition of soils was seen, where summer season showed higher amount of all cations than that of winter season (Figs. 58.4 and 58.5). Out of the four cations studied, Na^+ accounted for the highest percentages of total soluble cations content, ranging from 54.63 to 73.25% during winter and 47.31 to 62.74% during summer, and it was highest in rice–vegetable system for both seasons. It is evident from the table that sodium is the dominant cation followed by magnesium, calcium and potassium. High Na and Mg concentration in these salt-affected soil was possibly due to the effect of sea water intrusion in the ground water, which are used for irrigation purpose for crop cultivation.

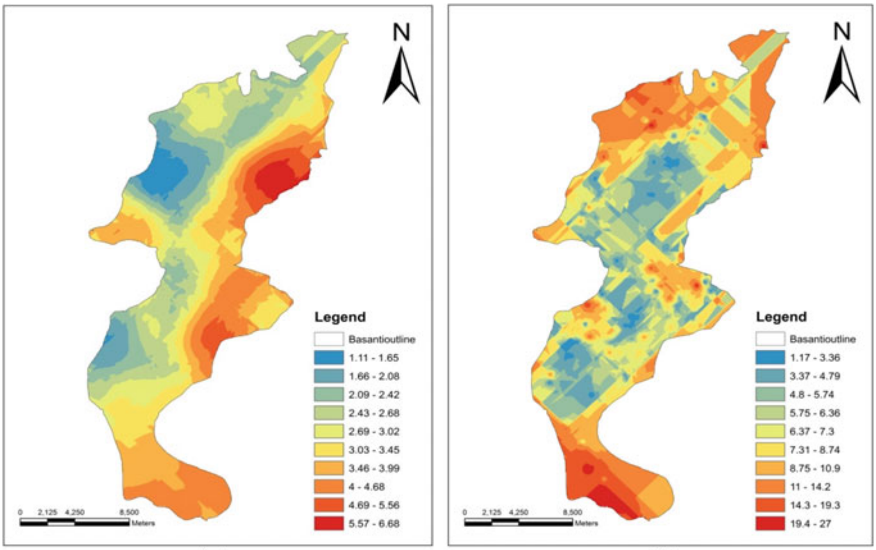
Table 58.2 Variability of soil salinity and dissolved ions with season

Land-use / Parameters	Rice-fallow	Rice-pulse	Rice-rice	Rice-vegetable	Vegetable-vegetable
Winter					
ECe (dS m^{-1})	3.82 ± 0.39	1.55 ± 0.42	3.28 ± 0.57	2.53 ± 0.35	2.57 ± 0.46
Ca^{+2} (me L^{-1})	6.45 ± 0.61	3.48 ± 1.28	5.32 ± 0.87	3.82 ± 0.82	7.76 ± 1.51
Mg^{+2} (me L^{-1})	13.04 ± 1.61	5.35 ± 0.99	9.63 ± 1.44	8.38 ± 1.06	7.85 ± 1.17
Na^{+} (me L^{-1})	30.39 ± 3.52	9.47 ± 1.73	23.00 ± 4.73	23.59 ± 3.26	14.10 ± 3.24
K^{+} (me L^{-1})	0.68 ± 0.06	0.42 ± 0.07	0.60 ± 0.05	0.50 ± 0.09	0.47 ± 0.10
Cl^{-} (me L^{-1})	24.54 ± 2.74	9.73 ± 2.20	21.01 ± 4.56	18.75 ± 3.27	14.04 ± 3.49
HCO_3^{-} (me L^{-1})	1.26 ± 0.06	0.38 ± 0.06	0.28 ± 0.09	0.66 ± 0.05	0.79 ± 0.07
SO_4^{-2} (me L^{-1})	14.76 ± 0.43	10.22 ± 0.46	9.76 ± 0.62	10.46 ± 0.36	11.00 ± 0.50
SAR	9.73 ± 0.13	4.51 ± 0.25	8.41 ± 0.19	9.55 ± 0.32	5.05 ± 0.73
Summer					
ECe (dS m^{-1})	9.77 ± 1.17	3.92 ± 1.48	5.33 ± 0.67	4.98 ± 0.93	3.55 ± 1.12
Ca^{+2} (me L^{-1})	14.03 ± 1.37	7.51 ± 1.64	9.96 ± 1.17	9.66 ± 1.57	12.15 ± 3.28
Mg^{+2} (me L^{-1})	35.34 ± 4.43	17.45 ± 8.50	15.44 ± 2.67	12.58 ± 2.06	10.39 ± 3.31
Na^{+} (me L^{-1})	56.81 ± 7.88	19.21 ± 8.04	30.26 ± 4.33	35.02 ± 5.17	18.12 ± 7.11
K^{+} (me L^{-1})	5.19 ± 0.14	3.30 ± 0.20	3.80 ± 0.10	3.36 ± 0.10	2.34 ± 0.09
Cl^{-} (me L^{-1})	77.74 ± 10.44	26.44 ± 9.79	38.30 ± 5.47	31.95 ± 6.94	25.16 ± 10.82
HCO_3^{-} (me L^{-1})	2.65 ± 0.21	0.80 ± 0.33	0.59 ± 0.30	1.39 ± 0.47	1.66 ± 0.21
SO_4^{-2} (me L^{-1})	31.00 ± 1.49	21.46 ± 2.35	20.50 ± 2.17	21.97 ± 3.39	23.10 ± 1.51
SAR	11.43 ± 0.37	5.44 ± 1.38	8.49 ± 0.90	10.50 ± 2.27	5.40 ± 0.81

Results are shown as mean ± SE

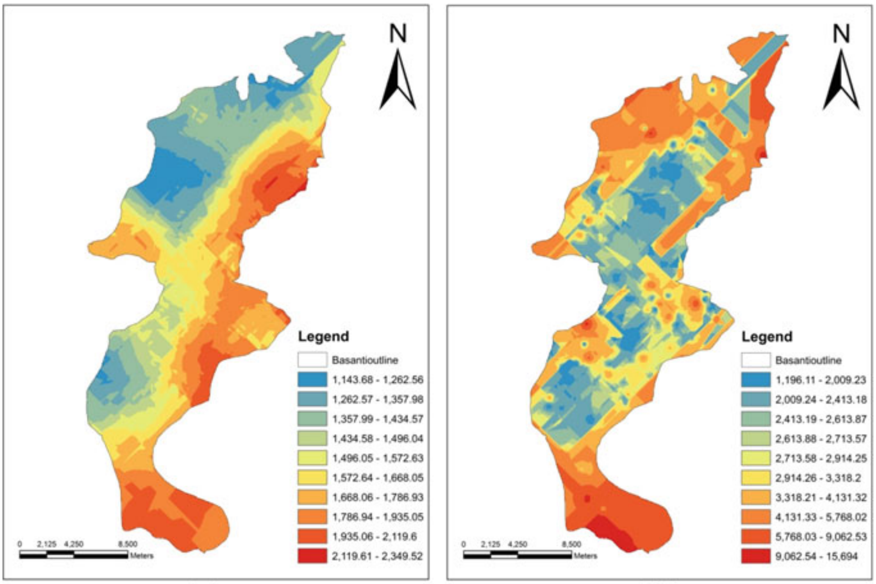
The content of soluble anions in me L^{-1} ranged from 2.7 to 244.8, 1.37 to 5.53 and 9.15 to 39.12 for Cl^{-}, HCO_3^{-} and SO_4^{-1}, respectively, during winter season and 4.05 to 613.6, 2.79 to 9.2 and 18.61 to 64.62 during summer season. The soluble anions showed seasonal variability, where considerable amounts of chloride was recorded, which was found to be the dominant anion, and sulfate was found to be second-dominant anion followed by bicarbonate. The mean percentage contribution of Cl^{-}, SO_4^{-2} and HCO_3^{-} content to total soluble anions for different land-use systems was 50.97, 45.72 and 3.31, respectively, during winter and 51.72, 45.05 and 3.22, respectively, during summer.

SAR value also differed under land-use systems which ranged from 4.51 to 9.73 during winter and increased to 5.4 to 11.43 during summer. The highest percent increase in SAR was seen for RP (20.62%) followed by RF (17.4%), RV (9.94%), VV (6.93%) and RR (0.95%). RR showed very least increase in SAR value over the seasons, mainly due to year round submergence. These findings are in accordance with the previous reports by Bandyopadhyay et al. (2003) and Tripathi et al. (2007).



(a) (b)

Fig. 58.3 Spatial change in ECe in **a** winter season and **b** summer season



(a) (b)

Fig. 58.4 Spatial change in total soluble anion (mg L^{-1}) in **a** winter season and **b** summer season

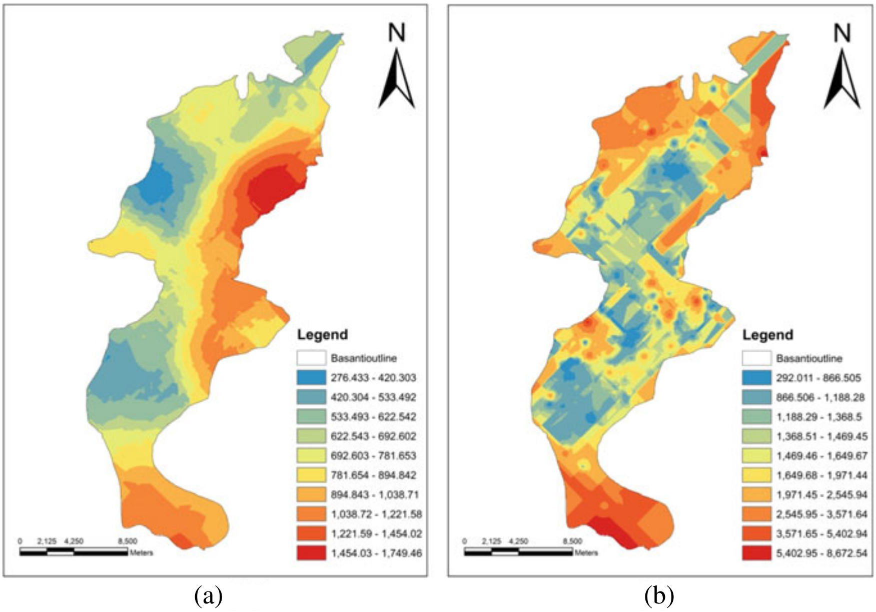


Fig. 58.5 Spatial change in total soluble cation (mg L^{-1}) in **a** winter season and **b** summer season

58.4 Conclusions

Soil salinity is highly variable and site-specific in nature; therefore, development of spatial maps can come in handy to tackle its negative effects. Thus Geostatistics and GIS are essential tools to understand spatial variability of soil salinity. Information from the spatial variability map is currently being used in techniques such as precision farming, smart agriculture to improve input use efficiency and to decrease adverse environmental effects. The spatial distribution maps developed for soil properties could serve as the primary guide for region-specific land management. Further, the information generated in the study could be useful in monitoring salinity status in the study area over a period of time.

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References

American Society of Civil Engineers (ASCE) (1990) Agricultural salinity assessment and management. ASCE manuals and reports on engineering practice, No 71, New York, NY 10017, USA

Bandyopadhyay BK, Maji B, Sen HS et al (2003) Coastal soils of West Bengal—their nature, distribution and characteristics, bulletin No. 1/2003. Central Soil Salinity Research Institute, Regional Research Station, Canning Town, West Bengal, India, pp 1–62

Blake GR, Hartge KH, (1986). Bulk density. In: Klute A, (ed) Methods of soil analysis. Part 1. Physical and mineralogical methods, 2nd edn. Agronomy Monograph 9. ASA and SSSA, Madison, WI, pp 364–367

Gee GW, Bauder JW (1986) Particle size analysis. In: Klute A (ed) Methods of soil analysis. Part 1. Physical and mineralogical methods, 2nd edn. Agronomy Monograph 9. ASA and SSSA, Madison, WI, pp 404–408

Jackson ML (1973) Soil chemical analysis. Prentice Hall of India Pvt. Ltd., New Delhi, p 498

Karim Z, Hussain SG, Ahmed M (1990) Salinity problems and crop intensification in the coastal regions of Bangladesh. Soils Publication No. 33, Soils and Irrigation Division, BARC, Farmgate, Dhaka 1215, Bangladesh, pp 1–20

Mandal UK, Burman D, Bhardwaj AK et al (2019) Waterlogging and coastal salinity management through land shaping and cropping intensification in climatically vulnerable Indian Sundarbans. Agric Water Manag 216:12–26

Sarangi SK, Maji B, Singh S et al (2014) Crop establishment and nutrient management for dry season (Boro) rice in coastal areas. Agron J 106(6):2013–2023

Tripathi S, Chakraborty A, Chakrabarti K et al (2007) Enzyme activities and microbial biomass in coastal soils of India. Soil Biol Biochem 39:2840–2848

Webster R, Oliver MA (2001) Geostatistics for environmental scientists. Wiley, New York

Chapter 59
Soil Quality and Productivity Assessment for Bridging the Yield Gap in Farmers' Fields of Coastal Deltaic Region of Karaikal

L. Aruna, K. Surekha, and Brajendra

Abstract The study was conducted in the form of sampling and survey in farmers' fields of Karaikal region representing the irrigated lowland rice ecosystems of the Cauvery deltaic region of Karaikal in the union territory of Puducherry. The main objective is to assess the variability in nutrient supply, its relationship with rice yields at farmers' fertilizer practices in the farm sites. The rabi season (2019–20) data from the survey, initial soil and post-harvest plant analyses revealed wide variations of rice yield among the farmers. Soil nutrient uptake varied between the sites but matched with the grain yields. Sharp variations were noticed in grain yields ranging from 3.59 t ha^{-1} among low yielders to 4.67 t ha^{-1} among high yielders of Karaikal region. Soil parameters data were pooled in different categories, and the resulting soil quality index generated showed variations in the quality and health of the soil across different farmer categories. Nutrient requirement for per ton of grain yield was calculated, and the recommendation for low yielders from the study was 13.7: 13.17: 27.54 kg NPK t^{-1} grain yield.

Keywords Rice production · Yield gap · Soil quality

59.1 Introduction

Crop production and food security are the two major concerns as inherent climatic variations and ever-increasing food demand are expected to affect the global community in an adverse manner (Bodirsky et al. 2015). Food demand is expected to increase by 60% to feed the growing global population by 2050 (FAO 2012). About 770

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million people, or close to 10% of the world population, were exposed to severe food insecurity in 2017 (Ten Berge et al. 2019).

Rice production had steadily increased during the Green Revolution, but recently its growth has been substantially slowed down. Moreover, crop intensification during the Green Revolution has exerted tremendous pressures on natural resources and the environment. On the other hand, under the globalization of the world economy, rice producers are exposed to competition not only among themselves but also with the producers of other crops. The future increased rice production, therefore, requires improvement in productivity and efficiency (Subhankar Debnath et al. 2021). There is a huge yield gap, and closing these gaps is possible by improving not only the productivity but also the efficiency of rice production. The term 'yield gap' has been commonly used to refer to the difference between the average farmers' yields and an estimate of a reference yield or potential yield at a specific area.

Yield gaps exist because the best available production technologies are not adopted in farmers' fields which could be due to farmers' personal characteristics (like lack of knowledge and skills, risk bearing ability, etc.), farm characteristics (soil quality, land slope, poor road, etc.), and unsuitability of the technology to farmers' circumstances (like labor-intensive, requirement of high initial investment, poor access to inputs, etc.). Yield gap has two components, the first one being environmental conditions which cannot be narrowed or not exploitable, because it is mainly governed by the factors that are non-transferable. The second component is mainly due to difference in management practices or farmer's inefficiency level, which is manageable and can be bridged.

Survey among farmers to estimate maximum yields from upper percentiles represents a simple approach to estimate yield potential. The best farmers' yields of a given region may give a better idea of what can be achieved under the normal edaphic conditions of that region (Lobell et al. 2009). It is also likely that the use of maximum farmers' yields as a proxy for potential yield is most appropriate in intensively managed cropping systems, with high levels of fertilizers and pesticides, where yield limiting factors such as nutrient deficiencies, insect attacks, diseases and competition with weeds are virtually eliminated.

In the scenario of ever-changing fertilizer management practices followed across rice fields in India, there cannot be a single blanket fertilizer formulation followed for diverse soil ecosystems with less importance given to management-induced site variations which has been the major reason for nutrient imbalances and unsustainability. As a first step in reversing this trend, researchers need to understand the local farmer's practice. However, this information is only valid when the potential use of this knowledge for maintaining soil quality and developing sustainable land management is assessed and put in the context of decision-making. Hence, researchers must continue to face the challenge to provide a base for bridge-building between the best management practices and scientists' knowledge. In this context, the present study was taken to assess the nutritional status and productivity of the crop under farmer's current management practices in selected farmer fields of Karaikal region for further improvement in rice productivity.

59.2 Materials and Methods

The study involved a survey, participatory rural appraisal and recording of all the package of fertilizer and crop management practices of the farmer. The questionnaire-based survey was conducted in twenty-four farmer's field spread across five villages of Karaikal during rabi season (Samba), 2019–20. The farmers had cultivated CR1009, BPT5204, ADT46, IW Ponni, Kichidi samba and TKM 13 applying varying levels of NPK (kg ha^{-1}) as 80:58:19, 80:58:10, 80:58:00, 80:58:37, 120:80:57, 40:29:00, 90:58:37, 90:53:75, 40:58:37, 90:10:29 and 160:44:60.

Besides, information about the nutrient status of the soils before cropping by collecting and analyzing the initial geo-referenced soil samples for their characteristic properties, along with the yield estimation and dry matter yield of rice in various farmers' field was recorded at the harvest stage of the individual farmer. The grain and straw samples were also collected and analyzed for their nutrient content to calculate their major nutrient uptake. The geo-reference of the farmers' field selected for soil quality and productivity assessment were also recorded.

For grouping the data for yield, two categories were formed, viz., low yielders having below 4 t ha^{-1} of productivity and high yielders having greater than 4 t ha^{-1} of productivity. Soil quality index (SQI) was worked out based on weighted additive SQI method (Mukherjee and Lal 2014) for various soil physico-chemical and chemical parameters of the soils. Nutrient uptake and nutrient requirement to produce per ton of rice grain were also calculated to assess the variability in nutrient supply, its relationship with rice yields at current recommended and farmers' fertilizer practices.

59.3 Results and Discussion

The information collected from different farm sites and initial soil properties of the site is furnished in Table 59.1. The soils were slightly acidic to alkaline (pH ranging from 6.52 to 8.18) and non-saline in nature with low to high organic carbon status (0.32–0.85%). The available nutrients ranged from low to medium in $KMnO_4$–N, high in Olsen's P, low to high in NH_4-OAC-K and high in $CaCl_2$-S.

The grain and straw yields obtained, major nutrients uptake (N, P and K) of rice grain and straw in different farmer's fields are furnished in Table 59.2. The rice grain yields varied from 3.59 to 4.03 t ha^{-1} among low yielders and from 3.72 to 6.20 t ha^{-1} among high yielders at Karaikal. The N and P in grain showed higher uptake when compared to straw uptake, whereas in case of K, the grain uptake was comparatively lesser than straw uptake in both low and high yielders. This shows that the N and P translocation was effective from source to sink, but such movement in K was less showing higher accumulation of K in straw than in grain which might be a major reason for lesser yield especially with BPT 5204 rice grown farm sites.

Soil parameters data of different categories and the resulting soil quality index generated showed variations in the quality and health of the soil across different

Table 59.1 Geo-reference of the farmers' site and initial soil data recorded prior to cultivation

Site No	GPS Coordinates		pH	EC (dSm^{-1})	Organic carbon (%)	$KMnO_4$-N (kg ha^{-1})	Olsen's-P (kg ha^{-1})	NH_4OAC–K (kg ha^{-1})	$CaCl_2$–S (mg kg^{-1})
	Lat	Long							
1	10.91879	79.84057	6.94	1.79	0.74	191.3	39.0	426.7	38.6
2	10.92517	79.83488	8.18	0.40	0.53	175.6	40.6	454.7	38.4
3	9.98225	78.86131	7.04	0.52	0.85	134.8	51.8	211.7	124.0
4	9.97339	78.76720	8.01	0.42	0.68	169.3	73.6	369.6	142.5
5	9.98458	78.84391	7.41	0.36	0.59	153.7	62.1	221.8	177.5
6	10.01396	78.80413	7.67	0.38	0.68	156.8	61.4	174.7	68.3
7	10.91809	79.81084	7.46	0.54	0.62	144.3	52.5	291.2	64.7
8	10.92126	79.81084	7.15	0.48	0.71	156.8	42.9	480.5	77.4
9	10.92771	79.84140	6.91	0.13	0.56	169.3	40.1	374.1	32.6
10	10.92392	79.82842	6.85	0.20	0.50	144.3	39.9	353.9	21.6
11	10.92324	79.84247	7.99	0.10	0.32	128.6	79.1	181.4	36.7
12	10.92508	79.84138	7.25	0.05	0.56	116.0	67.4	147.8	36.9
13	10.92334	79.83779	7.38	0.08	0.38	119.2	52.7	172.5	31.8
14	10.56300	79.46390	6.52	0.03	0.53	128.6	47.7	528.6	54.2
15	10.94253	79.77807	8.05	0.38	0.68	178.8	68.9	552.2	56.8
16	10.56190	79.46290	7.33	0.17	0.56	181.9	58.8	518.6	66.5
17	10.56160	19.46260	7.73	0.28	0.50	235.2	57.7	534.2	72.5
18	10.56190	79.46260	7.18	0.09	0.44	141.1	29.8	553.3	26.3
19	10.56190	79.46300	6.94	0.07	0.47	175.6	45.8	635.0	24.7
20	10.55580	79.46300	7.34	0.06	0.53	141.1	43.7	583.5	26.1

(continued)

Table 59.1 (continued)

Site No	GPS Coordinates		pH	EC (dSm^{-1})	Organic carbon (%)	$KMnO_4$-N (kg ha^{-1})	Olsen's-P (kg ha^{-1})	NH_4OAC–K (kg ha^{-1})	$CaCl_2$–S (mg kg^{-1})
	Lat	Long							
21	10.56350	79.46220	6.86	0.06	0.71	163.1	53.6	621.6	29.4
22	10.56510	79.45530	7.42	0.01	0.59	178.8	28.2	635.0	24.9
23	10.56510	79.45530	7.55	0.10	0.56	163.1	30.9	613.8	60.5
24	10.56570	79.46010	7.45	0.10	0.50	166.2	62.0	591.4	24.3
Minimum			6.52	0.01	0.32	116.0	28.2	147.8	21.6
Maximum			8.18	1.79	0.85	235.2	73.6	635.0	177.5
Mean			7.35	0.90	0.59	175.6	50.9	391.4	99.5

Table 59.2 Crop data and yield parameters of the experimental sites

Site No	Variety	Nutrient applied (kg ha^{-1})	Grain yield (t ha^{-1})	Straw Yield (t ha^{-1})	Grain uptake (kg ha^{-1})			Straw uptake (kg ha^{-1})		
					N	*P*	*K*	*N*	*P*	*K*
1	BPT 5204	80:58:19	4.34	4.94	25.52	36.11	19.53	31.42	25.59	59.06
2	ADT 46	80:58:19	4.65	5.94	31.90	37.06	25.58	36.38	25.59	67.73
3	BPT 5204	80:58:10	4.19	5.38	45.11	41.12	28.88	21.44	25.07	106.8
4	BPT 5204	80:58:37	5.81	5.98	52.89	49.89	22.09	15.41	20.1	73.48
5	Kichadi samba	organics	4.65	5.89	47.52	29.02	39.53	16.98	12.9	46.49
6	ADT 46	80:58:37	5.12	5.94	35.09	44.35	37.34	25.36	24.58	66.54
7	BPT 5204	120:58:37	4.65	4.94	53.38	41.55	17.67	30.87	18.25	85.44
8	BPT 5204	80:58:00	4.19	5.07	44.53	38.14	11.72	15.86	17.81	52.68
9	BPT 5204	80:58:37	3.41	4.19	30.55	28.67	19.44	15.01	10.50	48.34
10	ADT 46	80:58:37	5.81	6.50	58.59	51.94	18.60	23.52	23.34	68.60
11	White ponni	80:58:37	4.19	5.06	36.91	34.45	13.81	19.29	14.45	74.11
12	ADT 39	40:29:00	4.03	4.94	23.70	32.47	17.73	25.91	25.25	79.54
13	BPT 5204	80:58:37	4.65	5.13	29.30	27.04	17.67	20.21	15.71	55.13
14	TKM 3	80:58:37	4.65	4.68	33.20	31.82	23.25	16.98	19.19	85.63
15	BPT 5204	90:58:37	4.65	5.13	36.46	34.23	19.53	32.66	17.12	83.53
16	CR 1009	90:53:75	6.20	6.60	75.52	46.71	24.80	15.29	23.36	73.08
17	BPT 5204	40:58:37	4.03	4.63	27.65	32.82	17.33	18.74	14.82	55.39
18	ADT 46	90:58:37	4.34	6.03	53.47	37.63	15.62	12.40	16.64	76.07
19	BPT 5204	90:10:29	4.19	4.63	43.94	35.55	15.07	13.97	18.21	68.50
20	CR 1009	160:44:60	4.81	5.41	40.36	33.7	17.78	13.38	20.72	88.04

(continued)

Table 59.2 (continued)

Site No	Variety	Nutrient applied (kg ha^{-1})	Grain yield (t ha^{-1})	Straw Yield (t ha^{-1})	Grain uptake (kg ha^{-1})			Straw uptake (kg ha^{-1})		
					N	*P*	*K*	*N*	*P*	*K*
21	BPT 5204	80:58:00	3.72	3.94	32.81	35.55	12.65	23.15	25.25	87.81
22	BPT 5204	80:58:37	4.03	4.20	29.34	37.44	14.11	20.58	18.76	97.86
23	BPT 5204	80:58:37	3.72	4.53	23.96	18.49	12.28	23.10	23.41	116.3
24	CR 1009	80:58:37	4.03	4.68	40.62	28.96	15.31	22.12	7.65	92.61
Minimum			**3.41**	**3.94**	**23.70**	**18.49**	**11.72**	**12.40**	**7.65**	**48.34**
Maximum			**6.20**	**6.60**	**75.52**	**51.94**	**39.53**	**36.38**	**25.59**	**116.3**
Mean			**4.81**	**5.01**	**49.61**	**35.22**	**25.63**	**24.39**	**16.62**	**82.32**

farmers' categories and for nutrient uptake between low yielders and high yielders across the locations. At all locations, wide variations in grain yields and nutrient uptake were recorded while soil test values did not match with rice yield and nutrient uptake, suggesting less suitability of current soil testing methods for flooded soils. However, the soil quality index was at par with their resulting grain yield and nutrient uptake patterns by registering the mean soil quality index as poor with low yielders and average with high yielders (Table 59.3). Hence, the nutrient requirement per ton grain yields variations in the region was calculated as they are useful tools to know how the responses were for the fertilizers applied per ton of grain yield obtained. The nutrient recommendation arrived (Table 59.4) for low yielders from the study was 13.7: 13.17: 27.54 kg NPK per ton of grain yield, and for high yielders, the recommendation was 8.86: 8.02: 4.56 kg NPK per ton of grain yield.

59.4 Conclusions

Bridging yield gaps may not always be desirable or practical in the short term, given marginal returns for additional inputs, regional land-management policies, limits on sustainable water resources and socio-economic constraints (for example, access to capital, infrastructure, institutions and political stability). Hence, to close yield gaps, technological solutions must go hand in hand with lifting social and economic constraints through rights to land, critical infrastructure and links to the world market for food and raw materials.

Fertilizer nutrient management not matching with the variability in soil fertility of the farmer fields was found to be one among the factors responsible for low rice productivity, imbalanced nutrition and unsustainability. Variability in nutrient acquisition and its utilization by genotypes for yield expression is coupled with nutrient application in right proportions to meet the growth requirements of a genotype is vital for realizing the yield potential in any given farming situation. Additionally, use of organic fertilizers is also helpful for improving soil carbon, enhancing soil biota and increasing water holding capacity. The study, thus, indicated ample scope for improvement in nutrient use efficiency, precise assessment of nutrient requirements of such varieties under each farmer's condition for arriving at the fertilizer prescriptions to ensure harvestable yield potential on sustainable basis besides optimizing input use.

Table 59.3 Soil nutrient supply potential *vis a vis* nutrient uptake assessed among different farmers categories

Categories/nutrient	Low yielders (3 sites)			High yielders (21 sites)		
	Minimum	Maximum	Mean	Minimum	Maximum	Mean
Grain yield (t ha^{-1})	3.41	3.72	3.59	4.03	6.20	4.67
Total nutrient uptake (kg ha^{-1})						
N	45.6	56.0	49.5	23.7	76.4	41.4
P	39.2	60.8	47.3	23.4	60.9	37.5
K	67.8	128.6	98.9	11.3	52.7	21.3
Soil quality index (SQI)	0.4 (poor)	0.5 (average)	0.45 (poor)	0.5 (average)	0.6 (average)	0.55 (average)

Table 59.4 Nutrient requirement per ton grain yield for farmers categories

Farmer's category	Mean yield (t ha^{-1})	Mean nutrient uptake (kg ha^{-1})			Nutrient requirement (kg t^{-1} grain)		
		N	P	K	N	P	K
Low yielders (3 sites)	3.59	49.5	47.3	98.9	13.7	13.17	27.54
High yielders (21 sites)	4.67	41.1	37.5	21.3	8.86	8.02	4.56

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References

Bodirsky BL, Rolinsk S, Biewald A, Weindi I, Popp A, Lotze-Campen H (2015) Global food demand scenarios for the 21st century. PloS ONE 10(11):e0129201

Debnath S, Mishra A, Mailapalli DR et al (2021). Assessment of rice yield gap under a changing climate in India. J Water Clim Change (12.4):1245–1267

FAO (2012) World agriculture towards 2030/2050: the 2012 revision. FAO, Rome

Lobell DB, Cassman KG, Field CB (2009) Crop yield gaps: their importance, magnitude, and causes. Annu Rev Environ Resour 34:1–26

Mukherjee A, Lal R (2014) Comparison of soil quality index using three methods. PLoS ONE 9(8):e105981.https://doi.org/10.1371/journal.pone.0105981

Ten Berge HF, Hijbeek R, Van Loon MP (2019) Maize crop nutrient input requirements for food security in sub-Saharan Africa. Glob Food Security 23:9–21

Chapter 60
Assessment of Nutrient Index in the Post-Flood Scenario of *Pokkali* Soils

Neha Unni and A. K. Sreelatha

Abstract Kerala state experienced a devastating flood in 2018, causing significant damage to agricultural sector and human life. One of the most affected places was *Pokkali* lands of Ernakulam district. For assessing the nutrient index of *Pokkali* soils of Ernakulam district, composite soil samples were collected randomly from five selected panchayats of Ernakulam district, i.e., Kuzhuppilly, Nayarambalam, Elamkunnapuzha, Kottuvally and Edavanakkad. The soils were analysed for organic carbon, available nitrogen, phosphorus, potassium and nutrient index of the soil. Fertility status based on organic carbon and macro-nutrients came under high category. The comparison of nutrient indices with pre-flood data revealed that there is slight increase in nutrient index values of available nitrogen post flood.

Keywords Kerala flood · Pokkali · Nutrient index · Soil fertility · Available nitrogen

60.1 Introduction

In recent years, world has been facing extreme weather events due to climate change in the form of different havocs like flood. In August 2018, Kerala witnessed large-scale devastating flooding due to excess rainfall. As per India Meteorological Department (IMD) data, Kerala received 2346.6 mm of rainfall from 1 June 2018 to 29 August 2018 against the normal value of 1649.5 mm. One of the most affected districts was Ernakulam, especially agro-ecological unit 5 (AEU), i.e., *Pokkali* lands. *Pokkali* lands represent the lowlands, often below sea level, in coastal areas of Ernakulam district and extending to parts of Thrissur and Alappuzha districts. The soils are hydromorphic, often underlain by potential acid-sulphate sediments with

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unique hydrological conditions. The origin, genesis and development of *Pokkali* soils are under peculiar climatic and environmental conditions. These soils comprise low-lying marshes and swamps situated near streams and rivers and are not far from the sea. They are water-logged and ill-drained and are subjected to tidal action throughout the year.

60.2 Materials and Methods

A survey was conducted to identify the flood-affected areas of AEU 5 of Ernakulam district. Representative geo-referenced composite soil samples were collected randomly from five selected panchayats, i.e., Kuzhuppilly, Nayarambalam, Elamkunnapuzha, Kottuvally and Edavanakkad (Table 60.1). From each sampling site, soil samples were collected to a depth of 0–15 cm using soil auger. A total of 12 composite soil samples were collected and were analysed for organic carbon and macro-nutrients. Standard procedures were followed for the estimation of nutrients.

60.2.1 Estimation of Organic Carbon (OC)

Organic carbon content of the soil sample was estimated by Walkley and Black method or wet digestion method (Walkley and Black 1934).

Table 60.1 Details of locations of soil sample collection

Sample No	Name of the panchayats	N latitude	E longitude
1	Kuzhuppilly	10°6′50.4957″	76°11′54.6666″
2	Kuzhuppilly	10°6′50.0360″	76°11′12.2179″
3	Nayarambalam	10°3′43.0916″	76°13′20.0828″
4	Nayarambalam	10°3′43.092″	76°13′20.930″
5	Elamkunnapuzha	10°10′25.6152″	76°10′37.7726″
6	Elamkunnapuzha	10°10′25.600″	76°10′37.7693″
7	Kottuvally	10°7′6.564″	76°14′53.502″
8	Kottuvally	10°6′49.4020″	76°14′27.9596″
9	Kottuvally	10°6′49.40208″	76°14′27.95964″
10	Edavanakkad	10°4′49.6313″	76°12′58.1568″
11	Edavanakkad	10°4′47.8470″	76°12′55.6177″
12	Edavanakkad	10°6′27.9919″	76°11′49.5179″

60.2.2 Estimation of Available Nitrogen (N)

Available N was estimated using alkaline potassium permanganate method using Kelplus distillation system (Subbiah and Asija 1956).

60.2.3 Estimation of Available Phosphorus (P)

Available P in soil samples was determined by Bray method (Bray and Kurtz 1945) and estimated colorimetrically by reduced molybdate ascorbic acid blue colour method (Watanabe and Olsen 1965) using spectrophotometer at 660 nm.

60.2.4 Estimation of Available Potassium (K)

Available K in soil samples was determined by flame photometer using neutral normal ammonium acetate as an extractant (Jackson 1958).

60.2.5 Nutrient Index

For the comparison of the levels of soil fertility of one area with another, it was necessary to obtain a single value for each nutrient. Nutrient index (NI) value is a measure of nutrient supplying capacity of soil to the plants. This index is used to evaluate the fertility status of soils based on the samples in each of the three classes, i.e., low, medium and high (Table 60.2). The NI of the soil was calculated for the soil samples using the following formula given by Ravikumar and Somashekar (2013).

$$\text{Nutrient index (NI)} = (1 \times L) + (2 \times M) + (3 \times H)/N$$

where

L is the number of samples in low category,
M is the number of samples in medium category,

Table 60.2 Ratings of nutrient index

Nutrient index value	Interpretation
< 1.67	Low-fertility status
1.67–2.33	Medium-fertility status
> 2.33	High-fertility status

H is the number of samples in high category and
N is the total number of samples.

60.3 Results and Discussion

The soil analysis for OC and macro-nutrients showed that the soil samples were found to be high in all the parameters (Table 60.3). Fertility status based on OC, available N, available P and available K came under high category (NI > 2.33) in Kuzhuppilly, Nayarambalam, Elamkunnapuzha, Kottuvally and Edavanakkad panchayats (Table 60.4). The high status of OC in *Pokkali* soils is due to the paddy and shrimp culture (Krishnaniet al. 2011). Higher OC content is the reason for the high N status in the

Table 60.3 Analysis data of organic carbon, available nitrogen, available phosphorus and available potassium

Panchayats	Organic carbon (%)	Available nitrogen (kg ha^{-1})	Available phosphorus (kg ha^{-1})	Available potassium (kg ha^{-1})
Kuzhuppilly	4.52	735	51.31	3077.81
Kuzhuppilly	4.75	457.81	47.94	3108.61
Nayarambalam	1.48	264.88	37.11	1908.89
Nayarambalam	3.73	509.26	55.92	2725.81
Elamkunnapuzha	2.99	546.38	45.71	2333.50
Elamkunnapuzha	3.71	509.26	50.43	3596.46
Kottuvally	1.32	741.84	65.61	629.24
Kottuvally	2.47	476.95	57.17	1541.59
Kottuvally	4.53	1112.27	228.60	3577.93
Edavanakkad	1.70	998.81	111.01	3719.34
Edavanakkad	1.41	560.62	48.84	3547.7
Edavanakkad	1.31	739.49	54.99	4294.14

Table 60.4 Nutrient index (post flood)

Panchayats	Nutrient index (post flood)			
	Organic carbon	Available nitrogen	Available phosphorus	Available potassium
Kuzhuppilly	3	2.5	3	3
Nayarambalam	2.5	2.5	3	3
Elamkunnapuzha	3	2.6	3	3
Kottuvally	2.66	3	3	3
Edavanakkad	2.3	3	3	3

Table 60.5 Nutrient index (pre flood)

Panchayats	Nutrient index (pre flood)			
	Organic carbon	Available nitrogen	Available phosphorus	Available potassium
Kuzhuppilly	2	1.6	3	3
Nayarambalam	2.8	2.2	3	3
Elamkunnapuzha	2.6	2	3	3
Kottuvally	1.8	2.2	2.5	3
Edavanakkad	2	1.6	2.8	3

soil (Verma et al. 1980). Due to the submergence of the soil, the pH of acidic soil increased to near neutral and resulted in higher availability of P. Tidal action on the *Pokkali* soils contributed to the increased available K (Sasidharan 2004).

Joseph (2014) reported that nutrient indices of OC, available P and available K came under high category (NI > 2.33) and available N in medium-fertility status (NI 1.67–2.33) (Table 60.5). Fertility status of Kuzhuppilly, Kottuvally and Edavanakkad panchayats based on OC was rated as medium. Nayarambalam and Elamkunnapuzha recorded high OC status. Fertility status of Kuzhuppilly, Nayarambalam, Elamkunnapuzha, Kottuvally and Edavanakkad panchayats based on available N came under medium category. Fertility status of Kuzhuppilly, Nayarambalam, Elamkunnapuzha, Kottuvally and Edavanakkad panchayats based on available P and K came under high category (Joseph 2014).

In comparison with pre-flood data nutrient indices of OC, available P and available K observed no wide variation after flood, but there is slight increase in available N after floods (Table 60.6). The pre-flood data showed that nutrient index of available N was medium, but the results of the present study revealed that it is under high category (Fig. 60.1). Nitrogen status is mainly governed by OC content in the soil. This might be due to the deposition of organic debris after the floods. The *Pokkali* soils are high in organic carbon due to the integration of rice-prawn culture and the peculiar type of *Pokkali* cultivation in which the panicles alone are harvested, keeping the remaining plant parts in the field itself. The tidal action occurring daily twice enriches the soil with basic cations. The present study revealed that there was

Table 60.6 Comparison of nutrient indices with pre flood data

Nutrients	Nutrient index (pre flood)	Nutrient index (post flood)
Organic carbon	2.4	2.86
Available nitrogen	1.68	2.86
Available phosphorus	2.8	3
Available potassium	3	2.86

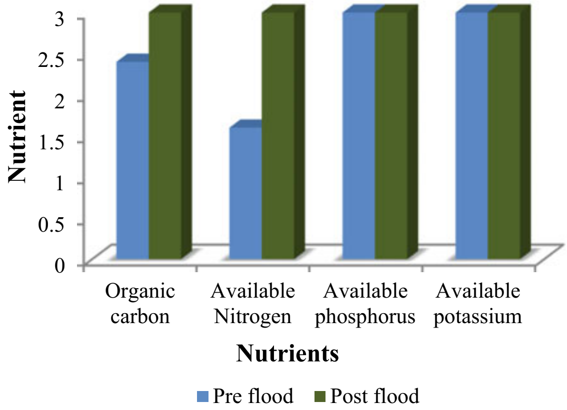

Fig. 60.1 Comparison of nutrient index of pre-flood and post-flood situation of study area

not much change in the fertility status of the soil even after flood in the study areas, which are low-lying and located at the end portion of flood water course, resulting in the deposition of silt carried from upstream. Due to this, there was no loss of nutrients and a slight increment in the available n content of soil.

60.4 Conclusions

Soil fertility varies within the soil, in each growing season in each year due to the change in climate and also by tidal action, resulting in deposition and depletion of nutrients in the soil. Hence, soil testing and computation of nutrient index will determine the fertility status and provide information regarding nutrient availability in the soils in each growing season.

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References

Bray RH, Kurtz LT (1945) Determining total, organic and available forms of phosphate in soils. Soil Sci 59:39–45

Jackson ML(1958) Soil chemical analysis. Prentice Hall of India Private Ltd., New Delhi, p 498

Joseph C (2014) Assessment of soil quality of acid saline *Pokkali* soils under different land uses. M.Sc. (Ag) thesis, Kerala Agricultural University, Thrissur, India, p 101

Krishnani KP, Gupta BP, Muralidhar M et al (2011) Soil and water characteristics of traditional paddy and shrimp fields of Kerala. Ind J Fish 58(4):71–77

Ravikumar P, Somashekar KP (2013) Evaluation of nutrient index using organic carbon, available P and available K concentrations on a measure of soil fertility in Varahi river basin, India. Proc Int Acad Ecol Environ Sci 3(4):330–343

Sasidharan NK (2004) Enhancing the productivity of the rice—fish/prawn farming system in *Pokkali* lands. PhD thesis, Kerala Agricultural University, Thrissur, 190p

Subbiah BV, Asija GLA (1956) A rapid procedure for the estimation of available nitrogen in soils. Curr Sci 25:259–260

Verma LP, Tripathi BR, Sharma DP (1980) Organic carbon as an index to assess N status of the soil. J Indian Soc Sci 28:138–139

Walkley AJ, Black IA (1934) Estimation of soil organic carbon by chromic acid titration method. Soil Sci 31:29–38

Watanabe FS, Olsen SR (1965) Test of an ascorbic acid method for determining phosphorus in water and $NaHCO_3$ extracts from soil. Soil Sci Soc Am J 29(6):677–678

Chapter 61
STCR-A Tool for Fertilizer Recommendation for Rice–Rice Cropping Sequence in UT of Puducherry

U. Bagavathi Ammal, R. Sankar, K. Coumaravel, and Pradip Dey

Abstract To develop the fertilizer prescription equations based on soil test crop response approach for rice–rice, field experiments were conducted at farmer's field in Arachikuppam village, U.T of Puducherry. Soil test data, yield and NPK uptake by rice–rice were used for obtaining four important basic parameters, viz. nutrient required to produce one quintal of rice, contribution of nutrients from fertilizers, contribution of nutrients from soil and contribution of nutrients from FYM (% CFYM) for both rice crops. The percent contribution of nutrients from soil (CS), fertilizer (CF) and FYM (CFYM) was found to be 11.83, 42.71 and 20.367 for N, 21.03, 57.18 and 19.01 for P_2O_5 and 19.27, 68.50 and 33.85 for K_2O, respectively, for rice (cv. ADT 43). The same for the rice (cv. White Ponni) was 20.18, 39.04 and 2306 for N, 21.39, 39.39 and 30.40 for P_2O_5 and 19.52, 70.97 and 55.03 for K_2O, respectively. Fertilizer prescription equations were developed, and nomograms were formulated based on the equations for a range of soil test values and desired yield target for rice. Under NPK + FYM @ 12.5 t ha^{-1}, 39, 28, 37 and 46, 26 and 35 kg ha^{-1} of fertilizer N, P_2O_5 and K_2O, respectively, could be saved for attaining target yield of 70 q ha^{-1} for rice cv. ADT 43 and cv. White Ponni as compared to NPK fertilizers alone.

Keywords Basic parameters · Fertilizer prescription equations · Rice–rice cropping sequence

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61.1 Introduction

In India, the net cultivated is about 142.60 million hectares, i.e., about 46.6% of the total geographical area. India accounts for only about 2.4% of the world's geographical area and 4% of its water resources but has to support about 17% of the world's human population and 15% of the livestock. Globally, rice is cultivated in an area of 160.9 M ha with a production of 480.1 mt of rice and with an average productivity of 4.44 t ha^{-1} in 2016 (USDA 2017). In the Union Territory of Puducherry, the area under rice cultivation was 16,263 hectares during the year 2015–16, with an average yield of 2699 kg ha^{-1} (Directorate of Economics and Statistics, Puducherry 2016). The conservative estimates show that the demand for food grains production of rice is imbalanced fertilization of N, P and K nutrients (Reddy and Ahmed 2000). Nutrient imbalances produce low yields, low fertilizer use efficiency and lower profit. Contrary to increasing food demand, the factor productivity and rate of response of crops to applied fertilizers under intensive cropping system are declining year after year. Although food grain production has increased many folds, the irony is that it has been achieved at the cost of deterioration of natural resources (Prasad 2004). In India, the nutrient use has increased by 173%, but average increase in total food grain was only 125% during the past five decades and at many places productivity got plateaued or showing decreasing trend.

In India, more than 44 million hectares area is occupied by rice under three major ecosystems, rainfed uplands (16% area), irrigated medium lands (45%) and rainfed lowland (39%), with a productivity of 0.87, 2.24 and 1.55 tons per hectare, respectively (Tiwari et al. 2013). Although the largest area under rice crop in the world (44 m ha) is in India, average productivity is lesser than China and Japan. The annual consumption of fertilizers, in nutrient forms (N, P and K), has increased from 0.07 million tons in 1951–52 to more than 28 million tons in 2010–11, and per hectare consumption has increased from less than 1 kg in 1951–52 to the level of 135 kg in 2010–11 (Karsangla and Gohain 2015); the nutrient use efficiency has gone down from 16 kg food grain produced per kg NPK applied during 1970s to 8 kg food grain produced per kg NPK applied during 1990s and around 6 kg now due to increasing deficiency of secondary and micronutrient (Tiwari et al. 2013).

The current fertilization practices do not put back in equal measure, the nutrients to the soil that has been removed by crops, resulting in continuous depletion of soil fertility status. This can be offset only by adopting soil testing and following integrated plant nutrition system (IPNS) as enunciated by "The Law of Optimum". This concept has been demonstrated and validated in farmer's field for obtaining targeted yield under the All India Co-ordinated Research Project on Soil Test Crop Response (AICRP-STCR) project (Ramamoorthy and Velayutham 2011; Tandon (2014) and Velayutham et al. 2016). The targeted yield approach wherein Ramamoorthy et al. (1967) established the theoretical basis and experimental proof for the fact that Liebig's law of minimum operates equally well for N, P and K. In Union Territory of Puducherry, this type of work has not yet been initiated. Hence, it is pertinent to develop soil test crop response relationship for giving fertilizer recommendations under IPNS for desired yield targets for rice–rice cropping sequence in an Inceptisol of Puducherry.

61.2 Materials and Methods

The experiments were conducted at farmer's holding of Arachikuppam in Bahour commune, Sanyasikuppam soil series of Pondicherry district, U.T. of Puducherry. The study area comes under coastal alluvial plain (PC1) classified as fine-loamy mixed isohyperthermic, *Typic Ustropept.* According to agro-climatic zonal classification, Puducherry is located at 11° 47′ and 12° 03′ N latitude and 79° 39′ and 79° 50′ E longitude. The soils of experimental field were neutral (pH 7.12) and non-saline in reaction and sandy clay loam in texture. The P and K fixing capacities of the soil were 150 and 100 kg ha^{-1}, respectively. The fertility status was low, high and medium with respect to available N (148.4 kg ha^{-1}), P (36.5 kg ha^{-1}) and K (131 kg ha^{-1}). The micronutrient status of the soil revealed that except zinc all other micronutrients were in optimum range (Zn-1.0, Cu-2.83, Mn-123.5 and Fe-28.0 mg kg^{-1}) (Lindsay and Norvell 1969), and 25 kg $ZnSO_4$ ha^{-1} was applied before transplanting of rice crop. Following the inductive methodology of Ramamoorthy et al. (1967), the experiment was conducted in two phases. In the first phase, fertility gradient experiment was conducted by raising rice (cv. ADT 39) as an exhaust crop. For this, the field was divided into three equal strips which were fertilized with $N_0P_0K_0$ (strip-I), $N_1P_1K_1$ (strip-II) and $N_2P_2K_2$ (strip-III) levels to create fertility gradient. Subsequently, in the second phase, after the harvest of the exhaust crop, test crop experiments were conducted with rice (cv. ADT 43) and rice (cv. White Ponni). Each of the fertility strips was subdivided into 24 sub-plots resulting in 72 plots. There were 24 treatments which consist of 4 levels of N (0, 60, 120 and 180 kg ha^{-1}), P_2O_5 (0, 25, 50 and 75 kg ha^{-1}), K_2O (0, 25, 50 and 75 kg ha^{-1}) and farmyard manure (FYM) (0, 6.25 and 12.5 t ha^{-1}). The moisture and N, P_2O_5 and K_2O contents of FYM were 28, 0.43, 0.31 and 0.41%, respectively. After the harvest of cv. ADT 43, the second test crop rice cv. White Ponni was conducted with 4 levels of N (0, 50, 100 and 150 kg ha^{-1}), P_2O_5 (0, 25, 50 and 75 kg ha^{-1}), K_2O (0, 25, 50 and 75 kg ha^{-1}) and farmyard manure (FYM) (0, 6.25 and 12.5 t ha^{-1}). Pre-sowing soil samples were collected from each plot for each crop and were analyzed for available N (alkaline potassium permanganate method), available P (Olsen's method) and available K (ammonium acetate method). Grain and straw yields of both rice crops were recorded, and these samples were analyzed for N, P and K contents and uptake values were computed. Using the data on crop yield, nutrient uptake, pre-sowing soil available nutrients and fertilizer doses applied, the basic parameters, viz., nutrient requirement (NR), contribution of nutrients from soil (CS), fertilizer (CF) and contribution of nutrients from FYM (%CFYM), were calculated as per procedure described by Ramamoorthy et al. (1967) and Santhi et al. (2002). These parameters were used for formulation

Table 61.1 Pre-sowing soil available NPK (kg ha^{-1}) in various strips

Strip	Available N		Available P_2O_5		Available K_2O	
	Range	Mean	Range	Mean	Range	Mean
Rice (cv. ADT 43)						
Strip-I	170.8–190.4	180.7	24.1–32.0	26.9	104–119	115
Strip-II	238.0–266.0	246.6	28.7–38.5	31.7	121–146	129
Strip-III	263.3–285.0	273.7	28.9–41.6	32.9	143–163	150
Rice (cv. White Ponni)						
Strip-I	159.6–201.6	182.0	19.2–35.3	25.9	101–127	114.0
Strip-II	176.4–229.6	209.3	20.6–36.8	28.7	119–145	129.0
Strip-III	193.2–271.6	249.3	24.0–35.9	29.9	122–168	148.0

of fertilizer prescription equations for deriving fertilizer doses, and the soil test-based fertilizer recommendations were prescribed in the form of a ready reckoner for desired yield target of rice–rice under NPK alone as well as NPK + FYM.

61.3 Results and Discussion

61.3.1 Soil Available Nutrients

Strip-wise range and mean soil test values of pre-sowing stage for available nutrients are furnished in Table 61.1. The average content of available nutrients was found to increase with increasing fertility strips, and the highest content was recorded in strip-III. The average available N content increased from 180.7 to 273.7 kg ha^{-1} and from 182.0 to 249.3 kg ha^{-1} for rice cv. ADT 43 and cv. White Ponni, respectively. The increase in N could be due to the addition of double dose of NPK fertilizers than single dose and control. The increased availability of P and K may be due to the application of graded levels of phosphatic and potassic fertilizers either on par with or over and above the P and K fixing capacity of the experimental field. Similar buildup of P and K was noticed by Coumaravel (2012) and Bagavathi Ammal et al. (2013).

61.3.2 Grain Yield and Nutrient Uptake

Range and mean values of grain yield and nutrient uptake under different strips are given in Table 61.2. Maximum yield in both the rice varieties was obtained in strip-III followed by strip-II and strip-I. A crop which is grown under favorable environment is bound to produce better yields, provided the nutrient supply is matching with

Table 61.2 Grain yield and nutrient uptake by rice (kg ha^{-1}) in various strips

Parameters	Strip-I		Strip-II		Strip-III	
	Range	Mean	Range	Mean	Range	Mean
Rice (cv. ADT 43)						
Grain yield	2780–6060	4876	3110–6890	5214	3530–7115	5444
N uptake	24.5–98.1	71.2	32.2–101.4	76.5	31.2–106.3	78.6
P_2O_5 uptake	7.3–21.0	15.6	10.6–21.9	16.8	10.8–22.8	17.4
K_2O uptake	22.0–58.4	45.6	34.5–61.2	48.9	35.2–65.5	51.3
Rice (cv. White Ponni)						
Grain yield	2750–7045	5278	2950–7665	5401	3250–8010	5490
N uptake	33.3–97.5	72.7	35.4–102.3	79.6	39.2–113.5	85.2
P_2O_5 uptake	6.0–18.1	12.7	6.6–19.0	14.6	7.6–21.1	15.5
K_2O uptake	25.4–54.9	45.9	27.1–62.5	49.9	32.1–65.2	53.6

nutrient accumulation that occurs in the crop. The strip-wise average nutrient uptake was in the order of strips III > II > I for both rice crops. The result indicated that a wide variability existed in the soil test values, grain yield and nutrient uptake which are a pre-requisite for calculating the basic parameters and fertilizer prescription equations for calibrating the fertilizer doses for specific yield targets (Santhi et al. 2002).

61.3.3 Basic Parameters

In targeted yield model, making use of the data on yield of crop, uptake of NPK, initial soil test values and doses of N, P_2O_5 and K_2O applied, the basic parameter for rice was computed and presented in Table 61.3. The basic parameters for developing fertilizer prescription equation for rice are (i) nutrient requirement in kg q^{-1} of rice (NR), (ii) percent contribution from soil available nutrient (Cs), (iii) percent contribution from fertilizer (CF) and (iv) percent contribution from FYM (CFYM).

Table 61.3 Basic parameters for rice

Parameters	Rice (cv. ADT 43)			Rice (cv. White Ponni)		
	N	P_2O_5	K_2O	N	P_2O_5	K_2O
Nutrient requirement (kg q^{-1})	1.44	0.73	1.13	1.46	0.60	1.12
Percent contribution from soil	11.83	21.03	19.27	20.18	21.39	19.52
Percent contribution from fertilizer	42.71	57.18	68.50	39.04	39.39	70.97
Percent contribution from FYM	20.67	19.01	33.85	23.06	30.40	55.03

The nutrient requirement for the production of one quintal of rice cv. ADT 43 and cv. White Ponni was computed as 1.44, 0.73 and 1.13 and 1.46, 0.60 and 1.12 kg of N, P_2O_5 and K_2O, respectively. The percent contribution from soil for rice cv. ADT 43 and cv. White Ponni was found to be 11.83 and 20.18 for N, 21.03 and 21.39 for P_2O_5 and 19.27 and 19.52 for K_2O, respectively. The percent contribution of nutrients from the fertilizer sources revealed that among the three nutrients contribution was more in the case of K than N and P. The high value of K could be due to interaction effect of higher doses of N and P coupled with priming effect of K doses, which might have caused the release of soil K, resulting in the higher uptake in the native soil sources by crop (Ray et al. 2000).

The percent contribution of N, P_2O_5 and K_2O from FYM was 20.67, 19.01 and 33.85, respectively, for rice cv. ADT 43 and 23.06, 30.40 and 55.03 for rice cv. White Ponni. In both the cases, higher contribution was recorded in the case of K, which might be due to the supply of carbon which acts as the source of energy for the buildup of bacterial population which in turn would have enhanced the release of K from organic sources and native sources. The findings are in close conformity with Natesan et al. (2007).

61.3.4 Fertilizer Prescription Equations for Desired Yield Targets

Based on the basic parameters, fertilizer prescription equations for targeted yield of both rice varieties under NPK alone as well as NPK + FYM were formulated and are furnished in Table 61.4. On the basis of these equations, a ready reckoner was prepared for making fertilizer recommendations for different soil test values to meet specified yield targets of rice under NPK alone and NPK + FYM (Tables 61.5 and 61.6).

Based on the fertilizer prescription equations for rice cv. ADT 43 for NPK alone, fertilizer N recommendation was found in the range from 146 to 197, fertilizer P_20_5 from 66 to 81 and fertilizer K_20 from 24 to 81 kg ha^{-1} for attaining a yield target of 70 q ha^{-1} (Table 61.5). When FYM was applied along with NPK fertilizers, fertilizer requirement of N, P_20_5 and K_2O was found in the range of 108 to 158, 38 to 53 and 20 to 44 kg ha^{-1}, respectively, at the same level of soil test values. Similar trend was also observed in rice cv. White Ponni. Under NPK + FYM @12.5 t ha^{-1}, 39, 28, 37 and 46, 26 and 35 kg ha^{-1} of fertilizer N, P_2O_5 and K_2O, respectively, could be saved for attaining target yield of 70 q ha^{-1} for rice cv. ADT 43 and cv. White Ponni as compared to NPK fertilizers alone. The combined use of organic manure and inorganic fertilizers checks nutrient losses and conserves nutrients by forming organic-mineral complexes and thus ensures continuous nutrient availability to rice plants so that the maximum yield can be achieved (Amanullah 2016). Furthermore, inorganic nutrients easily available from mineral fertilizer at the early growth stages and organic manure are mineralized at the later growth stages normally subjected to

Table 61.4 Soil test-based fertilizer prescription equations for targeted yield of rice

Particulars	Rice cv.ADT 43	Rice cv. White Ponni
	Fertilizer alone	Fertilizer alone
FN (Fertilizer N-kg ha^{-1})	3.38 T–0.25 SN	3.75 T–0.52 SN
F P_20_5 (Fertilizer P_20_5-kg ha^{-1})	1.27 T–0.79 SP	1.53 T–1.24 SP
F K_20 (Fertilizer K_20-kg ha^{-1})	1.65 T–0.34 SK	1.58 T–0.33 SK
	Fertilizer with FYM	**Fertilizer with FYM**
FN (Fertilizer N-kg ha^{-1})	3.38 T–0.25 SN–0.48 ON	3.75 T–0.52 SN–0.59 ON
F P_20_5 (Fertilizer P_20_5-kg ha^{-1})	1.27 T–0.79 SP–0.76 OP	1.53 T–1.24 SP–1.77 OP
F K_20 (Fertilizer K_20-kg ha^{-1})	1.65 T–0.34 SK–0.60 OK	1.58 T–0.33 SK–0.93 OK

T-yield target in q ha^{-1}.SN, SP and SK-soil available N, P and K. ON, OP and OK-N, P and K applied through organics

nutrient stress. Thus, ultimately the yield of the rice crop increased by maintaining the supply of nutrients to rice plants for longer time (Shah et al. 2010). Application of organic manures along with chemical fertilizers accelerates the microbial activity which in turn increased the nutrient use efficiency and enhanced the native nutrients to the plants resulting higher yield in the rice reported by Dekhane et al. (2014). Similar trend of encouraging response to FYM/organics application was also reported by Srinivasan and Angayarkanni (2008).

Higher yield of rice by the addition of FYM with recommended fertilizer amount is due to the higher supply of N and phosphorus to the soil. Furthermore, boosted yield was due to the reason that addition of organic nutrients brings positive changes in organic carbon and nitrogen content of the soil and increases tendency of available phosphorus and potassium content (Dixit and Gupta 2000). The improvement in soil nitrogen and phosphorus nutrient status due to FYM application could sustain high rice crop yields ensuring long sustainability of the system. In addition to that the application of FYM increases soil organic matter and available water holding capacity which enable the rice crop to withstand occurrence of terminal moisture stress and give better yield (Mengel et al. 1976). Ultimately, balanced supply of nutrients, especially macro- and micronutrients from both organic manure and chemical fertilizer, induces cell division, expansion of cell wall, meristematic activity, photosynthetic efficiency, regulation of water to cells, conductive physical environment, facilitating to better aeration, root activity and nutrient absorption leading to higher yield (Singh et al. 2014). Though there was marked response to the application of NPK fertilizers, the magnitude of response was higher under IPNS compared to NPK alone. Such enhancement of yield in IPNS-treated plots might be due to building up to

Table 61.5 Fertilizer recommendation (kg ha^{-1}) for yield targets of rice (cv. ADT 43) under NPK and NPK + FYM

$KMnO_4$-N	60 q ha^{-1}		70 q ha^{-1}		Olsen-P	60 q ha^{-1}		70 q ha^{-1}		NH_4OAc-K	60 q ha^{-1}		70 q ha^{-1}	
	NPK alone	NPK + FYM @ 12.5 t ha^{-1}	NPK alone	NPK + FYM @ 12.5 t ha^{-1}		NPK alone	NPK + FYM @ 12.5 t ha^{-1}	NPK alone	NPK + FYM @ 12.5 t ha^{-1}		NPK alone	NPK + FYM @ 12.5 t ha^{-1}	NPK alone	NPK + FYM @ 12.5 t ha^{-1}
160	163	124	197	158	10	69	41	81	53	100	65	28	81	44
200	153	114	186	148	14	65	38	78	50	140	51	20	68	31
240	143	104	176	138	18	62	34	75	47	180	38	20	54	20
280	133	94	166	128	22	59	31	72	44	220	24	20	41	20
320	123	84	156	118	26	55	29	69	41	260	24	20	28	20
360	113	74	146	108	30	51	27	66	38	300	24	20	24	20

Table 61.6 Fertilizer recommendation (kg ha^{-1}) for yield targets of rice (cv. White Ponni) under NPK and NPK + FYM

$KMnO_4$-N (kg ha^{-1})	70 q ha^{-1}		80 q ha^{-1}		Olsen-P	70 q ha^{-1}		80 q ha^{-1}		NH_4OAc-K (kg ha^{-1})	70 q ha^{-1}		80 q ha^{-1}	
	NPK alone	NPK + FYM @ 12.5 t ha^{-1}	NPK alone	NPK + FYM @ 12.5 t ha^{-1}		NPK alone	NPK + FYM @ 12.5 t ha^{-1}	NPK alone	NPK + FYM @ 12.5 t ha^{-1}		NPK alone	NPK + FYM @ 12.5 t ha^{-1}	NPK alone	NPK + FYM @ 12.5 t ha^{-1}
160	180	134	217	172	10	95	69	110	42	100	77	84	93	58
200	159	113	197	151	14	90	64	105	29	140	64	79	80	45
240	139	93	176	130	18	85	59	100	25	180	51	74	67	31
280	118	75	155	115	22	80	54	95	25	220	38	69	53	25
320	99	57	135	100	26	75	49	90	25	260	25	64	40	25
360	78	50	115	85	30	70	44	85	25	300	25	59	27	25

organic matter, maintaining favorable soil physical properties and balanced supply of nutrients (Sutaliya and Singh 2005). In the present investigation also, these factors might have contributed for the yield enhancement in rice when NPK fertilizers are combined with FYM.

61.4 Conclusions

Use of FYM resulted in saving of fertilizer nutrients in rice–rice cropping sequence. Target yield equations generated from soil test crop correlation approach technology ensures not only sustainable crop production but also economies of use of costly fertilizer inputs. Practice of fertilizing rice crop using fertilizer prescription equations developed would help in achieving higher productivity, nutrient use efficiency and profitability.

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References

Amanullah H (2016) Influence of organic and inorganic nitrogen on grain yield and yield components of hybrid rice in north eastern Pakistan. Rice Sci 23(6):326–333

Bagavathi Ammal U, Sankar R et al (2013) Studies on minimizing N fertilizer through STCR-IPNS. In: Proceedings international conference on conventional or non-conventional organic inputs in agriculture, Pondicherry, India, pp 209–210

Coumaravel K (2012) Soil test crop response correlation Studies through integrated plant nutrition system for Maize-Tomato sequence. Ph.D. (Ag.) Thesis, TNAU, Coimbatore, India

Dekhane SS, Patel DJ, Jadhav PB et al (2014) effect of organic and inorganic fertilizer on growth and yield of paddy CV GR 11. Int J Inf Res Rev 1:026–028

Directorate of Economics & Statistics, Puducherry and Public Works Department, Puducherry (2016). http://agri.puducherry.gov.in/apstat.htm

Dixit KG, Gupta BR (2000) Effect of farmyard manure, chemical and biofertilizer on the yield and quality of rice and soil properties. J Indian Soc Soil Sci 48:619–638

Karsangla AO, Gohain T (2015) Effect of different doses of NPK fertilizers on local rice (*Oryza sativa* L.) under direct-seeded upland condtion. J Soils Crops 25(1):54–61

Lindsay WL, Norvell WA (1969) Development of a DTPA micronutrient soil test. Agron Abst: 84

Mengel K, Vivo M, Hehl G (1976) Effect of potassium on uptake and incorporation of ammonium nitrogen of rice plants. Plant Soil 44:547–558

Natesan R, Murugesa Boopathi P, Santhi R et al (2007) Bulletin soil test crop response based fertilizer prescription for different soils and crops in Tamil Nadu

Prasad J (2004) Environmental implications of soil degradation in India—a review. Agric Rev 25:57–63

Ramamoorthy B, Velayutham M (2011) The law of optimum and soil test base fertilizer use for targeted yield of crops and soil fertility management for sustainable agriculture. Madras Agric J 98(10–12):295–307

Ramamoorthy B, Narasimham RK, Dinesh RS (1967) Fertilizer application for specific yield targets on Sonora 64 (wheat). Indian Farming 17:43–45
Ray P, Jana K, Maitra AK et al (2000) Fertilizer prescription on soil test basis for jute, rice and wheat in a *Typic Ustochrept*. J Indian Soc Soil Sci 48:79–84
Reddy KC, Ahmed SR (2000) Soil test based fertilizer recommendation for maize grown in inceptisols of Jagtiyal in Andra Pradesh. J Indian Soc Soil Sci 48(1):84–89
Santhi R, Natesan R, Selvakumari G (2002) Soil test based fertilizer recommendation under IPNS for aggregatum onion in Inceptisol of Tamil Nadu. Agropedology 12:141–147
Shah A, Shah SM, Shafi M et al (2010) Effect of integrated use of organic and inorganic N sources on wheat yield. Sarhad J Agric 2:554–563
Singh YV, Singh SK, Sharma PK et al (2014) Soil test based Integrated fertilizer recommendation for wheat in an Inceptisol of Eastern Plain zone of Uttar Pradesh. J Indian Soc Soil Sci 2(3):255–258
Srinivasan S, Angayarkanni A (2008) Effect of INM on yield and nutrient uptake by rice in STCR experiment. Agric Sci Digest 28(2):130–132
Sutaliya R, Singh RN (2005) Effect of planting time, fertility level and phosphate solubilizing bacteria on growth, yield and yield attributes of winter maize (*Zea mays*) under rice (*Oryza sativa*)—maize cropping system. Indian J Agron 50(3):173–175
Tandon HLS (2014) Soil testing for balanced fertilization. FDCO, New Delhi, p 170
Tiwari RK, Jha A, Tripathi SK et al (2013) Rice based cropping system and climate change. JNKVV Res J 47:239–247
USDA (2017) United States Department of Agriculture. World Agricultural Production 2016. Nat Agricultural Statistics Service Circular Series:121.WAP 06-17
Velayutham M, Santhi R, Subba Rao A et al (2016) The law of optimum and its application for realizing targeted yields in India—a mini-review. https://www.ipipotash.org/uploads/udocs/e-ifc44-law-of-optimum-india.pdf

Chapter 62
Effect of Saline Water Irrigation Through Drip System on Okra (*Abelmoschus esculentus* L.) in Salt Affected Soils of West Bengal

K. K. Mahanta, Dhiman Burman, Sukanta Kumar Sarangi, Uttam Kumar Mandal, and B. Maji

Abstract The confluence of river Ganges and sea Bay of Bengal has resulted in formation of the coastal West Bengal. Topographically, the coastal area consists of low lands which are flat with little or no slope and often suffer from inadequate drainage and waterlogging during the rainy season (June–Sept.). The region is the mixing zone of inland fresh water, rain, and brackish water of the sea. Agriculture in the lean period of eight months suffers from acute fresh water scarcity and salinity. Ground water in this region varies spatially and temporally and often carries threats for water table depletion and sea water intrusion. The upper aquifer is available at shallow depth but saline. In many places, ground water salinity is too high and not usable for agriculture. Less saline water may be available at deeper depths. In this scenario, cultivating more with little available water propels the idea of using highly efficient drip irrigation system. Experiments were conducted at ICAR-CSSRI, RRS, Canning Town farm during 2014–18 to evaluate the impact of saline water irrigation by drip system on okra crop and soil. Water of different salinities was prepared by mixing the saline groundwater with fresh water for the four treatments such as T1: 2 dSm^{-1}, T2:6 dSm^{-1}, T3: 10 dSm^{-1}, and T4:14 dSm^{-1}. Only, one quality of water was applied through the drip irrigation system at a time. The treatments were imposed after 20–25 days of fresh water irrigation when the crop is established. The highest fruit yield (14 t ha^{-1}) of okra was obtained for the treatment T1. The amount

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of irrigation water applied was in the range 36–48 cm during the cropping periods depending upon the unseasonal rainfall received time to time. There was about 50% less yield in case of T4 in comparison to T1. The NDVI value was higher (up to 0.2) for the irrigation water of lower salinity (T1 > T2 > T3 > T4) throughout the experimental period. There was less mortality of okra plants due to application of saline water even in case of T4. The water use efficiency was highest for treatment T1 whereas lowest for T4. The salinity build up was highest for T4 during the experimental period, but the salts were leached out by the runoff during rainy season.

Keywords Coastal region · Drip irrigation · *Rabi* crop · Salt affected soils

62.1 Introduction

The confluence of the river Ganges and Bay of Bengal sea has resulted in formation of the coastal West Bengal. Topographically, the coastal area consists of low lands which are flat with little or no slope and often suffer from inadequate drainage and waterlogging during the rainy season (June–Sept.). The rainfall in the Sundarbans area is confined to a few months of monsoon during which about 80% of annual rainfall occurs (Mandal et al. 2019). In the rest period of the year, the rainfall is erratic. The coastal low lands are criss-crossed by rivers, rivulets and creeks carrying salty water of the sea which influence the surface water, soil salinity as well as ground water (Mandal et al. 2018). The region is the mixing zone of inland fresh water, rain and brackish water of the sea. Ground water in many parts of the region is available at shallow depth, but due to constraint of high salinity, this water cannot be used for agriculture in the lean period of eight months. Therefore, agriculture suffers from acute fresh water scarcity and salinity (Burman et al. 2015). Less saline water is available at deeper depths of the aquifer; however, the extraction is expensive. Ground water in this region also varies spatially and temporally and often carries threats for water table depletion and sea water intrusion.

Scarcity of fresh water during the non-monsoon period prevents the farmers to go for multiple cropping. Most of the land remains fallow during the dry season because of increased salinity and scarcity of freshwater for irrigation (Sarangi et al. 2020). Besides fresh water scarcity in non-monsoon period in the coastal West Bengal, water quality is also a major concern. The salinity of surface water as well as ground water is highly variable spatially and temporally, directly, or indirectly coming under the influence of tidal water and inter-connected aquifers. In the *rabi* (dry) season also, paddy is the principal crop in the coastal area using the conventional methods of irrigation (Mandal et al. 2019). Conventional method of irrigation is very cumbersome, laborious, and the efficiency of water use is very less, and there is lot of wastage of water resources. As the soil of the coastal West Bengal is silty clay loam, if flood irrigation is given, it becomes very inconvenient to move inside the cropping land for the inter-cultural operations. Labor scarcity sometimes prevents the timely agricultural operations affecting the crop growth and yield. It necessitates the use of advanced irrigation technologies such as drip irrigation system and sprinklers.

Drip irrigation can be used instead of hand-watering with minimal water losses and a significant reduction in labor, and it has the potential to increase crop yield (Singh 1978). Different technical aspects of the design of drip irrigation systems have been discussed in detail (Bucks and Nakayama 1986; Keller and Bliesner 1990). Wu assessed drip irrigation systems with respect to the relative effects of hydraulic design, emitter manufacturing variation, grouping of emitters, and emitter plugging (Wu 1997). The design of multi-diameter and multi-outlet pipes laid on flat or sloping lands has been analyzed by many researchers (Ajai et al. 2000; Anwar 1999; Jain et al. 2002; Juana et al. 2004; Mahar and Singh 2003; Valiantzas 2002; Yieldirim 2007). Procedures for the optimal design and operation of a multiple subunit drip irrigation system on flat ground were developed (Dandy and Hassanli 1996). Ravindra et al. (2008) also developed a design procedure for drip irrigation subunits. Bhatnagar and Srivastava investigated gravity-fed drip irrigation systems for hilly terraces in which low-pressure emitters were used, but without dividing the irrigated area into subunits with different pressure ranges (Bhatnagar and Shrivastava 2003).

Driven by the need to produce more under water scarce conditions, larger amounts of saline groundwater are pumped for irrigation in several countries in the Middle East as well as in numerous areas elsewhere (Qadir et al., 2007). For example, India's annual net groundwater draft is 135 km^3, of which 32 km^3 is estimated to consist of saline and/or sodic water, which is about one-fourth of the total volume of groundwater used in the country (Sharma and Minhas 2005). In China, especially North China Plain, as less and less fresh water is available for agriculture with increasing population and rapid economic growth, saline water has been included as an important substitutable resource of fresh water in agricultural irrigation (Wan et al. 2007). They were often divided further into subgroups as brackish water (with salinity of 1.67–5.0 dS m^{-1}), semi-saline water (5.0–8.33 dS m^{-1}), and saline water (8.33–16.67 dS m^{-1}) according to salt concentrations (Zhang et al. 2009). In this region, annual exploitable volume (average from 1991 to 2003) of fresh water, brackish water, and semi-saline water (including saline water) is 11.644, 6.495, and 2.223 km^3, comprising 57.2, 31.9, and 10.9% of total exploitable volume of water resources, respectively. However, most of these saline water resources remain unexplored. The salinity of coastal saline soil is high and with the same ion composition as sea water (Khan et al. 1996). Moreover, the groundwater table is shallow and the soil salinity changes seasonally (Shi et al. 2005).

Drip irrigation is considered the most efficient irrigation method because it applies water precisely and uniformly at high frequencies, maintaining high soil matric potential (SMP) in the root zone and thus compensating for the decreased osmotic potential caused by irrigation with saline water, and constant high total water potential can be maintained for crop growth (Goldberg et al. 1976; Kang and Wan 2005; Mahanta et al. 2019). Additionally, well-aerated conditions can be maintained under drip irrigation (Keller and Bliesner 1990). However, most studies have concentrated on crops such as tomato (Wan et al. 2007), oleic sunflower (Chen et al. 2009), and waxy maize, and few studies have considered vegetation rehabilitation under drip irrigation in coastal saline soils.

Many studies have investigated irrigation scheduling for a wide variety of crops in different saline soils (Kang and Wan 2005; Wang et al. 2011) based on SMP. Moreover, irrigation by controlling the SMP at a depth of 20 cm immediately under the emitter throughout the growing season has been accomplished in saline soils with arid and semi-arid climates in the Ningxia Plain, China (Tan and Kang 2009) and was applied in saline wasteland with an inland arid climate in Xinjiang, Northwest China (Wang et al. 2011) and also in saline-sodic soils of the Songnen Plain, China (Liu et al. 2011).

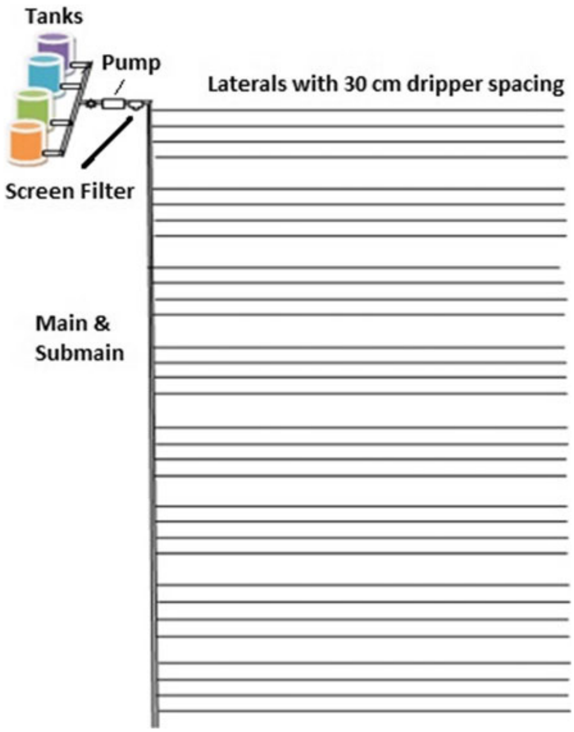
In coastal West Bengal, the lands are flat and low with little slope. The salts in the soils are diluted during the rainy season. But, again, the soil salinity increases toward the late summer due to evaporation. The tidal surface water sources are brackish and not utilizable for the agriculture (Mandal et al. 2021). Also, the ground water which is utilized in this region varies too much in salinity. Mahanta had conducted an experiment on drip irrigation, taking *Abelmoschus esculentus* as the crop using fresh water (Mahanta 2004). There is little study on irrigation with saline water in the coastal region of West Bengal.

62.2 Materials and Methods

As irrigation water quality varies a lot in the coastal region influenced by sea water, desired quality of water was prepared by mixing fresh water and the saline water (ground water or surface water from tidal river). The experiment was conducted during the *rabi/summer* season in the institute farm of CSSRI, RRS, Canning Town, West Bengal, India during the years 2014–2018. The experimental plot was medium land with silty clay loam soil. The cropping system was rice-okra, rice during the rainy season when the land is submerged with rainwater. Normal dose of fertilizers was applied in three splits through the fertigation tank during the crop growing period. The treatments were imposed after 20–25 days of fresh water irrigation when the crop is established. For the experiment, fresh ground water available at ICAR-CSSRI, RRS, Canning Town farm in a tubewell of 250 m depth was mixed with saline ground water available in tubewell of 20 m for making the saline water for different treatments. The salinity of the ground water of the deep tubewell (depth 250 m) was about 1.4 dS m^{-1}, whereas the salinity of the shallow tubewell (20 m depth) varied from 25 ~ 30 dS m^{-1}. Separate tank of 500-L capacity was kept for each water quality treatment. Tank water was applied to the test crop through drip irrigation system operating through individual valve from one tank at a time (Fig. 62.1). Total four different water qualities (salinity) such as T1: 2 dS m^{-1}, T2: 6 dS m^{-1}, T3: 10 dS m^{-1}, T4:14 dS m^{-1} were applied taking okra as the test crop.

The laterals diameter was 16 mm having inbuilt inline drippers with the dripper discharge rate 2.4 L per hour (lph) at 1 kg cm^{-2} pressure. Containers were placed all over the experimental plot to collect discharge within a specified time to evaluate

Fig. 62.1 Layout of the drip irrigation system



the uniformity of water application. Then, Christiansen uniformity coefficient was evaluated by the formula:

$$C_u = \left(1 - \frac{\sum|x|}{mn}\right) \times 100 \tag{62.1}$$

m = average application rate, mm.
n = total number of points,
x = numerical deviation of individual observations from the average application rate, mm.

Then, efficiency of the system was computed by:

$$\eta = \frac{\text{Actual discharge}}{\text{Design discharge}} \tag{62.2}$$

The performance of the experimental crops was evaluated based on normalized difference vegetation index (NDVI) values. The yield was recorded treatment wise. Soil samples were collected at different times to see the impact of saline water irrigation.

62.3 Results and Discussion

62.3.1 Evaluation of System Parameters

The system was laid as per the layout. At the beginning, the laterals were flushed with good quality water to remove the foreign materials as well as salts if any present inside. The aluminum containers were placed under the drippers in grid pattern, and the amounts of water collected at different points during specific time were measured. The uniformity coefficient and the irrigation efficiency were evaluated to be 92.5% and 87.2%, respectively, computed through Eqs. (62.1) and (62.2). Therefore, the system's performance was similar to the observations made by Arya et al. (2017) and was satisfactory.

62.3.2 The NDVI of Okra Crop

After the test crop was established, normalized difference vegetation index (NDVI) values were recorded at different times (Fig. 62.2). The NDVI value was low when the okra plants were small. There was increase in NDVI values as the plants grew and later decreased gradually as the production stage proceeds. In the figure, it was observed that NDVI values are best for the treatment T1 where irrigation water of lowest salinity (2 dS m^{-1}) was used. The NDVI values were lowest for treatment T4 where saline water of 14 dS m^{-1} was used for irrigation. It indicates that the performance of the okra crop was inversely proportional to the water salinity.

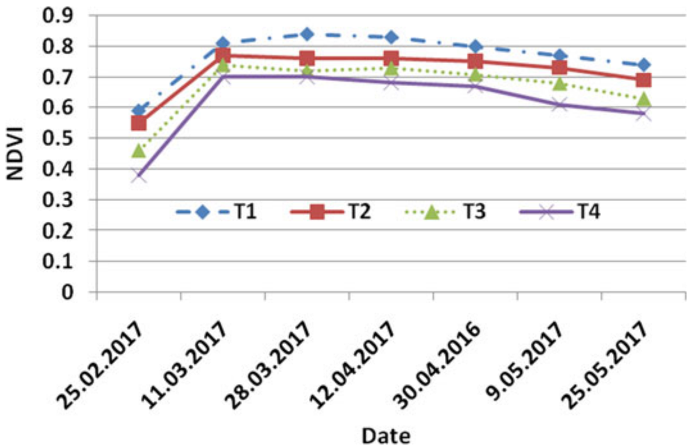


Fig. 62.2 Temporal variation of NDVI of drip irrigated okra under different irrigation water salinity

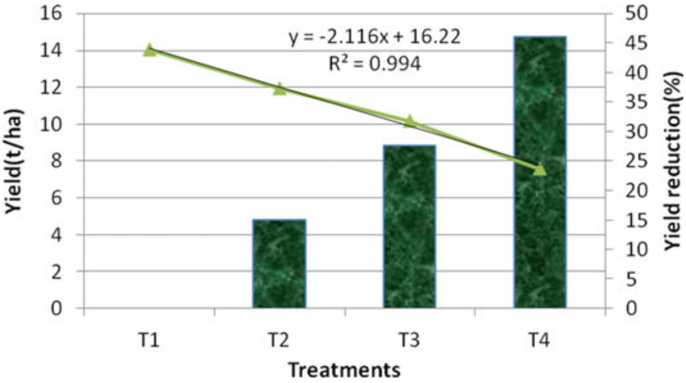


Fig. 62.3 Yield of drip irrigated okra under different irrigation water salinity

62.3.3 Yield of Crop

The okra fruits were harvested regularly in the edible stage, and the yield data were recorded treatment wise. The highest yield (14 t ha^{-1}) of okra was obtained for the treatment T1 where lowest saline water was used for irrigation. There was yield reduction of about 46% in case of T4 where highest saline water was used for irrigation in comparison to T1 (Fig. 62.3).

62.3.4 Effect on Soil Salinity

The soil salinity was evaluated at the beginning of the experiment at three depths 0 ~ 15 cm, 15 ~ 30 cm, and 30 ~ 45 cm and at different times later on. Though initial soil salinity was less than 4 dS m^{-1}, the rate of salinity increase was highest for treatment T4 in the top layer (Fig. 62.4). For treatment T1, the soil salinity further reduced near to 2 dS m^{-1}.

The rate of salinity development in the layer 15 ~ 30 cm was medium (Fig. 62.5) and lowest at the bottom layer, i.e., 30 ~ 45 cm. Even though saline water up to 14 dS m^{-1} was applied, there was less mortality of the plants. Total amount of water applied was 45 cm through 24 number of irrigations for the okra crop. Among the different physiological parameters, the plant height of okra varied in the range 80–87 cm, root depth: 27–42 cm and number of fruits $plant^{-1}$: 37 ~ 47, and there was no clear trend of these parameters with respect to the treatments.

The experimental site belongs to humid zone with average annual rainfall of about 1800 mm. As the soil is heavy (silty clay loam), the cultivated land was submerged with water, whenever there is heavy intensity of rain. Paddy crop was cultivated in the same plot during kharif season, when the land remained ponded with water throughout the season. The salts applied through the saline water during the *rabi*

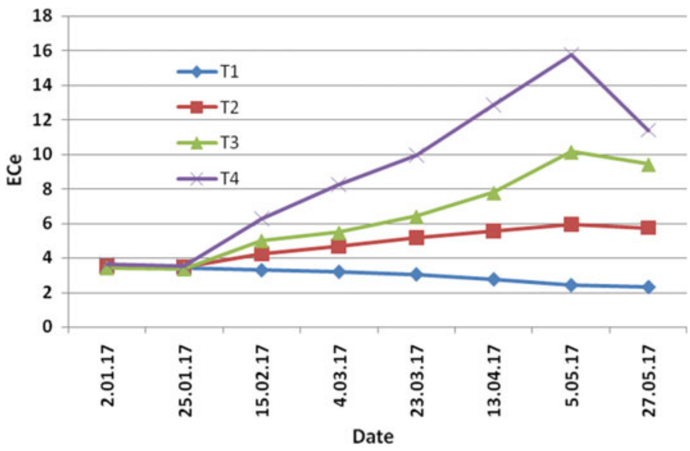


Fig. 62.4 Temporal variation of ECe (dS m^{-1}) of soil (0 ~ 15 cm) under drip irrigation and different irrigation water salinity

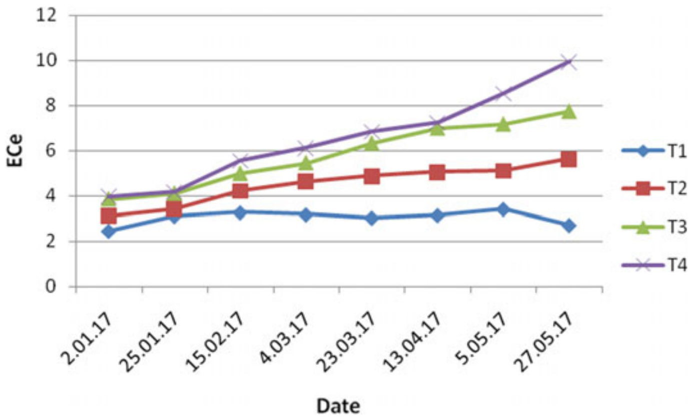


Fig. 62.5 Temporal variation of EC_e (dS m^{-1}) of soil (15–30 cm) under drip irrigation and with different irrigation water salinity

season were flushed away by the run off during rainy season, and there was no incremental increase in soil salinity in the root zone. Therefore, the farmers in the coastal region can use saline water up to 14 dS $m^{-1}$for cultivating okra crop using drip irrigation system (Fig. 62.6).

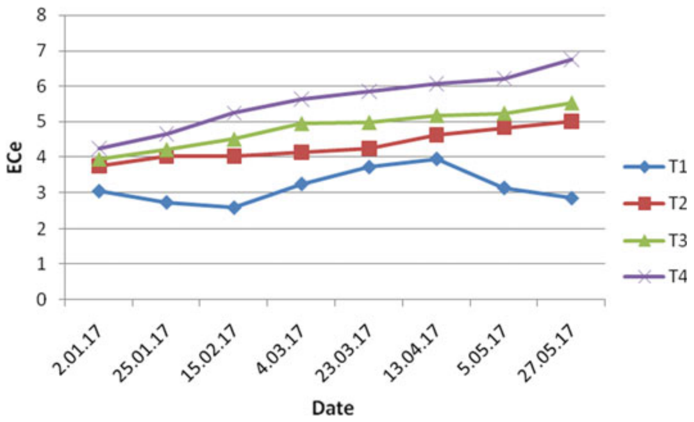


Fig. 62.6 Temporal variation of ECe (dS m^{-1}) of soil (30–45 cm) under drip irrigation and different irrigation water salinity

References

Ajai S, Singh RP, Mahar PS (2000) Optimal design of tapered micro irrigation sub main manifolds. J Irrig Drain Eng 122(2):371–374

Anwar AA (1999) Factor G for pipelines with equally spaced multiple outlets and outflows. J Irrig Drain Eng 125(1):34–38

Arya CK, Purohit RC, Dashora LK et al (2017) Performance evaluation of drip irrigation systems. Int J Curr Microbiol Appl Sci 6(4):2287–2292

Bhatnagar VK, Srivastava RC (2003) Gravity-fed drip irrigation system for hilly terraces of the northwest Himalayas. Irrig Sci 21:151–157

Bucks DA, Nakayama FS (1986) Trickle irrigation for crop production: design, operation and management. Elsevier, New York

Burman D, Mandal S, Bandopadhyay BK et al (2015) Unlocking production potential of degraded coastal land through innovative land management practices: a synthesis. J Soil Salinity Water Qual 7(1):12–18

Chen M, Kang YH, Wan SQ et al (2009) Drip irrigation with saline water for oleic sunflower (*Helianthus annuus* L.). Agric Water Manage 96:1766–1772

Dandy GC, Hassanli AM (1996) Optimum design and operation of multiple subunit drip irrigation systems. J Irrig Drain Eng 122(5):265–275

Goldberg D, Gornat B, Rimon DE (1976)Drip irrigation: principles design and agricultural practices. Drip Irrigation Scientific Publications, Kfar Shmaryahu, Israel

Jain SK, Singh KK, Singh RP (2002) Microirrigation lateral design using lateral discharge equation. J Irrig Drain Eng 128(2):125–128

Juana L, Losada A, Rodriguez L et al (2004) Analytical relationships for designing rectangular drip irrigation units. J Irrig Drain Eng 130(1):47–59

Kang YH, Wan SQ (2005) Effect of soil water potential on radish (*Raphanus sativus* L.) growth and water use under drip irrigation. Sci Hortic- Amsterdam 106:275–292

Kang YH, Chen M, Wan SQ (2010) Effects of drip irrigation with saline water on waxy maize (*Zea mays* L. var. ceratina Kulesh) in North China Plain. Agric Water Manage 97:1303–1309

Kang YH (1998) Microirrigation for the development of sustainable agriculture. Trans CASE 14 (Suppl.): 251–255

Keller J, Bliesner RD (1990) Sprinkler and trickle irrigation. Van Nostrand Reinhold, New York

Khan HR, Ahmed IU, Blume HP (1996) Effects of gypsum and Zn on uptake ratios of Na, K and growth-yield of rice grown on a coastal saline soil. Z Pflanzenernahr Bodenk 159:351–356
Liu SH, Kang YH, Wan SQ et al (2011) Water and salt regulation and its effects on *Leymus chinensis* growth under drip irrigation in saline-sodic soils of the Songnen Plain. Agric Water Manage 98:1469–1476
Mahanta KK (2004) Performance evaluation of *Abelmoschus esculentus* under drip irrigation system in Sundarbans area. J Indian Soc Coastal Agric Res 22(1&2):108–109
Mahanta KK, Burman D, Sarangi SK et al (2019) Drip irrigation for reducing soil salinity and increasing cropping intensity: Case studies in Indian Sundarbans. J Indian Soc Coastal Agric Res 37(2):64–71
Mahar PS, Singh RP (2003) Computing inlet pressure head of multioutlet pipeline. J Irrig Drain Eng 129(6):464–467
Mandal UK, Nayak DB, Samuia A et al (2018) Trend of sea-level-rise in West Bengal coast. J Indian Soc Coastal Agric Res 36(2):64–73
Mandal UK, Burman D, Bhardwaj AK et al (2019) Waterlogging and coastal salinity management through land shaping and cropping intensification in climatically vulnerable Indian Sundarbans. Agric Water Manage 216:12–26
Mandal UK, Nayak DB, Mullick S et al (2019) Trend analysis of weather parameters over Indian Sundarbans. J Agrometeorol 21(3):307–315
Qadir M, Sharma BR, Bruggeman A, Choukr-Allah R, Karajeh F (2007) Non-conventional water resources and opportunities for water augmentation to achieve food security in water scarce countries. Agric Water Manage 87:2–22
Ravindra VK, Singh RP, Mahar PS (2008) Optimal design of pressurized irrigation subunit. J Irrig Drain Eng 134(2):137–146
Sarangi SK, Singh S, Srivastava, AK et al (2020) Crop and residue management improves productivity and profitability of rice–maize system in salt-affected rainfed lowlands of East India. Agron 10, 2019. https://doi.org/10.3390/agronomy10122019
Sharma BR, Minhas PS (2005) Strategies for managing saline/alkali waters for sustainable agricultural production in South Asia. Agric Water Manage 78:136–151
Shi Z, Li Y, Wang R, Makeschine F (2005) Assessment of temporal and spatial variability of soil salinity in a coastal saline field. Environ Geol 48:171–178
Singh SD (1978) Effects of planting configurations on water use and economics of drip irrigation systems. Agron J 70:951–954
Tan JL, Kang YH (2009) Changes in soil properties under the influences of cropping and drip irrigation during the reclamation of severe salt-affected soils. Agric Sci China 8:1228–1237
Valiantzas JD (2002) Continuous outflow variation along irrigation laterals: effect of the number of outlets. J Irrig Drain Eng 128(1):34–42
Wan SQ, Kang YH, Wang D, Liu SP, Feng LP (2007) Effect of drip irrigation with saline water on tomato (*Lycopersicon esculentum* Mill) yield and water use in semi-humid area. Agric Water Manage 90:63–74
Wang RS, Kang YH, Wan SQ et al (2011) Salt distribution and the growth of cotton under different drip irrigation regimes in a saline area. Agric Water Manage 100:58–69
Wu IP (1997) An assessment of hydraulic design of micro-irrigation systems. Agric Water Manage 32:275–284
Yildirim G (2007) Analytical relationships for designing multiple outlet pipelines. J Irrig Drain Eng 133(2):140–155
Zhang ZJ, Luo GZ, Wang Z et al (2009) Study on sustainable utilization of groundwater in North China Plain. Resour Sci 31:355–360

Part IV
Climate Change Trend and Its Impact

Chapter 63
Climate Change and Coastal Agriculture: Can Developing Countries Adapt?

M. Monirul Qader Mirza, Khawaja Minnatullah, and Zahra Noorisameleh

Abstract Living in the coastal areas of the developing countries is already a profoundly challenging task. At present, approximately, 40% of the developing countries population lives in the coastal areas. The coastal people and their economies are at constant threats of natural hazards. Life and livelihoods of the coastal population have been largely dependent on agriculture. Natural forces including heavy rainfall from cyclonic storms and high tidal flows destroy crops. Salinity intrusion reduces agricultural productivity. Waterlogging due to unplanned infrastructure development and drainage obstruction has proven to be destructive to coastal agriculture. In addition to rising temperature and changing precipitation patterns, increasing episodes of cyclonic storms, salinity intrusion, waterlogging, and sea-level rise could further impact coastal agriculture in the future. Adaptation challenges of coastal regions are different from other parts of any country due to differential risks. Historical accounts show that despite adaptation investments in the coastal regions, key economic sectors especially agriculture has remained vulnerable. For developing countries, the current rate of innovation and institutional reform in the agricultural sector is insufficient to address future climate change and accompanying extremes.

Keywords Climate change · Coastal agriculture · Adaptation · Food security

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63.1 Introduction

Oceans cover approximately 72% of the surface area of the world, and the vast coastal areas are abode of 40% of the global population in 2017 (UN 2021) as enriched soil and climatic conditions of coastal areas provide favorable environment for thriving agriculture (Singh 2020). Attracted by the economic opportunities of the coastal areas, until recently, approximate 2.4 billion of the global population lived within 100 km of the world coasts, especially in the developing countries. Singh (2020) identified three key facets of coastal agriculture. First, by producing food and raw materials for industries, coastal agriculture makes significant contributions to local and national economy. Second, in developing countries, a large share of population relies on coastal agriculture for their livelihoods and well-being. Third, intensive agriculture and over extraction of raw materials significantly impact natural ecosystems in the coastal regions.

Major contributions to economy and human well-being of coastal agriculture are intertwined with challenges posed by natural hazards. Since agriculture shapes around climate, weather extreme can easily damage its production (Motha 2011) depending on the magnitude, extent, and arrival time. Extreme rainfall variability occurs with floods and droughts that can cause serious damage at different stages of plant and tree growth (IPCC 2012). Furthermore, coastal areas are usually low-lying and therefore vulnerable to high tides and cyclonic storms. Super cyclone 1999 inflicted devastating effect on crops across the Odisha coastline in India (Parida et al. 2018). In the Philippines, typhoons cause extreme rainfall and result in floods and mudslides which are found to be destructive to human lives, infrastructure, agriculture, and other assets. In 2012, Typhoon Bopha destroyed about US$ 1 billion of agricultural products, infrastructure, and private properties in Eastern Mindanao, the Philippines. Just a year after in 2013, Typhoon Haiyan (locally called Yolanda) swept through the central region of the Philippines. The typhoon associated heavy rain and extreme winds affected 14.1million people, caused devastation to 600,000 hectares of farmland and inflicted over US$ 700 million in damage to the agriculture sector (FAO 2017). In 2007, cyclone Sidr devastated 92,000 hectares of crops, over half a million hectares sustained partial damage and caused US$ 483 million losses in agriculture in Bangladesh (FAO 2021; GoB 2008).

The world is poised to reach and probably exceed a rise in global mean temperature to 1.5 °C by 2040 or before (Fig. 63.1) as the target set in the Paris Agreement. However, recently, year-to-year variability has been fluctuating around that target. For example, in 2020, the global mean temperature was 14.98 °C. Already, our planet is in the grip of an unpredictable variations in the weather pattern, extreme weather events including cyclonic storms, high tides and tidal surges, sea-level rise, extreme precipitation, and floods, droughts, heat waves, and even, cold waves are frequenting the earths habitations. Vulnerability of the world's coast especially in the developing countries will certainly increase due to low adaptive capacity and high dependency on agriculture. Gopalakrishnan et al. (2019) found that in coastline of developing countries, agriculture damage under climate change will increase because of intensify

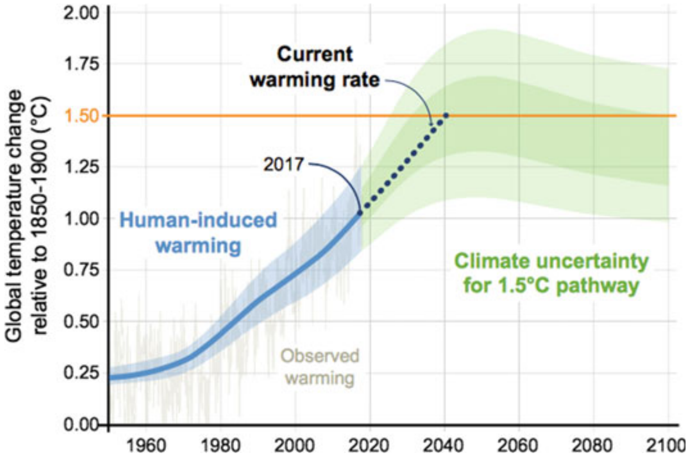

Fig. 63.1 How close we are to 1.5 °C (IPCC 2018)

changes in rainfall, temperature, tropical cyclones, etc. Increased strength of cyclone and associated heavy precipitation, strong winds, heat waves, sea-level rise, and intrusion of saline water will certainly make coastal agriculture more vulnerable in the future. Although technological innovations and institutional transformations are taking place, in this chapter, we will examine whether the current pace of their advance is enough for the coastal agriculture sector to adapt to the changing climate, to ensure food security and human well-being in the developing countries.

63.2 Characterizing Risks to Coastal Agriculture

Coastal agriculture in developing countries is generally vulnerable to common hazards: extreme temperatures, dryness and droughts, cyclones and associated extreme rainfall, storm surges, salinity intrusion, and sea-level rise and high tides. Climate change will, however, accelerate the incidence of these hazards in the future, posing considerable risks, and threats to coastal agriculture in developing countries (IPCC 2019). A large pool of literature is available on the relationship between agriculture productivity and climatic variables. However, most of the research works focused on temperature and precipitation.

Praveen and Sharma (2019) examined the relationship for 15 crops in India using climatic data from 1967–2016 and found reduction in land productivity with an increase in annual mean temperatures in most of the cases. They also concluded that a rise in temperature in the future due to climate change could further impact productivity of Indian agriculture. Significant climate change impacts are suggested in the medium-term (2010–2039), 12 which is predicted to reduce yields between 4.5 to 9% of certain crops. Studies conducted by the National Innovations in Climate

Resilient Agriculture (NICRA) suggest unirrigated rice yields are projected to decline marginally (less than 2.5%) in both 2050 and 2080, and irrigated rice yields may be reduced 7% and 10% in 2050 and 2080, respectively. Key climatic risks to agriculture in Africa include reduced crop productivity caused by heat and drought stress and increased pest damage, disease damage, and flood impacts on food system infrastructure, resulting in serious adverse effects on food security and on livelihoods at the regional, national, and individual household levels.

Rising water levels due to global warming and salinity intrusion threaten land use diversity of coastal areas (Chen and Mueller 2018; Richardson and Otero 2012). Tran et al. (2021) showed that intensification of drought and salinity due to climate change decrease adaptation of coastal agriculture in developing countries. Climate extremes and sea-level rise under climate change are main concerns in agriculture sector of Mediterranean coastal regions (Navarra and Tubiana 2013). Sea-level rise in combination with increasing frequency of catastrophic cyclonic storms will put the coastal population of Bangladesh at the risk of inundation. In addition to climate change induced sea level rise, subsidence will cause another 10–18 mm of relative sea-level rise annually (Higgins et al. 2014). Inundation from rising sea level would likely to threaten severely 40% of productive agricultural land in southern Bangladesh (Yu et al. 2010). African coasts experience a significant regional variation in sea-level rise. While several oceanic areas in the continent, sea-level rise has reached 5 mm year^{-1}, which exceeded the rate in the southwestern Indian Ocean region, from Madagascar eastward toward and beyond Mauritius. Overall, the rate of sea-level rise in Africa is higher than that of global rate of 3–4 mm year^{-1}. The African coastal challenge from coastal degradation, erosion, and sea-level rise combined with other factors could exacerbate environmental changes (WMO 2020) in that region.

63.3 Climate Change and Food Security in Developing Countries

The number of hungry people in the world is on the rise again. In 2019, almost 690 million people went hungry that was up by 10 million from 2018 and by nearly 60 million from 2014 (FAO 2020). Most of the global hungry population resides in developing countries. While there are many causes for food insecurity, climatic hazards are identified as one of major driver of hunger which is accelerated by crop failures. According to the World Bank (2021), the food security challenge posed by climate change will be exacerbated by declining production, with the world needing to produce 70% more food by the middle of the century to feed an estimated 9 billion people.

Climate change induced poverty, hunger, malnutrition, and health consequences in developing countries will lead to an unstable socioeconomic future with crumbling law and order at the local level. Esam et al. (2018) discussed food security situation in Sri Lanka due to climate change and concluded that declining agriculture productivity, food loss along supply chains, low livelihood resilience of the rural poor, and prevalence of high levels of undernourishment and child malnutrition would pose a serious threat to food security of Sri Lanka in the future. Agriculture sector in the entire African continent will be hard hit by climate change by the middle of the present century with variations in regions and crops. Projected yield decline under RCP 8.5 was 13%, 11%, and 8% for West and Central Africa, North Africa, and East and Southern Africa, respectively. Rice and wheat would likely to suffer the most by 12% and 21%, respectively. However, coastal millet and sorghum would be affected by 5% and 8%, respectively as these crops are resilient to heat stress (WMO 2020).

The agricultural sector's contribution to overall global GDP will be reduced due to production losses. Although this will vary from country to country in the developing world, it may become serious for some countries with agriculture-dominated economies. For example, Guinea-Bissau's agriculture sector contributed 62% to the GDP in 2009 but was projected to decline to 32.7% without carbon fertilization by 2080 (Keane et al. 2009). The impacts on development and food security, as well as on nutrition, will be enormous. Therefore, WMO (2020) concluded that in Africa, future warming scenarios together with increased flooding would cause impacts on all food system infrastructure, resulting in serious adverse effects on food security and on livelihoods at the regional, national, and individual household level.

63.4 Advancement and Adaptation Challenges

63.4.1 Innovation

Innovation in agricultural sector implies the fusion of technological advancement and infrastructure, genetic breakthrough, improved farming process, mitigating adverse influence of natural forces, pest control, improved harvesting techniques, reliable storage, and transportation, resulting in increased yield and improved quality of the products. Marketing and finance are other important factors to ensure a sustainable industry. In the developed world, an enabling environment of policy, economic, and physical infrastructure ensures stable farming and productivity. Large-scale production, modern storage, research, efficient supply chain management has enabled financial gains and prosperity of the agro-giants mostly in the developed nations, to thrive largely at the cost of the poor in the developing nations. In the developing countries, the above features are uncommon, even for countries with some of the features available, there are huge uncertainties, posing serious challenges for improvement in sector productivity. However, recent changing weather pattern has made the agro-products, particularly crops, fish, and livestock costlier and beyond the purchasing powers of the climate vulnerable communities in the developing world. Climate change will compound the current complexity with a vast range of additional factors including local, regional, and global weather extremes and consequent unpredictable patterns of the natural forces.

Changes in local weather will have an impact on seasonality and cause farming techniques to be disrupted. Heat, dry weather, flood, and salinity tolerant agricultural varieties, for example, have previously been investigated and applied in various parts of the world. Many places have experimented with efficient water utilization in irrigated agriculture. Flood protection, water logging prevention, and salinity intrusion all require climate resilient infrastructures to be built. Through a dynamic detection and control mechanism, the innovative pest management must be sensitive to the needs of the time.

Innovations in small-scale farming are still at a pilot phase, with little or no support from the country system for scaling up. Furthermore, with changing weather patterns at local level, successful small-scale agricultural innovations are facing serious challenges from temperature variations, drought, flood, water logging, and salinity intrusion, calling for adaptation techniques for effective implementation.

Lessons from laboratory tests, pilot programs, and small-scale efforts must be assimilated and utilized in a programmatic approach across the country's already designated climatic zones and regions. The policy structure must be flexible and adaptable.

63.4.2 Institutional Transformations

Climate change will present numerous obstacles to the agriculture sector in developing countries, ranging from crop production to export. For fiscal and sociopolitical stability, poor countries with significant rural economies rely on agricultural exports (Christoplos 2009). Agricultural export revenues may be jeopardized unless alternatives are identified, or climate-proof investments are made (Keane et al. 2009). The agriculture sector has a reverse problem for climate change as it is a significant contributor to the global climate crisis. Presently, agriculture sector accounts for 19–29% of all greenhouse gas (GHG) emissions. If nothing substantial is devised to plug this, the emissions will further rise. In addition, one-third of all food produced worldwide is wasted through various mechanisms. To meet the climate targets as well as ensuring food security, food loss and waste must be reduced (World Bank 2021).

To address multi-faceted challenges of the agriculture sector due to climate change and to devise reversal of further deteriorations, a two-edged institutional transformation is required. The threat of climate change to agriculture in inland areas in developing countries is much different from the coasts due to onslaught of additional extreme hazards and unique geo-hydrologic ecosystems. Therefore, coastal agriculture transformation will be increasingly diverse (Thanh et al. 2021) because of the following factors. First, institutional transformation for mainstreaming climate change into agriculture policies would need to be handled differently as the challenges are different. Second, uncertainties in extreme weather events like cyclone and storm surges under future climate change need to be incorporated in coastal agriculture as well as in the water resources planning simultaneously. Third, most of the attention is now focused on reducing damage caused by excessive temperatures and precipitation. Crop damage from salinity intrusion and soil salinity, on the other hand, must be grouped together. Institutions engaged in crop development must collaborate with departments responsible for management of hazards. Fourth, adoption of policies and relevant institutional transformations are required for climate smart agriculture (CSA). World Bank (2021) suggested three outcomes from the CSA: increased productivity, enhanced resilience, and reduced emission. Fifth, along with impacts of climate change on cereal crops, institutional research focus must include fishery and livestock.

63.5 Concluding Remarks

Risks to coastal agriculture from climate change in developing countries are different from those of the inlands. The coastal population is at additional threat of food insecurity and sustainable livelihood challenges. Innovations for coastal agriculture are essential and must deal with both climate change impacts and contribution of the sector to climate change. Investment in agricultural innovations in developing countries is taking place at a slow pace which must be faster. In addition to investments, massive institutional transformations are also required focusing at multi-faceted agricultural and livelihood challenges of the coastal regions. The current pace of progress in innovations and institutional transformations is not adequate to tackle future climate change and associated extremes for coastal agriculture developing countries.

References

Chen J, Mueller V (2018) Coastal climate change, soil salinity and human migration in Bangladesh. Nat Clim Change 8:981–985

Christoplos I (2009) Aid for pro-poor agricultural trade in the context of climate change. London/ Glemmingebro, Sweden: GRM International/Glemminge Development Research. http://www.acp-eu-trade.org/library/fi les/Christoplos_EN_040509_GRM-GDR_Aid-for-pro-poor-agricultural-trade-in-a-context-of-climate-change.pdf

Esham M, Jacobs B, Rosairo HSR et al (2018) Climate change and food security: a Sri Lankan perspective. Environ Dev Sustain 20:1017–1036

FAO (Food and Agriculture Organization of the United Nations) (2017) Typhoon haiyan: emergency, recovery and rehabilitation programme. FAO, Manila, the Philippines

FAO (Food and Agriculture Organization of the United Nations) (2020) State of food security and nutrition in the world. FAO, Rome

FAO (Food and Agriculture Organization of the United Nations) (2021) Bangladesh: agricultural sector devastated in cyclone-hit areas (Bangladesh: agricultural sector devastated in cyclone-hit areas. https://www.fao.org/resilience/news-events/detail/en/c/147902/. Accessed 09 July 2021

Gopalakrishnan T, Hasan MK, Haque ATMS et al (2019) Sustainability of coastal agriculture under climate change. Sustainability 11:7200. https://doi.org/10.3390/su11247200

Hall C, Dawson P, Macdiarmid I et al (2017) The impact of population growth and climate change on food security in Africa: looking ahead to 2050. Int J Agric Sustain 15(2):124–135

IPCC (Intergovernmental Panel on Climate Change) (2018) Global warming of 1.5 °C. IPCC Special Report. IPCC, Geneva

IPCC (Intergovernmental Panel on Climate Change) (2019) Food security. In: Climate change and land: an IPCC special report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems. IPCC, Geneva

Keane J, Page S, Kergna A et al (2009) Climate change and developing country agriculture: an overview of expected impacts, adaptation and mitigation challenges, and funding requirements, ICTSD–IPC Platform on Climate Change, Agriculture and Trade, Issue Brief No.2, International Centre for Trade and Sustainable Development, Geneva, Switzerland and International Food & Agricultural Trade Policy Council, Washington DC, USA

Motha Raymond P (2011) Chapter 30: The impact of extreme weather events on agriculture in the United States. USDA-ARS / UNL Faculty. 1311. https://digitalcommons.unl.edu/usdaarsfacpub/1311

Navarra A, Tubiana L (2013) Regional assessment of climate change in the Mediterranean: agriculture, forests and ecosystem services and people. Springer, Netherlands. https://doi.org/10.1007/978-94-007-5772-1

NICRA (National Innovations on Climate Resilient Agriculture) (2021) Effect of climate change on agriculture. Ministry of Agriculture and Farmers Welfare, Govt of India, New Delhi, India

Parida BR, Behera SN, Oinam B (2018) Investigating the effects of episodic super-cyclone 1999 and Phailin 2013 on hydro-meteorological parameters and agriculture: An application of remote sensing. Remote Sensing Applications: Society and Environment 10:128–137. https://doi.org/10.1016/j.rsase.2018.03.010

Praveen B, Sharma P (2019) A review of literature on climate change and its impacts on agriculture productivity. J Public Aff 19 (4): e1960. https://doi.org/10.1002/pa.1960

Richardson GRA,Otero J (2012) Land use planning tools for local adaptation to climate change. Ottawa, Ont.: Government of Canada, p 38

Singh AK (2020) Coastal agriculture and future challenges. In: Singh A , Fernando RLS, Haran NP (eds) Development in coastal zones and disaster management, Disaster Research and Management Series on the Global South, Palgrave Macmillan, Singapore, p 61–89. doi:https://doi.org/10.1007/978-981-15-4294-7_5

Thanh BN, Thuy TL, Anh MN et al (2021) Drivers of agricultural transformation in the coastal areas of the Vietnamese Mekong delta. Environ Sci Policy 122:49–58. https://doi.org/10.1016/j.envsci.2021.04.010

United Nations (2021) Fact sheet: people and oceans. https://www.un.org/sustainabledevelopment/wp-content/uploads/2017/05/Ocean-fact-sheet-package.pdf. Accessed 09 July 2021)

WMO (World Meteorological Organization) (2020) State of the climate in Africa 2019. WMO, Geneva

World Bank (2021) India: rising sea forces villagers to abandon rice farming. https://www.preventionweb.net/news/india-rising-sea-forces-villagers-abandon-rice-farming. Accessed 02 July 2021)

Yu WH, Alam M, Hassan A et al (2010) Climate change risks and food security in Bangladesh. Earthscan, New York

Chapter 64
Innovative Solutions for Managing Tropical Cyclone Risk in India–Bangladesh Coastal Region of Bay of Bengal

Prangya Paramita Gupta, Maria Bernadet Karina Dewi, Shashwat Avi, Akash Shrivastav, and Jeongwon Min

Abstract Tropical cyclones originating in Indian Ocean region and Bay of Bengal are one of the most devastating hazards causing loss of life and properties along the coastal areas of India and Bangladesh. With anthropogenic-induced climate change and related meteorological effects, they are expected to intensify in the future. Although both countries have already taken several measures toward cyclone risk management reflected through the drastic reduction in the number of human fatalities due to cyclone, loss and damages of properties and critical infrastructure are continuing. Over a long period, the exploitation of mangrove forests, the natural buffer to the impacts of cyclone, has aggravated the situation. The present study attempts to identify the exposure of population and critical infrastructure to the probable future cyclone scenario and how they can be safeguarded by using advanced frontier technologies.

Keywords Tropical cyclone · Climate change · Coastal resilience · India. Frontier technologies · Gray and green infrastructure

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64.1 Introduction

In 2020, the world experienced 98 tropical cyclones, the number of which is above long-term average (WMO 2021). Over the past 50 years, 1942 tropical cyclones have attributed to 779,324 fatalities and USD 1407.6 billion of economic loss around the world (WMO 2020a). Tropical cyclones are intensive risk disaster, which are often combined with storm surges, high velocity winds, lightning, tornedo and flooding, and threaten life and property of the exposed regions. The multi-hazard nature of tropical cyclones imparts cascading impacts on the exposed population and properties. The coastal region of Asia Pacific is prone to tropical cyclones which are frequent during summer and early autumn season. Primarily, higher sea surface temperature (among six Gray's parameters) during this period triggers the formation of tropical cyclones (Bhardwaj et al. 2019). The extensive coastlines, small islands, and low-lying areas of Asia–Pacific are susceptible to the impacts of cyclones and associated coastal flooding. About 2.4 billion people of Asia, which is the half of Asia's total population, live in low-lying coastal areas (UNDP 2019). The average annual loss from tropical cyclones in Asia–Pacific has been estimated as 12.8% of total disaster losses of US$675 billion (including Tsunami, flood, drought, tropical cyclones, and earthquake) (APDR 2019). The overall social and economic impacts of tropical cyclones have been increasing since 1970s, often attributed due to climate change and increase in population in coastal urban agglomerations, and Asia–Pacific is not any exception (Guha–Sapir and CRED 2020). With climate change, future changes in the cyclone pattern and its impacts are of great concern, especially in the coastal regions of Asia–Pacific.

64.1.1 Tropical Cyclones/Storms in India–Bangladesh Region

The Indian subcontinent with its 8041 km long coastline is exposed to nearly 10% of world's tropical cyclones most of which originate in Indian Ocean and the Bay of Bengal (BoB) and affect the east coast of India as well as Bangladesh and Myanmar (NDMA n.d.). Tropical cyclones developed in North Indian Ocean during pre-monsoon season make the landfall in eastern coast of India, Bangladesh, and Myanmar coast, while during post-monsoon season, they affect the entire BoB coast (Bhardwaj and Singh 2020). Eighty percent of the North Indian Ocean tropical cyclones form in the BoB, many of which had devastating impacts on life and property (IMD 2011).

In Indian subcontinent, the year 2020 marked the 50th anniversary of the super cyclone Bhola, the deadliest tropical cyclone in the world, which developed from a depression in the south-central BoB and had a landfall in Bangladesh on November 12–13, 1970. The cyclone caused 300,000–500,000 fatalities due to 6–7 m high storm surges which inundated the tidal flats and low-lying areas of the costal Bangladesh

(WMO 2020b). The most recent in the list is the super cyclone *Amphan* which was developed in BoB and created severe winds, storm surges, and coastal flooding in India and Bangladesh on May 20, 2020, causing 118 fatalities. Table 64.1 enlists 10 most impactful tropical cyclones in India–Bangladesh coastal region.

Figure 64.1 represents the degree of cyclone hazard proneness of districts of India as identified by the National Disaster Management Authority, India (Mandal and Mahapatra n.d.) and the cyclone-prone districts of Bangladesh (START Network 2018). The degree of proneness depends on the frequency and intensity of landfalling cyclones accompanied by associated hazards such as rainfall, wind, and storm surge. The study by Mandal and Mahapatra (n.d.) also found that in the BoB coast of India, Nellore and East Godavari (Andhra Pradesh), Balasore, Kendapar and Jagatsinghpur (Odisha), South and North 24-Parganas and Medinipur (West Bengal) are the cyclone hotspots based on composite rating on the occurrence of severe cyclones, total number of cyclones, wind speed, and probable maximum storm surge. Likewise, in Bangladesh, all the coastal districts are prone to tropical cyclone and its impacts.

In Bangladesh, the most cyclone affected districts are Khulna, Patuakhali, Barisal, Noakhali, and Chittagong. Most of the tropical cyclones in this region makes their landfall in Chittagong-Cox's Bazar area. The entire coastal region, being highly populated, makes this area vulnerable to the impacts of cyclones. There are large number of small and large low-lying islands in this region which are inundated every year due to storm surges associated with tropical cyclones.

Looking at the long-term data (1919–2020) on the annual distribution of the number of tropical cyclones in India and Bangladesh, it is evident that the frequency of tropical cyclones has increased over the period (Fig. 64.2). The increase is higher in India. Additionally, emerging evidence suggest that anthropogenic-induced climate change and associated meteorological changes in the region have resulted in increased annual global proportion of the high intensity tropical storms and cyclones (e.g., categories 4 and 5) (IPCC 2019).

In case of 2 °C global temperature rise above the baseline period, the proportion of higher intensity tropical storms and cyclones along with associated average precipitation are projected to increase further in this region. Under extreme case scenario (RCP 8.5), the projected changes are likely to be more profound though the frequency of occurrence may either decrease or remain the same (IPCC 2019).

64.1.2 Existing Coastal Cyclone Protection—India

Recognizing the cost of damage of recurrent tropical cyclone and its impacts, cyclone disaster management has been enhanced both in India and Bangladesh with greater emphasis on prevention, preparedness, and mitigation. Both government sponsored schemes as well as initiatives of the international organizations have significantly scaled up the cyclone management actions since the deadliest cyclone Bhola hit this region causing huge fatalities. Since then, there has been consistent decrease in the

Table 64.1 10 Most impactful tropical cyclones in India–Bangladesh coast of BoB

Year	Location	Name	Winds (kmh^{-1})	Storm surge height (m)	Fatality
1970	Bangladesh (Khulna, Chittagong)	Bhola	185	6–7	300,000 –500,000
1991	Bangladesh (Cox's Bazar, Chittagong, Patuakhali, Noakhali, Bhola, Barguna)	Gorky (02B)	250	6	138,866
1999	India (parts of Odisha, Andhra Pradesh and West Bengal)	BOB 06 (Super cyclone)	276	5–6	9887–15,000
2007	India (West Bengal and Odisha states) and Bangladesh (parts of Khulna, Barisal, and Dhaka provinces)	SiDR	215	3	3447–15,000
2008	Bangladesh (parts of Barisal province)	Rashimi	85	2	28–100
2009	India (parts of Indian Sunderbans) and Bangladesh (Khulna, Barisal, and Chittagong provinces)	Aila	120	2–3	339
2015	Bangladesh (Chittagong and Barisal provinces)	Komen	85	1–2	180–280
2019	India (Odisha) and Bangladesh (Khulna, Barisal, and Satkhira provinces)	Fani	215	2–3	89
2019	India (Assam, Meghalaya, Tripura, Mizoram, West Begal, Odisha states)	Bulbul	145	1–2	41

(continued)

Table 64.1 (continued)

Year	Location	Name	Winds (kmh^{-1})	Storm surge height (m)	Fatality
2020	India (Odisha and West Bengal states)	Amphan (Super cyclone)	260	5–6	118

Source DYNT (2020)

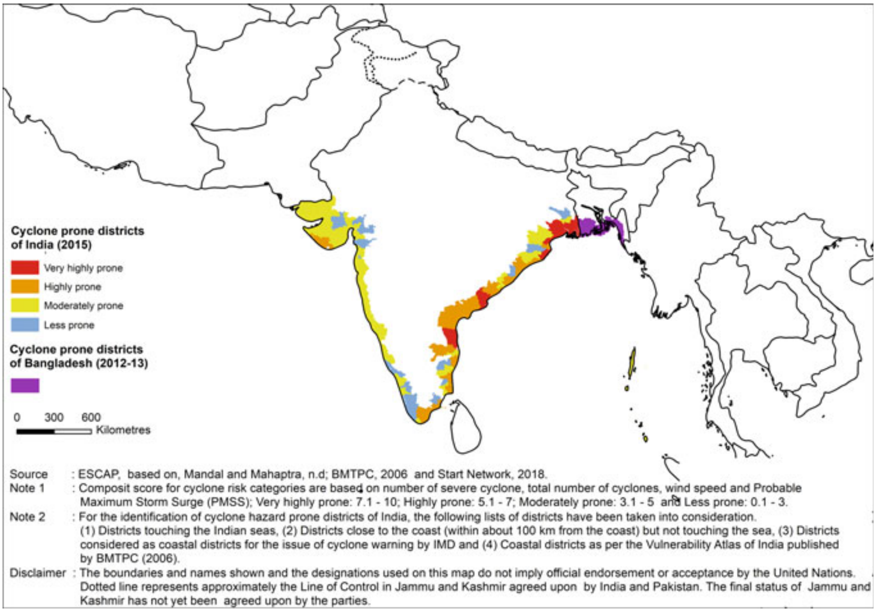

Fig. 64.1 Cyclone-prone districts of India and Bangladesh *Data source* BMTPC (2016), Mandal and Mahapatra (n.d.), and START Network (2018)

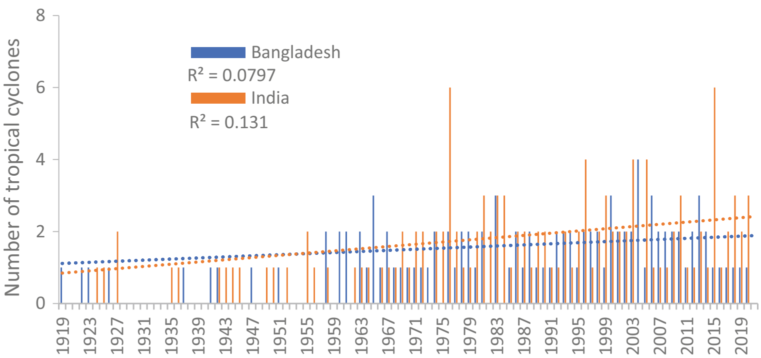

Fig. 64.2 Annual distribution of tropical cyclones in India and Bangladesh (Guha–Sapir 2021)

number of human fatalities due to cyclone and associated events over the 50 years, which validates the developments (Table 64.1).

Post-2013 cyclone *Phailin* that hit Odisha and Andhra Pradesh in India, Government of India in collaboration with the World Bank initiated the Cyclone Risk Mitigation Project for Indiato expand cyclone risk mitigation infrastructure in the cyclone-prone coastal states and Union Territories of the country. The project facilitated construction of multipurpose cyclone shelters and approach roads and bridges, underground cabling and saline water intrusion embankment. The project also involved risk assessment, capacity building, and knowledge creation on cyclone preparedness. To facilitate accurate forecast on the genesis, track, intensity and probable adverse weather events, the early warning and communication system was strengthened to ensure last mile connectivity for information dissemination and associated actions (NDIM 2017). The infrastructure in the Indian Meteorological Department was also upscaled through inclusion of new technologies and instruments to provide precise early warning on cyclone. Large-scale fatalities were avoided due to efficiency of cyclone early warning system as well as timely evacuation of about 1.5 million people to the cyclone shelters during cyclone Fani (2019) in Odisha (Dash and Walia 2020).

Likewise, Emergency 2007 Cyclone Recovery & Restoration Project and similar initiative in Bangladesh facilitated construction of cyclone shelters and improvement of existing shelters, construction of bridges, sanitation facilities, approach roads, and capacity development of the local community in 9 (Nine) districts, namely Barguna, Bagerhat, Pirojpur, Patuakhali, Bhola, Barisal, Jhalokati, Khulna, and Satkhira (World Bank 2015). Moreover, Cyclone Preparedness Program (CPP), a joint venture between Bangladesh Red Crescent Society, and the Government of Bangladesh, also established cyclone early warning and information dissemination to every household of the 13 coastal districts of Bangladesh (CPP, Government of Bangladesh n.d.).

64.1.3 Role of Mangroves in Building Coastal Resilience

Mangrove forests act as natural buffer against cyclones and storm surges through obstructing the flow of water and waves. The aerial roots, wide trunks, and canopy of mangroves can attenuate storm surges by reducing 66% of the wave energy in first 100 m of the forest (Dasgupta et al. 2019; Mcivor et al. 2016, 2012a, b). The natural protective nature of mangroves adds huge economic value to the cyclone hazard management. The economic benefit of the mangrove under cyclone and storm surge scenario was estimated by Menéndez et al. (2020) through a rigorous process-based models, which quantified the extent of coastal flood and storms for various return period under (i) with mangrove and (ii) without mangrove scenario at different geographical scales (Fig. 64.3). The results suggest that globally, population exposure, loss of properties, and extent of flood is less under "with mangrove" scenario than "without mangrove."

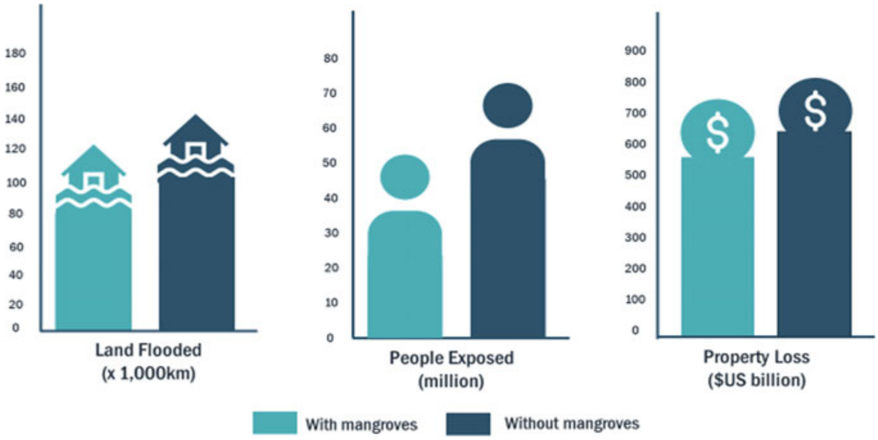

Fig. 64.3 Global annual expected benefit from flood protection (Menéndez et al. 2020)

Table 64.2 Benefit of mangroves in protecting land, people, and property in India and Bangladesh (Menéndez et al. 2020)

Country	Land (thousand km^2)	People (million)	Property (billion USD)
India	1.63	2.87	7.84
Bangladesh	0.82	1.11	1.56

The mangrove forest of Sundarbans in India–Bangladesh region spans across 10,000 km^2 area in the Ganga–Brahmaputra–Meghna (GBM) delta in BoB (UNESCO 2021). Mangroves, in this region, generate huge ecological benefit through protecting lands from inundation and salinization, social benefit through protecting life and economic benefit through protecting important infrastructure and assets from cyclone and storms (Table 64.2). In contrast to the more economically developed states such as United States and China, which generates more economic benefit from mangroves than ecological and social benefits, major contribution of the mangroves in this region is in protecting vulnerable and highly dense coastal population and assets in this region.

64.2 Results and Discussion

64.2.1 Mangrove Coverage Over the Years

Despite being an environmental assent of such importance, the mangrove cover is undergoing significant losses over the last decades globally as well as in the BoB coastal region (Hamilton and Casey 2016). To understand the extent of changes in

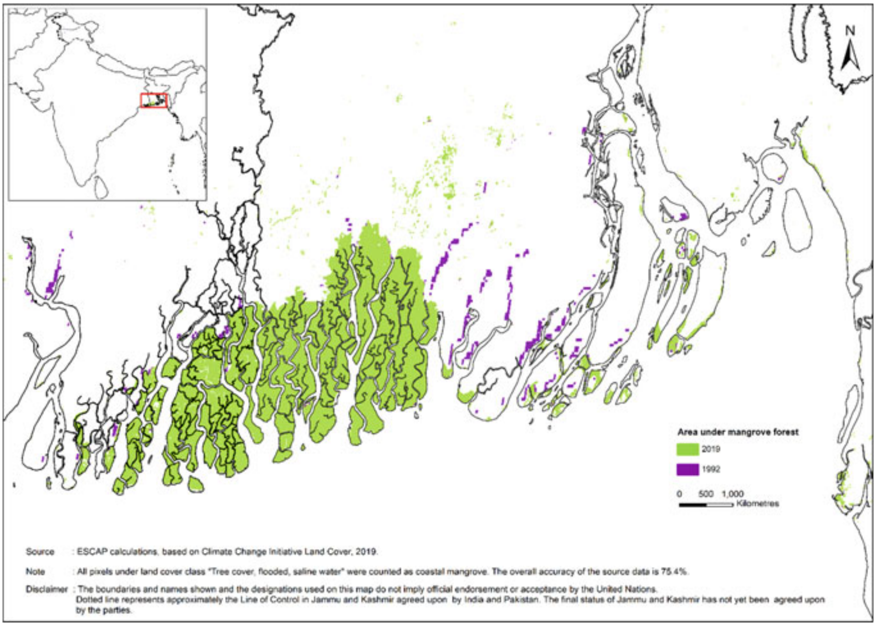

Fig. 64.4 Area under mangrove forest in BoB coastal region of India and Bangladesh (UNESCAP 2021)

mangrove cover in the BoB coastal region, spatiotemporal analysis was undertaken using Climate Change Initiative Land Cover (CCI-LC) data, a global landcover data with 300 m spatial resolution. Figure 64.4 represents the mangrove cover in this region during 1992 and 2019.

Analysis on the area under mangrove cover for nearly three decades (1992–2019) reveal that Bangladesh has been losing it's mangrove cover consistently since 1992 with a cumulative loss of around 19% till 2019. On the contrary, India has an overall gain of around 5.6% of mangrove cover during 1992–2003. In both the countries, the maximum losses occurred between 1992 and 2003, which is similar to the global trend (Menendez 2020). Most of the mangrove losses around the world happens either due to anthropogenic interventions such as expansion of agricultural areas, mostly in the periphery of mangrove forests, development of commercial aquaculture farms, expansion of urban and industrial areas, or natural and climate-induced causes such as marine pollution, coastal erosion, and sea level rise (Gopal and Chauhan 2018; Giri et al. 2007; Alongi 2002). However, in GBM basin, uncontrolled expansion of agriculture and aquaculture, and sea level rise and coastal storm and surges have been the major driving force for mangrove cover loss (Dasgupta and Shaw 2017). Figure 64.5 depicts two such locations in Bangladesh where agriculture and aquaculture developed at the cost of mangroves.

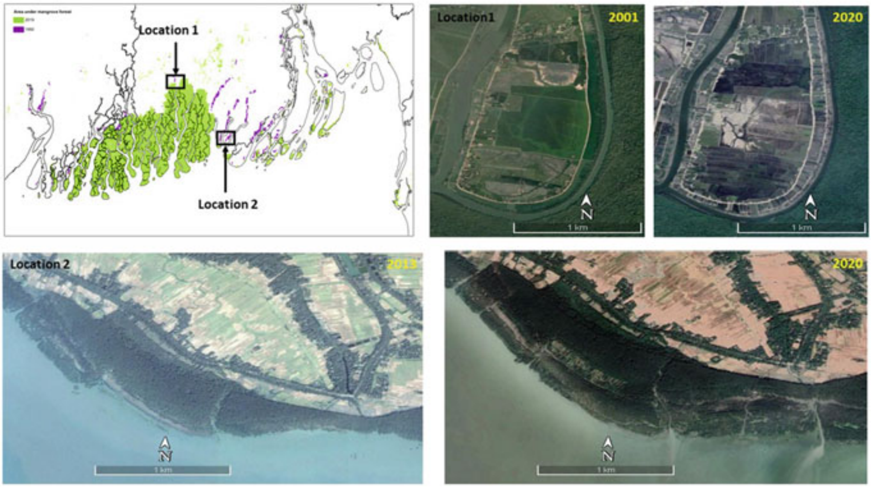

Fig. 64.5 Change in landcover in mangrove forest areas of India and Bangladesh. Location 1 shows the conversion of mangrove cover area in agricultural land, and location 2 shows the cutting of mangrove forest for aquaculture in coastal area of Bangladesh (UNESCAP 2021)

64.2.2 Population Exposure (Coastal Area) to Cyclone/Storms—Social Case

The cyclone hotspot analysis shows that for a long-term return period (100 years) the frequency and intensity of cyclones in this area are very likely to increase in this region. Additionally, under climate change scenario, this area is exposed to very high risks of coastal flooding and related disasters (UNESCAP 2021). UNESCAP calculations on population exposure to cyclones reveal that in 100 years return period more intense (category 2) cyclones will affect the population in this region. Moreover, population exposure will also increase for less-intense cyclone and storm in long-term scenario due to expansion in the impact area and high population density of this region (Table 64.3 and Fig. 64.6). Most of the area under consideration are low in Human Development Index thus vulnerability of population to cyclone will be high (Global Data Lab 2018).

Predominantly, being an agrarian economy, most of this region consist of agricultural lands. They are low-lying areas with average elevation below 10 m and hence are vulnerable to cyclone-related storm surges (Fig. 64.7). It causes direct impacts such as loss of production and indirect impacts such as soil infertility. Due to saltwater intrusion, the soil becomes infertile and unfit, not only for agriculture but also for other usages such as making mud houses.

For long-term less-intense scenario (Category 1 cyclone with 100 years return period), more than 0.2 million square km of agricultural lands are potentially vulnerable. However, for long-term higher-intensity scenario (Category 2 cyclone with 100 years return period), the extent of exposed area might be much less (23,987 km^2)

Table 64.3 Percent of population exposed to different categories of cyclone in India and Bangladesh

Country	Total pop	Percent of population exposed to cyclone (RT 100/category 1)	Population exposed to yclone (RT 100/category 2)
Bangladesh	164,689,000	36.6%	2.2%
India	1,380,004,000	8.5%	0.7%
Country	**Total pop**	**Percent of population exposed to cyclone (RT 50/category 1)**	**Percent of population exposed to cyclone (RT 50/category 1)**
Bangladesh	152,401,936	2.5%	0.0%
India	1,377,605,017	1.0%	0.0%

Source UNESCAP (2020), UNESCAP calculations (UNESCAP 2021). Asia Pacific Disaster Resilience Network Portal

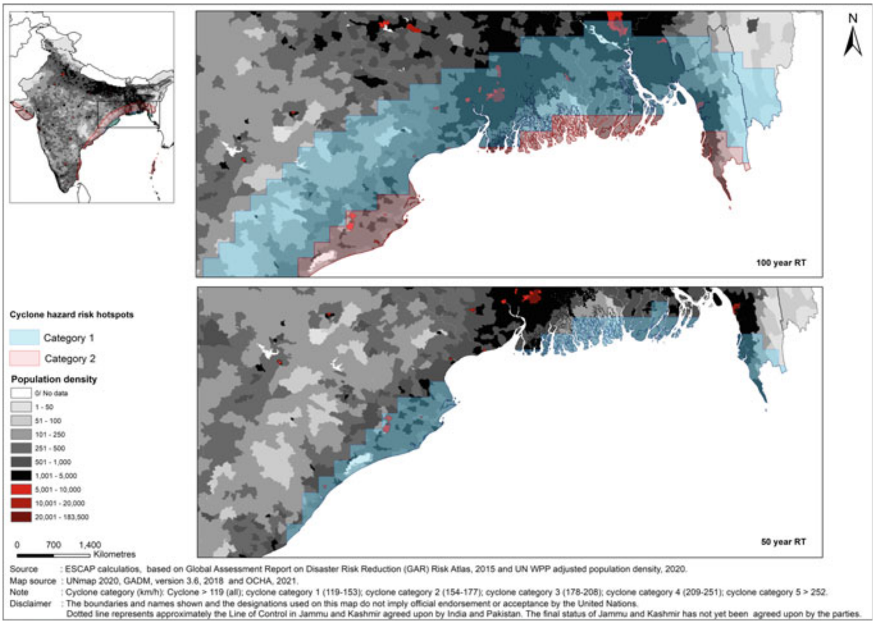

Fig. 64.6 Areas with different population density exposed to different categories of cyclones under 50 years and 100 years return period scenario. *Data source* CIESIN (2018), UNESCAP (2020)

than less-intense scenario, but the extent of damage might be higher due to higher intensity of cyclone. In short-term low-intensity scenario (Category 1 cyclone with 50 years return period), around 30,157 km^2 of agricultural lands are exposed to the impacts of cyclone.

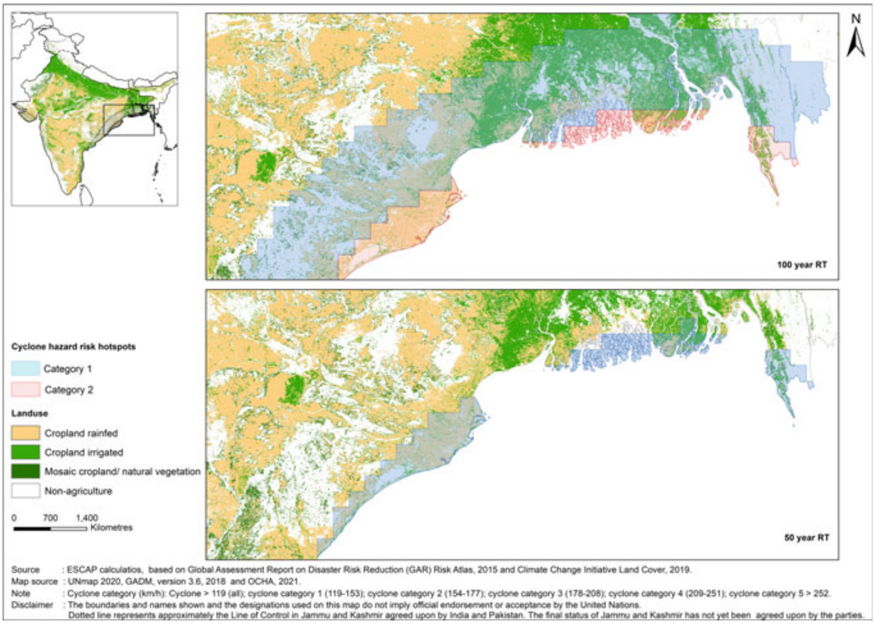

Fig. 64.7 Agricultural lands exposed to different categories of cyclone. *Data source* CCI-LC (n.d.), ESA (2021), GADM (2018), UNESCAP (2020)

64.2.3 Infrastructure Exposure to Cyclone/Storms, Loss, and Damage—Economic Case

Although the fatalities due to the impacts of cyclones could be reduced through preparedness and early warning, critical infrastructures which provide essential services are still vulnerable and cause physical and economic losses if damaged or lost due to cyclone. These infrastructures are backbone for post-disaster "building back better" and hence highlighted in Sendai Framework calling for actions to enhance their resilience to disaster by 2030. Figure 64.8 represents the spatial distribution of critical infrastructures, e.g., health facility, educational facilities, transportation, and power network exposed to the impacts of different categories of cyclones.

In long-term scenario, the less intense cyclones will have larger area of exposure; hence, they will have higher impacts on the infrastructure under consideration (Table 64.4). As the transportation and power networks provide consistent emergency support to health infrastructure, access to cyclone shelters during post-disaster recovery, identification and maintenance of vulnerable networks will enhance the resilience of the entire system.

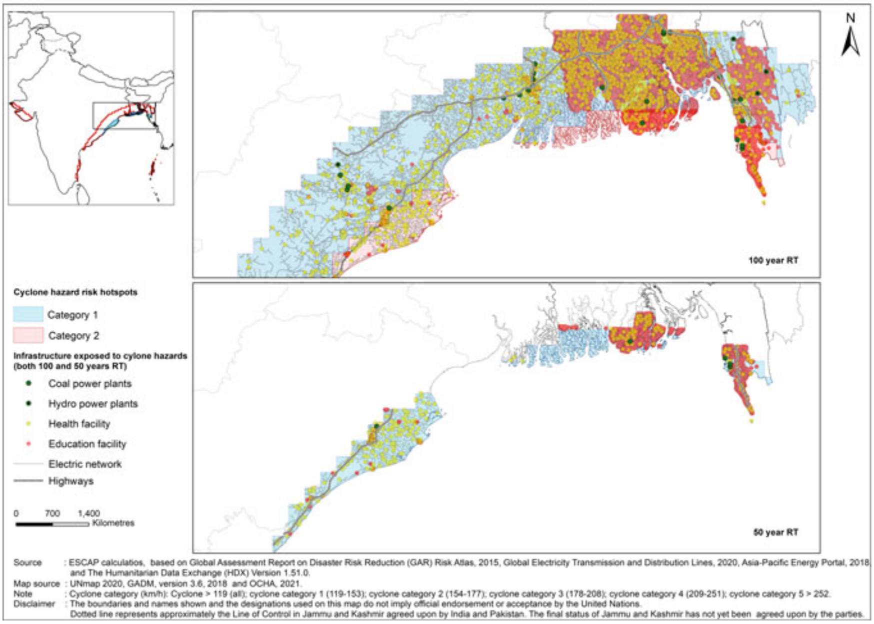

Fig. 64.8 Health, education, and transportation facilities exposed to impacts of cyclones in India–Bangladesh region. *Data source* Arderne et al. (2020), APEP (n.d. a, b), OCHA (2021), UNESCAP (2020)

Table 64.4 Number of critical infrastructures exposed to different categories of cyclone in India–Bangladesh region

Infrastructure	Category 2 cyclone with 100 years return period	Category 1 cyclone with 100 years return period	Category 1 cyclone with 50 years return period
Educational facility (No.)	2131	28,904	2906
Health facility (No.)	592	4079	755
Highways (km)	493.41	2112.68	342.08
Coal power plants	5 (total design capacity = 5268 MWe)	35 (total design capacity = 39,211 MWe)	5 (total design capacity = 5268 MWe)
Hydro power plants	–	4 (total design capacity = 495 MWe)	–
Electric network (km)	5315.14	68,751.37	7403.78

64.3 Recommendations

64.3.1 Using Frontier Technologies

Frontier technologies are new and rapidly developing technologies that take advantage of digitalization and connectivity and thus are key to address systemic risks such as cyclones (Fig. 64.9). These technologies already represent a $350 billion market and could grow to over $3.2 trillion by 2025 (UN 2021).

64.3.1.1 Gridded, Smart, and Impact-Based and Risk-Informed Early Warning

Earlier, the forecasting and warnings during cyclones were designed to express the atmospheric variables and their changes throughout the cyclone events, which could not be interpreted to the needful action at the time of disaster. However, impact-based forecasting and warning provides information about the impact of cyclone events at the community level, e.g., disruption in transportation services or flooding of roads. This system relays early warning on cyclone track, wind, and rain prediction under different scenario with a clear public messaging which can be easily translated into actions to the people at risk.

To facilitate such precise forecasting and early warning, numerical weather prediction (NWP) models are needed to be used along with Big Data. Current weather observations are fed into the NWPs through data assimilation for forecasting future state of weather. NWPs are very important part of cyclone tracking because of its significant accuracy and reliability (Kotal et al. 2016). Incorporation of satellite imageries providing real-time weather observation along with NWPs enhances the model output in tracking cyclones and predicting its trajectories.

To translate the severe weather forecast into impact services, risk-informed early warning is essential. Along with hazard information with location and timing, exposure and vulnerability information should be explicitly considered. Exposure of different priority sectors such as agriculture, power, and transportation along with social dynamics (e.g., population, human development, age and gender) contribute to the vulnerability of a particular region. In a simple case, data-driven analytical tools can be applied to identify vulnerabilities and decide on adaptation strategies.

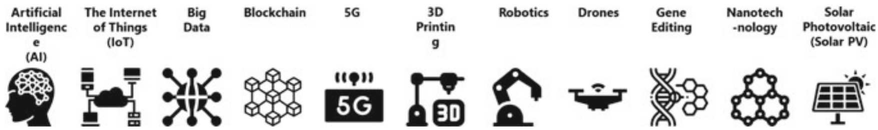

Fig. 64.9 Frontier technologies relevant for cyclone risk management

However, use of Big Data can enhance the process functioning multifold by undergoing iterative process to identify based on the current climate variables, but also anticipate the changes in climate and identify necessary relevant strategies (Data-Pop Alliance 2015). Hence, it can help both in pre- and post-disaster management phases by filling the input information gap through artificial intelligence. In cyclone hazard management, this can produce profound impacts, such as nature and track of cyclone may vary throughout the process altering adaptation actions accordingly. This type of forecast system helps in contingency planning and decision-making for wider social benefit.

64.3.1.2 Post-disaster Damage Assessment Using Drones and Satellite Imagery

Post-disaster damage assessment is necessary for precise actionable information and for speedy recovery of the affected area. Post-disaster damage assessment used to be carried out using satellite sensor data which dates back to 1906 (Baker 1989). Despite huge technological advancement in this field, majority of the damage assessment process was mostly manual exercise. It is very much challenging when the damage assessment results are required within a short time span for relief planning. In such cases, advanced automated techniques such as machine learning including artificial neural network (ANN) and convolutional neural network (CNN) can be used to obtain damage information from optical satellite data or radar data (Kerle et al. 2020).

Along with that unmanned aerial vehicles (UAVs/drones) have immense prospect in inspecting and capturing post-disaster damage for both structural (development infrastructures) and non-structural assets (forest, agricultural lands). The use of UAVs is flexible and faster than satellite sensors, in absence of legal restrictions on flying them. They expedite data collection process and generating data-driven information using CNN and machine learning technologies for recovery and rehabilitation.

64.3.1.3 Smart Digital Technologies to Empower Disaster Communication

Smart digital technologies can provide reliable and accessible disaster information and hence build community's resilience. Information dissemination from a single point source is important to avoid any confusion during disaster. Satellite radios are important mode of communication during disaster which ensures last mile connectivity. Mobile phones due to their number and coverage represent a very effective mode of information dissemination for early warning. Cyclone-specific mobile app could be developed and interlinked with representative authority to receive timely alert on the disaster events. Along with digital and print media, social media has a huge role to play during cyclone early warning.

64.3.1.4 Integrating Climate Risk Scenarios for Building Resilient Cities

The coastal cities in the BoB are vulnerable to the impacts of cyclone because they are densely populated. Therefore, city development plans/works should be risk informed. Digital elevation models can be used to identify the areas under the risk of inundation due to coastal flooding. As the variation in elevation in coastal region is very less over a wide area, in such case, LiDAR-based elevation models can produce better results than available elevation models, as LiDAR data are produced from high density point clouds. Potentially, vulnerable areas can be identified using Big Data supported inundation modeling for different future climate scenario. The power sector, particularly, incurs huge losses due to wind and storm surges. Building infrastructure for alternate power sources should be planned, which can withstand the highest category of cyclonic winds and storms, as a contingency strategy. In addition, scenarios of impacts on infrastructure including power, road, and social infrastructures such as hospitals and potential evacuation shelters are also significant in risk-informed planning to enhance resilience.

64.3.2 Climate Action Through Green–Gray Infrastructure

For adaptation to the escalating impacts of climate change and associated impacts in the coastal areas, there is need to change the perspective of building resilience from traditional approach to new innovative ways. Coastal flooding is a post-cyclone phenomenon, which is a major threat in the lives and properties in the low-lying coastal areas. Traditional gray infrastructures such as embankments, dikes, sea walls, storm surge barriers and cyclone shelters, and sluice gates are built for long-term protection of populations and assets in cyclone-prone locations from the impacts of cyclone. However, these infrastructures need maintenance, and with increasing intensity of the cyclones in future, they may not sustain for a long time.

Green infrastructures, on the other hand, are the components of natural ecosystem strategically nurtured or restored to build low-cost services. Mangroves, sea grasses, and coastal wetlands act as natural barrier of cyclones and storm surges by attenuating their height and velocity. They are highly cost-effective in terms of low investment, high return, and need no maintenance once initiated. They have natural adaptive and regenerative capacity. Their multiple benefits can generate both monetary value as well as non-market benefits. Hence, they enhance the systems resilience through economic, ecological, and social dividends. Despite their immense values, they are at risk due to different developmental activities.

Green infrastructures, if used in combination with the gray one, can boost infrastructure system resilience multifold. In combination, green–gray infrastructure can enhance the performance cost-effectively, promote resilience and brings about multiple co-benefit (Browder et al. 2019). Cyclone protection through mangroves can be effective in wide-spread rural coastal areas with comparatively low population density where building sea walls for a long stretch will be cost and maintenance

Fig. 64.10 Bamboo T-fence in combination with mangrove forest for coastal cyclone and flood management in Bac Lieu Vietnam (Dao et al. 2018)

intensive. In such case, a combination of dyke in the floodplain supported by the mangroves can reduce the impacts of cyclone to greater extent. Dykes can also restore eroded floodplains and maintain healthy mangroves. Similar strategy is in practice in Nha Mat, Bac Lieu province, Vietnam where wooden fences were constructed in combination with mangrove (Fig. 64.10) as a cyclone management strategy (Dao et al. 2018; Albers and Schmitt 2015). On the contrary, in densely populated coastal regions, only mangrove forests cannot protect the population assets from the impacts of cyclones. In such cases, mangroves in the foreshore of embankments can be a better green–gray combination, where mangrove can act as first line of defense by reducing the storm surge height. Mangroves can reduce the flow velocity and protect the embankment. In such cases, a relatively shorter height of embankment can also provide necessary protection and reduce the cost of investment.

Green–gray infrastructure for coastal protection must also be risk informed. Location-specific design and assessment is essential for mainstreaming green–gray infrastructure. An integration of green–gray infrastructure can be used for spatial risk zonation to build resilient societies (Dipietri and McPhearson 2017). The infrastructure designs must take local ecological, social, and political conditions into consideration. To do that there has been huge development in the area of Big Data through technological breakthrough and sophisticated computer models, which can use multi-temporal, multi-sectoral database and identify spatial distribution of risks, and vulnerabilities for life and assets. This enables to precisely decide the location specific adaptation strategies targeted for specific communities.

64.4 Conclusions

Tropical cyclones are recurring phenomena in the coastal regions of BoB spanning along the coast of India and Bangladesh. In future, the cyclones are expected to intensify, if not the number, which may be attributed by climate change. The exposure and vulnerabilities in social, ecological, and economic sectors are also going to increase due to increasing population. Mangrove forests, the natural buffer system to cyclone, are being destroyed and cut exposing the region more to the adverse impacts of cyclonic events. To build the overall resilience of the region, two main recommendations have been put forward in this study. Frontier technologies can prepare the region to withstand the impacts of cyclones, whereas green–gray infrastructures in reducing the actual impacts of the cyclone. Frontier technologies consist of impact-based and risk-informed early warning, drone, and satellite imagery to support post-disaster damage assessment, smart digital technologies to empower disaster communication right in the aftermath of disaster, and integration of climate risk scenarios for building resilient cities.

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References

Albers T, Schmitt K (2015) Dyke design, floodplain restoration and mangrove co-management as parts of an area coastal protection strategy for the mud coasts of the Mekong Delta, Vietnam. Wetl Ecol Manag 23(6):991–1004

Alongi DM (2002) Present state and future of the world's mangrove forests. Environ Conserv 29(3):331–349

APDR (2019) Asia-Pacific disaster report: the disaster riskscape across Asia-Pacific-Pathways for resilience, inclusion and empowerment. United Nations Publication, Bangkok, Thailand, p 130

APEP (n.d.a) Asia-Pacific Energy Portal. Hydro % TPES in South-East Asia 1990–2015. https://asiapacificenergy.org/#main/lang/en/graph/1/type/0/sort/0/time/[1990,2015]/indicator/[2948:2810]/geo/[SOEA]/legend/1/inspect/0. Accessed 23April 2020

APEP (n.d.b) Asia-Pacific Energy Portal. Coal % TPES in South-East Asia 1990–2015. https://asiapacificenergy.org/#main/lang/en/graph/1/type/0/sort/0/time/[1990,2015]/indicator/[2948:2810]/geo/[SOEA]/legend/1/inspect/0. Accessed 23 April 2020

Arderne C, Nicolas C, Zorn C et al (2020) Data from: predictive mapping of the global power system using open data. https://zenodo.org/record/3628142#.YK9mJKgzY2w. Accessed 28 May 2021

Baker S (1989) San Francisco in ruins. The 1906 aerial photographs of George R. Lawrence. Landsc 30:9–14

Bhardwaj P, Pattanaik DR, Singh O (2019) Tropical cyclone activity over Bay of Bengal in relation to El Niño-Southern Oscillation. Int J Climatol 39(14):1–18

BMTPC (2016) Vulnerability atlas of India: Earthquake, windstorm and flood hazard maps and damage risk to housing. 3rd edn. Building material and technology promotion Council. Government of India, New Delhi, p 478

Browder G, Ozment S, Bescos IR et al (2019) Integrating green and grey-creating next generation infrastructure. World Bank and WRI, Washington, p 140

CCI-LC (Climate change initiative land cover) (n.d.) Climate change initiative land cover v2.0.7cds 2019 https://cds.climate.copernicus.eu/cdsapp#!/dataset/satellite-land-cover?tab=overview. Accessed 8 March 2021

CIESIN (Center for International Earth Science Information Network, Columbia University) (2018) Gridded population of the world, version 4 (GPWv4): population density, revision 11. NASA Socioeconomic Data and Applications Center (SEDAC) GREG, Palisades, NY https://sedac.ciesin.columbia.edu/data/set/gpw-v4-population-density-rev11. Accessed 20 May 2021

CPP, Government of Bangladesh (n.d.) Cyclone preparedness programme. http://www.cpp.gov.bd/. Accessed 25 May 2021

Dao T, Marcel S, Hofland B et al (2018) Wave damping due to wooden fences along mangrove coasts. J Coast Res 34(6):1317–1327
Dasgupta R, Shaw R (2017) Mangroves in Asia-Pacific: a review of threats and responses. In: Dasgupta R, Shaw R (eds) Participatory mangrove management in a changing climate, disaster risk reduction. Springer, pp 1-16
Dasgupta S, Islam MS, Huq M et al (2019) Quantifying the protective capacity of mangroves from storm surges in coastal Bangladesh. PLoS ONE 14(3):1–14
Dash B, Walia A (2020) Role of multi-purpose cyclone shelters in India: last mile or neighbourhood evacuation. Trop Cyclone Res Rev 9(4):206–217
Data-pop Alliance (2015) Big data for climate resilience. In: Inputs for world development report 2016, digital dividends, October 2015. http://datapopalliance.org/wp-content/uploads/2017/03/WDR-Data-Pop-Alliance-input-2-Climate-Change-Resilience.pdf. Accessed 26 May 2021
Dipietri Y, McPhearson T (2017) Integrating the grey, green, and blue in cities: nature-based solutions for climate change adaptation and risk reduction. In: Kabisch N, Korn H, Stadler J, Bonn A (eds) Nature-based solutions to climate change in urban areas: linkages between science, policy, and practice. Springer, pp 91–110
DYNT (2020) Cyclone Amphan and Sundarban: a probable long-term impact of storm surge inundation. http://www.dyntland.com/environment/cyclone-amphan-and-sundarban-a-probable-long-term-impact-of-storm-surge-inundation/. Accessed 28 May 2021
ESA (European Space Agency) (2021) Climate change initiative land cover (CCI-LC) v 2.0.7cds 1992. https://cds.climate.copernicus.eu/cdsapp#!/dataset/satellite-land-cover?tab=overview. Accessed 8 March 2021
GADM (2018) GDAM Data. https://gadm.org/data.html. Accessed 14 April 2021
Giri C, Pengra B, Zhu Z et al (2007) Monitoring mangrove forest dynamics of the Sundarbans in Bangladesh and India using multi-temporal satellite data from 1973 to 2000. Estuar Coas Shelf Sci 73(1–2):91–100
Global assessment report on disaster risk reduction (GAR) (2015) https://risk.preventionweb.net/capraviewer/main.jsp?countrycode=g15. Accessed September 2018 to January 2019
Global Data Lab (2018) Subnational human development index (HDI) version 4.0 (1). https://globaldatalab.org/shdi/download_files/. Accessed May 2020
Gopal B, Chauhan M (2018) The transboundary Sundarbans mangroves (India and Bangladesh). In: Finlayson C, Milton G, Prentice R et al (eds) The wetland book. Springer, Dordrecht, The Netherlands, pp 1733–1742
Guha-Sapir D, CRED (2020) EM-DAT: the emergency events database. Technical report, Université Catholique de Louvain (UCL). https://www.emdat.be. Accessed 19 May 2021
Guha-Sapir D, CRED (2021) EM-DAT: the emergency events database. Technical report, Universitécatholique de Louvain (UCL). https://www.emdat.be. Accessed 19 May 15, 2021
Hamilton SE, Casey D (2016) Creation of a high spatio-temporal resolution global database of continuous mangrove forest cover for the 21st century (CGMFC-21). Glob Ecol Biogeogr 25(6):729–738
IMD (2011) Tracks of cyclones and depressions over North Indian Ocean (from 1891 onwards) (Cyclone eAtlas—IMD, Version 2.0). Cyclone Warning and Research Centre, India Meteorological Department, Regional Meteorological Centre, Chennai
IPCC (2019) Summary for policymakers. In: HO Pörtner, DC Roberts, V Masson-Delmotte et al (eds) IPCC special report on the ocean and cryosphere in a changing climate. https://www.ipcc.ch/site/assets/uploads/sites/3/2019/11/03_SROCC_SPM_FINAL.pdf, Accessed 23 May 2021
Kerle N, Nex F, Gerke F et al (2020) UAV-based structural damage mapping: a review. ISPRS Int J Geoinf 9(1):1–23
Kotal SD, Bhattacharya SK, Roy Bhowmik SK (2016) Development of NWP based objective cyclone prediction system (CPS) for North Indian Ocean tropical cyclones—evaluation of performance.Trop Cyclone Res Rev 3(3):162–177
Mandal GS, Mahapatra M (n.d.) Cyclone hazard prone districts of India, a report. National Disaster Management Authority, Government of India, New Delhi, p 44

McIvor AL, Möller I, Spencer T et al (2012a) Reduction of wind and swell waves by mangroves. Natural Coastal Protection Series: Report 1. Cambridge Coastal Research Unit Working Paper 40. Published by The Nature Conservancy and Wetlands International, Wageningen, The Netherlands, p 27

McIvor AL, Spencer T, Möller I et al (2012b) Storm surge reduction by mangroves. Natural Coastal Protection Series: Report 2. Cambridge Coastal Research Unit Working Paper 41, The Nature Conservancy and Wetlands International, Wageningen,The Netherlands, p 35

Menéndez P, Losada IJ, Torres-Ortega S et al (2020) The global flood protection benefits of Mangroves. Sci Rep 10:4404. https://doi.org/10.1038/s41598-020-61136-6

NDMA (n.d.) Cyclone. https://www.ndma.gov.in/Natural-Hazards/Cyclone. Accessed 22 May, 2021

NDMI (2017) National Cyclone Risk Mitigation Project (NCRMP). https://ndmindia.mha.gov.in/programs. Accessed 23 May 2021

OCHA (2021) Humanitarian data exchange v1.51.0—Education and health facilities for India and Bangladesh. https://data.humdata.org/. Accessed 29 May 2021

START Network (2018) Disaster summary sheet-Bangladesh tropical storm and cyclone. https://reliefweb.int/sites/reliefweb.int/files/resources/180409%20Start%20Fund%20Tropical%20Storm-Cyclone%20Disaster%20Summary%20Sheet.pdf. Accessed 21 May 2021

UN (2021) Technology and innovation report. United Nations Publications, New York

UNDP (2019) Climate change in Asia and the Pacific. What's at stake? Available at https://www.asia-pacific.undp.org/content/rbap/en/home/presscenter/articles/2019/climate-change-in-asia-and-the-pacific.html. Accessed 22 May 2021

UNESCAP (United Nations, Economic and Social Commission for Asia and the Pacific) (2021). Asia-Pacific Disaster Report 2021, Bangkok, Thailand

UNESCO (2021) The Sunderbans. https://whc.unesco.org/en/list/798/. Accessed 24 May 2021

United Nations Economic and Social Commission for Asia and the Pacific (UNESCAP) (2020) Population number in 2020. https://data.unescap.org/

WMO (World Meteorological Organization) (2020a). World's deadliest tropical cyclone was 50 years ago. WMO, Geneva, Switzerland. https://public.wmo.int/en/media/news/world%E2%80%99s-deadliest-tropical-cyclone-was-50-years-ago. Accessed 22 May 2021

WMO (World Meteorological Organization) (2020b) Tropical cyclones. WMO, Geneva, Switzerland. https://public.wmo.int/en/our-mandate/focus-areas/natural-hazards-and-disaster-risk-reduction/tropical-cyclones. Accessed 21 May 2021

WMO (World Meteorological Organization) (2021) State of the global climate 2020. WMO, Geneva, Switzerland, p 56

World Bank (2015) Emergency 2007 Cyclone Recovery and Restoration Project. https://documents1.worldbank.org/curated/en/509281468203643114/pdf/ISR-Disclosable-P111272-05-21-2015-1432224466732.pdf, Accessed 23 May 2021

Chapter 65
Projection of Future Coral Bleaching Events and Sustainability of Coastal Fishery Around Andaman Islands in the Perspective of Climate Change

Sayani Datta Majumdar, Sugata Hazra, Partho Protim Mondal, and Sourav Samanta

Abstract The present paper analyses the rising trend of sea surface temperature and coral bleaching events around the Andaman Islands, attempts to link it to the fluctuation of reef-fish catch and predict such future events under the RCP 4.5 scenario of climate projection. The Andaman Islands, enclosed by around 950 km^2 of fringing coral reef, provide an ideal habitat for both pelagic and demersal fish stocks. The coral reef with the largest species diversity in the country hosts a sizable stock of ornamental reef fishes along with tunas, snappers, anchovies, groupers, mullets, etc., in the surrounding coastal water. Whilst the climatic change in the form of rapidly rising summer temperature since the 1990s repeated strong El Nino phenomena and warm Indonesian through flow, rising rainfall since 2009 resulting in excess sediment runoff has already taken a toll on the health of coral reefs, but their impact is hardly discernable on the marine fishery sector where even 30% of the estimated potential has not been exploited so far. With the climate projection under the bias-corrected CNRM-C5 run of RCP4.5 scenario for the area, and projected bleaching frequency and intensity estimated from degree heating week (DHW), the paper investigates their potential impacts on the corals and associated marine fisheries of Andaman Islands and argues for improving the fishery strategies ensuring sustainable fishing practices as well as preserving the pristine environmental conditions of this critically sensitive eco-region.

Keywords Andaman · Climate change · Coral bleaching forecast · Marine fisheries

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65.1 Introduction

The Andaman group of islands is bestowed with 948.8 km^2 (Jeyabhaskaran 2007) of fringing reefs and around 615 km^2 of mangrove forests (FSI 2015) which provide habitat to a large variety of pelagic and demersal fish stock (Advani et al. 2013). The fish fauna of Andaman and Nicobar make up more than 1200 species from the coastal and offshore waters, of which 282 species are economically significant edible fishes (EQMS 2018). The marine fisheries in Andaman and Nicobar Islands are classified into (a) coastal fisheries and (b) offshore fisheries. The potential marine fish resource of Andaman is 1,48,000 tonnes out of which pelagic, demersal and oceanic stock constitutes 56,000, 32,000 and 60,000 tonnes, respectively (Dam Roy and George 2010). Whilst the pelagic resources include anchovies, sardines, and mackerel, the demersal stock comprises carangids, perches, silver bellies, pomfrets, scads, shrimps, and lobsters, etc. The oceanic resources are mainly dominated by a large variety of tunas. Diglipur, Mayabunder, Rangat, South Andaman, Little Andaman, Car Nicobar, Nancowry and Campbell Bay are the major fishing centres of Andaman and Nicobar Islands (Dam Roy and George 2010).

Out of a total 1434 species of fishes recorded from the islands, 75.68% of the species was reported as coral inhabitants (1089 species) (Rajan et al. 2013). Some of the coastal fish catch statistics during 1997–2015 period from Andaman depicting fish catch from coastal water of Andaman are shown here (Dam Roy and George 2010) (Fig. 65.1). Whilst catches of perch, silver bellies or even neritic tuna appeared to be somewhat responsive to the bleaching events of 1998, 2005, 2010 or 2015–16, a clear signal could not be obtained due to lack of respective data on efforts.

Due to differences in temperature and humidity of the atmosphere, the world's oceans are being affected by changes in temperature, precipitation, wind and currents.

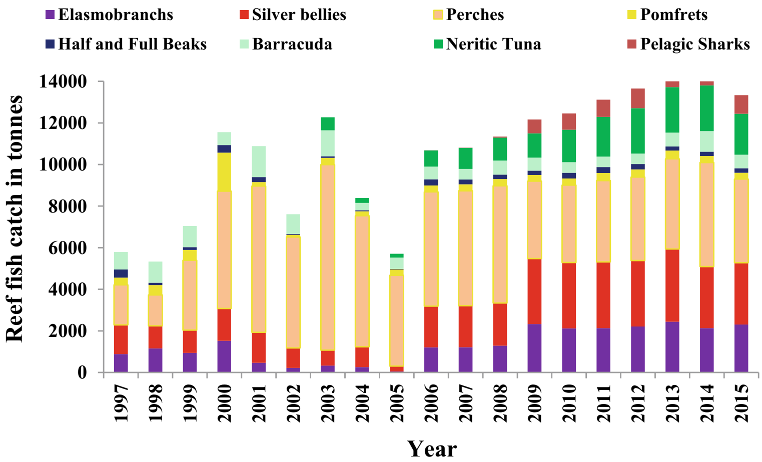

Fig. 65.1 Reef fish species of Andaman and their yield in tonnes. *Source* Dam Roy and George 2010

Consequently, important oceanic weather systems such as the *El Niño* Southern Oscillation (ENSO) and Indian ocean monsoon are also getting influenced by warming oceans and associated climate change (Vivekanandan 2011). The climate models in IPCC's report (IPCC 2014), projected that for their lowest and highest emissions scenarios, the global surface temperature during the twenty-first century would rise from 0.3 to 1.7 °C and 2.6 to 4.8 °C, respectively (Zacharia et al. 2016). Whilst sea-level change, sea warming or precipitations significantly affect the mangroves and corals; a rise in sea surface temperature can affect the spawning of fish species or alter their physiology, and El Nino–Southern Oscillation can bring changes in larval distribution (Vivekanandan 2011).

Various indicators of climate change such as increased sea surface temperature, sea-level rise and ocean acidification and increased rainfall are likely to affect the coral reefs, mangroves which could successively impact the productivity of coastal fisheries (Gillet 2014; Shiva Shankar et al. 2021). The devastating effects of recent climate were most distinctly evident on coral reefs through increased sea temperatures and consequent bleaching of scleractinian corals (Parmesan 2006; Wilson et al. 2008). The coral reefs of Andaman experienced various bleaching events (years 1998, 2002, 2005, 2010, 2016), but the 2010 bleaching episode took a heavy toll on the health of corals (Majumdar et al. 2018). About 77% of the corals was found to be bleached (Arora et al. 2019), with fully bleached corals being recorded at Havelock Islands, South Button, Nicolson islands, North Bay and Chiriyatapu (Srivastava 2012).

Although the Indian marine fisheries sector is facing various challenges such as unsustainable fishing, low catch per unit effort, the issues of climate change and associated sea warming are distinctly visible in the exclusive economic zone (EEZ) of the country and surrounding seas (Zacharia et al. 2016). Analysis of past rainfall records in the Andaman and Nicobar Islands revealed that although the amount of rainfall remained unchanged, the pattern of rainfall showed alterations with an increase in the number of extreme rainfall events (Velmurugan et al. 2018). Temperature is the key environmental factor that affects any aquatic organisms be it coral or fish stock (Vivekanandan 2011). Elevated sea surface temperature (SST) that persist through weeks put coral reefs under severe thermal stress which finally result in bleaching and mortality (Liu et al. 2003). Moreover, a rise in the temperature of aquatic systems by 1 °C increases the metabolic activities in fish by 10% (Vivekanandan and Pandian 1977). Mass coral bleaching (MCB) events at regional scales have been reported worldwide since 1980 (Eakin et al. 2009) and 1997–98, 2010, 2015–16 bleaching events in association with El Niño–Southern Oscillations significantly affected the coral reefs of tropical oceans (Arora et al. 2019). Climate change-induced coral bleaching and loss of coral cover could bring devastating effects on topographic complexities thus affecting the fisheries which nestle there (Spalding et al. 2001; Wilson et al. 2006; Munday et al. 2008; Pratchett et al. 2008).

By using the relationship between historical temperatures and bleaching events and SST predictions for another 100 years, Vivekanandan et al. (2009) predicted that the number of decadal catastrophic bleaching events would increase from 0 during 2000–2009 to 8 during 2080–2089 and that the reefs would likely become remnant between 2030 and 2040 in the Lakshadweep Sea and between 2050 and 2060 in adjacent Indian Seas.

For the present purpose, a reliable climate model for the Andaman Region appears to be an essential tool to anticipate future bleaching events for planning the coastal and marine fisheries activities through appropriate risk-reduction mechanisms.

Although global climate models (GCMs) are the efficient tools to provide climate change-related information, due to their limitation in grid size, the regional climate models (RCMs) come in handy by downscaling the global climate simulations to minute grid sizes in the area of interest. Whilst the emission scenarios of IPCC-AR4 (IPCC 2007) were built based on economic, environmental and sustainable developments concerning the developed as well as developing nations, anthropogenic radiative forcing was the foundation for building the AR5 scenarios (IPCC 2013). Each model has its way to reach for the four different radiative forcings that further correspond to different concentration paths of the greenhouse gases—representative concentration pathways (RCPs). The Coupled Model Intercomparison Project Phase 5 (CMIP5) is a set of coordinated climate model intended to simulate the probable effects of future climate change under the scenarios known as the RCPs (Moss et al. 2010). The four different scenarios: RCP 8.5, RCP 6.0, RCP 4.5 and RCP 2.6, correspond to radiative forcings of 8.5 Wm^{-2}, 6.0 Wm^{-2}, 4.5 Wm^{-2} and 2.6 Wm^{-2}, respectively (Akhiljith et al. 2019).

With the help of CNRM-CM5 earth system model run of RCP 4.5 scenario for the study area, this paper aims to find out the possible impacts of climate change on corals in the form of probable bleaching events, their frequency and intensity and corresponding stress on the fisheries they support and to suggest ways for risk reduction through sustainable fishing practices as well as conserving pristine condition of the island.

65.2 Materials and Methods

In this study, the possible model projections were analysed for one of the most vital oceanographic variables—sea surface temperature (SST), for the Northern Bay of Bengal in 2030, 2050 and 2080 based on a suitable CMIP5 model under appropriate RCP 4.5 scenario.

65.2.1 Study Area

The Andaman and Nicobar Islands with a coastline stretching 1912 km in length and a continental shelf of 16,000 km^2 in the area accounts for 28% of India's Exclusive Economic Zone (Advani et al. 2013; Kaliyamoorthy et al. 2020) (Fig. 65.2). Located between 6° 45′ N to 13° 41′ N and 92° 12′ E to 93° 57′ E, the oceanic islands are fringed by some spectacular coral reefs. These tropical islands witness heavy

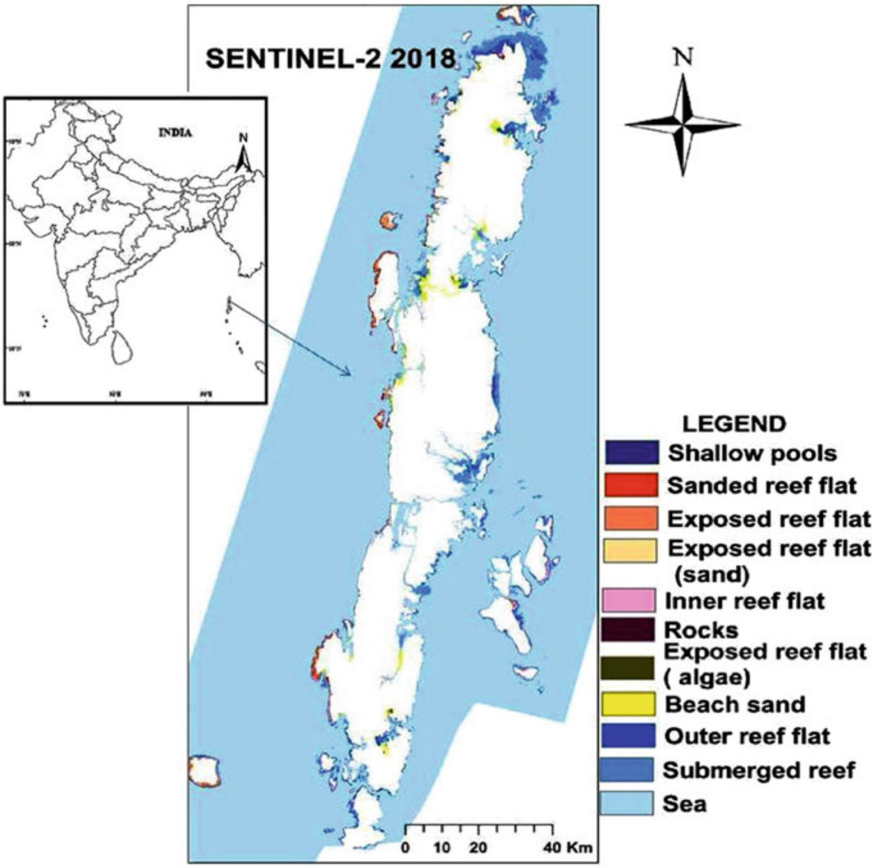

Fig. 65.2 Study area of Andaman Islands, India

cyclones, hot and humid weather conditions throughout the year (Bandopadhyay and Carter 2017). The daily temperature ranges from 27 to 38 °C in the summer and 21–25 °C in the winter, whilst the entire island receives an average annual rainfall of 2851.9 mm (Bandopadhyay and Carter 2017).

65.2.2 Observation Data Set Used

Sea surface temperature (SST) data for the period 1982–2019 from GHRSST Level 4 AVHRR_OI Global Blended Sea Surface Temperature Analysis (GDS version 2) data from National Centres for Environmental Information (NCEI 2016; Reynolds et al. 2007) were used for the present study, along with MODIS Terra Level 3 SST

Thermal IR daily 4 km nighttime V2019.0 data from 2000–2019 (Werdell et al. 2013; NASA OBPG 2020) accessed from (http://podaac.jpl.nasa.gov).

65.2.3 Model Data Set Used

Observation data were combined with the daily forecast SST data for the year 2006 to 2099 from two climate models under the CMIP5 project.

1. UK Met Office Hadley Centre HadGEM2-ES (ensemble = r1i1p1; experiment = Historical, RCP 4.5 and RCP 8.5), and
2. Centre National de Recherches Meteorologiques/Centre Europeen de Recherche et Formation Avanceesen Calcul Scientifique (CNRM/CERFACS) CNRM-CM5 (ensemble = r1i1p1; experiment = Historical, RCP 4.5 and RCP 8.5) accessed from Earth System Grid Federation (ESGF) node esgf-data1.ceda.ac.uk and esgf-node.ipsl.upmc.fr.

65.2.4 Methodology to Identify Bleaching Events

With the objective to identify coral bleaching events based on thermal stress, two separate approaches were used. A simple threshold technique was used considering that corals undergo bleaching when the SST is warmer than the bleaching threshold, i.e., one degree celsius (1 °C) above the highest summertime mean temperature or maximum monthly mean (MMM) (Glynn and D'Croz 1990). A more sophisticated technique based on the degree of heating week (DHW) concept of NOAA coral reef watch (https://coralreefwatch.noaa.gov/coralreefwatch.nooa.gov) where DHW shows how much heat stress has accumulated in an area over the past 12 weeks.

65.2.5 Maximum Monthly Mean

Maximum monthly mean (MMM) is defined as the warmest monthly mean value. The daily GHRSST-AVHRR observation SST data of 1982–2005 were used to calculate monthly mean composites.

65.2.6 Hot Spot

Coral bleaching hot spot (HS) is a measure of the occurrence of thermal stress approaching conducive to coral bleaching for a location. The HS anomaly is based on the climatological mean SST of the hottest month (Liu et al. 2003, 2005; Skirving et al. 2006). Hot spots are identified as regions where the SST is warmer than the MMM of SST. The value of HS gives the difference between the measured near-real-time SST and the MMM SST climatology, calculated as

$$\text{Hot Spot }(^{\circ}\text{C}) = \text{SST} - \text{MMM}$$

Only positive values are considered since the hot spot signifies the bleaching heat stress exceeding the MMM climatology.

65.2.7 Degree of Heating week

It measures the accumulation of heat stress that coral reefs experienced over the prior 12 weeks (3 months). Degree of heating week (DHW) accumulates coral bleaching hot spots greater than 1 °C, over a 12-week window. It is a cumulative measurement of both intensity and duration of heat stress, and it is expressed in the unit °C-weeks. DHWs over 4 °C-weeks have been shown to cause significant coral bleaching, and values over 8 °C-weeks have caused severe bleaching and significant mortality in coral reefs.

The formula used to calculate the DHW is given below. In this mathematical equation, the DHW value for a given day i (DHW_i) is calculated as the summation, over a 12-week (84 days) running window up to and including that day (i), of 1/7 of each coral bleaching hot spot (HSj) value of 1 °C or more. The factor of 1/7 is used to express the final DHW value in terms of degree celsius-weeks (°C-weeks), as the development of coral bleaching is usually on the order of weeks:

$$\text{DHW}i = \sum_{j=i-83}^{i} \left(\frac{\text{HS}j}{7}\right), \text{ where HS}j \geq 1$$

It is possible for a location to have a non-zero DHW value on a day when the HS value is less than 1 °C or even 0 °C. This condition simply means that heat stress was present at that location within the last three months, but local conditions are not stressful for corals, on the day displayed in the corresponding DHW product. Exposure to previous heat stress still may have had adverse impacts on the corals, although recovery also may be possible.

65.3 Results

65.3.1 Projected Temperature Changes

Under RCP 4.5 scenario, in various time slices, the SST projections indicated moderate warming scenarios, with little variable results under two models. Whilst the SST trend of 2006–2020 indicated a rise of temperature (+0.024 °C yr^{-1}) in the CNRM-CM5 model, the same is half (0.012 °C yr^{-1}) in HadGEM2-ES output. The trend of warming continues to be steeper in subsequent decades under the CNRM-CM5 projection till 2070 after which a more subdued warming (@ 0.011 °C yr^{-1}) is seen. This however leads to an overall 0.015 °C yr^{-1} trend of sea surface warming during the present century (Fig. 65.3) The HadGEM 2-ES output, on the other hand, with initial subdued warming (0.012 °C yr^{-1} and less) up to 2050 (Fig. 65.4), exhibits a steeper and consistent rise in the second half of the century, leading to an overall higher rate of rise @ 0.022 °C yr^{-1}. However, considering the observed temperature data set over the Andaman Islands, the trend obtained from the CNRM-CM5 projection under the RCP 4.5 scenario appears to be more realistic and is used in the study for projection of bleaching events.

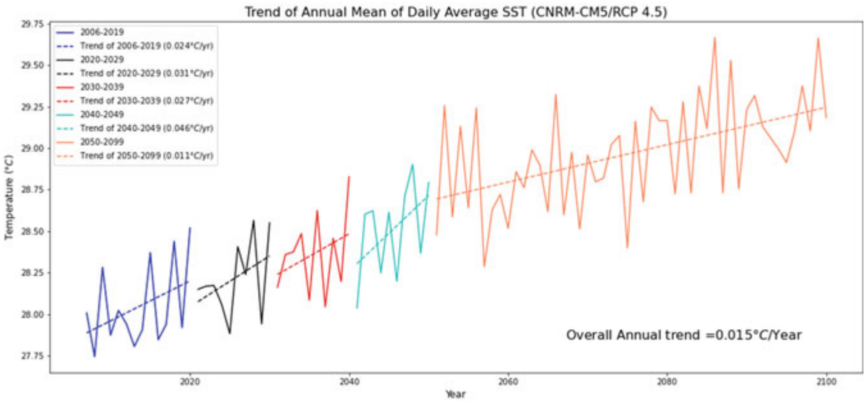

Fig. 65.3 CNRM-CM5 projection of future sea surface temperature around the Andaman Island under the RCP 4.5 scenario

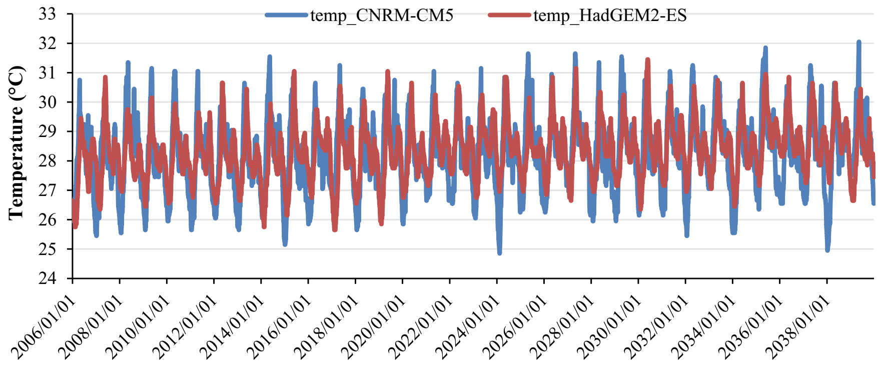

Fig. 65.4 Intercomparison of HadGM2-ES and CNRM-CM5 projections around the Andaman Islands

65.3.2 Validation of Bleaching Events in Andaman from Temperature Records and Model Output

Three mass bleaching events of corals due to elevated sea surface temperature were targeted for confirmation of the assessment method and model efficacy, with validation from field observations by various researchers.

From the AVHRR data set of 1982–2005 (Fig. 65.5) monthly SST climatology, the maximum monthly mean temperature (MMM) was calculated to be 29.8 °C. This confirms to the value obtained by Arora et al. (2019) for Andaman for the warmest month of May.

Similarly, bleaching hot spots were identified when the observed SST was at least 1 °C above the MMM values, i.e., 30.8 °C. Thermal stress was calculated based on the cumulative number of heating days the bleached segment experienced, as calculated

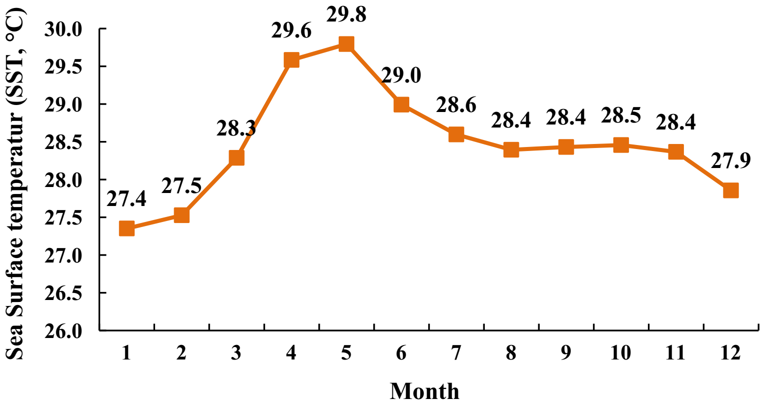

Fig. 65.5 Monthly average SST climatology from daily obs SST data of 1982–2005

in the DHW method. Before proceeding with the forecast of future bleaching events, mathematical assessment based on SST derived from four different sources (AVHRR data, MODIS data, CNRM-CM5 output, HadGEM2-ES output) were compared with field observations published by various scientists from Andaman. The validation results are given in Table 65.1.

It may be seen that the three most widespread bleaching events of 1998, 2005 and 2010 could be picked up successfully both from the AVHRR data set and CNRM-CM5 model output and subsequent calculations of DHW. MODIS data set, with its limitation of the observation period, could also identify the bleaching events of 2005, 2010 and 2016. Both MODIS and AVHRR indicated mass mortality of corals in 2010 with DHW values above 4 up to 9 °C-week. Whilst only CNRM-CM5 could

Table 65.1 Validation of bleaching events in Andamans assessed from satellite-derived SST data and model projections

Year	AVHRR		MODIS		RCP4.5 CNRM-CM5		Validation in field
	Max (SST-MMM)	DHW	Max (SST-MMM)	DHW	Max (SST-MMM)	DHW	
1998	1.9	1.89	No data		1.1	0.45	Ravindran et al. (1999)
2002	1.2	0.48			No event above threshold		Krishnan et al. (2011)
2003	1.3	1.30	No event above threshold		No event above threshold		No reference found
2004	1.7	2.00	No event above threshold		1.4	1.41	No reference found
2005	1.4	0.87	1.4	0.69	1.6	2.12	Krishnan et al. (2011) Sarkar and Ghosh (2013)
2010	2.2	9.83	2.2	5.65	1.3	2.70	Marimuthu et al. 2013 Mondal et al. (2014) Mohanty et al. (2017)
2014	1.0	1.56	No event above threshold		1.8	4.00	No reference found
2015	1.5	1.27	No event above threshold		No event above threshold		No reference found
2016	1.9	7.41	1.8	2.26	No event above threshold		Mohanty et al. (2017)
2018	1.6	2.79	1.7	1.09	No event above threshold		No reference found

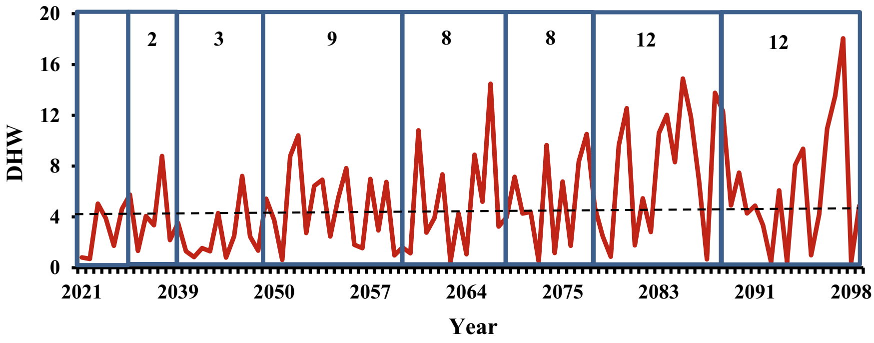

Fig. 65.6 Projection of future bleaching events and their intensities (DHW) around Andaman Island using CNRM-CM5 model

pick up the bleaching event of 2010 with a limited intensity, HadGM2-ES missed it completely due to its inherent problem of under assessment of the SST in the initial years. Thus, bias correction with AVHRR derived data set and application of CNRM-CM5 model projection would allow us to predict the future bleaching events, their duration and intensities (Fig. 65.6) around Andaman islands with more than 70% confidence.

It is apparent from this assessment that both the number of bleaching events, as well as its duration and intensity, leading to mortality of corals, are likely to increase from the present decade onwards. Whilst we may witness two such intense bleaching events in 2025 and 2029 in the present decade and 2032 and 2035 in the next, three intense bleaching events may be anticipated in the 2040s. The number of mass bleaching and coral mortality events can be further anticipated in 2051, 2053, 2055 and 2058. The interval between two successive bleachings offers no time for the coral to recover from the thermal shock of high intensity (over 8 °C-week) bleaching.

65.4 Discussion

The present study analysed the rise in sea surface temperature around coastal water of the Andaman Islands and possible coral bleaching events and intensities. Also, attempts were made to provide a quantitative assessment of the projected changes of sea surface temperature and their trend (in RCP scenario 4.5) for a general understanding of their effects in the coral reefs and coastal fishery in the Andaman Region.

In general, monthly sea surface temperatures around the Andaman Islands ranged from 28.1 °C in January which reached a maximum of 29.8 °C in May (Brown et al. 1996). Warming trends as observed by various researchers (Brown et al. 1996; Hoegh-Guldberg 1999) in the Indian Ocean Region are considered to have serious implications on a variety of marine fauna, especially the sensitive coral reefs which tend to lose their pigments through the loss of host algae when the temperature exceeds the seasonal maximum by only 1 °C (Majumdar et al. 2018).

Anthropogenic forcing, greenhouse gas emissions, El Niño and La Niña events, Indian Ocean Dipole and monsoonal winds are considered the principal factors that lead to the variation in SST in the Indian Ocean (Yoo et al. 2006; Roxy et al. 2014). Monthly comparison analysis of SST in 2030, 2050 and 2080 showed that maximum SST rise occurs in April and May, with bleaching temperatures persisting for more than three days. Whilst the period 2001–2010 witnessed the maximum bleaching events, the frequency of occurrence could vary from 4 to 5 in the coming years (Fig. 65.6). Apart from El Niño events, the Indian Ocean SSTs are also influenced by the Indian Ocean Dipole (Gnanaseelan et al. 2017), whereby the Western Basin of the Indian Ocean witness considerable warming with higher sea levels, lowered thermocline and reduced upwelling. In contrast, the eastern Indian Ocean experience lowered sea level, elevated thermoclines and enhanced upwelling (Webster et al. 1999; Gibson et al. 2007). Such sea-level depressions are responsible for the mortality of shallow coral reefs throughout the Andaman Sea (Brown and Phongsuwan 2004).

Varying degrees of bleaching events were witnessed in the Andaman Region during 2002 and 2005 when the average SST was 32.5 ± 0.6 °C and 30.8 ± 0.5 °C, respectively (Majumdar et al. 2018). During April and May 2010, 95% of the corals was found to have been heavily bleached in North Bay, Tarmugali and Chidiyatapu due to the rise in SST. The impact of bleaching on reef fishes was particularly found in the yield of perch resources (Fig. 65.7). Perch is one of the most important target fisheries of Andaman Island. A total of 274 species of perch were recorded from the island with prominent ones being *Lutjanidae, Lethrinidae* and *Serranidae* (Anrose et al. 2010).

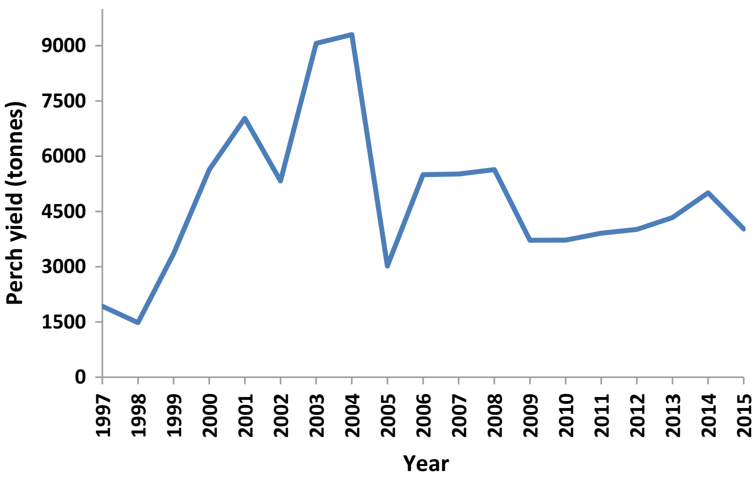

Fig. 65.7 Perch yield in the Andaman Islands (1997–2015)

During 1998, 2002 and 2005 bleaching years, the yield of perch drastically decreased from the previous years. The decrease in yield from 9303 (2004) to 3019 tonnes in the year 2005 was almost 68% which was not only due to coral bleaching but also due to December, 2004 Tsunami. During Central Pacific El Niño 2009–2010, the elevated SST of the Andaman Sea in April and May resulted in the formation of highest intensity hot spots which further indicated the onset mass bleaching of greater intensity in the Andaman Islands during 2010 (Krishnan et al. 2011; Lix et al. 2016). The high temperatures recorded over the ocean during March 2010 lasted for 5–6 months with peak temperature increase (DHW temperatures >10 °C-weeks and HS temperatures over 2 °C) between April to June (Tun et al. 2010). Since July is the peak season for the optimum catch, the yield was merely 0.08% higher than the previous year in the year 2010. Moreover, the year witnessed significantly reduced rainfall (483.6 mm) (Krishnan et al. 2013) which otherwise could have revived the bleached reefs and thermally stressed corals.

After assessing the SST data generated hot spot (HS) and degree of heating weeks (DHWs), Mohanty et al. (2017) observed elevated temperatures in the surface waters of the Andaman and Nicobar Islands, during April–May 2016, and the coral cover of the North Bay region showed signs of bleaching. The in situ temperatures varied between 31.8° to 32.3 °C, whilst at 5-m and 10-m depth, temperatures recorded 32.00 and 31.50 °C, respectively (Mohanty et al. 2017). To establish the impact of 2015–2016 El Nino triggered bleaching on reef fisheries, secondary fish catch data were collected from Kaliyamoorthy et al. (2020) study of ring operation of Andaman's fish landing centres. Although the original data were collected over four years (2014–2018) from various important landing centres of Andaman, to highlight the effect of bleaching on the catch, the present study only dealt with two previous years and the bleaching year of 2016. It could be found that in North Bay the annual average fish catch per trip drastically decreased from 8110 to 1014 tonnes in the year 2016. Except for Havelock, Chiriyatapu all other landing centres had lower catch per trip as compared to the year 2015 (Fig. 65.8).

Although the coral bleaching phenomena have affected the abundance and diversity of reef fishes temporarily, the recovery of the bleached and recruitment of new coral has previously increased the live coral cover and subsequently the fish stock (Krishnan et al. 2013). Whilst repeated bleaching events within a short period of time could hamper the recovery rate of corals, ample precipitation and sediment-free substrates could speed up the recovery process (Bellwood et al. 2003; Mondal et al. 2014).

65.5 Sustainable Fishing in the Time of Climate Change

In spite of repeated bleaching events, the exploitation of fish stock has steadily increased from 31,058 to 39,284 metric tonnes from 2003–04 to 2017–2018 (Fig. 65.8). The management of coral reef fisheries largely involves restricting fishers'

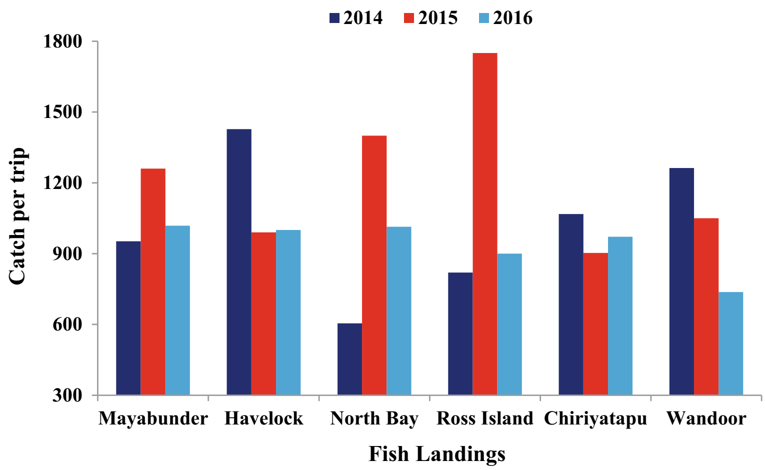

Fig. 65.8 Coastal fish catch per trip in landing centres of Andamans during before and after a bleaching event

access to marine resources of economic value like edible invertebrates and fish, ornamental fish and decorative shells for tourists. (Rajan et al. 2012). Some of the common management practices include licencing fishers and fishing vessels, restricting the use of certain fishing gear, setting catch limits. Since coral reefs cater to a wide range of interests of ranging from commercial and sport fishing to snorkelling, diving, research activities, glass-bottom tourism, and other stakeholders, officials are often faced with the dual challenges of addressing the needs of stakeholders on one hand and protecting the reef ecosystem on the other (Rajan et al. 2012).

The discovery and subsequent routine availability of commercial fine resolution (0.6–10 m) multispectral and hyperspectral satellite images, and other high-quality remote-sensing data and products, allowed upgradation of the existing reef fisheries management practices. The use of habitat maps in sampling strategies, mapping resources, locating conservation areas could facilitate the successful adoption of ecosystem-based fishery management (EBFM) approaches. However, despite their potential, the remote sensing products designed specifically for fishery management could be of little use largely due to high costs, inbuilt technical limitations and lack of awareness (Hamel and Andréfouët 2010).

In Lakshadweep Island 'fishing beyond reef' (Skipjack Tuna fishing) became widely popular as a sustainable fishing option, whereby combining fuel training and boat subsidies, the local communities who otherwise depended on reef fish for each meal could multiply their catch simply by changing the target species (https://www.discovery.com/nature/the-fish-that-saved-the-reef). In Andaman, the aforesaid method could be implemented to reduce overdependence on nearshore fishing and further boost the growth and development of deep-sea fishing. The islands do not have mechanised fishing, and the existing motorised crafts operate only within a few kilometres away from the coast.

The tuna resources have slowly increased to 181 metric tonnes (2015–2016) over the years; although in all the sectors, the exploited stock is far less than the potential yield. A successful development of tuna fishery could be the backbone for the overall development of the marine fisheries in the Andaman and Nicobar Islands, and any strategy for fisheries development should focus on the exploitation of coastal tunas together with pelagic sharks, barracudas and seer fishes (Pillai and Abdussamad 2009). Whilst laying down the Andaman fishery policy 2018, it was decided that mechanised fishing using vessels of different kinds would start operating beyond six nautical miles. Arur et al. (2014) through their study established that mesoscale eddies enhance fish productivity by upwelling in the seas surrounding the Andaman and Nicobar Islands as well as opened up the possibility of integrating satellite data for delineating potential fishing zones (PFZs). Moreover, by following the PFZ forecasts, there has been an increase in harvestable fish catch by 30% in the Andaman waters (George et al. 2011). The exploitation of juvenile fish, in the fisheries sector, has largely affected the global fish landings. For not using nets of proper mesh size, a huge amount of juvenile fishes are brought to the landing centres. To avoid juvenile catch, minimum legal size (MLS) which sets the smallest size at which a particular species of fish if caught can be validly retained can be used as an important tool to protect juvenile fish to sustain spawning stocks for future generations (Takar and Gurjar 2020). By increasing the size of the species caught, or maintaining the size of the stock, overall sustainability in fish stock can be achieved which in turn can address two major existing problems in fisheries management—growth overfishing and recruitment overfishing (Takar and Gurjar 2020). Certification of place, time and method of fish catch or certification of the quality of catch, have become an integral tool of fisheries management (Potts and Haward 2007). In order to deal with illegal, unreported and unregulated fish catch, 'Eco-labelling and certification' programmes have become important measures of the seafood trade which ensure that the products have been harvested and managed sustainably (Lallemand et al. 2016; Tsantiris et al. 2018; Ramachandran and Parappurathu 2020). Some of the international certification programmes such as Marine Stewardship Council (MSC) recognise well-managed capture fisheries through regular structured assessments (Hilborn et al. 2015; Lallemand et al. 2016; Opitz et al. 2016; Parkes et al. 2016).

65.6 Conclusions

The marine fisheries sector in the bay islands is facing several snags like dearth of information on fish stock status, conflicts between artisanal and industrial fishing, illegal poaching, insufficient logistical support, etc. Moreover lack of infrastructure, skilled manpower has restricted the growth of industrial fishing in the Andaman and Nicobar Islands (Shiva Shankar et al. 2021). Till now, the fishing activities in these islands are largely restricted to coral reef-dependent narrow coastal belts, whilst the offshore and deep-sea areas have remained unexplored mostly due to the prevalence of non-mechanised forms of fishing operations and dearth of knowledge about the availability of more lucrative catches in deep-sea regions (EQMS 2018). With 30,000 tonnes of production, the present marine fish stock of the islands accounts for only 19% of the total available resource (Kaliyamoorthy et al. 2020). The intention of the present study was to demonstrate the impact of ocean warming and its effects on Andaman coral reefs and their associated fisheries from a suitable CNRM-CM5 model under the RCP scenario 4.5. Few significant results could be found from this study—SST projections under RCP 4.5 scenario of the above model showed a significant rising trend in 2030, 2050 and 2060s. Along with the rising SST trend, the future occurrences of bleaching phenomena could also be identified to have an increasing decadal trend for 2030, 2040 and 2050–60. The past bleaching phenomena and the 2016 one had a significant influence on the Andaman fish catch, especially the perch species. The 2016 catch per trip in North Bay recorded a significant reduction as compared to the earlier year, and this was in close conformity with Mohanty et al (2017) s' observations on the coral cover showing signs of bleaching due to elevated temperatures. Thus information related to climate projections and their probable impacts could be beneficial for proper adaptation planning. The most important strategy to adapt to such changes is to conduct fishing further away from the reefs and the coast and to search deeper.

Satellite-based fishing forecasts have been already proven to be advantageous with the notable increase in total fish catch in PFZs. Although the island fisheries are underutilised, it is also exhaustible like any other resources, and therefore, sustainable fishing practices should be adhered to as praxis. Also, any action plan or strategy in strengthening the fisheries sector should reckon with preserving the pristine condition of the islands as well as ensuring the promotion of sustainable tourism which is another key to the economic development of the islands.

EEZ around Andaman and Nicobar Islands has a rich diversity of fish resources, 3/4th of which is accounted by tunas. Having high demand in the international market and the island's proximity to the world's largest tuna markets like Singapore and Bangkok, any sort of development in the fisheries sector should prioritise the exploitation of otherwise untapped tuna resources which so far appeared to have escaped the impact of coral bleaching.

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References

Advani S, Sridhar A, Namboothri N et al (2013) Emergence and transformation of marine fisheries in the Andaman Islands. Dakshin Foundation and ANET, p 50

Akhiljith PJ, Liya VB, Rojith G et al (2019) Climatic projections of Indian Ocean during 2030, 2050, 2080 with implications on fisheries sector. J Coast Res 86:198–208

Anrose A, Sinha M, Kar A et al (2010) Diversity of Perch resources in Andaman and Nicobar waters. In: Raghunathan C, Sivaperuman C (eds) Ramakrishna. Recent trends in biodiversity of Andaman and Nicobar Islands, Zoological Survey of India, Kolkata, India, pp 343–359

Arora M, Chaudhury NR, Gujrati A et al (2019) Coral bleaching due to increased sea surface temperature in Gulf of Kachchh Region, India, during June 2016. Indian J Geo Mar Sci 48(3):327–332

Arur A, Krishnan P, George G (2014) The influence of mesoscale eddies on a commercial fishery in the coastal waters of the Andaman and Nicobar Islands, India. Int J Remote Sens 35(17):6418–6443

Bandopadhyay PC, Carter A (2017) Introduction to the geography and geomorphology of the Andaman-Nicobar Islands. Geol Soc Lond Mem 47(1):9–18

Bellwood DR, Hoey AS, Choat JH (2003) Limited functional redundancy in high diversity systems: resilience and ecosystem function on coral reefs. Ecol Lett 6(4):281–285

Brown BE, Phongsuwan N (2004) Constancy and change on shallow reefs around Laem Pan Wa, Phuket, Thailand over a twenty year period. Phuket Mar Biol Cent Res Bull 65:61–73

Brown BE, Dunne RP, Chansang H (1996) Coral bleaching relative to elevated seawater temperature in the Andaman Sea (Indian Ocean) over the last 50 years. Coral Reefs 15:151–152

Dam Roy S, George G (2010) Marine resources of islands: status and approaches for sustainable exploitation/conservation with special emphasis to Andaman and Nicobar. Indian J Anim Sci 80(4):57–62

Eakin CM, Lough JM, Heron SF (2009) Climate variability and change: monitoring data and evidence for increased coral bleaching stress. In: van Oppen MJH, Lough JM (eds) Coral bleaching, ecological studies, vol 205. Springer, Berlin, Heidelberg, pp 41–67. https://doi.org/10.1007/978-3-540-69775-6_4

EQMS (2018) Environmental assessment for Chennai-Andaman Nicobar Island submarine cable system, environmental impact assessment report. EQMS India Pvt. Ltd., Delhi

George G, Krishnan P, Sarma K et al (2011) Integrated potential fishing zone (IPFZ) forecasts: a promising information and communication technology tool for promotion of green fishing in the islands. Indian J Agri Econ 66(3):513–519

Gibson RN, Atkinson RJA, Gordon JDM (2007) Coral reefs of the Andaman Sea—an integrated perspective. Oceanogr Mar Biol Annu Rev 45:173–194

Gillet R (2014) Pacific perspectives on fisheries and sustainable development. United Nations Economic and Social Commission for Asia and the Pacific, Suva, Fiji Islands

Glynn PW, D'Croz L (1990) Experimental evidence for high temperature stress as the cause of El Niño coincident coral mortality. Coral Reefs 8:181–191. https://doi.org/10.1007/BF00265009

Gnanaseelan C, Roxy MK, Deshpande A (2017) Variability and trends of sea surface temperature and circulation in the Indian Ocean. In: Rajeevan M, Nayak S (eds) Observed climate variability and change over the Indian region. Springer Geology, Springer, Singapore, pp 165–179

Hamel MA, Andréfouët S (2010) Using very high resolution remote sensing for the management of coral reef fisheries: review and perspectives. Mar Pollut Bull 60(9):1397–1405

Hilborn R, Fulton EA, Green BS et al (2015) When is a fishery sustainable? Can J Fish Aquat Sci 72(9):1433–1441

Hoegh-Guldberg O (1999) Climate change coral bleaching and the future of the world's coral reefs. Mar Freshw Res 50(8):839–866

IPCC (2007) Climate change 2007: the physical science basis. In: Solomon S, Qin D, Manning M et al (eds) Contribution of working group I to the fourth assessment report of the intergovernmental panel on climate change. Cambridge University Press, Cambridge, United Kingdom and New York, p 996

IPCC (2013) Climate change 2013: the physical science basis. In: Stocker TF, Qin D, Plattner GK et al (eds) Contribution of working group I to the fifth assessment report of the intergovernmental panel on climate change. Cambridge University Press, Cambridge, United Kingdom and New York, USA, p 1535

IPCC (2014) Climate change 2014: synthesis report. In: Core Writing Team, Pachauri RK, Meyer LA (eds) Contribution of working groups I, II and III to the fifth assessment report of the intergovernmental panel on climate change, IPCC, Geneva, Switzerland, p 151

Kaliyamoorthy M, Roy SD, Sahu VK (2020) Analysis of ring operation from south Andaman fish landing centres (FLC). Flora Fauna 2(1):117–133

Krishnan P, Roy SD, George G et al (2011) Elevated sea surface temperature during May 2010 induces mass bleaching of corals in the Andaman. Curr Sci 100(1):111–117

Krishnan P, George G, Immanuel T et al (2013) Studies on the recovery of bleached corals in Andaman: fishes as indicators of reef health. In: Venkataraman K, Sivaperuman C, Raghunathan C (eds) Ecology and conservation of tropical marine faunal communities. Springer, Berlin, Heidelberg, pp 395–407

Lallemand P, Bergh M, Hansen M et al (2016) Estimating the economic benefits of MSC certification for the South African hake trawl fishery. Fish Res 182:98–115

Liu G, Strong AE, Skirving W (2003) Remote sensing of sea surface temperatures during 2002 barrier reef coral bleaching. EOS Trans Am Geophys Union 84(15):137–141

Liu G, Strong AE, Skirving W et al (2005) Overview of NOAA coral reef watch program's near real-time satellite global coral bleaching monitoring activities. In: Proceedings of 10th international coral reef symposium, Okinawa, Japan, 28 June–2 July 2004, pp 1783–1793

Lix JK, Venkatesan R, Grinson G et al (2016) Differential bleaching of corals based on El Niño type and intensity in the Andaman Sea southeast Bay of Bengal. Environ Monit Assess 188(3):175. https://doi.org/10.1007/s10661-016-5176-8

Majumdar SD, Hazra S, Giri S et al (2018) Threats to coral reef diversity of Andaman Islands, India: a review. Reg Stud Mar Sci 24:237–250

Marimuthu N, Wilson JJ, Vinithkumar NV et al (2013) Coral reef recovery status in South Andaman Islands after the bleaching event 2010. J Ocean Univ China 12(1):91–96

Mohanty PC, Venkateshwaran P, Mahendra RS et al (2017) Coral bleaching along Andaman coast due to thermal stress during summer months of 2016: a geospatial assessment. Am J Environ Prot 6(1):1–6

Mondal T, Raghunathan C, Venkataraman K (2014) Post bleaching assessment of corals in Andaman and Nicobar Islands. Proc Zool Soc 67(2):136–139

Moss RH, Edmonds JA, Hibbard KA et al (2010) The next generation of scenarios for climate change research and assessment. Nature 463(7282):747–756

Munday PL, Jones GP, Pratchett MS et al (2008) Climate change and the future for coral reef fishes. Fish Fish 9(3):261–285

NASA OBPG (2020) MODIS terra global level 3 mapped SST. Ver. 2019.0. PO.DAAC, CA, USA. https://doi.org/10.5067/MODST-1D4N9

NCEI (2016) Daily L4 optimally interpolated SST (OISST) in situ and AVHRR analysis. Ver. 2.0. PO. DAAC, CA, USA. https://doi.org/10.5067/GHAAO-4BC02. Accessed 20 May 2020

Opitz S, Hoffmann J, Quaas M et al (2016) Assessment of MSC-certified fish stocks in the Northeast Atlantic. Mar Policy 71:10–14

Parkes G, Swasey JH, Underwood FM et al (2016) The effect of catch share management on MSC certification. Fish Res 182:18–27

Parmesan C (2006) Ecological and evolutionary responses to recent climate change. Annu Rev Ecol Evol Syst 37:637–669

Pillai NGK, Abdussamad EM (2009) Development of tuna fisheries in Andaman and Nicobar Islands. In: Dam Roy S, Krishnan P, Sarma K et al (eds) Proceedings of brainstorming session on

development of island fisheries, ICAR-Central Island Agricultural Research Institute, Port Blair, pp 23–34
Potts T, Haward M (2007) International trade, eco-labelling, and sustainable fisheries–recent issues, concepts and practices. Environ Develop Sustain 9(1):91–106
Pratchett MS, Munday PL, Wilson SK et al (2008) Effects of climate-induced coral bleaching on coral-reef fishes-ecological and economic consequences. Oceanogr Mar Biol 46:251–296
Rajan PT, Roy TC, Sreeraj CR (2012) The contribution of coral reef fishes to andaman fisheries production: grouper fishery and its monitoring and implications for management. In: Raghunatha C, Sivaperuman C, Venkataraman K (eds) Recent advances in biodiversity of India. Zoological Survey of India, Kolkata, India, pp 285–295
Rajan PT, Sreeraj CR, Immanuel TITUS (2013) Fishes of Andaman and Nicobar Islands: a checklist. J Andaman Sci Assoc 18(1):47–87
Ramachandran C, Parappurathu S (2020) Who should certify the sustainability of our fisheries? a property rights perspective on ecolabelling. Curr Sci 118(10):1496–1499
Ravindran J, Raghukumar C, Raghukumar S (1999) Disease and stress-induced mortality of corals in Indian reefs and observations on bleaching of corals in the Andamans. Curr Sci 76(2):233–237
Reynolds RW, Smith TM, Liu C et al (2007) Daily high-resolution blended analyses for sea surface temperature. J Clim 20:5473–5496
Roxy MK, Ritika K, Terray P et al (2014) The curious case of Indian Ocean warming. J Clim 27(22):8501–8509
Sarkar S, Ghosh AK (2013) Coral bleaching a nemesis for the Andaman reefs: building an improved conservation paradigm. Ocean Coast Manag 71:153–162
Shiva Shankar Y, Kumar A, Mohan D (2021) Climate change and water resources: emerging challenges, vulnerability and adaptation in Indian scenario. In: Singh VP, Singh V (eds) Jha R. Climate change impacts on water resources, Springer International Publishing, pp 365–376
Skirving W, Liu G, Strong A et al (2006) Extreme events and perturbations of coastal ecosystems. In: Richardson L, LeDrew E (eds) Remote sensing of aquatic coastal ecosystem processes. Remote sensing and digital image processing, vol 9. Springer, Dordrecht
Spalding M, Spalding MD, Ravilious C et al (2001) World atlas of coral reefs. University of California Press, Berkeley, USA
Srivastava RC (2012) Ecological threats to an islands ecosystem due to climate change: the Andaman experience. Proc Natl Acad Sci India Sect B Biol Sci 82(2):335–340
Takar S, Gurjar UR (2020) Minimum legal size: a tool for sustainable fisheries management. Biotica Res Today 2(7):658–660
Tsantiris K, Zheng L, Chomo V (2018) Seafood certification and developing countries: focus on Asia. FAO fisheries and aquaculture circular No 1157, FAO, Rome, p 45
Tun K, Chou LM, Low J et al (2010) A regional overview on the 2010 coral bleaching event in southeast Asia. In: Status of coral reefs in east Asian seas region, Ministry of Environment, Tokya, Japan, pp 9–28
Velmurugan A, Subramani T, Swarnam TP et al (2018) Climate of Andaman and Nicobar Islands: long-term pattern analysis. J Andaman Sci Assoc 23(1):1–7
Vivekanandan E (2011) Marine fisheries policy brief—3: climate change and Indian marine fisheries. CMFRI Spec Publ 105:1–97
Vivekanandan E, Pandian TJ (1977) Surfacing activity and food utilisation in a tropical air-breathing fish exposed to different temperatures. Hydrobiologia 54(2):145–160
Webster PJ, Moore AM, Loschnigg JP et al (1999) Coupled ocean-atmosphere dynamics in the Indian Ocean during 1997–1998. Nature 401:356–360
Werdell PJ, Franz BA, Bailey SW et al (2013) Generalized ocean color inversion model for retrieving marine inherent optical properties. Appl Opt 52:2019–2037
Wilson SK, Graham NA, Pratchett MS et al (2006) Multiple disturbances and the global degradation of coral reefs: are reef fishes at risk or resilient? Glob Change Biol 12(11):2220–2234
Wilson SK, Fisher R, Pratchett MS et al (2008) Exploitation and habitat degradation as agents of change within coral reef fish communities. Glob Change Biol 14(12):2796–2809

Yoo SH, Yang S, Ho CH (2006) Variability of the Indian Ocean sea surface temperature and its impacts on Asian Australian monsoon climate. J Geophys Res 111:D03108. https://doi.org/10.1029/2005JD006001

Zacharia PU, Gopalakrishnan A, Grinson G et al (2016). Climate change impact on coastal fisheries and aquaculture in the SAARC region: country paper—India. Paper presented at SAARC agriculture centre video conference on climate change impact on coastal fisheries and aquaculture, 20 Dec 2016

Chapter 66
The Challenge of Climate Change in Agriculture Management in the Persian Gulf-Oman Sea Coasts in Iran

Zahra Noorisameleh and William A. Gough

Abstract Agriculture is a major part of Iran's economy that will face different threats and opportunities and threats from future climate change. Changing rainfall and temperature patterns challenge long-term agricultural management and planning. In this study, the effect of climate change on agricultural management on the coasts of the Persian Gulf and the Makran (Oman Sea) has been investigated. For this purpose, precipitation and temperature parameters of 30 synoptic stations under RCP scenarios (2.6, 4.5, and 8.5) have been simulated with the SDSM tool. The results show that the probability of increase and decrease of temperature and precipitation, respectively, in Persian Gulf stations is higher than that of the Makran coast. The southern coasts of Iran have the longest growing season in the country due to their unique geographical and climatic characteristics. Also, in the northwest of the Persian Gulf, where agricultural production is especially important, under RCPs 2.6, 4.5, and 8.5, the maximum temperature shows a further increase in the future. However, increasing maximum temperature could decrease crop diversity and threaten plants with lower temperature thresholds in the Persian Gulf coast. Also, in the east of the Makran coast, the temperature will increase significantly for RCP 8.5. Generally, agricultural management and the effects of climate change in the Persian Gulf coastal require the application of mitigation/adaptation plans.

Keywords Agricultural management · Growing season · Climate change · Persian Gulf · Oman Sea

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66.1 Introduction

One of the main factors in sustainable development is food security, which is dependent on other indicators such as water, agriculture, and human resources (Sidibé et al. 2018). According to forecasts for developing countries, with increasing urbanization and social changes, hunger and reduced food security will be inevitable in the coming decades (Abu Hatab et al. 2019). Food, water security (Bacon et al. 2021), agricultural livelihoods (Bouroncle et al. 2019), and land use (Tahmasebi et al. 2020) change will be more vulnerable under climate change. Adaptation and management in agricultural planning are important to controlling climate change effects (Vermeulen et al. 2012).

Extreme events in inland and coastal flooding affect agricultural production and food security (IPCC 2019). Also, the expansion of soil salinity due to climate change with the reduction of available agricultural lands poses a serious challenge to food security (Mukhopadhyay et al. 2021). Iran's agriculture-scarce Iranian agriculture is very vulnerable to climate change due to water shortages and frequent droughts (Karimi et al. 2018).

The coastline area of the Persian Gulf and the Makran in the south of Iran is around 5000 km (Dibajnia et al. 2012). Persian Gulf coast has three main economic approaches that include communications and maritime transport, oil and gas activities, and fisheries industry. Also, The Makran is the best coast of Iran for economic development due to its geographical location, water deep, multiple estuaries, proximity to major Asian ports and international trade and fisheries industry, etc. (ICZM 2014). One part of the important agricultural needs of Iran in the cold season is produced in the Persian Gulf and the Makran coastline. The northwest coast of the Persian Gulf as the agricultural hub of Iran with an annual production of 17 million tons of crops had the highest production of wheat and rapeseed in Iran in 2020 (IRNA 2021). In Makran coasts, 22,000 ha of agricultural land are exploited, which play an important role in the production of tropical fruits (ISNA 2018). According to reports, the production of tropical and subtropical fruits in southern Iran reaches 165,000 tons (HAJO 2021).

Agriculture is a major part of Iran's economy that will face different threats and opportunities and threats from future climate change (FAO 2017(. Changing rainfall and temperature patterns challenge long-term agricultural management and planning (IPCC 2019). The climate determines the type of agricultural products that can be cultivated in the region (Baker and Capel 2011).

Important factors for defining the growing season are the temperature and humidity (precipitation) that will be affected by climate change (Gornall et al. 2010). Low latitude and consequently high temperatures compared to northern Iran and access to southern sea moisture have increased the growing season in these areas. The Persian Gulf and the Makran coastlines have the maximum length of the growing season in the whole country (365 days) (Sari Sarraf et al. 2018).

In this study, precipitation and temperature of historical periods (1980–2018) and future (2030–2080) under climate change scenarios have been studied to investigate their impact on agricultural activities in the coastal areas of southern Iran.

66.2 Methodology

The Persian Gulf and the Oman Sea are located in south Iran and the north Indian Ocean. The Persian Gulf with an average depth of 35 m and 240,000 km^2 area is located in the southwest of Iran (Akhbarizadeh et al. 2021). Due to the location of the Persian Gulf in subtropical, high temperatures and humidity and low precipitation are climatic characteristics of the region (NaderiBeni et al. 2021). The maximum depth of the Oman Sea is 200 m, and its climate is defined by its low latitude with high temperature and low rainfall under the monsoon phenomenon (Layeghi et al. 2019). Precipitation and temperature parameters of 30 synoptic stations (Fig. 66.1) under RCP scenarios (2.6, 4.5, and 8.5) have been simulated with the SDSM tool.

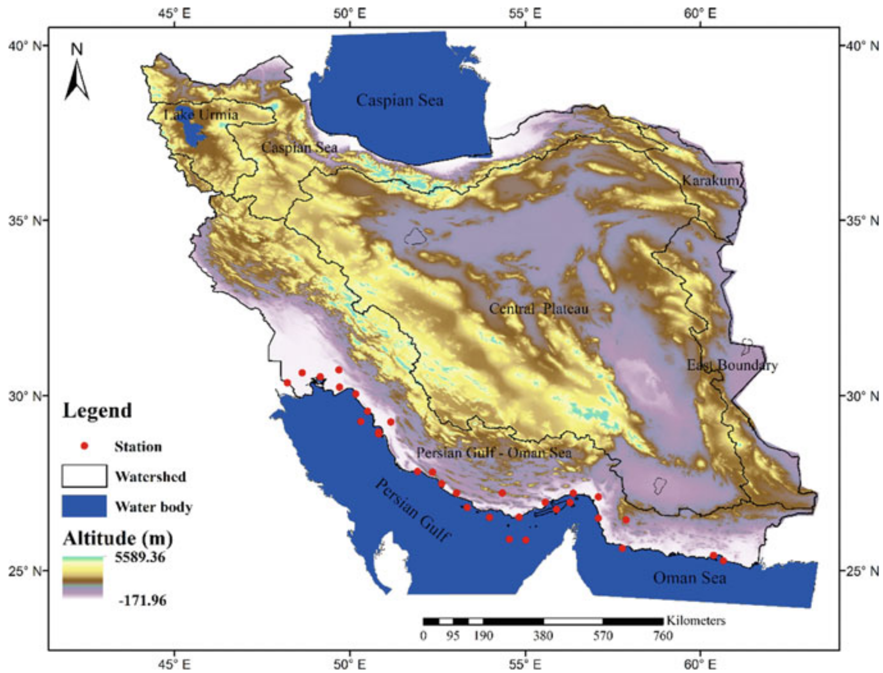

Fig. 66.1 Geographical location and distribution of stations in the study area

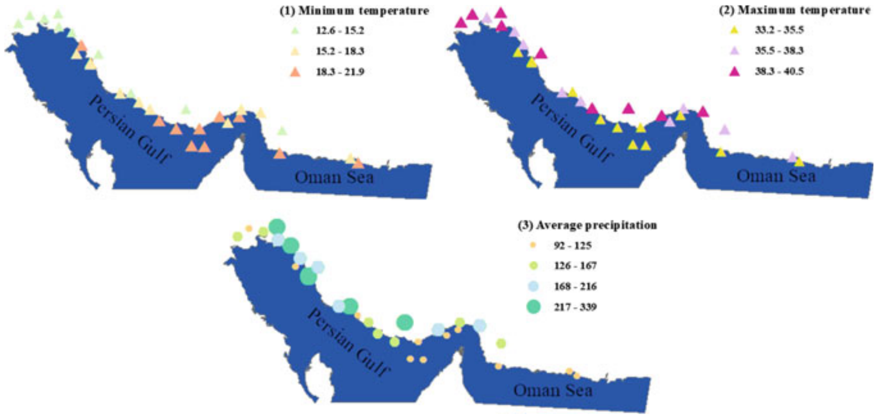

Fig. 66.2 Long-term average temperature (1 and 2) and precipitation (3) in the study area (1980–2018)

66.3 Results

According to Fig. 66.2, despite the small area, precipitation, and temperature have high variability in the study basin. Maximum rainfall and temperature are observed in the Persian Gulf coast, which has more variability than the Makran coast. The average minimum temperature on the southern coast of Iran is 17.1, and the average maximum temperature is 36.8°. The maximum temperature is observed in the northwest of the Persian Gulf. The average rainfall on these beaches is 171 mm, which is one of the dry but humid regions in Iran. The results showed that there will be no significant rainfall changes in the Makran coast, but in the Persian Gulf coastline, the maximum increase in temperature and decrease in precipitation in the northwest is more probable under all three scenarios. The number of stations whose precipitation decreases under climate change will decrease in Scenario 8.5, but the temperature will increase further (Fig. 66.3). These changes decrease from the northwest to the southeast coast of the Persian Gulf. Although in the southern coastline of Iran, the length of the growing season equals the whole year, the temperature thresholds of crops are threatened. Also, due to the salinity of the Persian Gulf and Oman Sea, rainfall plays the most important role in agriculture, and water stress may increase.

66.4 Conclusions

The purpose of this study is to provide an overview of the historical and future situation of the southern coastal climate of Iran, which can be important in the agricultural sector. The results show that the probability of increase and decrease of temperature and precipitation, respectively, in Persian Gulf stations is higher than that

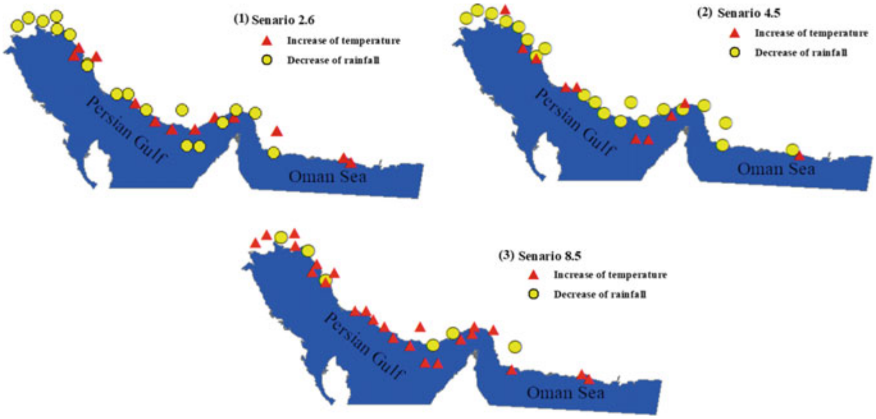

Fig. 66.3 Geographical distribution of precipitation and temperature changes based on RCP scenarios (2030–2080)

of the Makran coast. The southern coasts of Iran have the longest growing season in the country due to their unique geographical and climatic characteristics. Also, in the northwest of the Persian Gulf, where agricultural production is especially important, under RCPs 2.6, 4.5, and 8.5, the maximum temperature shows a further increase in the future. However, increasing maximum temperature could decrease crop diversity and threaten plants with lower temperature thresholds in the Persian Gulf coast. Also, in the east of the Makran coast, the temperature will increase significantly for RCP 8.5. Climate-based agriculture according to water resource limitation (tropical and halophyte crops) and high-tech and adaptable agriculture under climate change are important solutions to this industry development in the southern coasts of Iran (PBOI 2019). Intensification drought under climate change (Rezapour et al. 2013) may challenge the development of agriculture in coastal areas of Iran. Also, stronger storms due to increasing sea surface temperature (SST) under climate change in the Persian Gulf and the Makran coasts (NCCOI 2017) cause more damage to agricultural products. Generally, agricultural management and the effects of climate change in the Persian Gulf coastal require the application of mitigation/adaptation plans.

References

Abu Hatab A, Cavinato MER, Lindemer A et al (2019) Urban sprawl, food security and agricultural systems in developing countries: a systematic review of the literature. Cities 94:129–142. https://doi.org/10.1016/j.cities.2019.06.001

Akhbarizadeh R, Russo G, Rossi S et al (2021) Emerging endocrine disruptors in two edible fish from the Persian Gulf: occurrence, congener profile, and human health risk assessment. Mar Pollut Bull 166 https://doi.org/10.1016/j.marpolbul.2021.112241

Bacon CM, Sundstrom WA, Stewart IT et al (2021) Towards smallholder food and water security: climate variability in the context of multiple livelihood hazards in Nicaragua. World Dev 143. https://doi.org/10.1016/j.worlddev.2021.105468

Baker NT, Capel PD (2011) Environmental factors that influence the location of crop agriculture in the conterminous United States. U.S. Geological Survey Scientific Investigations Report 2011–5108, p 72

Bouroncle C, Müller A, Giraldo D et al (2019) A systematic approach to assess climate information products applied to agriculture and food security in Guatemala and Colombia. Clim Serv 16. https://doi.org/10.1016/j.cliser.2019.100137

Dibajnia M, Soltanpour M, Vafai F et al (2012) A shoreline management plan for Iranian coastlines. Ocean Coast Manag 63:1–15. https://doi.org/10.1016/j.ocecoaman.2012.02.012

FAO (Food and Agriculture Organization) (2017) The future of food and agriculture—trends and challenges. Italy, Rome

Gornall J, Betts R, Burke E et al (2010) Implications of climate change for agricultural productivity in the early twenty-first century. Phil Trans R Soc Lond. Ser B, Biol Sci 365(1554):2973–2989. https://doi.org/10.1098/rstb.2010.0158

HAJO (Hormozgan Agricultural Jahad Organization) (2021) Production of 165 thousand tons of tropical fruits in the country. https://hormozgan-agri-jahad.com/news/5328

ICZM (Integrated Coastal Zone Management of Iran) (2014) Iran Ministry of Roads & Urban Development: Ports and Maritime Organization, p 48

IPCC (2019) Summary for policymakers. In: Shukla PR, Skea J, Calvo Buendia E et al (eds) Climate change and land: an IPCC report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems. https://www.ipcc.ch/site/assets/uploads/sites/4/2020/02/SPM_Updated-Jan20.pdf

IRNA (Islamic Republic News Agency) (2021) Khuzestan stood in the first place in the country in the production of wheat and rapeseed. https://www.irna.ir/news/84347500

ISNA (Iranian Students News Agency) (2018) Production of more than 29,000 tons of tropical fruits in Chabahar. https://www.isna.ir/news/97021005650

Karimi V, Karami E, Keshavarz M (2018) Climate change and agriculture: impacts and adaptive responses in Iran. J Integr Agric 17(1):1–15. https://doi.org/10.1016/S2095-3119(17)61794-5

Layeghi B, Bidokhti AA, Ghader S et al (2019) Numerical simulation of oceanic and marine meteorological characteristics of Persian Gulf and Oman Sea using coupled model WRF and ROMS. Nivar 43(106–107):50–53. https://doi.org/10.30467/nivar.2019.91474

Mukhopadhyay R, Sarkar B, Jat HS et al 2021 Soil salinity under climate change: challenges for sustainable agriculture and food security. J Environ Manage 280:111736. https://doi.org/10.1016/j.jenvman.2020.111736

NaderiBeni A, Marriner N, Sharifi A et al (2021) Climate change: a driver of future conflicts in the Persian Gulf Region? Heliyon 7(2). https://doi.org/10.1016/j.heliyon.2021.e06288

NCCOI (National Climate Change Office of Iran) (2017) Third national communication to UNFCCC. National Climate Change Office of Iran. https://unfccc.int

PBOI (Plan and Budget Organizationof Iran) (2019) Makran coastal zone development document. Supreme Council of Land Management. https://www.mporg.ir

Rezapour F, Bakhtiari B, Ghaderi K (2013) Investigating the characteristics of severity, duration and frequency of agricultural drought in the southern coasts of Iran and the effects of climate change on it. The 2nd International Conference on Plant, Water, Soil and Weather Modeling. Kerman-Iran. https://en.civilica.com/doc/209786

Sari Sarraf B, Khorshiddost AM, PeymanMahmoudi P et al (2018) Impacts of climate change on the growing season in the Iran. Ital J Agrometeorol 23(3):15–30. https://doi.org/10.19199/2018.3.2038-5625.015

Sidibé A, Totin E, Thompson-Hall M et al (2018) Multi-scale governance in agriculture systems: interplay between national and local institutions around the production dimension of food security in Mali. NJAS Wagening J Life Sci 84:94–102. https://doi.org/10.1016/j.njas.2017.09.001

Tahmasebi T, Karami E, Keshavarz M (2020) Agricultural land use change under climate variability and change: drivers and impacts. J Arid Environ 180. https://doi.org/10.1016/j.jaridenv.2020.104202

Vermeulen SJ, Aggarwal PK, Ainslie A et al (2012) Options for support to agriculture and food security under climate change. Environ Sci Policy 15(1):136–144. https://doi.org/10.1016/j.envsci.2011.09.003

Chapter 67
Groundwater Modelling for Sustainable Management of Coastal Aquifers in the Context of Climate Change

S. P. Rajaveni, Indu S. Nair, and L. Elango

Abstract Climate change and the increase of agricultural production affects coastal aquifers around the world. Groundwater is the major source of irrigation in most of the coastal parts of India. Seawater intrusion is affecting the area just north of Chennai city as a result of over-extraction of groundwater for agricultural and drinking water supply to Chennai city. The objective of this study is to evaluate the impact of climate change for identifying measures for sustainable management of groundwater resources in the coastal aquifer by groundwater modelling. A density-dependent model was used to forecast changes in hydrological stresses at the groundwater head. The study indicates that 10% increase in rainfall recharge with additional new check dams and 1 m increase in crest level of all the existing check dam's scenario raised the groundwater head by about 3 m in the upper and 5.5 m in the lower aquifers. Thus, the construction of managed aquifer recharge structures can reduce the chloride concentration and restore this seawater intruded aquifer. Thus, the groundwater modelling tool was used to identify measures to manage the coastal groundwater resources in an intensively cultivated region.

Keywords Coastal aquifer · Climate change · Managed aquifer recharge · Density-dependent · Sustainable management

67.1 Introduction

Groundwater has long been considered the most significant source of fresh water for drinking and irrigation in the north Chennai coastal aquifer. Agriculture is the

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chief occupation of this study region. The major crops grown in this area are rice, ragi, green gram, black gram, sugar cane, groundnut, and horticultural crops like mango, guava, and vegetables are also cultivated. Around 47% of the total workforce is engaged in the agricultural sector (District Agriculture Plan 2008). The shallow and deep alluvial aquifers along Arani and Korattalaiyar rivers serve as an important source of drinking water for the Chennai Metropolitan area, and five well fields have been constructed for this purpose. The wells from each well field has been pumping different quantities of water such as Poondi—18 MLD (million litres per day), Tamaraipakkam—44 MLD, Flood plains—3 MLD, Kannigaipar—5 MLD, Panjetty—17 MLD, and Minjur—3 MLD. A total of 100 MLD of water is continuously being pumped from each well field (CGWB 2007). In addition to well fields, CMWSSB (Chennai Metropolitan Water Supply and Sewerage Board) has hired private agricultural wells since 2000 to augment Chennai water supplies. Based on such sources, the average yield was 77 MLD (CMWSSB) during the year 2005. The yield of dug wells range from 50–200 m^3 day^{-1} in weathered crystalline rocks, 20–100 m^3 day^{-1} in Gondwana formations, and up to 400 m^3 day^{-1} in recent alluvial formations along with major drainage courses (CGWB 2007). Since 1984, seawater has been intruding to this aquifer for about 3 km (CGWB 2007) due to its continuous over-extraction of groundwater for Chennai water supply and agricultural activities. According to research conducted by Indu et al. (2013), seawater intruded up to a distance of 8 km in this aquifer during 2011.

The groundwater models are the good management tool used to understand past and present condition of the aquifer system and used to predict the future reaction of the seawater intrusion under different scenarios of natural forcing and human interactions (Kourgialas et al. 2016). Seawater intrusion has become one of the principal causes of groundwater quality deterioration in coastal aquifers stressed by urban growth and anthropogenic activities (Hugman et al. 2015; Gopinath et al. 2018). Finite element-based software of FEFLOW is a powerful, comprehensive tool to simulate complex subsurface processes (Yang and Radulescu 2006). Therefore, this research used the groundwater modelling as a tool to assess the effects of climate change in order to define strategies for sustainable management of groundwater resources in the coastal aquifer.

67.2 Study Area Description

This aquifer basin is situated 45 kms north of Chennai, between the geographical coordinates of 79° 15′ 0″ E and 80º19′ 0″ E longitude and 12° 50′ 0″–13° 30′ 0″ N latitude. This area seems to have a maximum temperature ranging from 32 °C to 44 °C during summer (April to June) and minimum temperature ranges from 23 °C to 30 °C during winter (December to January). The annual average rainfall is about 1200 mm, with 35% falling during the southwest monsoon (July–September) and 60% falling during the northeast monsoon (October–December).

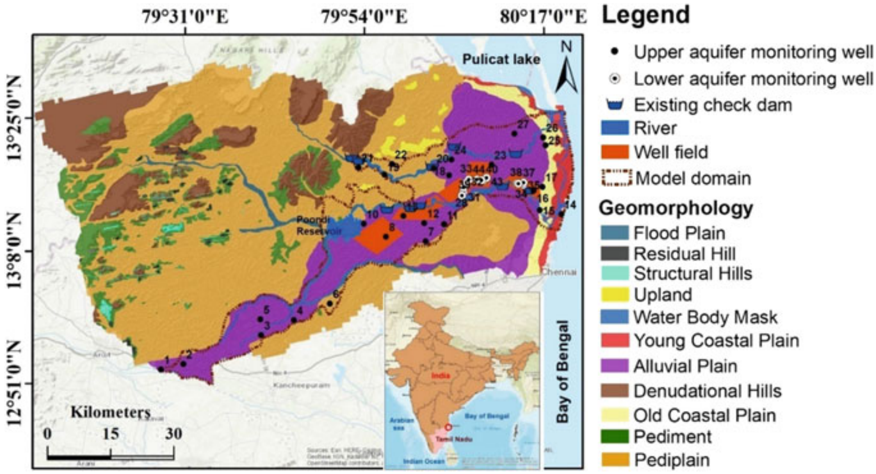

Fig. 67.1 Location of the Arani-Korttalaiyar (A-K) river basin

The type of geomorphologic features identified in this area is an alluvial plain, pediplain, paleochannels, coastal plain, waterbody, flood plain, denudational hills, pediments, residual hill, structural hill, and upland (Fig. 67.1). During the period of quaternary, the marine regression and displacement of the major watercourse was identified through the morpho-structural study (UNDP 1987). Due to the subsequent sedimentation, the old river course of Palar is buried in this area. Paleo and buried channels were identified and mapped from LISS-III imagery based on tonal difference. This paleo and buried channels are yielding a large quantity of groundwater (Suganthi et al. 2013). Six well fields are constructed in this buried paleo channel of Palar river. The area considered for the groundwater modelling was delineated based on the geomorphology, geology, and hydrogeological conditions. That is, the potential aquifer zones with a thickness of greater than 10 m were delineated to carry out groundwater modelling.

67.3 Hydrological Characterization

The analysis and interpretation of borehole logs collected from CMWSSB and private drilling companies were used to characterize the aquifer system in this region. The thickness of the alluvium is generally less than 50 m, and all the lithologs collected from the CMWSSB penetrate only up to the tertiary clay. Fine to coarse sand, sand with gravels and pebbles, sandy clay, and some small patches of clay that occur as lenses make up this aquifer (Fig. 67.2). Clay exists as thin lenses and is mostly deposited in fluvial and marine environments. The impermeable layer and the bottom of this aquifer system are formed by tertiary clay and shale formations. A long and

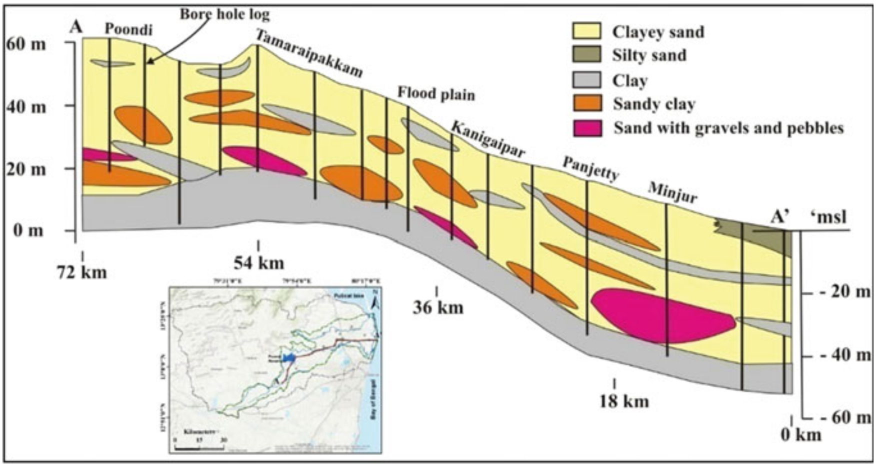

Fig. 67.2 West to east subsurface geological cross section along A-A'

thin clay formation is present up to a distance of about 30 km from the coast. Up to a distance of around 30 km from the shore, the groundwater head measured in two different shallow and deep wells situated very close to each other was different, indicating the existence of two aquifers. The same groundwater head was observed in the wells beyond 30 kms from the coast. Up to 30 kms from the coast, a two-aquifer system consisting of unconfined and semi-confined aquifers was identified; beyond this distance, the two aquifers combine and become a single aquifer.

67.4 Materials and Methods

67.4.1 Model Description

Three-dimensional variable density groundwater flow simulation in an anisotropic and heterogeneous porous media was carried out by Finite Element subsurface FLOW (FEFLOW) version 6.2. The model area of 1456 km^2 was divided into finite element mesh consisting of around 1.5 million triangular finite element cells. The area of interest is divided into various irregular triangular-shaped elements. This complex two aquifer system was vertically discretized into nine layers considering the lithological variations observed in the area. For a distance of about 30 km from the coast, the layers 1 and 2 represent the upper aquifer, layers 3 and 4 represent semi-confining layer (aquitard), and layers from 5 to 8 represent the lower semi-confined aquifer. Beyond 30 km from the coast, the layers from 1 to 8 represent the single unconfined aquifer. Layer 9 represents the bottom of the aquifer which is impermeable. The eastern portion of the mesh was discretized into much smaller cells in size ranging from 200 to 800 m^2 in order to account for the density difference in groundwater along the coast. Further, a total of 13 layers were considered to precisely evaluate depth-wise variation in the density of groundwater.

67.4.2 Boundary, Initial Conditions, Groundwater Source and Sink

The Bay of Bengal is situated on the eastern side of the study area, which is considered a constant head boundary. Northern and southern boundaries were fixed based on the watershed, hence which is taken as the no-flow boundary (Fig. 67.3a). The Palar River flows on the southwest side; it was identified as the variable head boundary. The time-dependent groundwater head in this boundary was calculated using the groundwater head measured in the wells on either side of the boundary. River head boundaries were assigned to the Arani and Korttalaiyar rivers. The chloride concentration in river water was determined as 1500 mg L^{-1}. The eastern boundary was assigned as the chloride concentration in seawater of 19,500 mg L^{-1}. The average chloride concentration in groundwater near the Palar river in the southwestern area is about 300 mg L^{-1}, and this value was applied to the variable boundary. The groundwater recharge was given a percentage range from 10 to 20 based on previous studies and GEC (1997) norms (Fig. 67.3b). A return flow from an agricultural region recharges the groundwater. Nearly, 39% of irrigation water returns to this aquifer (Charalambous and Garratt 2009; Anuthaman 2009). As a result, irrigation return flow accounted for 39% of pumped water. Based on analysis of groundwater head and seawater intrusion from the year 1990 to 2010, it was noticed that in January 1996 the region experienced very less seawater intrusion and the groundwater head measured in both the aquifers was zero m msl at the coast. Hence, the groundwater head measured during January 1996 was used as an initial head (Fig. 67.4).

Water requirements for different crop types and aquaculture were obtained from the TNAU (2004). This crop water requirement was used to calculate the monthly

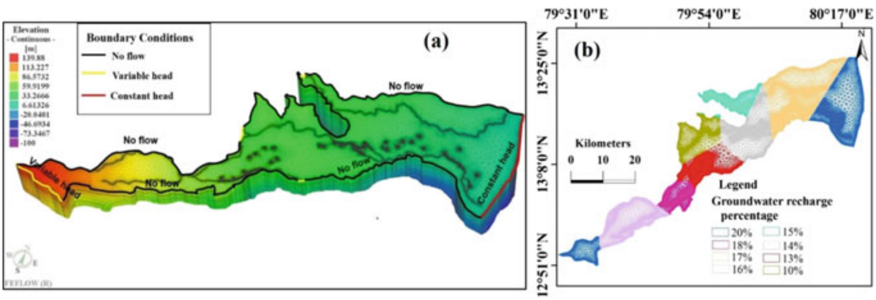

Fig. 67.3 **a** Boundary conditions along the study area, and **b** Percentage of rainfall recharge used for the groundwater modelling

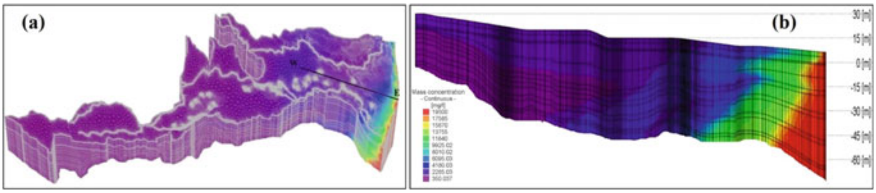

Fig. 67.4 **a** Discretization of the solute transport model and **b** Initial chloride concentration in the vertical profile from Kannigaipper well field to the coast

volume of groundwater pumping. Based on this process, the total irrigation pumping in the area is estimated to be about 480 Mm^3 $year^{-1}$. Groundwater pumping for domestic use was estimated a 3.79 Mm^3 $year^{-1}$ based on per capita demand. The actual rates of groundwater pumping from the wellfield wells were obtained from CMWSSB, which is about 120 MLD (from 15 years' average).

67.4.3 Aquifer Parameters and Solute Transport Parameters

The hydraulic conductivity values from the twenty pumping tests were extrapolated to the area around them by the Thiessen polygon method. Thiessen polygon is a preferred method over contouring due to the shortage of data points. Initial values for hydraulic conductivity (K_x, K_y, K_z), specific storage (S_s), and porosity (N) of the different hydrogeological units used in the model are listed in Table 67.1. Longitudinal dispersivity, transverse dispersivity, and coefficient of molecular diffusion were considered as 66.6 m, 6.6 m, and 1 x 10^{-6} m^2 s^{-1} respectively as reported by Sherif

Table 67.1 Initial values of hydraulic conductivities (K_x, K_y, K_Z), specific storage (S_S), and porosity (N) for the different hydrogeological units used in the model

Units	Description	Range of values			
		K_x (m day^{-1})	K_y (m day^{-1})	K_z (m day^{-1})	Sy
Upper aquifer	Sandstone with calcareous gritstone, clayey sand, laterite, beach sand, sand and silt	35–100	35–100	3.5–10	0.025–0.33
Aquitard	Clay	0.001–0.005	0.001–0.005	0.0001–0.0005	0.1
Lower aquifer	Coarse sand, coarse gravel, medium gravel, sand and gravel, sand and silt	100–250	100–250	10–25	0.2

and Singh (1999). To represent density difference, the density ratio was calculated by using the density of freshwater and seawater as 1000 kg m^{-3} and 1025 kg m^{-3}, respectively.

67.5 Results and Discussion

67.5.1 Model Calibration and Simulation

The flow model calibration was conducted in two stages. The first stage involved calibrating the flow model under steady-state conditions. After obtaining the data, the model output was assessed visually using a scatter plot graph between observed and simulated head values. The presence of error in the model was identified by searching for an adjustment close to the 1:1 axis. The multiple runs were carried out to achieve the best possible match between the observed and simulated groundwater head. Then, the regression value of 0.99 and 0.90 was obtained between the observed and simulated head for the upper and lower aquifers. Following that, transient state calibration was performed using automated time steps with an initial time step of 0.001 days for the period January 1996 to December 2003. Spatial variation of observed and simulated groundwater heads in upper and lower aquifers is shown in Fig. 67.5. The post- and pre-monsoon months of January and June groundwater head were taken to verify the real aquifer system which was conceptualized in FEFLOW. It shows the reasonable match between the observed and simulated head indicating the accuracy and predictive capacity of this model.

After calibrating the groundwater model, the chloride concentration was simulated. The density-dependent model was calibrated by adjusting the longitudinal and transverse dispersivity values and subsequently obtained values are 70 and 7 m. Several simulations were made and finally a reasonable match were obtained between the observed and the simulated values with a regression value of 0.731. Spatial variation of observed and simulated chloride concentration in upper and lower aquifers is shown in Fig. 67.6. After the successful calibration of the solute transport model, the predictive capability of the density-dependent model was verified by validation. The groundwater samples collected from different wells in the upper and lower aquifers from the year 2011 to 2013 were analysed, which was used for the validation of the solute transport model.

67.5.2 Future Scenarios for Sustainable Management of Coastal Aquifers

The main goal of this study is to look at how the groundwater head and chloride concentration in the north Chennai coastal aquifer react to climate change and

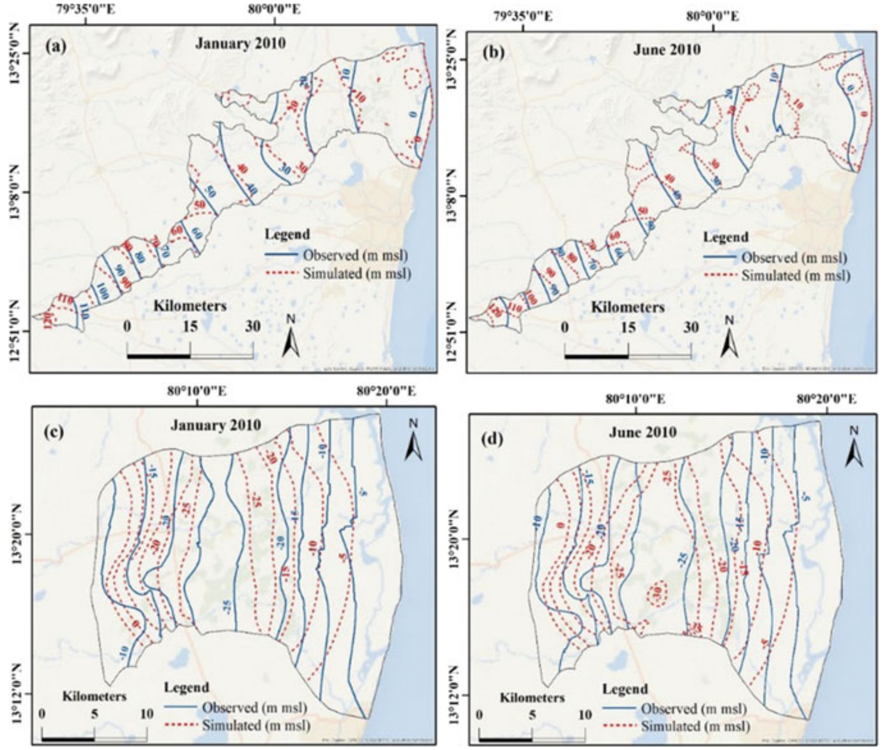

Fig. 67.5 Spatial distribution of observed and simulated groundwater head in the upper aquifer. **a** January 2010, **b** June 2010 and in the lower aquifer, **c** January 2010, **d** June 2010

recharge structures. As per INCCA (2010) report, the projected climate change represents the increase of rainfall by 10–40% in the northern parts of Tamil Nadu (where the study area is located). The various Managed Aquifer Recharge (MAR) options possible in this area are the construction of additional check dams and raising the crest level of the existing check dam. Therefore, in order to forecast the effects of projected changes in rainfall recharge and MAR on this coastal aquifer, a density-dependent groundwater model was simulated. The various scenarios were predicted from the year 2021 to 2030. The 50-year monthly average rainfall was used to estimate groundwater recharge during these predictive runs. The scenarios considered are

- Scenario 1: 10% increase in rainfall recharge
- Scenario 2: 10% increase in rainfall recharge with an additional check dams
- Scenario 3: 10% increase in rainfall recharge with an additional check dams and 1 m increase in crest level of all the existing check dams.

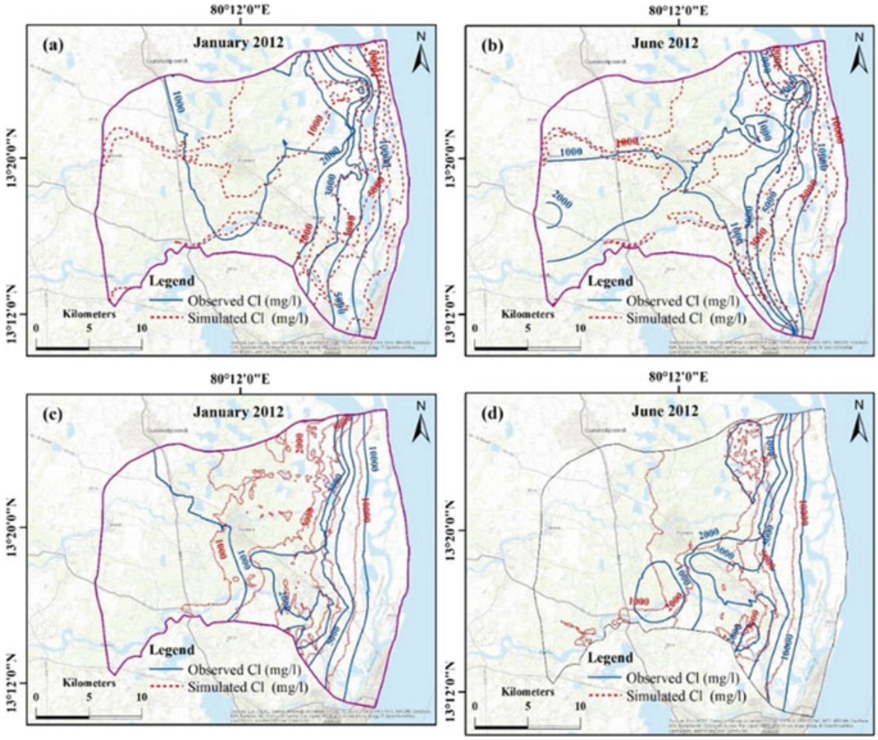

Fig. 67.6 Spatial distribution of observed and simulated chloride concentration in the upper aquifer. **a** January 2012, **b** June 2012 and in the lower aquifer, **c** January 2012, **d** June 2012

When comparing predicted 2030 results for scenario 1 to current conditions (2021), it was noticed that the projected change in rainfall recharge has a significant impact on the groundwater head both in summer and winter periods. In the upper aquifers, the groundwater head rises by around 1–2 m, and in the lower aquifers, it rises by 3.5–4 m (Fig. 67.7a, b). Because the groundwater is leaching into lower aquifer through the semi-confining layer, scenario 1 has a greater effect on the lower aquifer than the upper aquifer. By scenario 2, the groundwater head in the upper aquifer is expected to increase by around 1.5–2.5 m. Scenario 2 increases the projected groundwater head by around 4.3 m in the lower aquifer. Scenario 2 almost increases same quantity of groundwater in both the aquifers. In the upper and lower aquifers, the groundwater head has risen by around 3 m and 5.5 m, respectively, when implementing scenario 3. Scenario 3 indicating the enhancement of hydraulic communication (discharge of fresh groundwater) between this coastal aquifer and Bay of Bengal in the upper and lower aquifers. It is evident that increasing the groundwater head that discharges into the sea reduces the saltwater front.

The predicted chloride concentration for three different scenarios in the wells located in the upper and lower aquifers is shown in Fig. 67.7c, d. By scenario 1, the

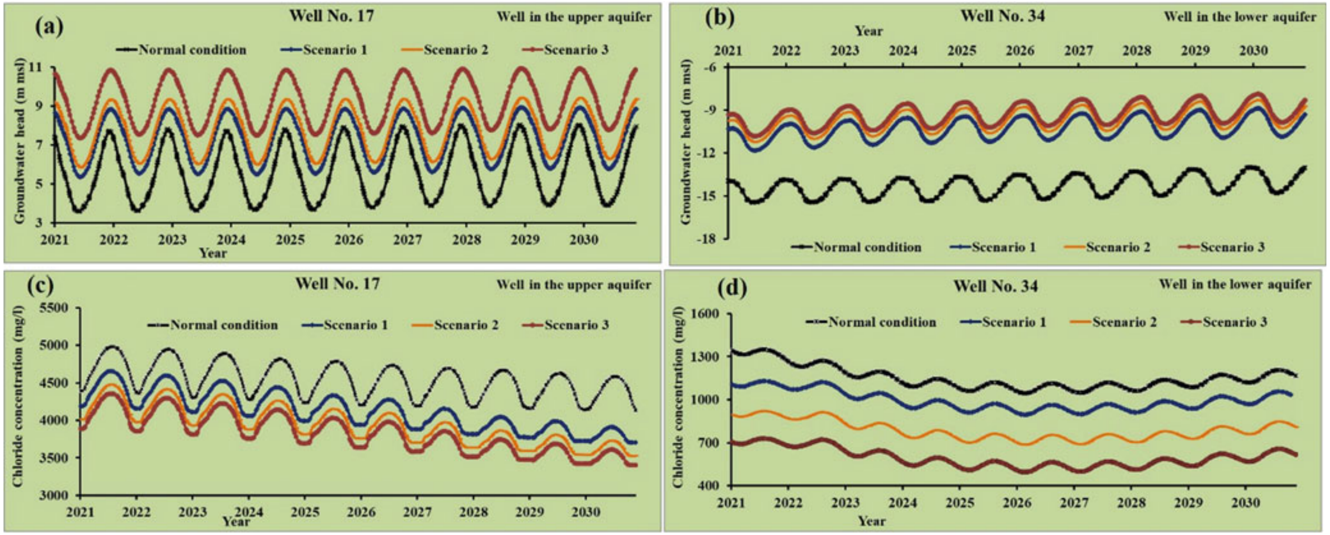

Fig. 67.7 Predicted groundwater head for different scenarios in **a** upper aquifer, **b** lower aquifer and chloride concentration for different scenarios in, **c** upper aquifer, **d** lower aquifer

chloride concentration reduces by about 300 mg L^{-1} to 700 mg L^{-1} in the upper aquifer and 180 mg L^{-1} in the lower aquifers, respectively. The model forecasts that by raising the crest level of existing check dams by 1 m and constructing new additional check dams (scenario 2), the chloride concentration can reduce by about 500–850 mg L^{-1} in the upper aquifer and 380 mg L^{-1} in the lower aquifer. The model predicts that chloride concentrations in the upper and lower aquifers will decrease by about 1000 mg L^{-1} and 600 mg L^{-1}, respectively, under scenario 3. The 10 percent increase in rainfall recharge seems to have a greater effect on the chloride concentration in the upper aquifer (which reduces the chloride concentration very well), and this could be considered as one of the potential measures for sustainable water resources. As a result, increasing groundwater recharge due to climate change, raising the crest level of existing check dams by 1 m, and constructing new check dams are all viable options for restoring this heavily exploited coastal aquifer. This finding clearly shows that existing pumping practices are unsustainable, especially in the lower aquifer, and that possible water conservation scenarios must be considered in the near future for sustainable management of this coastal aquifer which has been extensively used for various purposes such as irrigation and Chennai city water supply.

67.6 Conclusions

The density-dependent groundwater model was developed to assess the effect of climate change on groundwater resources in the coastal aquifer in order to identify strategies for sustainable management. The developed model was calibrated and validated with the field conditions. The over-exploitation of groundwater pumping from wellfields produced a large cone of depression, and movement of sea water towards the freshwater aquifer is clearly shown in January and June 2010 spatial distribution of groundwater head and chloride concentration in the lower aquifer. The groundwater head increased by around 3 m in the upper and 5.5 m in the lower aquifers after scenario 3 was implemented. In the case of chloride concentration, scenario 3 significantly reduces the chloride concentration in the upper and lower aquifers by about 1000 mg L^{-1} and 600 mg L^{-1}, respectively. This tool will help decision-makers in an arid to semi-arid coastal area with increased water demand due to urbanization, and agriculture make more sustainable groundwater management decisions.

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References

Anuthaman NG (2009) Groundwater augmentation by flood mitigation in Chennai region, a modelling based study. Ph.D. thesis, Anna University Chennai, India

CGWB (Central Ground Water Board) (2007) District ground water brochure Tiruvallur district. CGWB, Ministry of Jal Shakti, Department of Water Resources, River Development and Ganga Rejuvenation, Government of India

Charalambous AN, Garratt P (2009) Recharge–abstraction relationships and sustainable yield in the Arani-Kortalaiyar groundwater basin, India. Q J Eng Geol Hydrogeol 42:39–50

District Agriculture Plan (2008) District agriculture plan Thiruvallur district. Centre for Agricultural and Rural Development Studies (CARDS), Tamil Nadu Agricultural University, Coimbatore, India

GEC (1997) Groundwater resource estimation methodology. Report of the Groundwater Resource Estimation Committee, Ministry of Water Resources, Government of India, p 100

Gopinath S, Srinivasamoorthy K, Saravanan K et al (2018) Discriminating groundwater salinization processes in coastal aquifers of southeastern India: geophysical, hydrogeochemical and numerical modeling approach. Environ Dev Sustain. https://doi.org/10.1007/s10668-018-0143-x

Hugman R, Stigter TY, Monteiro JP et al (2015) Modeling the spatial and temporal distribution of coastal groundwater discharge for different water use scenarios under epistemic uncertainty: case study in South Portugal. Environ Earth Sci 73:2657–2669

INCCA (Indian Network for Climate Change Assessment) (2010) Climate change and India: a 4 $\times$ 4 assessment- a sectoral and regional analysis for 2030's. Ministry of Environment & Forests, Government of India. http://www.indiaenvironmentportal.org.in/files/fin-rpt-incca.pdf

Indu SN, Parimala RS, Elango L (2013) Identification of seawater intrusion by Cl/Br ratio and mitigation through managed aquifer recharge in aquifers North of Chennai, India. J Groundw Res 2:155–162

Kourgialas NN, Dokou Z, Karatzas GP et al (2016) Saltwater intrusion in an irrigated agricultural area: combining density-dependent modeling and geophysical methods. Environ Earth Sci 75:15

Sherif MM, Singh VP (1999) Effect of climate change on seawater intrusion in coastal aquifers. Hydrol Process 13:1277–1287

Suganthi S, Elango L, Subramanian SK (2013) Groundwater potential zonation by remote sensing and GIS techniques and its relation to the groundwater level in the coastal part of the Arani and Koratalai river basin, Southern India. Earth Sci Res 17(2):87–95

TNAU (Tamil Nadu Agricultural University) (2004) Alternative cropping pattern for Tamil Nadu. Directorate of Research, TNAU, Coimbatore, Tamil Nadu, India

UNDP (1987) Hydrogeological and artificial recharge studies Madras, Technical report, United Nations Department of technical co-operation for development, New York, USA

Yang JW, Radulescu M (2006) Paleo-fluid flow and heat transport at 1575 Ma over an E-W section in the Northern Lawn Hill Platform, Australia: theoretical results from finite element modelling. J Geochem Explor 89(1–3):445–449

Chapter 68
Dynamic Behaviour of the Estuaries in Response to the Phenomenon of Global Warming in the Coastal Ecosystems of West Bengal and Odisha, India

Ashis Kumar Paul

Abstract Estuaries of the low-lying coasts are highly vulnerable to the ephemeral rise of seawater during cyclones and the global warming induced sea-level rise process in the northern Bay of Bengal. West Bengal and Odisha coasts of the region are classified into unique coastal sections to identify the estuarine behaviours in terms of hydrodynamics and sediment movements. Global warming induced phenomena like high sea surface temperature (SST), increased sea surface height (SSH) and increased frequency of high magnitude cyclones influenced the effects of ephemeral rise sea waters into the coastal zones. Morphological, hydrological and ecological signatures of the alluvium coasts and coastal plain estuaries are identified in this study to highlight their behavioural adjustment with the effects of the global warming phenomenon in the tropical coasts.

Keywords Coastal ecosystems · Global warming · Sea-level rise · Sea surface temperature · Sea surface height

68.1 Introduction

The coastal plain estuaries are sediment sinks, and they try to adjust with the changing environment of hydrodynamics and sediment input systems but never achieve the equilibrium. Odisha and West Bengal coasts represent several estuaries such as the Hugli, Ichhamati–Raimangal, Subarnarekha, Brahmani–Baitarani, Mahanadi, Daya and Bhargav and Rushikulya rivers along the shore fringes of the Bay of Bengal. A disturbance regime is generated in the tropical coastal system at present due to the impacts of the global warming phenomenon and for which the estuaries are affected by bank line shifting, shoreline retreats, sediment encroachments, thalweg shifting and widening of estuary fringe tidal flats. The study also reveals that the erosion–accretion processes are induced by dynamic behaviours of estuaries on the other hand producing damages to the sensitive coastal habitats of the region at an alarming rate.

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The high rate of sea surface temperature (SST), high magnitude cyclone landfalls, warming induced sea-level rise, delta land subsidence process and human interventions into the coastal systems have created the disturbance regimes of episodic energy inputs. Mangrove ecosystems and dune ecosystems of the coastal fringes are largely affected by such dynamic behaviours of estuary channels, episodic energy inputs, shifting sands, the ephemeral rise of sea waters and tidal drainage loss into the higher tidal flats of the coast.

The present study is focused on the dynamic behaviours of estuaries in West Bengal and Odisha and the impacts of the phenomenon of global warming on the coastal environments. The physiography, hydrology and ecology of the alluvium coasts have been studied in detail by earlier workers (Niyogi 1970; Morton 1979; Chauhan et al. 1988; Paul 1996, 2000, 2002; Davis and FitzGerald 2004; Paul et al. 2005; Mukhopadhyay 2007; Barman et al. 2009; Maiti and Bhattacharya 2009; Mukhopadhyay et al. 2011; Bhattacharyya et al. 2013; Paul 2011; Paul et al. 2014, 2017, 2018; Paul and Jana 2018; Paul and Kamila 2018; Kamila et al. 2021) which represented the tropical coastal dynamics, but the present study attempts to highlight the effects of global warming phenomenon on the estuaries and adjacent shorelines.

68.2 Materials and Methods

68.2.1 Study Area

Odisha and West Bengal coasts are bounded by ten administrative units of districts and drained by several estuaries like Rushikulya, Daya, Bhargavi, Devi, Mahanadi, Baitarani, Brahmani, Budhabalanga, Subarnarekha, Hooghly (Hugli), Matla and Ichhamati–Raimangal rivers. The estuarine coast, deltaic coast, embayed coast and other non-deltaic strand plain coast of the region are extended between 1–5 m and 6–10 m elevated surfaces above mean sea level and fringed with the northern Bay of Bengal. Topographically, they are exhibited by shore fringed sandy beaches, shore parallel sand dunes, paleo beach ridges, backshore clay zones, tidal flats, backwaters, lagoons, estuaries and deltaic islands along the sedimentary depositional coasts. The irregular shorelines of the Sundarban coastal tract are separated by estuaries and larger tidal rivers into isolated delta plain tidal flats with forest cover areas by mangroves and reclaimed tidal flats by protective embankments. Mangrove forests are also distributed in the parts of Mahanadi delta (Kendrapara–Paradip), Brahmani–Baitarani delta (Bhitarkonica), Subarnarekha delta (Bichitrapur–Talsari) and along the bay fringed tidal flats (Bhadrak) of Odisha coast. The coastal plain and delta plain estuaries have reduced their 80% flows and sediment discharges into the coastal zones of the Bay of Bengal (Das 2021a, b; Mukhopadhyay 2007) due to sharing of waters and construction of barrages and dams across the rivers in the drainage catchment areas at present. They are mostly influenced by tidal flushing at their lower sections except for the monsoon months. Chilika lake comprises barrier spits, tidal inlet and

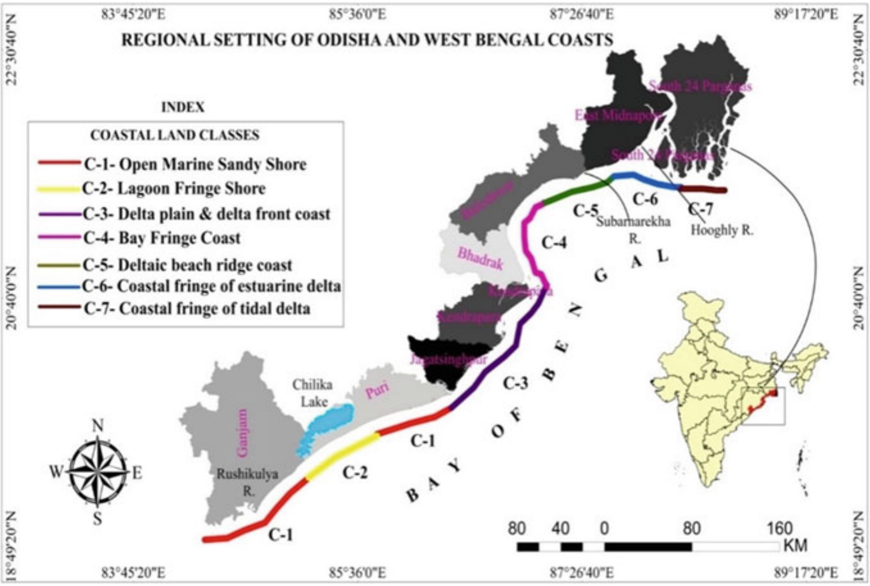


Fig. 68.1 Types of the coastal sections of West Bengal and Odisha (India)

lagoon water body, and to the north-east, it is connected with Daya and Bhargavi river systems. The water spread areas occupy 1309.63 km^2 of the lagoonal basin in the monsoon months but usually get shrunk into 797.77 km^2 during dry months in the region. The entire coast of the regional settings is categorized into 7 (seven) land classes from the Ganjam District of Odisha state to the South 24 Parganas district of West Bengal based on the landforms, shoreline configurations, composition of alluvium materials and drainage systems (Fig. 68.1).

68.2.2 Materials Used

The study has been carried out in the coastal region with the involvement of students and research scholars of the Department of Geography, Vidyasagar University. Extensive field surveys were conducted in each coastal section using total station survey, echo sounder, hand piston augurs, GPS, time series photographic documentation and other digital equipment (refractometer, pH meter, thermal infrared, water analyser, etc.) to monitor changes in the coastal environment. Survey of India's toposheets (1972), Kolkata Port Trust bathymetry charts (2011, http://environmentclearance.nic.in), Naval Hydrographic Charts (1978–2017, https://www.toddchart.com), The General Bathymetric Chart of the Oceans gridded bathymetry data (2018, https://www.gebco.net), Sea Surface Temperature (SST) data from National Oceanic and Atmospheric Administration (NOAA 2020, https://www.psl.noaa.gov), Sea Surface

Height (SSH) data from AVISO satellite derived Sea Surface Height above Geoid (1992–2020, https://www.aviso.altimetry.fr/), Satellite Images (Landsat 7 and 8, SRTM DEM, https://earthexplorer.usgs.gov/, 1973–2018 & LISS-III https://geospatialawarenesshub.com, 2005–2011; Google Earth, https://earth.google.com/2019-2021) and other collateral data from National Cyclone Risk Mitigation Project, NCRMP (Cyclone data with NCRMP 2017), Indian National Centre for Ocean Information Services, INCOIS (Data on Tides, Sea Waves, Currents, Winds, 2020) and Kolkata Port Trust project reports (KPT 2017) were used in the present work to fulfil the objectives of the paper.

68.2.3 Methodology

The methodology followed for carrying out the current study of the coastal plain estuaries is depicted as a flow chart shown in Fig. 68.2.

The present study was carried out using the SRTM DEM, Landsat 7 and Landsat 8 OLI/TIRS multispectral satellite data obtained from the Geological Survey of USGS (https://earthexplorer.usgs.gov/) for analysis of the topographic diversity. The gap fill correction (using SNAP software) of the SRTM digital elevation model has been also used for the preparation of the microcoastal land classification of the study area (https://step.esa.int). The time series analysis was conducted with the spatio-temporal

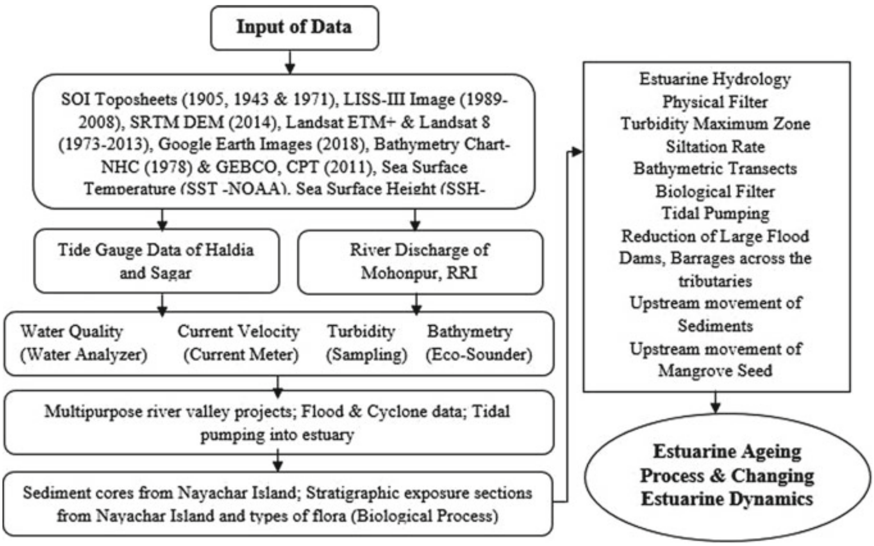


Fig. 68.2 Methodological flow chart of the study

Landsat (1973–2013) data and LISS-III images which provided surface reflectance of the study area. The satellite images were rectified, as well as the dark object subtracted and atmospherically corrected by using FLAASH (Fast Line-of-sight Atmospheric Analysis of Hypercubes) model with the help of ERDAS Imagine and ENVI-5.1 software. The shoreline could be extracted in single band images (reflectance of water is zero in the reflective infrared band) by using histogram threshold methods in ERDAS Imagine software. The temporal change of shoreline retreats has been delineated with the linear regression rate (LRR) methods from the DSAS tool in ARC GIS software in the present study. The Landsat images were used to study the estuarine erosion and depositional features of the present area to demarcate the short wave infrared channel in the electromagnetic spectrum of the remote sensing tool.

The Chilika lake operates a system of exchange of waters and sediment loads into the basin with activities of tidal inlet and connecting inland rivers in the tropical coastal belt. Marine water and sediment exchange occur by tidal inlet channel and seasonal surface runoff waters with sediment delivery system through inland drainage channels. The lake was extensive towards the north-east in the early Holocene phase (Paul 2014), but the marginal areas were partially filled up with sediment loads of Daya and Bhargavi river systems, and the sea face was blocked by sand spits during the Late Holocene period. Now the entire lagoon system is regulated by the exchange of tide waters with the tidal inlet and monsoonal rainwaters supply with little runoff from the inland areas.

The inlet throats were studied with measurement of tidal prisms, the position of high-tide level–low-tide level (HTL–LTL) limits, the current velocity at different tidal stages and temporal satellite images (Landsat 8 and Google Earth) of the lake basin as well as the delineation of the position of sand spits of the lagoon. However, the lake water qualities were assessed by the random sampling of lake water sites with a water analyser and GPS, and the final maps were prepared by interpolation method. The lake water volumes and water spread areas were estimated with the temporal satellite images (dry season and wet season) and application of echo sounder for measuring depths of the shallow water lake areas (Paul 2013).

The siltation rates, bathymetric configurations of the Hugli estuary, and morphology of the estuary are measured and assessed by overlay method of cross-sectional forms of the river valleys from temporal bathymetry charts (National Hydrographic Charts, 1978–2017 and Bathymetry Survey of Kolkata Port Trust, 2011) and by using the Google Earth images, tide gauge data of different sections (Kolkata Port Trust tide table), currentmeter data (velocity of surface waters) and also by suspended sediment sampling method employed in the field survey for validation of the estimated data on turbidity maximum zone (TMZ) for the estuary reaches. Nayachar, Ghoramara, Sagar, Jambu and Chuksar Islands of the Hugli estuary were monitored on several occasions from 1990 to 2018 by extensive field survey methods. Various exposure sites of erosive banks and accretionary parts were documented by field photographs and recording of the stratigraphic sections of the islands. The temporal images of LISS-III data and Landsat ETM+ and Landsat 8 data are used to delineate the island configurations of different years (1973–2013). A 40 m drilling core site of Nayachar Island was visited when the drilling was going on in the island during the year 2007, and the depth of different layers and their composition were documented in the field. The contour plans of the northern part of the island and surface profiling across the island from east to west were documented with the total station survey and dumpy level survey to validate the SRTM DEM for the Nayachar Island of the study area.

68.3 Results and Discussion

The word "estuary" is derived from the Latin word "*aestuarium*", which means tidal. It is here that the rivers begin to sense the rhythm of the tides. All types of estuaries have resulted from the rise of sea level during the Holocene epoch. Perhaps the most common origin is the drowning of the mouth of a river valley (e.g. West Bengal coastal plain estuaries). In the high latitudes, glaciers have carved deep, narrow, steep-walled valleys, and many have glacial moraines (ridges of sediments scraped off the land by moving glaciers) at their mouths. Flooding of these valleys with seawater creates fjords. Bar-built estuaries evolve by spit extension across an embayment (e.g. Odisha coastal estuaries), and tectonic estuaries commonly result from block faulting (Fig. 68.2).

Odisha and West Bengal coasts fringed with the northern Bay of Bengal are classified into regional settings of unique coastal sections. All types of estuaries of the alluvium coasts have resulted from the rise of sea level during the Holocene epoch. Estuaries are classified based on the circulation, which depends on the degree of freshwater and seawater mixing. Water mixing is controlled by the relative influence of tidal currents and river discharge as they produce a net circulation. There are salt-wedge estuaries in the river-dominated region as influenced by the sharp halocline. The partially mixed estuary, however, has a weakly developed halocline, and it is influenced by the strong incoming bottom flow and outgoing surface flow. The well-mixed estuaries are strongly tidal dominated. Surprisingly, they are thoroughly mixed and have no halocline.

68.3.1 The Hugli Estuary

The Hugli estuary is a funnel-shaped coastal plain river mouth environment that is dominated by the large volume of tidal inflows and seasonal discharge of freshwater into the coastal zones in West Bengal (Table 68.1). The Sundarban tidal river mouths are influenced by tidal inflows and outflows. Only, the Ichamati–Raimangal river section discharges seasonal freshwater flows into the Sundarban coastal zone, though the downstream is highly influenced by tides. The tidal features of the Hugli estuary represent the semi-diurnal tide type, and the high spring tide ranges in the order of 4.27–4.57 m and also represent the ranges of the neap tides were about 1.83–2.83 m.

Table 68.1 Average discharge in the river system of Hugli downstream section and maximum tidal elevation at Haldia

Month	Discharge in km^3 per month	Maximum tidal elevation (m)
May	0.88	5.92
June	4.02	6.01
July	18.70	6.24
August	8.47	6.21
September	20.47	6.49
October	1.93	6.45

Source Based on CPT project report (2011)

Surprisingly, the tidal influence is felt up to a distance of 300 km along the Hugli estuary upstream section up to Nabadwip.

The major feature of the tide exhibits a positive asymmetry as they propagate along the channel, and the short duration of flood tide ranges from 3 to 4 h period but the reaming ebb flows continue for 8–9 h period in the Hugli estuary section to complete the one tidal cycle. The estimated flood velocities remained much higher than the ebb tides in the region. The studies also highlighted the high concentration of suspended particulate matter (SPM) flux into the downstream section during calm conditions by the tidal pumping process. However, the strong landward SPM flux was recorded during the windy period in the estuarine sections of Hugli. The freshwater and saltwater mixing zone with turbidity maximum zone (TMZ) of Hugli estuary has been identified in the downstream section near Diamond Harbour (Fig. 68.3). The disturbance regimes have been identified in the events of large floods and high magnitude cyclones in and around the Hugli estuary of the northern Bay of Bengal (Table 68.2).

The salinity front and turbidity maximum zone (TMZ) of the estuary section with suspended load and tidal elevations acts as a physical filter to attract the siltation rate into the downstream section. The average discharge in the river system of the Hugli downstream section was about 10% of the average discharge of the Indo-Gangetic Delta (Mukhopadhyay 2007). The rapid siltation rate at the mouth of the downstream section of the river Hugli was measured by Haldia Port Authority during 2010, when the feared gap between the river bed and the water surface was only 7.1 m in depth. The minimum required gap was needed as 7.7 m, but the dredging activities removed the spoils and maintained the depth up to 8.6 m in the region to navigate the ships into the Haldia dock.

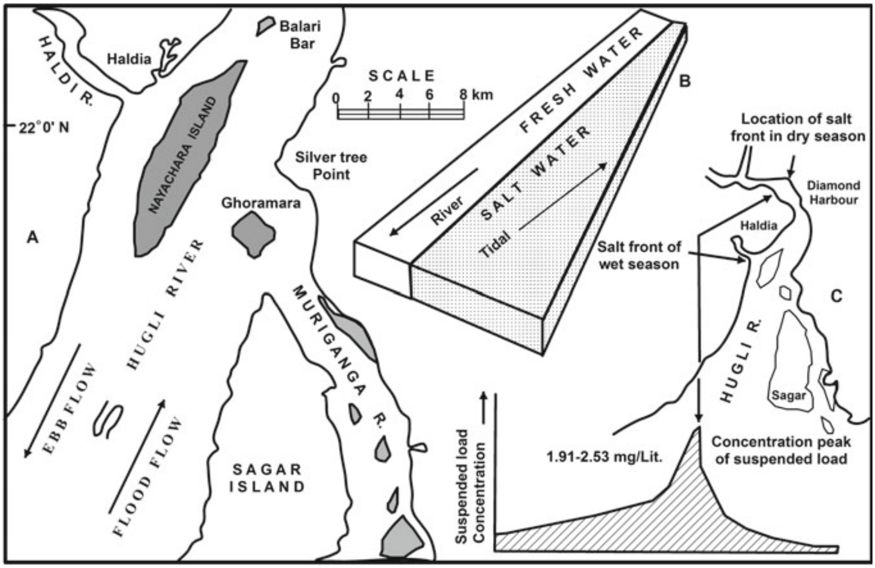


Fig. 68.3 Freshwater and saltwater mixing zone with TMZ in Hugli estuary section at Diamond Harbour. *Source* Paul (2002)

Table 68.2 Events of large floods and high magnitude cyclones in and around the Hugli estuary as disturbance regimes in the coastal system

Event of large flood	Year	Event of high magnitudes cyclones	Year	Remarks
Large flood	1950	Severe cyclone	1942	Emerged sand bar
Largest flood	1978	Severe cyclone	1971	Mud deposition
Moderate flood	1984	Sundarban cyclone	1989	Vegetation cover
Moderate flood	1991	Sundarban cyclone	1991	Mangrove wetland extension
Moderate flood	2000	Cyclone Cedere	2007	Sand bar extension
Large flood	2008	Nargis cyclone	2008	Balari extension
Large flood	2021	Aila cyclone	2009	Erosion and siltation

Source Based on Paul (2002); IMD Cyclone data, and Irrigation and Waterways Department Govt. of West Bengal, 1950–2021

68.3.2 Present-Day Estuarine Landform Types of the Hugli River

Macro-tidal setting, funnel-shaped plan and low gradient channel of the Hugli estuary provide an ideal situation of depositional landforms which, however, has been altered by strong tidal currents and the landward residual flow near the bed (Table 68.3 and

Table 68.3 Morphological variation in Hugli estuary

Group A: sub-aerial parts	Group B: inter-tidal parts	Group C: subaqueous parts
1. Channel margins and banks	**4. Tidal flats**	**7. Channel bottom features**
Estuary banks	Sheltered flats	Shoaling flats
Island banks	Open sea flats	Sand banks
Minor tidal channel banks	**5. Sea beaches**	Deeper channels (low-tide channels)
2. Islands	Shore line beaches	
Inner estuarine islands	Detached beaches	
Middle estuarine islands	**6. Sand bars**	
Outer estuarine islands	Point bars	
3. Sand dunes	Min-channel bars	
Transverse foredune ridges	Island attached bars	
Isolated dune ridges	Offshore bars	
Embryo dunes	Channel fringed bars	

Source Paul (2002)

Fig. 68.4). The present-day topography of the estuary is very irregular and complex in form. The types of estuarine landforms are grouped into following ways (Paul 2002).

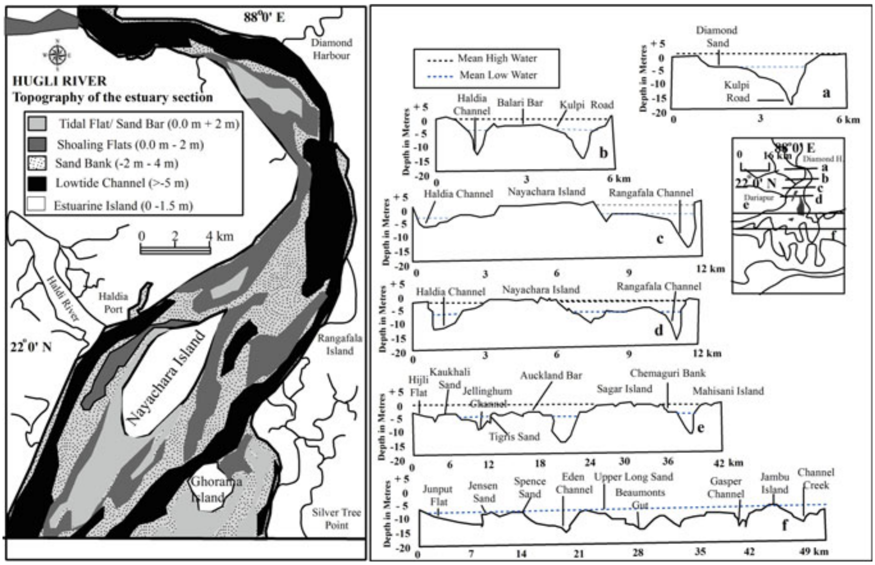


Fig. 68.4 Bathymetric characters of the Hugli estuary fringed by Purba Midnapore coastal district. *Source* Paul (2002)

The erosion and accretionary processes around the Hugli downstream estuary sections have produced dynamic configurations of the island shorelines, bank line depositional features and river bed sediment movement particularly in the events of floods and cyclones (Table 68.4 and Fig. 68.5).

The shoreline change rates are significant as recorded in 2018 along the Muriganga bank of south-east Sagar. Tidal prisms of the Muriganga estuary are measured in 1987, 2016 and 2018 to compare the changes in hydrodynamics. The result shows a significant increase in tidal prisms along the Muriganga estuary. Severe bank erosion is probably responsible for the arising hydrological stress resulted from increased tidal prisms in the estuary section (Table 68.5).

Table 68.4 Shifting sand bar areas in Hugli estuary during the events of storms

Year	Change in area of sand bar (ha.)
1973	00.65
1975	120.54
1989	680.58
1999	206.37
2002	543.00
2006	222.09

Source Based on remote sensing study, 1973–2006

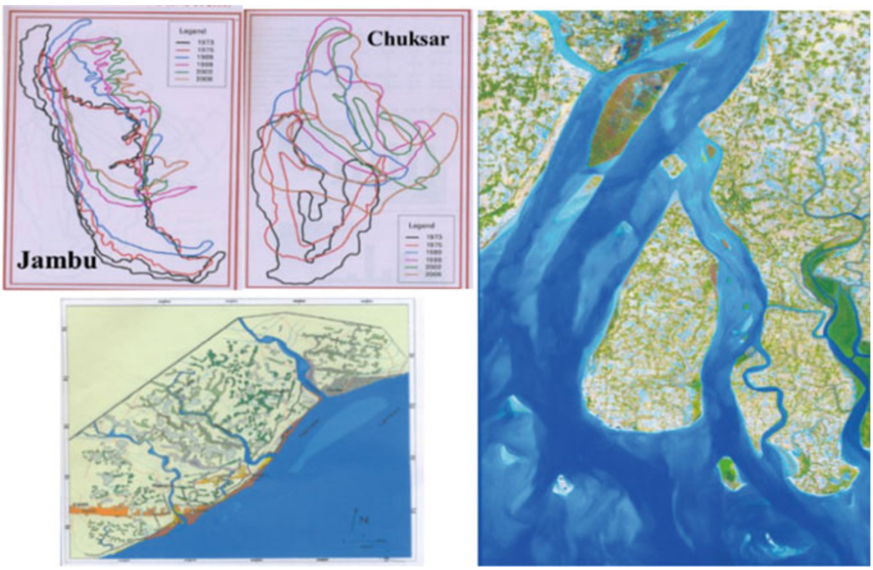


Fig. 68.5 Island drift at the Hugli estuary by the impact of storm surges. *Source* Based on Remote Sensing data, Landsat 4, 5, 7, 8 & LISS-III

Table 68.5 Shoreline erosion rate and increased tidal prisms near Muriganga–Baratala estuary bank

Estimated shoreline erosion rate (1987–2018)	Estimated tidal prisms in Muriganga–Baratala estuary (1987–2018)
Bisalakshimipur Village (28.6 m yr^{-1})	1,58,840 m^3 in 1987
Dhablat Village (16.8 m yr^{-1})	2,34,600 m^3 in 2016
Chemaguri Village (14.4 m yr^{-1})	2,36,049 m^3 in 2018

Source Based on Paul et al. (2018) and field survey

68.3.3 Siltation Rates in Hugli Estuary

The siltation rate at Haldia channel and Rangafala channel in between northern Nayachar and Balari Islands (with reach distance 8 km) represents 11 million t yr^{-1}. The bathymetric chart of 1972 (Indian Naval Hydrographic Office, Dehradun) is compared with the bathymetric sections of Kolkata Port Trust (2011) to estimate the Hugli estuarine bed morphology patterns. The estimation shows that Haldia channel on the eastern portion of Nayachar Island is heavily silted up with emerged bars, tidal flats and tidal shoals. However, the Rangafala channel on the western bank of Nayachar Island is shifted towards the east by the bank recession of Nayachar Island. The Rangafala channel sections indicated the emerged silted bed on the western portion. The growth of Nayachar Island in terms of area, length and width was assessed using remote sensing techniques from 1973 to 2010. It was observed that the growth was maximum in the years 1993 and 2002 due to an alarming rate of siltation process on the island fringes of the estuary section (Table 68.6 and Figs. 68.6, 68.7, 68.8, 68.9 and 68.10).

Table 68.6 Estimated area and length versus width of Nayachar Island using the IRS LISS-3 data

Year	Area (ha)	Length/width (km)
1973	2745.297	8.0/2.3
1975	2989.957	10.0/3.5
1989	4156.726	12.5/3.8
1999	5134.214	14.3/4.0
2002	4865.927	15.1/4.5
2006	4814.712	15.4/4.5
2008	4850.231	15.9/4.4
2010	5018.549	16.2/4.6

Source Based on the temporal analysis of remote sensing data, LISS-III images

Fig. 68.6 Siltation rate in Haldia and Rangafala channels (Hugli estuary section) *Source* Based on field survey, NHC bathymetric chart, 1978, CPT Survey, 2011 and area calculated from Google Earth Image

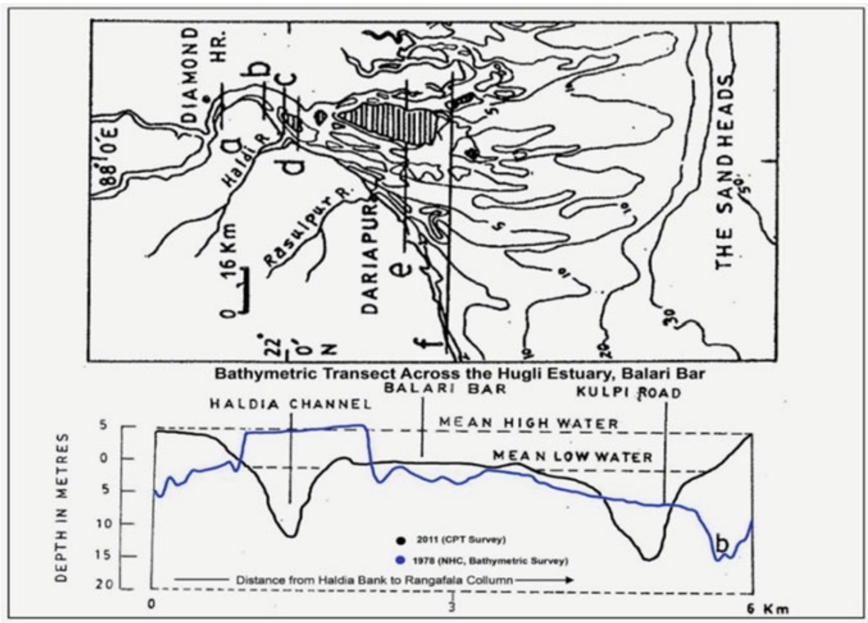


Fig. 68.7 Bathymetric transect across the Hugli estuary adjacent to Balari bar. *Source* NHC bathymetric survey, 1978 and CPT survey, 2011

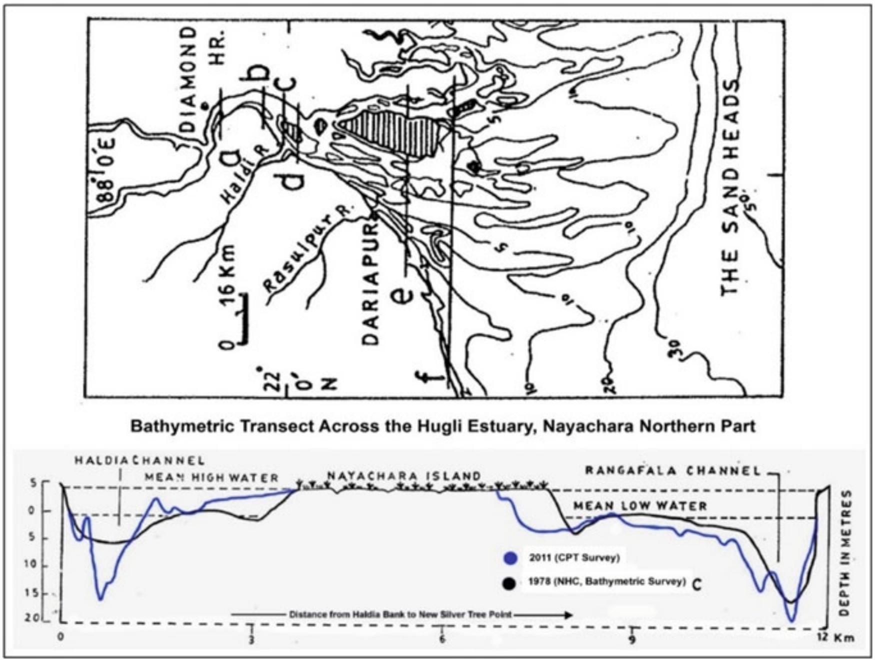


Fig. 68.8 Bathymetric transect across the Hugli estuary adjacent to the northern part of Nayachar. *Source* NHC bathymetric survey, 1978 and CPT survey, 2011)

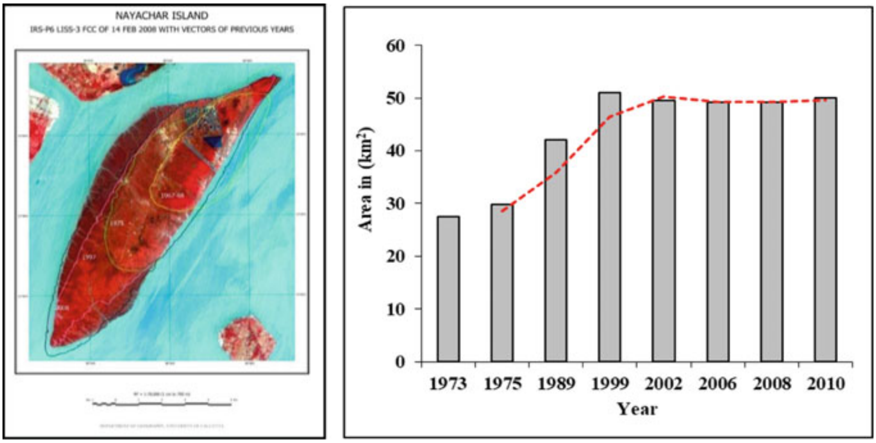


Fig. 68.9 Increasing area of Nayachar Island in the Hugli estuary section (Dotted red line represents two year moving average). *Source* Based on Remote Sensing data

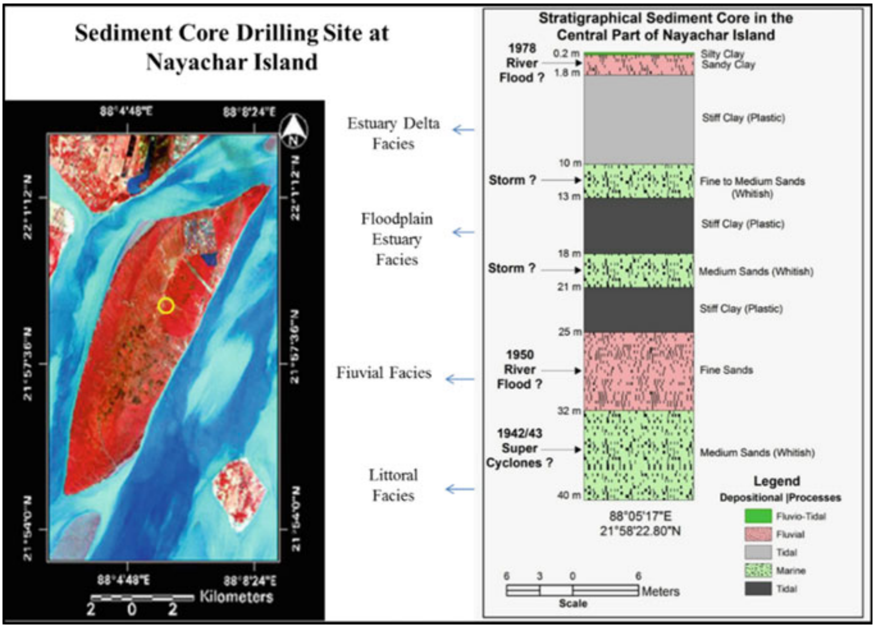


Fig. 68.10 Sediment core drilling site and the stratigraphical section of Nayachar Island. *Source* Based on field survey in the drilling site and sediment analysis under in-house study

68.3.4 Effects of Global Warming

The events of large-scale marine inundations caused by storm surge transport sediment loads into the estuaries along the shoreline sections of the northern Bay of Bengal. The high magnitude cyclone frequency has increased in the previous decades in the region. The concentration of cyclone landfalls on West Bengal and Odisha coasts enhanced the movement of shifting sands along the shoreline section fed by estuaries and wetlands (Fig. 68.11).

The regional coastal systems of West Bengal and Odisha are also affected by the ephemeral rise of seawater during the events of storms and south-west monsoon current drifts. The abnormal rise of SST in the summer months develops low pressures centres on the sea, and among them, a few get intensified into severe storm in northern Bay of Bengal. The satellite altimeter recorded a trend of a steady rise of the SSH from 1992 to 2020 in the region at the rate of 2.0 cm to 6.5 cm yr^{-1}. Such rising sea surface height (SSH) has increased the magnitude of water level into the coastal embayments during the windy period (Fig. 68.12). Thus, sediments are dumped into the downstream section of the larger estuaries at present. The low height shores are also breached by overwash transport of sand size sediments from nearby estuary fringed coasts in West Bengal and Odisha.

The tropical cyclone Amphan landfall took place on the passage of Hugli estuary and moved towards Kolkata on 28 May 2020, with 2.5 m height of storm surge

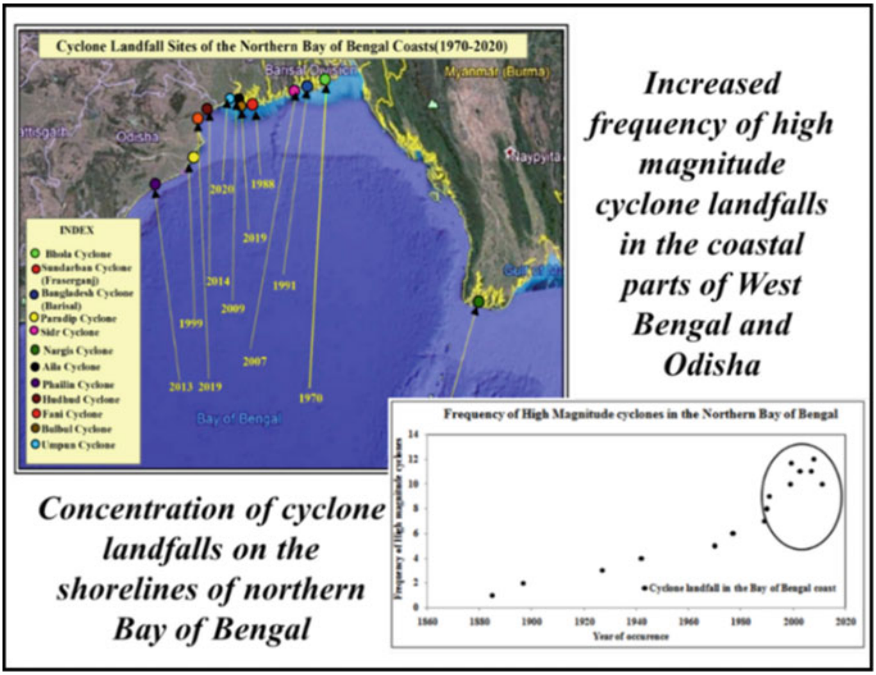


Fig. 68.11 Cyclone landfall sites of the northern Bay of Bengal coasts (1970–2020). *Source* Based on the data source from IMD, 1970–2020

elevation. Bank erosion, sediment transport and tidal flat deposits with external input of inorganic sands were recorded along the passage of Hugli estuary banks after the storm (Fig. 68.13).

Landward extension of soil salinity towards north and encroachment of tidewaters up to Nadia river section (Nabadwip) indicated the role of high tides and occurrences of power full tidal bores in the Hugli estuary (Fig. 68.14). The Hugli river bed deposits of tidal sands near the Dakshineswar (Haora) temple point also indicated the influences of tidal bores in the funnel-shaped estuary section. The spread of soil salinity usually occurs after each event of cyclone landfall and associated storms surge phenomenon into the coastal zones.

There is a progressive change of the shorelines along the coastal sections which indicated the impact of advancing sea into the deltaic islands. The horizontal shifting, as well as vertical surface etching of the tidal flats, has reduced the underlying clay banks alarmingly along the island fringes of the region. This is a process of "coastal squeeze" which occurred significantly on the shoreface of reclaimed islands (Fig. 68.15). A few islands are surprisingly reduced and engulfed into the estuaries (Haliday Island, Jambu Island, Chuksar Island, and New Moore Island) by the dynamics of coastal hydraulics particularly during the ephemeral rise of sea waters.

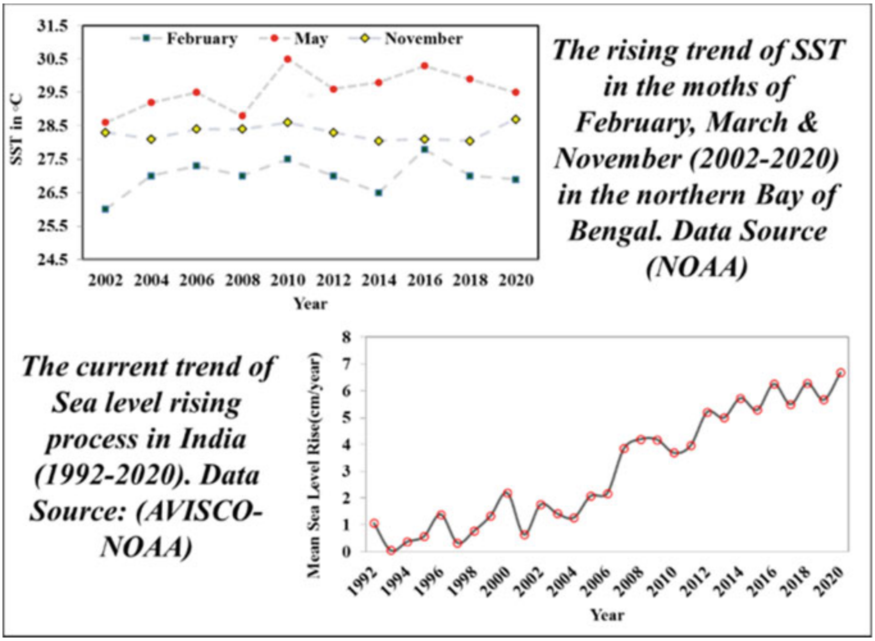


Fig. 68.12 Variation in sea surface temperature (SST) and sea surface height (SSH) in the northern Bay of Bengal. *Source* Based on the data from NOAA, AVISO-NOAA

Mangroves are lost from the open tidal flats, and forest floors are trapped by blanketed sands through overwash transport.

Mangrove seeds are transported into the estuaries by tidal bores and made their colony of emerging mangroves over the tidal flats of Hugli estuary section up to 115–145 km distance upstream from the current shoreline position. Such adjustment process of mangroves by horizontal shifting of colony development along the open mouth of the Hugli estuary is also an indication of rising sea level in the region (Fig. 68.16).

The erosion accretion trend of the Odisha coast represents a directional change of sediment movements along the shoreline from southern districts to northern districts. Strong longshore current and south-west monsoon current drifts moved the bulk sediments into the deltaic shores and Chandipore Bay shoreline of the region. The estuaries are modified into bar-built river mouths by deposition of sand size sediments, and finer sediments on the other hand are arrested into the inner estuaries in the form of expanded tidal flats, tidal shoaling flats and channels bars. However, the low-lying sandy shores with narrow beached and unconsolidated dune sands are breached and overwashed by the ephemeral rise of sea waters and associated surging waves. Backshore mangrove wetlands are trapped by shifting sands through the progressive movement of overwash sand fan lobes along and across the shorelines of Bhitarkanika and Mahanadi delta (Fig. 68.17).

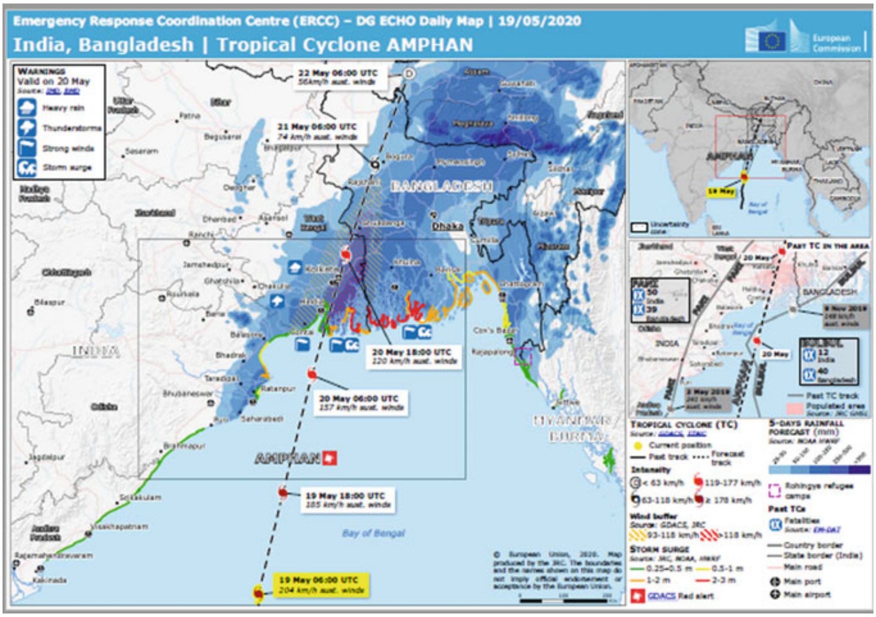
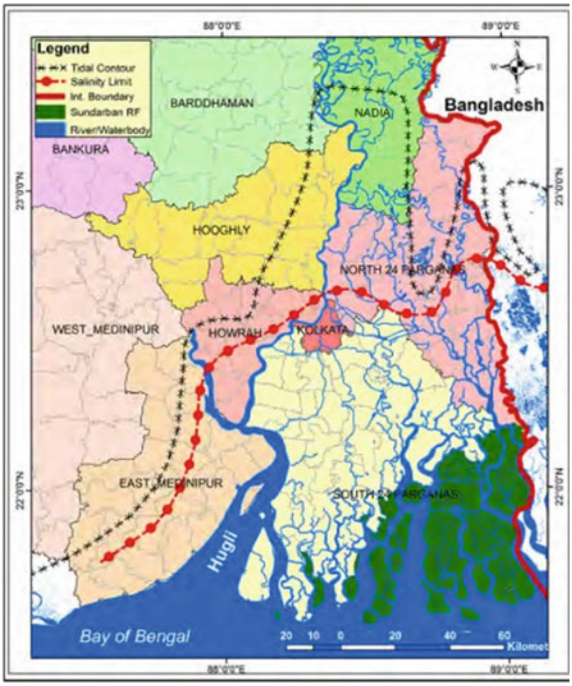


Fig. 68.13 Tropical cyclone Amphan landfall, storm surge and rainfall affected areas. *Source* INCOIS (2020)

Fig. 68.14 Landward salinity limit and tidal limit of deltaic coastal tract, West Bengal. *Source* Based on remote sensing study and field survey



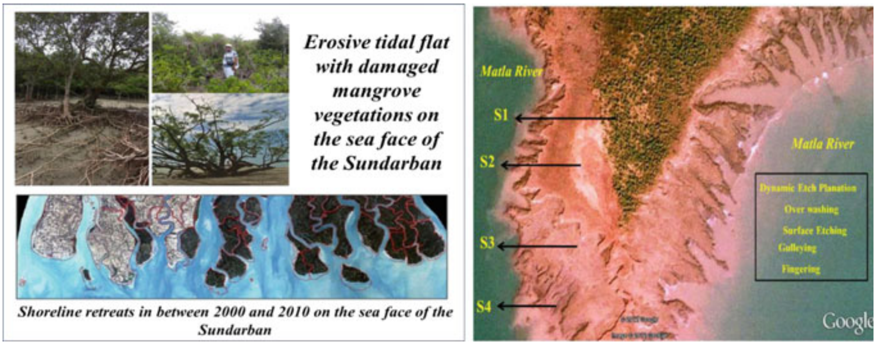


Fig. 68.15 Shoreline change between 2000 and 2010 in the Sundarbans estuary fringed coast and erosion of basement clay in Haliday Island. *Source* Based on remote sensing study, Google Earth image and field survey

Fig. 68.16 Adjustment of mangroves in "coastal squeeze" and mangrove degradation by external input of sand size sediments at Hugli and Subarnarekha estuaries. *Source* Based on field survey

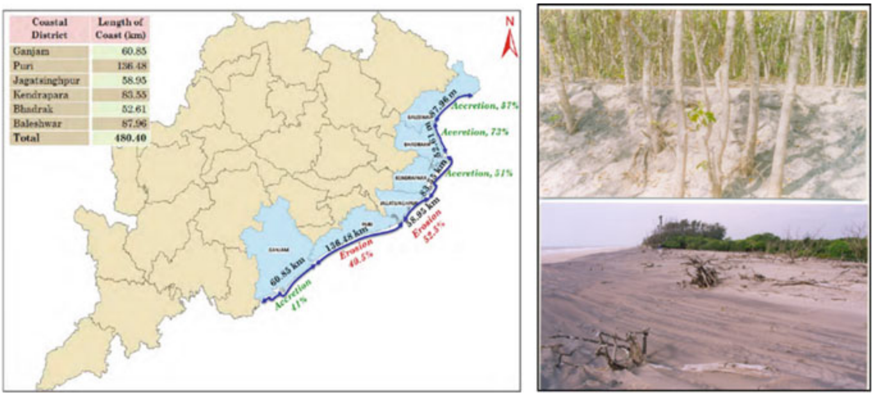


Fig. 68.17 Coastal erosion affected areas of Odisha state and mangrove degradation by shifting sands (Bhitarkanika delta). *Source* Based on NCSCM (2011) and field survey in Odisha coast

The sand size sediments are mostly arrested along the shorelines of Chandipore Bay and Subarnarekha beach ridge delta of northern Odisha. Though the tidal flats of Chandipore Bay are wider (over 4.5 km), high-tide shoreline usually encroached into the beach berms and backshore sand dunes in many places occasionally during the ephemeral rise of sea waters.

Sometimes, the tidal current exceeds the effects of longshore currents particularly during dry months (December to March) when sediment movements are directed towards the Subarnarekha estuary mouth. There is a strong correlation between tidal inlet throat cross-sectional area and tidal prisms (O'Brien 1931, 1969). Tidal inlet throats are gradually open by increased tidal prisms in Chilika lagoon and the beach ridge fringed shorelines of Subarnarekha delta. The increased effects of SSH probably influenced the sediment movement into the inlets and produced erosion on the adjacent shorelines backed by sand dunes in the region (Fig. 68.18).

68.3.5 Tidal Inlet Relationships

Tidal inlets throughout the world exhibit several consistent relationships that have allowed coastal engineers and marine geologists to formulate predictive models. Through analysis of inlets, whereby inlet parameters are plotted against one another, two important correlations have been discovered: i. inlet throat cross-sectional area is closely related to the tidal prism, and ii. ebb tidal delta volume is a function of the tidal prism (Fig. 68.19).

The tidal prisms are estimated in the new mouth inlet channel of Chilika lagoon with the help of the echo-sounding method during the rising tides and falling tides. The tidal prisms were 93 million cubic metres in 1972, and they declined to 38 million cubic metres in the year 2000 when the lagoon was affected by environmental degradations. However, after cutting the new mouth channel as an artificial inlet by the dazing method in 2002, the tidal prisms increased rapidly from 93 million cubic metres (2009) to 202 million cubic metres, (2013) which influenced the ebb tidal delta formation at the new mouth entrance (Table 68.7).

The Walton and Adams relationship indicated that a strong correspondence exists between the inlet's tidal prisms (p) and the volume of its ebb tidal delta (V) (Walton and Adams 1976). As the tidal prisms gradually increased in the inlet throat of the new mouth of Chilika lagoon the, ebb tidal delta has advanced seaward in a significant form in the open marine environment of the Bay of Bengal (Odisha coast). Therefore, the Walton and Adams relationship has matched with the growth of the ebb tidal delta in the Chilika lagoon very strongly in this case (Fig. 68.20).

There is a strong diversity in the hydrological behaviours of estuaries and tidal rivers of different categories in the coastal plain sections of West Bengal and Odisha. Maximum tidal elevations are found in the Hugli estuary and Sundarban tidal rivers of West Bengal. The freshwater discharges are surprisingly significant in the Mahanadi rivers and Hugli downstream section of the Bay of Bengal fringed coasts. Other river systems of the alluvium coasts are discharging an insignificant amount of freshwater

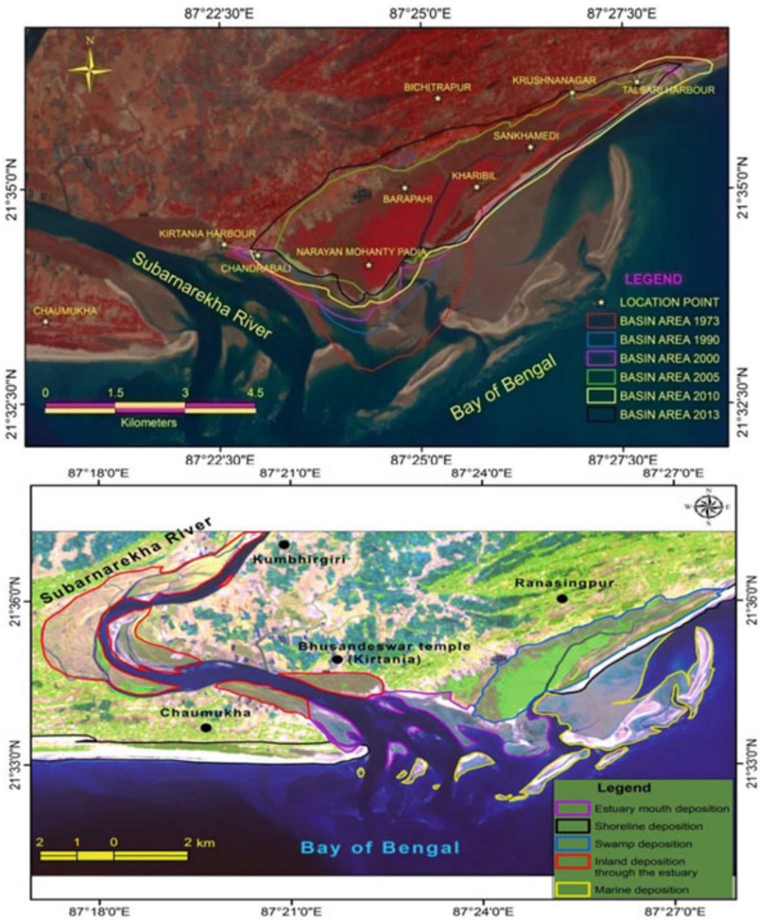


Fig. 68.18 Estuarine erosion and depositional features of Subarnarekha delta (Odisha coast). *Source* Based on remote sensing data

into the coastal zones. However, the wave heights (1.5–2.5 m) are dominating over the tidal elevations in the shoreline section of Puri, Ganjam and Chilika coasts of Odisha (Table 68.8).

68.4 Conclusions

The marine sediments have been pushed into the estuaries by storm surges during the cyclone landfall occasionally along the low-lying coastal plains of West Bengal and Odisha. The islands and bar-built estuaries are changing in shape as they were influenced by the strong longshore currents from the southern shoreline of Odisha

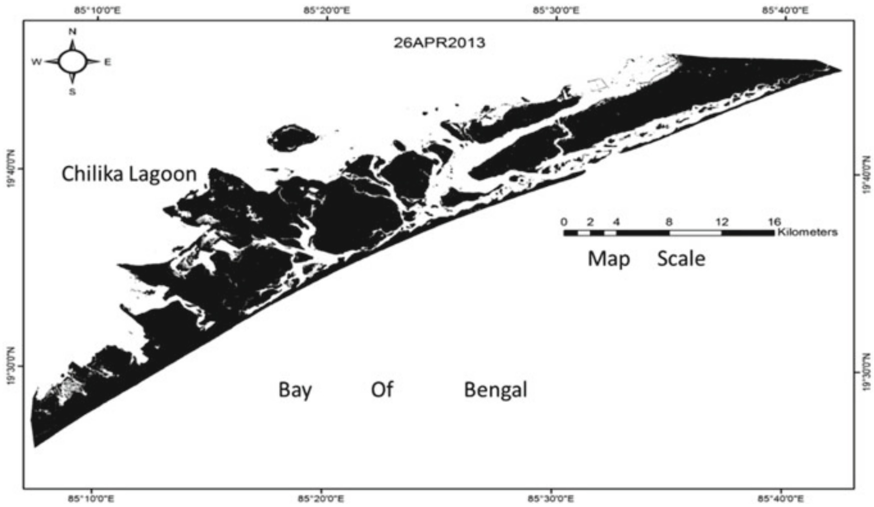


Fig. 68.19 Tidal inlet position across the sand spits at Chilika barrier, 2013. *Source* Based on remote sensing study, Landsat 8 2013

Table 68.7 Tidal inlet opening and variation of tidal prisms of Chilika lagoon

Year	Date	No. of openings	Tidal prisms (million m^3)
1972	07 November	03	93.31
1980	18 January	02	62.21
1990	28 November	01	62.21
2000	12 September	01	38.88
2002	15 November	02	54.53
2004	02 November	01	62.21
2009	13 September	02	93.31
2013	26 April	01	202.18

Source Paul (2014)

coast to the northern shore fringes. A series of offshore bars have been developed in the mouth of Subarnarekha estuary inshore, in a parallel direction with the longshore current drift during south-west monsoon period. As a result of the effect of global warming, the high SST in summer months and steady rise of SSH per year are causing erosion, shoreline changes and frequent saltwater inundations into the coastal low lands of the region. The overwash sand fan lobes are rapidly encroaching into the backshore wetlands dominated by mangroves and salt marshes due to the ephemeral rise of sea waters. The estimation of tidal prisms across the sections of tidal inlets (Subarnarekha delta, Brahmani delta and Mahanadi delta) in Odisha coast represents increased tidal prisms into the estuaries and inlets, and for which the adjacent sand dunes of the shoreline are affected by severe erosion. The study also revealed that high

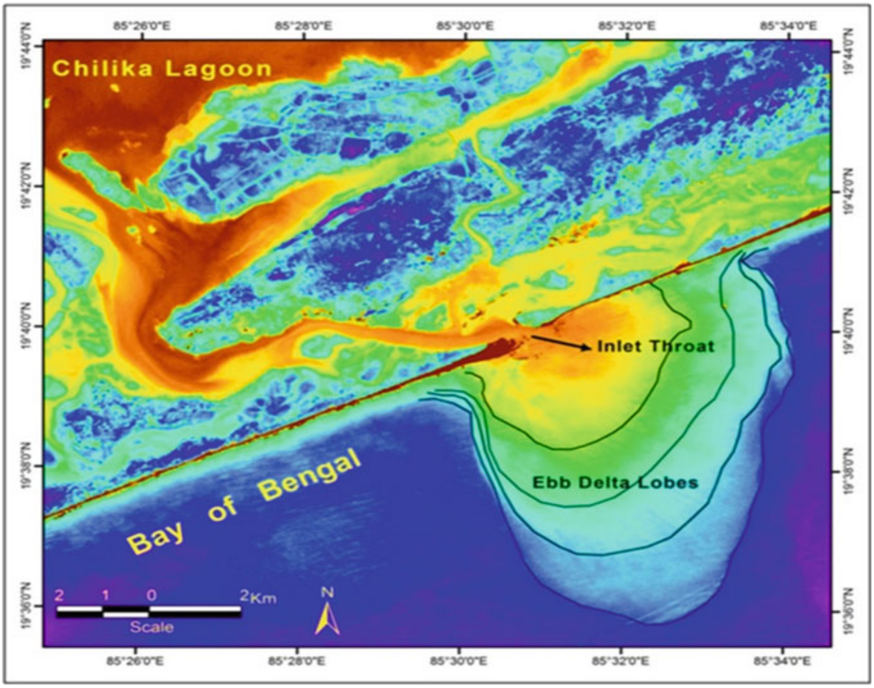


Fig. 68.20 Formation of ebb tidal delta at the new mouth tidal inlet in the Chilika embayed coast. *Source* Based on remote sensing study, Landsat 8 2013

magnitude storm frequencies have increased in the previous decades. The landfall concentration of cyclones is found on the alluvium shores of West Bengal and Odisha coasts in the three decades from 1990 to 2020. As a result of the occasional rise in seawater in the ephemeral stage, the bars and barrier breaching events have increased during the storms. The "Coastal Squeeze" on the sea face and widening of estuaries in the inner section of coastal plain rivers are directly responsible for the loss of mangroves, salt marshes and other associate plants of the intertidal region.

Field studies in the coastal plains also indicated the gradual shifting of salt-affected soils towards the inland areas after each cyclone event. The soil salinity and tidal limit of river mouths thus advanced inland along the estuaries of the coastal plains. Strong longshore currents during the summer months transport sediment load from south-west to the north-east direction in the northern Bay of Bengal, which is reflected in the sedimentary depositional landforms along the alluvial shorelines of the tropical coast. Chilika lagoon is the largest embayment on the Odisha coast which is connected with the Daya river system of Mahanadi delta on the upstream section. The seasonal constriction and enlargement of water spread areas occurring in Chilika lagoon and currently extended towards the inland parts during the summer monsoon. All the estuaries and lagoon are acting as significant sediment sinks into the coastal environment by advancing sea and ephemeral rise of sea waters. Surprisingly, the coastal

Table 68.8 Hydrologic behaviours of the coastal plain estuaries in West Bengal and Odisha states

Shoreline section	Processes	Estuaries	Sedimentary depositional landforms	Tidal elevation/wave height	Fluvial discharge (km^3 yr^{-1})
Indian Sundarban	Tidal	Ichamati, Matla, Thakuran, Saptamukhi	Islands, shoals, bars	4.5 m/0.70–1.0 m	40
Hugli estuarine coast	Fluvio-Tidal	Hugli downstream	Islands, bars, tidal flats	5.5 m/1.0–1.2 m	62
Midnapore littoral tract	Coastal–Marine	Rasulpur estuary	Tidal flats	3.5 m/1.0–1.2 m	0.5
Subarnarekha delta	Fluvial–Tidal–Marine	Subarnarekha estuary	Tidal flats, bars, meander course	3.5 m/1.5 m	7.94
Chandipore Bay	Coastal and Marine	Burahbolong R	Tidal flats, meander course	2.8 m/0.70 m	2.0
Brahmani–Baitarani–Mahanadi delta	Fluvio-Marine	Brahamani–Baitarani–Mahanadi–Devi estuaries	Islands and bar-built morphology	2.50 m/1.5 m	18.31/66.64
Puri coast	Coastal–Marine	Daya river	Abandoned tidal mouths	2.00 m/1.5–2.0 m	1.5
Lagoonal coast (Chilika)	Fluvio-Marine–Transitional–Lagoonal	Daya–Bhargab	Bars, abandoned channels	1.00 m/1.5–2.0 m	2.5
Ganjam coast	Coastal–Marine	Rushikulya	Bars	1.50 m/2.0 m	1.8

Source Based on remote sensing study, field survey, CPT tide data, NHC tide data and Paul (2014) dune ecosystems and mangrove ecosystems are largely affected by the impacts of global warming at present in the regional setting of alluvium coasts fringed with the Bay of Bengal.

Acknowledgements The research scholars and M.Sc. students of the Geography Department of Vidyasagar University, Midnapore, are duly acknowledged for their assistance in the different stages of fieldworks from 2000 to 2016 in Odisha and the West Bengal coasts. The UGC-unassigned grant and DST project of the department supported the works that have been reported in this paper.

References

AVISO Satellite derived sea surface height above geoid https://climatedataguide.ucar.edu

Barman NK, Paul AK, Chatterjee S (2009) Assessment of flooding characteristics in Kaliaghai-floodplain for appropriate flood preventive measures and control of peoples sufferings from unsafe conditions. Indian J Geomorph 13&14:137–152

Bhattacharyya S, Pethick J, Sarma KS (2013) Managerial response to sea level rise in the tidal estuaries of the Indian Sundarbans: a geomorphological approach. Water Policy 15(S1):51–74. https://doi.org/10.2166/wp.2013.205

Chauhan OS, Verma VK, Prasad C (1988) Variations in mean grain size as indicators of beach sediment movement at Puri and Konark beach, Orissa. J Coast Res 4(1):7–35

Das S (2021a) Hydro-geomorphic characteristics of the Indian (peninsular) catchments: based on morphometric correlation with hydro-sedimentary data. Adv Space Res 67(8):2382–2397. https://doi.org/10.1016/j.asr.2021.01.043

Das S (2021b) Dynamics of streamflow and sediment load in peninsular Indian rivers (1965–2015). SciTotal Environ 799:149372. https://doi.org/10.1016/j.scitotenv.2021.149372

Davis RA Jr, FitzGerald DM (2004) Beaches and coasts. Blackwell, London

GEBCO Gridded Bathymetry Data. https://www.gebco.net

INCOIS (2020) Emerging Response Coordination Centre (ERCC) DG ECHO Daily Map 19-05-2020 ESSO-INCOIS-Indian National Centre for Ocean Information Services. https://incois.gov.in

Kamila A, Paul AK, Bandyopadhyay J (2021) Exploration of chronological development of coastal landscape: a review on geological and geomorphological history of Subarnarekha chenier delta region, West Bengal. India. Reg Stud Mar Sci 44:101726. https://doi.org/10.1016/j.rsma.2021.101726

KPT (2017) Kolkata Port Trust - Detailed project report to MoEF&CC for environmental clearance (with reference to Haldia Dock and Nayachar Island).http://environmentclearance.nic.in/

Maiti S, Bhattacharya AK (2009) Shoreline change analysis and its application to prediction: a remote sensing and statistics based approach. Mar Geol 257(1–4):11–23

Morton RA (1979) Temporal and spatial variations in shoreline changes and their implications, examples from the Texas gulf coast. J Sediment Res 49(4):1101–1111

Mukhopadhyay A, Mukherjee S, Hazra S et al (2011) Sea level rise and shoreline changes: ageoinformatic appraisal of Chandipur coast, Orissa. Int J Geol Earth Environ Sci 1:9–17

Mukhopadhyay SK (2007) The Hooghly estuarine system, NE coast of Bay of Bengal, India. Paper presented at the workshop on Indian estuaries, CSIR-National Institute of Oceanography, Goa, 25 June 2007

Niyogi D (1970) Morphology and evolution of the Balasore shoreline, Orissa. In: Studies in Earth Sciences, West Commemoration Vol, Today and Tomorrow's Printers and Publishers, New Delhi, India, pp 289–304

NOAA Optimum Interpolation (OI) Sea Surface Temperature. https://www.psl.noaa.gov

O'Brien MP (1931) Estuary tidal prisms related to entrance areas. CivEng 1(8):738–739
O'Brien MP (1969) Equilibrium flow areas of inlets on sandy coasts. J Waterw Harb Coast Eng Div 95:43–55
Paul AK (1996) Identification of coastal hazards in West Bengal and parts of Orissa. Indian J Geomorphol 1(1):1–17
Paul AK (2000) Cyclonic storms and their impacts on West Bengal coasts. In: Rajamanickam GV, Toley MJ (eds) Quaternary sea level variation, shoreline displacement and coastal environments. New Academic Publishers, Delhi, pp p8-31
Paul AK (2002) Coastal geomorphology and environment: Kanthi coastal plain, Sundarban coastal tract and Subarnarekha delta plain. ACB Publications, Kolkata, West Bengal, India
Paul AK (2011) Coastal drainage problems in response to sea level rise: a study in Midnapore-Balasore coastal zones and Sundarban coastal tracts. Indian J Geol 83(1–4):41–60
Paul AK, Jana S (2018) Genetical classification of deltaic and non deltaic sequences of landforms of Subarnarekha middle course and lower course sections in Odisha and parts of West Bengal with application of geospatial technology. J Coast Sci 5(1):16–26
Paul AK, Chatterjee S, Paria S (2005) Morphodynamics and vulnerability issues of Nayachar Island in the Hugli Estuary section of Ganga Delta. Indian J Geog Environ (10):76–92
Paul AK, Islam SM, Jana S (2014) An assessment of physiographic habitats, geomorphology and evolution of Chilikalagoon (Odisha, India) using geospatial technology. In: Finkl CW, Makowski C (eds) Remote sensing and modelling—advances in coastal and marine resources, Springer, Cham, pp 135–160. https://doi.org/10.1007/978-3-319-06326-3
Paul AK, Ray R, Kamila A et al (2017) Mangrove degradation in the Sundarbans. In: Finkl CW, Makowski C (eds) Coastal wetlands: alteration and remediation, Springer, Cham, pp 357–392. https://doi.org/10.1007/978-3-319-56179-0
Paul AK (2014) Morphology of estuaries and tidal inlets: an emphasis on Hugli, Subarnarekha and Chilika systems along the Bay of Bengal shoreline. In: Proceedings of the national conference on modern trends in coastal and estuarine studies, Tilak Maharashtra Vidyapeeth, Pune, Maharashtra India, 6–7 Feb 2014
Paul AK, Kamila A, Ray R (2018) Natural threats and impacts to mangroves within the coastal fringing forests of India. In: Makowski C,Finkl CW (eds) Threats to mangrove forests—hazards, vulnerability, and management, Springer, Cham, pp 105–140. https://doi.org/10.1007/978-3-319-73016-5
Paul AK, Kamila A (2018) Studies on coastal morphometry with total station survey in shore face of Sagar island to assess the impacts of sea level rise. Paper presented at the 38th INCA international congress on emerging technologies in cartography, Indian National Cartographic Association, Hyderabad, 1–3 Nov 2018
Walton TL, Adams WD (1976) Capacity of inlet outer bars to store sand. In: Proceedings of the 15th conference on coastal engineering, University of Hawai, Honolulu, 11–17 Jan 1976, pp 1919–1937

Chapter 69
Analysis of Morphodynamics of Bhasan Char Island of Bangladesh Using Time Series Satellite Data and Its Vulnerability to Cyclones

D. Dutta, Tanumi Kumar, Chiranjivi Jayaram, Arati Paul, Wasim Akram, and C. S. Jha

Abstract Morphodynamic and vegetation changes of the Bhasan Char Island were analysed using Landsat data of 2002–2020 winter season. The changes in landmass and shoreline have been assessed under both high-tide and low-tide conditions. The differences in the landmass between high-tide and low-tide condition varied from 1.58 km^2 to 12.86 km^2 in 2003 and 2020, respectively. Images representing high-tide and low-tide conditions revealed that the area of the island was increased by about five times in 2020 as compared to 2003 with annual growth rate of 3.47 $km^2\ yr^{-1}$ and 4.13 $km^2\ yr^{-1}$, respectively. Out of four temporal intervals, the landmass gain was minimum in 2003–2010 and maximum in 2010–15. In comparison with accretion, the erosion was negligible accounting less than 0.06 $km^2\ yr^{-1}$. Similar to landmass, the shorelines were also increased by 2.54 km yr^{-1} and 3.86 km yr^{-1}, respectively, under high- and low-tide conditions. The net increase in shoreline length between 2003 and 2020 was 43.23 km. Present study also revealed that there had been a clockwise orientation of the shoreline by about 8 km towards east during 2004–2008. The vegetation condition of the island was assessed using Normalized Difference Vegetation Index (NDVI) in which the mean NDVI values reached to its maximum

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(>0.16) in 2013, and thereafter, a decrease was noticed which was continued till 2018. After 2018, the NDVI values again started increasing which demonstrates the natural succession and implementation of conservation measures. Besides landmass and shoreline change, the vulnerability of the island with respect to tropical cyclones and storm surge heights were also examined. It was found that some of the most devastating cyclones developed over Bay of Bengal had trajectory passing over the Bhasan Char Island. The storm surge height recorded in the nearby station indicates that the island is prone to flooding due to storm surge, especially if coincided with spring tide. Several recommendations have been suggested for monitoring, disaster warning and conservation needs keeping in view the dynamic nature of the island and coastal vulnerability. The findings of this study could be useful in the informed decision-making by the policy-makers and planners working in the area of land-use planning including resettlement, ecological restoration and management of ecosystem services.

Keywords Bhasan Char · Landsat · Landmass · Shoreline · NDVI · Cyclone storm surge

69.1 Introduction

The Ganges–Brahmaputra–Meghna (GBM) is one of the largest estuaries in terms of sediment water discharge into the Bay of Bengal. The estuary forms a complex network of braided tidal channels with strong tidal streams in many places. The rivers originating from the Himalayas throughout their vast catchment areas (1.52 million km^2) carry billions of tons of silt along with water of about 1200 km^3 yr^{-1} and deposit in the Bay of Bengal, resulting in significant changes in the morphology of the coastal areas (Islam et al. 2019). According to Rahman et al. (2018), sediment load in the Brahmaputra and the Ganges river vary from 402–710 and 516–721 million tons yr^{-1}, respectively. The extent of production and transportation of the sediments, however, is shaped by different land use/land cover, their alteration and management practices both at upstream and downstream (Kidane and Alemu 2015; Uddin et al. 2018) as well as human interventions. This results in substantial physical transformations of the coastal landscape (Nienhuis et al. 2020). Among different coastal zones of the world, the Meghna Estuary of Bangladesh is considered to the one of the most morphologically dynamic areas, undergoing significant change in land formations (Paul and Rashid 2017). Due to high sediment input from upstream and high tidal energy, Meghna Estuary is very dynamic in nature and characterized by erosion and accretion on the scale of several thousand hectares of land per year, although accretion is the dominant process (DABW). In this natural process, the rainfall, sea-level rise, ocean waves, erosion, sedimentation, wind and tides directly interact with materials to build coastal islands (Brammer 2014; Coleman et al. 2020). The deposition of sediments in the floodplains turns into raised landforms gradually over time (Al et al. 2018; Datta and Deb 2012) and manifests in different shapes and sizes, ranging from low line flat beaches to undulating high hills through natural coastal geomorphodynamic processes (Paul and Rashid 2017). For example, the confluence of the Ganges and the Brahmaputra has witnessed new island formation across the Bay (Abdullah et al. 2019; Brammer 2014; Jakobsen et al. 2002). Besides the total river discharge, there is pronounced seasonal variation in water and sediment supply from the river system. Seasonal variation of the freshwater input into the estuary ranges from 20–30 times. The highest discharge occurs during August–September and the lowest in February. Besides the influence of upstream catchment, the entire Meghna Estuary (and a part of the upstream river system) is tide influenced throughout the year. The region is strongly dominated by semi-diurnal tidal regime with a range of 4 m in height and tidal currents up to 300 cm^{-1} (Barua 1990). The tidal range increases in the direction from south-west (abound 4 m at South Bhola) towards north-east (around 7 m at Sandwip). In the tide dominated deltas, sediments are reworked and re-deposited (Hori and Saito 2007). Long-term predicted sediment budget for the Meghna delta by Goodbred and Kuehl (2000) reveals that one-third of the sediment carried by these rivers is deposited on the flood plain and tidal plain and one-third is trapped in the sub-aqueous delta, but no clear picture was obtained about the remaining sediment load; hence, it was concluded that probably the remaining sediments were transported to the deep ocean floor. The dynamics of coastal morphology is further restructured due to occurrence of frequent cyclone and storm surges in the Bay of Bengal which may intensify under present scenario of global warming.

During 1978, land reclamation project (LRP), Meghna Estuary studies (MES) and estuary development programme (EDP) studies have greatly increased the understanding of the physical processes of sediment transport, erosion and accretion. The data have been analysed to understand the land formation and sediment dispersion processes and to assess the impact of exogenic factors and human interventions. Brammer (2014) mapped the coastal regions and sea-level rise to develop the disaster risk reduction (DRR) strategies for coastal flooding. Ciavola et al. (2015) used Landsat images of 1978, 1989, 2001, 2006 and 2014 to develop a land cover map for Sandwip Island. The shoreline position change between 1989 and 2010 for Hatiya Island in Bangladesh was monitored using Landsat image-based indices (Ghosh et al. 2015). Abdullah et al. (2019) have reported that the formation of new islands along the coastal zone of Bangladesh has been significant over the years. They have made an effort to study the dynamics of land gain and loss along the Bangladesh coast. Uddin et al. (2020) have found that high volume of sediment load and its deposition across the Bay of Bengal has caused significant changes in the morphology of the Bay, including the development of islands across the Bay area. However, very few studies are available on the geomorphological changes of newly evolved islands on the regional scale.

From the available literature, it is apparent that not much studies have been carried out on the landmass changes of Bhasan Char Island since its existence and its implication on rehabilitation of migrant refugees from Myanmar. Therefore, we have attempted to present first comprehensive local-level assessment to analyse the morphological changes that have occurred in the Bhasan Char Island since 2003. The specific objectives of the study are to (i) examine the landmass change over 2003 to 2020, (ii) study the status of vegetation change in the island and (iii) likely severity of cyclone on the island based on historic data. In doing so, we aimed to discuss the implications of morphological changes and recommend actions for conservation and development planning. The outcome of the study may be useful for developing more nuanced adaptation strategy in the newly evolved island.

69.2 Study Area

In this study, Bhasan Char, a newly emerged offshore island off the coastal region of Bangladesh was selected to determine the rapid changes in the shoreline and area since its evolution, till December 2020. This island has special significance due to the proposed relocation of Rohingyas from various refugee camps of Kutup along and Chittagong areas under the 'Ashrayan' project of the Government of Bangladesh. The island is influenced by the Meghna estuarine system, belonging to the active Ganga–Brahmaputra–Meghna deltaic region, wherein large volume of sediments are being deposited from the upper catchments. The area of the island is highly variable due to the accretion and erosion processes and varies between 17 km^{-2} in 2003 and 66 km^{-2} in 2020. The island is located in the jurisdiction of Noakhali District of Bangladesh, between 22° 19′ 31″N and 22° 24′ 42″N latitude and 91° 21′ 26″E to 91° 26′ 15″E longitude. The island is surrounded by Bamni River in the north, Meghna River in the west, Sandwip Island in the north-east, Hatiya Island in the south-west and Bay of Bengal in the south (Fig. 69.1). The East Hatiya Channel, the Sandwip Channel and the channel linking the Hatiya and Sandwip channels are dominated by strong tidal currents (Barua 1997). A prominent, counterclockwise, residual circulation is present (DHV 2001; Sokolewicz et al. 2007). The tidal regime of the island is characterized by macro-tidal type, with tidal variation in the range of 3–6 m from neap to spring tides (Hayes 1979; Sokolewicz et al. 2007). The average elevation of Bhasan Char is 2.84 m above the mean sea level (Banerjee 2020). The island is still undergoing considerable landmass changes and natural consolidation processes. According to the Koppen climate zone, the study area has a tropical Savanna climate (Aw) with an average rainfall of 2424 mm (Climate-Data, Org, 2019). The average annual rainfall of the nearest observatory at Chittagong is 2735 mm. The rainy season is from April to October. Generally, July is the wettest month, and January is the driest month.

69.3 Data Used and Methodology

69.3.1 Images Used

Data from Landsat satellite images from 2000 to 2020 were used to quantify the shoreline changes and landmass gain or loss. The Landsat 7 Enhanced Thematic Mapper Plus (L7 ETM+) (2000–2012) and Landsat 8 Operational Land Imager (L8

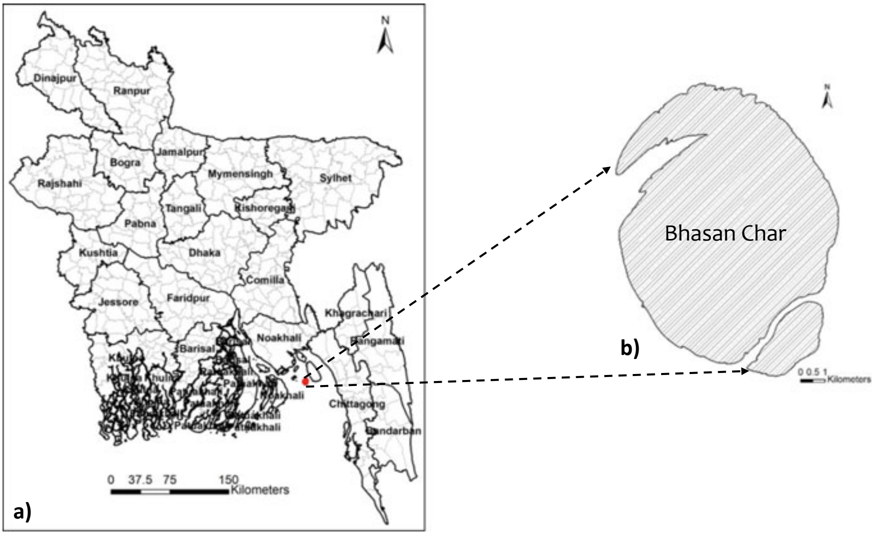

Fig. 69.1 **a** Location of the study area, **b** satellite view as on 2020

OLI) data (2013–2020) of December month were used for the study. L7 ETM + data are available since June 1999, while L8 OLI and thermal infrared sensor (TIRS) are available since March 2013. Both the satellites have 710 km sun-synchronous circular orbit with 98.2° inclination and overpass at every 16 days with the equatorial crossing time of 1:00 am (local time). In the present study, level 1TP product (radiometrically and ortho-corrected) data were used. L8/OLI has nine spectral bands ranging from 433 to 1390 nm at 30 m spatial resolution and one panchromatic channel at 15 m spatial resolution. All the images used in the study were of December month to minimize the seasonal effects (Emran et al. 2016) as the sea level is the lowest during winter months when the rainfall is very low (Ghosh et al. 2015) helping in easy identification of shoreline. The images were selected considering the cloud cover, image quality and also the tidal prediction data from the Chittagong Port, Bangladesh. An effort was made to select the satellite data, based upon the overpass time and the tide chart. The data were downloaded from the Earth Explorer website (https://earthexplorer.usgs.gov/). Fifty-five data sets were checked for data quality and also neap and spring tide prediction data corresponding to Chittagong Port of Bangladesh. The area falls in the path and row of 136/45. The details of the selected scenes used for shoreline and landmass change analysis are given in Table 69.1. Additionally, Sentinel-2 scenes were examined to understand the changes in the shoreline and landmass of the Bhasan Char Island.

Table 69.1 Landsat satellite data selected for shoreline and landmass change

Date	Tide			Satellite overpass	
	Peak time	Height (m)	Type	Start time	End time
28.01.2003	09:57	0.62	Low tide	10:07:18	10:07:45
01.12.2010	09:03	0.79	Low tide	10:11:43	10:12:10
07.12.2015	10:56	0.93	Low tide	10:18:54	10:19:26
19.01.2020	08:17	0.6	Low tide	10:18:56	10:19:27
14.12.2003	09:53	3.38	High tide	10:07:34	10:08:02
15.01.2010	06:37	3.4	High tide	10:10:19	10:10:46
05.01.2015	06:33	3.58	High tide	10:18:49	10:19:21
04.12.2020	08:54	3.77	High tide	10:19:07	10:19:38

69.3.2 Image Processing

Time series Landsat data (ETM+ and OLI) from 2000 to 2020 were analysed for the land water mask (LWM) and normalized difference vegetation index (NDVI) calculation. Land–water boundary was demarcated using modified normalized difference water index (MNDWI, Xu 2006). The normalized difference water index (MDWI) provided by McFeeters (1996) was modified by the substitution of a middle infrared band in the NDWI. The modified NDWI can enhance open water features while efficiently suppressing and even removing built-up land noise as well as vegetation and soil noise. Green and shortwave infrared bands of Landsat satellite data were used to delineate the land water boundary. Band 2 (0.52–0.60 μm) and band 5 (1.55–1.75 μm) of L7 and Band 3 (053–0.59 μm) and band 6 (1.57–1.65 μm) of L 8 OLI were used for computing MNDWI. It is given as follows:

$$\text{MNDWI} = (R - R_{\text{swir}})/(R + R_{\text{swir}}) \tag{69.1}$$

where R = spectral values of the green band and R_{swir} = spectral values of the shortwave infrared band in the Landsat imagery.

A Boolean approach was used over the MNDWI images to create two classes, viz., land and water. The threshold MNDWI for land–water boundary was kept >0.15 for OLI and >0.1 for ETM+. It was also observed that the OLI band 6 (1.57–1.65 μm) and ETM + band 5 (1.55–1.75 μm) are equally effective in discriminating land and water. Hence, a hybrid approach was followed using MDWI, shortwave infrared band and online digitization to precisely delineate the shorelines. On-screen digitizing of shoreline was undertaken to create the shoreline layers. Using the resulting coastal boundary, coastal morphological changes were examined.

NDVI was used as proxy to vegetation growth and calculated using the infrared and red bands. It is calculated as follows:

$$\text{NDVI} = (R_{\text{nir}} - R_{\text{r}})/(R_{\text{nir}} + R_{\text{r}}) \tag{69.2}$$

Table 69.2 Look up table for change analysis

T1	T2	Output	Code
Land	Land	No change	1
Land	Water	Erosion	2
Water	Land	Accretion	3

T1 and T2 refer to two different years

where R_{nir} = spectral values of the near infrared band and R_r = spectral values of the red band. The values of which can vary from −1 to + 1. The values of the index for the waterbody are usually negative, while that for plants will be generally high positive (Huete and Jackson 1987).

For change detection in terms of land gain or loss over different temporal intervals, the coastline vectors were generated with polygon feature and rasterized with spatial resolution of 30 m. Using 'Modeller' tool of ERDAS image processing software, a look up table was generated using rasterized polygon of two different time intervals. Three combinations were generated as given in Table 69.2.

69.3.3 Administrative Boundaries of Bangladesh

These files were extracted from the Database of Global Administrative Area (GADM) version 1.0, in March 2009. GADM is a geographic database of global administrative areas (boundaries). The data were downloaded from www.gadm.org.

69.3.4 High-Resolution Optical Satellite Data

High-resolution data of Google Earth were used for visualization and analyses of detailed anthropogenic interventions in the Bhasan Char area including houses, flood protection barrier, drainages, roads, cyclone shelters, plantations, etc.

69.3.5 Tide Data

Tide prediction data were generated using WTides, which is an enhanced port to Windows, of David Flaters Unix programme XTide, for Chittagong Port. The data for the period 2017–2020 were downloaded from http://cpa.portal.gov.bd/. The data set provides date, time, tide height and type of tide. The tide data of Chittagong Port is given in Annexure II and tide type with respect to satellite overpass date and time in Annexure III.

69.3.6 Cyclone Data

Historic cyclone data were obtained from International Best Track Archive for Climate Stewardship (IBTrACS) which provides global tropical cyclone best track data in a centralized location to understand distribution, frequency and intensity of tropical cyclones worldwide. The data were downloaded from https://www.ncei.noaa.gov/data/ (Knapp et al. 2010). The ‘ibtracs.ALL.list.v04r00.csv’ file contains 179 years data (1842–2020) including basin, sub-basin, name, ISO time, nature, latitude, longitude, landfall velocity, stage, storm speed and direction, among others. In addition to the .csv files, the .shp files related to cyclone tracks (lines, IBTrACS.ALL.list.v04r00.lines; points, IBTrACS.ALL.list.v04r00.points) were also used in the study. In order to know the local details of the cyclone, available literature was also studied and referred (e.g. Hossain and Mullick 2020).

69.4 Results

69.4.1 Changes in the Shoreline and Landmass of Bhasan Char Island

A total of 51 Landsat (ETM+ and OLI) and Sentinel-2 scenes were examined to understand the changes in the shoreline and landmass of the Bhasan Char Island. The scenes were classified as high-tide and low-tide images (hereinafter referred as HT images and LT images) by comparing the satellite overpass time and the tide chart. When the satellite overpass date and time were within ± 2 h of the high tide of the day, the images are considered as HT images. Similarly, when the overpass time was within ± 2 h of the low tide of the day, the images were considered as LT images. Figure 69.2 shows the tide chart of the Chittagong Port, the nearest tide gauge station. As per Fig. 69.2, the difference in water level between satellite overpass time and time of maximum/minimum tide height was not more than 1 m. Hence, it was considered reasonable to compare the shoreline and landmass change using the satellite data

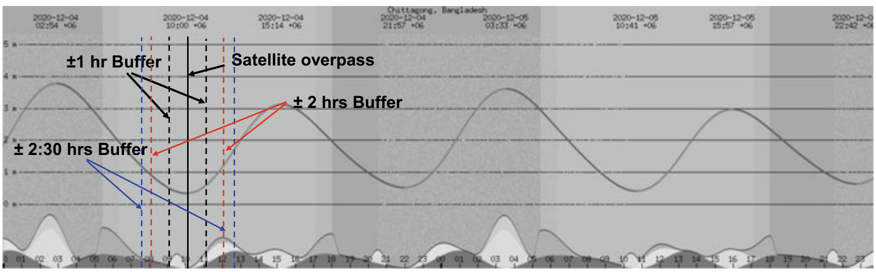

Fig. 69.2 Satellite overpass time (mean) overlaid on tide chart of Chittagong Port

sets that satisfied the above-mentioned criteria. Out of 51 scenes, 25 scenes were HT images, and rest 24 were LT images.

The landmass (km^2) and the length of the shorelines of all the images were plotted to examine the temporal pattern (Fig. 69.3). The landmass increased steadily during the study period. Similar to landmass, the shoreline length also increased over the years; however, the rate of shoreline increase was less compared to the changes in landmass. In 2020, high value of shoreline length could be due to the formation of isolated landmasses in the north of the main island. To avoid the high dynamic features at short temporal scale, further analyses were carried out at four temporal intervals, e.g. 2003–2010, 2010–2015, 2015–2020 and 2003–2020 to obtain an overall change pattern. Keeping in view the temporal intervals and tide types, eight images of Landsat (four each of high tide and low tide) were judiciously selected (Table 69.1).

The magnitude of the landmass and corresponding shoreline length over different temporal intervals is given in Table 69.3. Under high-tide condition, the area of the island was only 14.80 km^2 in 2003 which increased to 73.85 km^2 in the year 2020, i.e., there is 498% increase over the study period. Landmass increase was more in 2015 and 2020 in comparison with earlier years. Uddin et al. (2020) have reported island area of 13.33 km^2 in 2013 and 41.78 km^2 in 2018 which shows high reformation tendency of the island and its high variability across the years.

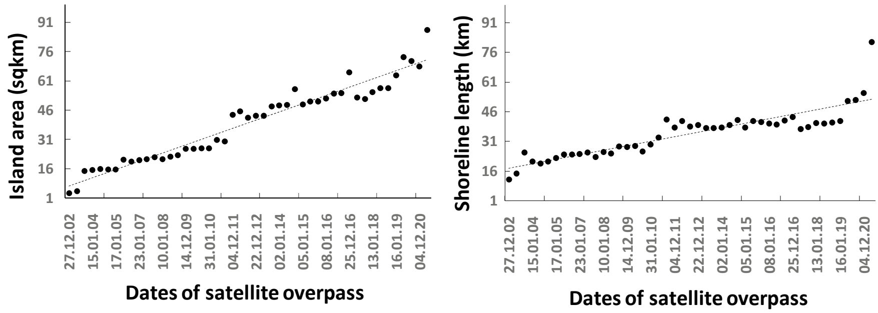

Fig. 69.3 **a** Landmass area (km^2), **b** shoreline length (km)

Table 69.3 Shoreline length and landmass area of Bhasan Char between 2003 and 2020 under different tide conditions

Parameter/year	2003	2010	2015	2020
High tide				
Landmass area (km^2)	14.80	26.54	51.93	73.85
Shoreline length (km)	25.35	25.93	40.09	68.58
Low tide				
Landmass area (km^2)	16.38	30.75	54.41	86.71
Shoreline length (km)	28.03	32.92	39.53	93.75

Under low-tide condition, the landmass area was higher than high tide in all the temporal intervals. It was 16.38 km^2 in 2003 which increased to 86.71 km^2 in 2020, signifying 529% growth over a span of 17 years. The difference in the landmass between low-tide and high-tide condition varied from 1.58 km^2 (in 2003) to as high as 12.87 km^2 (in 2020) which is more than 17% of high-tide condition. It demonstrates the importance of satellite data selection while carrying out change detection study especially in dynamic estuarine tidal regime. From the present study, the rate of landmass increase is 3.47 km^2 yr^{-1} and 4.13 km^2 yr^{-1} between 2003 and 2020 under high-tide condition and low-tide condition, respectively. Figure 69.4a, b shows the landmass changes at regular intervals from 2002 to 2021 under both high- and low-tide conditions, respectively. During 2002, the island appeared as a tiny landmass extended along NE-SW direction. The extension remained unabated till date. In 2012, another isolated landmass was developed in the south-east of the main island but started eroding from 2016, the area of which reduced to less than half in 2020 with respect to the area of 2014 (Fig. 69.4a). While erosion took place from south-east of the island, significant amount of landmass was added in the north of the main island to give it a north–south extended landmass. Close observation of the satellite images of 2004, 2006 and 2008 reveals that there is clockwise reorientation of the island by about 8 km.

The landmass change during low tide is also similar as that of high-tide condition with the exception that during 2010 the isolated landmass in the south-east of the island emerged which was not evidenced in the high-tide image of 2010 (Fig. 69.4b).

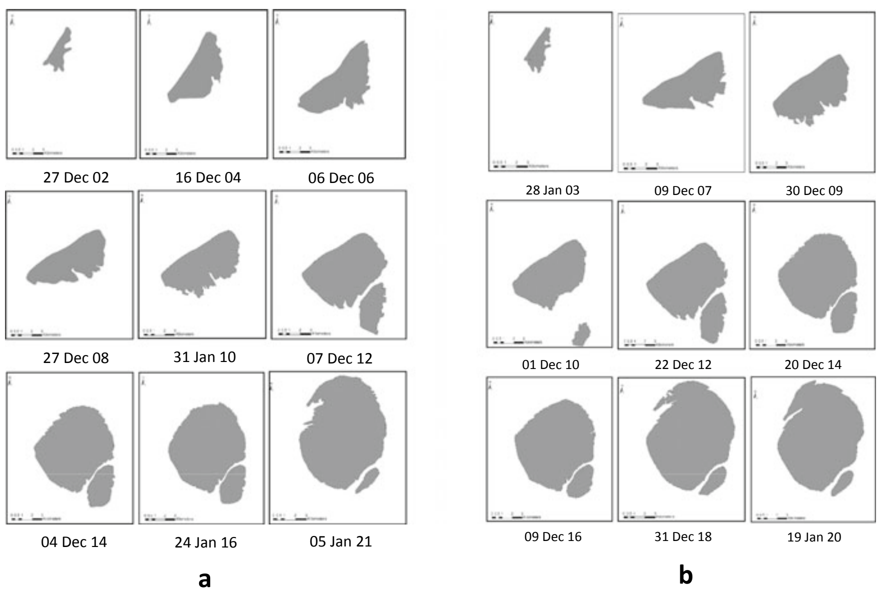

Fig. 69.4 Landmass change during **a** high-tide, **b** low-tide condition over different dates of satellite overpass

The consistent erosion of the isolated landmass in the south-east of the main island is evident in LT images also.

Figure 69.5 shows large variation in the shoreline under both the high- and low-tide conditions. In comparison with 2003, the growth of the island was more towards south-east direction (Fig. 69.5a, b), the trend of which remained similar till 2015, but with a growth in the north direction. After 2015, there was significant growth in the north direction of the island. The clockwise reorientation of the island along SW-NE direction is evident between 2004 and 2008 (Fig. 69.5c). However, after 2008 it is not evidenced. Consistent increase in landmass since December 2012 resulted in considerable increase in area during January 2016. During January 2018, the northward extension was further accelerated as isolated landmass close to north-west direction of the island. While advancing towards north, the isolated landmass developed in the south-east of Bhasan Char during 2009 got significantly reduced in December 2010 with marginal increase in December 2011 under high-tide condition. Thereafter, it reduced continuously till 2020 especially along the eastern direction. Uddin et al. (2020) had reported that the erosion for Sandwip Island occurred in the southern part of the island. Our observation is also similar to what had been observed for Sandwip Island.

Under the high-tide conditions (Table 69.4), the shoreline length increased from 25.35 km in 2003 to as high as 68.58 km in 2020 recording 270% growth over the time span. Interestingly, the shoreline length did not change much between 2003 and

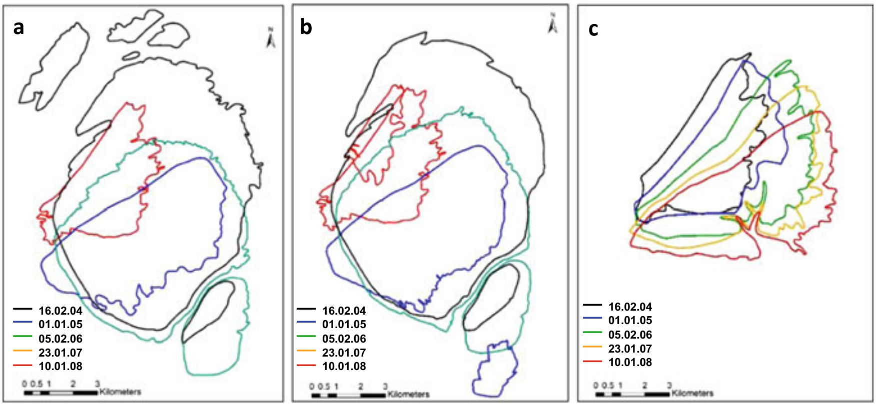

Fig. 69.5 Shoreline changes over the years **a** hide tide, **b** low tide, **c** clockwise orientation of the island during 2004–2008 under high tide

Table 69.4 Changes in shoreline length (km) between 2003 and 2020 under different tide conditions

Parameter/year	2003–2010	2010–2015	2015–2020	2003–2020
High tide	+0.58	+14.16	+28.49	+43.23
Low tide	+4.89	+6.61	+54.22	+65.72

2010, but thereafter it increased to more than double. The annual rate of shoreline increase was 2.54 km yr^{-1}. Unlike high-tide condition, during low tide the shoreline did not change much between 2003 and 2015, but afterwards there was a sharp increase due to formation of Char lands in the north and north-west of main island.

Time series Landsat data also revealed that the Swarnadwip and Sandwip Islands have gained landmasses over the years and extended seawards towards east and west, respectively, where as Bhasan Char got extended in the north and north-west. Till December 2016, there was insignificant extension of the Bhasan Char in the north, but in January 2018, an annular northern extension was evident on the satellite data. This got further extended in January 2021 and reached close to the Sawarnadwip Island. From the image, it is also evident that both the Swarnadwip and Sandwip were accreted along the east and west directions, respectively, leaving the channel narrower (Fig. 69.6). It appears from the satellite data of March 2021 that in future the Bhasan Char may merge with Swarnadwip and Sandwip Islands in the north if the sediment transport continues at the present rate.

69.4.2 Temporal Shoreline and Landmass Change Analyses

Change detection was carried out keeping in view the high-tide and low-tide conditions, as the changes were significant under different tide conditions contradictory to what has been reported by Ghosh et al (2015). The changes in the shoreline for four different epochs are given in Table 69.4. Under high-tide conditions, the changes in the shoreline at different temporal intervals were positive with minimum value (+0.58 km) in 2010–2015 and maximum value (+28.49 km) in 2015–2020. The net increase between 2003 and 2020 was 43.23 km under high-tide condition. Under low tide, the net change was positive (+65.72 km) which could be due to the addition of large isolated Char lands in the north and north-west of the main island, as well as some ambiguity in delineating the land–water boundary due to shallow standing water on the mudflats devoid of any vegetation.

Figure 69.7 depicts the spatial change in landmass corresponding to erosion and accretion over different temporal intervals under high-tide (Fig. 69.7a) and low-tide (Fig. 69.7b) conditions. Over the years, the changing pattern is not uniform. However, the erosion and accretion patterns clearly showed a continuous geomorphic sculpturing over the coastal tract in each temporal interval (Hossain et al. 2016). The study reveals that between 2003 and 2010, significant erosion took place from the north and north-west of the island during its reformation; whereas between 2015 and 2020, most of the erosion had taken place from the isolated landmass located in the south of the main island as well as all along the southern periphery of the island. In contrast, significant deposition had taken place in the south, north–south and north during the time span of 2003–2010, 2010–2015 and 2015–2020, respectively. Overall, there were large aggradations during the study period all around the island, except in the western part. The unchanged area had increased during 2010–2015 and 2015–2020 in both high-tide and low-tide conditions indicating the relative stability

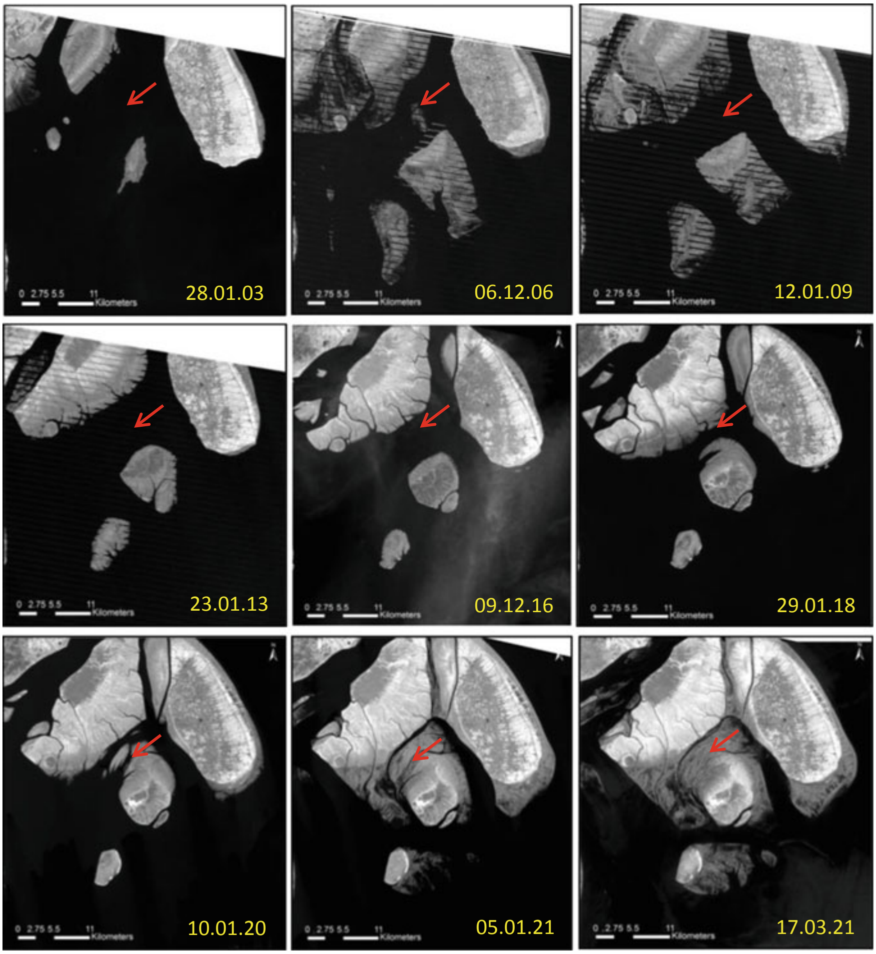

Fig. 69.6 Changes in the landmass of Bhasan Char and adjoining islands between 2003 and 2021

of the landmass. While comparing over the entire temporal span (2003–2020), there was net gain in the landmass in the north and east of the island while loss was confined to a small patch in the west of the island (Fig. 69.7). Significant sediment deposit (Char) had happened from 2015 onwards in the north of the island which helped further addition of landmass as 'Char' land.

Table 69.5 reveals that erosion was very high (12.03 km^2) during 2003–2010 constituting 31.20% of total landmass considering the high-tide condition. However, in subsequent temporal intervals (2010–15 and 2015–2020), the erosion was considerably less, the rate of which reduced from 4.45 $km^2\ yr^{-1}$ in 2003–2010 to only 0.25 $km^2\ yr^{-1}$ in 2010–2015 with noticeable increase during 2015–2020. Considering the entire study period, the rate of erosion was 0.05 $km^2\ yr^{-1}$ only under high-tide

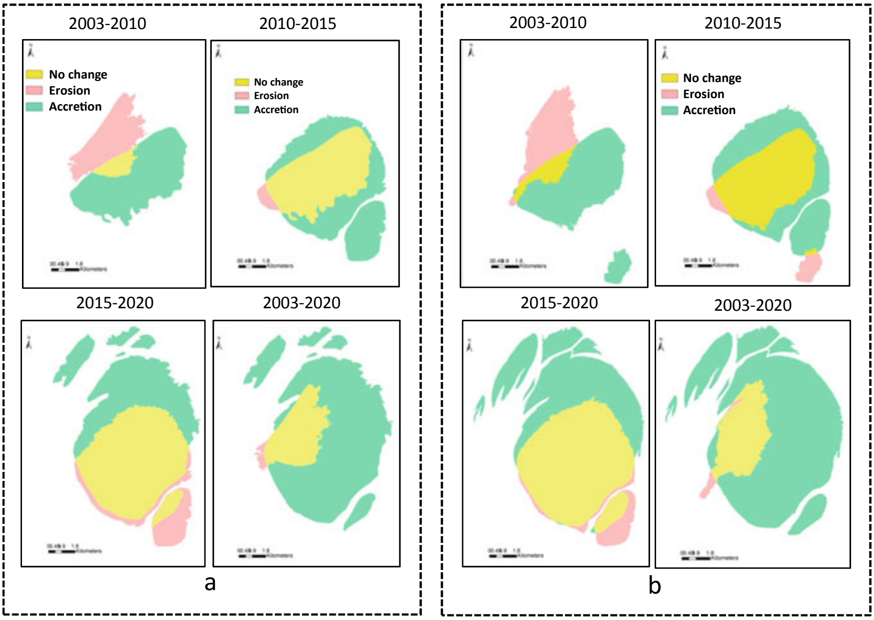

Fig. 69.7 Landmass changes over different temporal intervals **a** high-tide and **b** low-tide condition

Table 69.5 Landmass changes (km^2) at different temporal intervals between 2003 and 2020 under different tide conditions

Temporal intervals	Area in km^2				
	Unchanged	Erosion	Accretion	Total landmass	Net gain/loss
High tide					
2003–10	2.77 (7.17)	12.03 (31.20)	23.77 (61.64)	38.57	11.74
2010–15	25.25 (47.44)	1.29 (2.43)	26.69 (50.14)	53.22	25.40
2015–20	42.01 (50.14)	9.93 (11.85)	31.84 (38.01)	83.77	21.91
2003–20	13.93 (18.64)	0.87 (1.16)	59.92 (80.19)	74.71	59.05
Low tide					
2003–10	3.89 (8.98)	12.49 (28.89)	26.87 (62.13)	43.24	14.38
2010–15	27.09 (46.66)	3.66 (6.30)	27.32 (47.04)	58.07	23.66
2015–20	48.08 (51.68)	6.32 (6.80)	38.63 (41.52)	93.04	32.31
2003–20	15.34 (17.49)	1.03 (1.18)	71.37 (81.34)	87.75	70.34

Figures in the parentheses indicate the per cent of total landmass condition. On the other hand, the physical process of sedimentation and accretion was very high ranging between 38.01% (2015–2020) and 61.64% (2003–2010) with progressive increase in the rate of accretion from 3.39 $km^2\ yr^{-1}$ (2003–2010) to 6.36 $km^2\ yr^{-1}$ (2015–2020). The overall rate of accretion under high-tide condition was 3.52 $km^2\ yr^{-1}$, which was about 70 times more than the rate of erosion over the study period.

Under low-tide condition, in all the temporal intervals, aggradation was the dominant physical force in bringing about changes in the landmass ranging between 26.87 and 38.63 km^2 with an average annual rate of 4.19 $km^2\ yr^{-1}$ that was higher than the low-tide condition. The pattern of erosion is similar to high-tide condition with maximum value of 12.49 km^2 (1.78 $km^2\ yr^{-1}$) in 2003–2010 and minimum of 3.66 km^2 (0.73 $km^2\ yr^{-1}$) during 2010–2015. Considering the entire study period, the rate of land loss was only 0.06 $km^2\ yr^{-1}$, which is about 70 times less than rate of accretion, similar to the high-tide condition. Table 69.5 shows that unchanged area was the highest during 2015–2020, which indicates the stability of the landmass over this period. Comparison of Landsat images taken in 2003 and 2020 showed a net land gain of 50.05 km^2 representing an average annual growth rate of 4.13 km^2 which was higher than the high-tide condition (3.47 km^2). Therefore, it may be inferred that the changes of land areas for the Bhasan Char are inclined towards the gaining phase with a considerable seaward extension of landmass. This historical evidence of large-scale net annual land gain in the Meghna Estuary suggests that land gain might exceed the loss resulting from the slow rate of sea-level rise projected for the twenty-first century (Brammer 2014).

69.4.3 Changes in the Vegetation Cover

Vegetation growth was examined over a period of 20 years (2001–2021) using satellite-derived proximal indicator. At the time of evolution, most of the landmass was mudflat, and gradually the vegetation came up during 2004–05 time period. The scatterplot (Fig. 69.8) shows the temporal variability of maximum NDVI ($NDVI_{max}$)

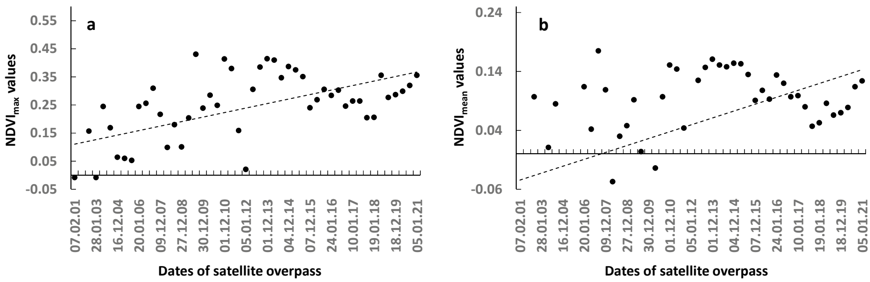

Fig. 69.8 Temporal NDVI values of the island **a** maximum NDVI and **b** mean NDVI

and average NDVI ($NDVI_{mean}$) data. Both the temporal $NDVI_{max}$ and $NDVI_{mean}$ values abruptly decreased during 2018, after which the values regained the increasing. This abrupt decrease could be due to anthropogenic disturbances caused by construction activities for relocation of Rohingya shelter homes. During December 2007 and 2009 as well as in January 2012, the mean NDVI values of the island were negative, which could be due to additional mudflat area added to the south of Bhasan Char. Although the maximum value of NDVI was more than 0.3 in the recent years, the overall value of NDVI was less than 0.2.

Figure 69.9 shows the ecological transformation of the island based upon the NDVI data over selected dates of satellite overpass. From the figure, it can be seen that during the reformation of the island (2002–2008), vegetation density was very

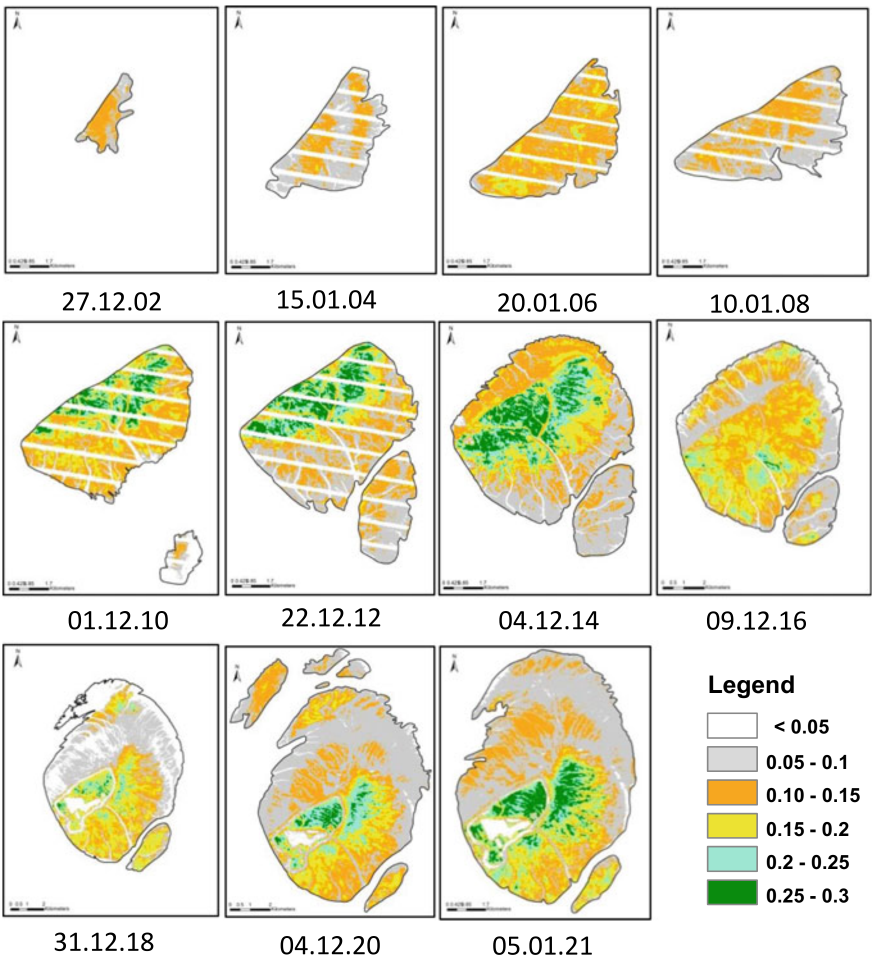

Fig. 69.9 Spatio-temporal change in the NDVI values in the island

poor (between 0 and 0.1), but in 2010 NDVI values increased, particularly in the older part of the island. The extent of higher NDVI values (~0.3) increased along the south-east direction of island till 2014. After 2014, there was an abrupt decrease in the NDVI values in the central portion of the island, but the values regained the increasing trend after December 2020. The large void in the western part of the island in the image of January 2021 is due to the new habitation of the Rohingyas developed under the 'Ashrayan' project by the Government of Bangladesh. The study reveals that the overall vegetation greening process picked up after 2019 based on the spatio-temporal changes in the NDVI values. However, considerable area in the north of the island was devoid of vegetation (mudflat) with NDVI values between 0 and 0.1 only. High values of NDVI are maintained after 2019 in the refugee camp area which could be due to the plantation activities. Uddin et al. (2020) reported NDVI value of 0.34 for Jhajer Char Island in 2018 which corroborates the findings of the present study.

69.4.4 Historical Cyclones and Storm Surges in the Lower Meghna Estuary and like Impact on Bhasan Char

The Bay of Bengal is a potentially energetic region for the development of cyclonic storms accounting for about 7% of the global annual total number of tropical storms (Barua 1990). Tropical cyclones forming over the Bay of Bengal have a lifetime of one week or longer. The coastal regions of Bangladesh are subject to cyclonic devastation almost every year. The cyclones occur mostly between May and November, but the cyclones during early summer (April–May) and post-rainy season (October–November) are more destructive due to greater instability in the atmosphere and weak vertical winds. The low-lying coastal areas are particularly vulnerable, thus placing the population, infrastructure, agriculture, livestock and economic development in a high-risk situation.

The reasons for the disproportionate large impact of storm surges on the coast of Bangladesh can be explained as a unique combination of (i) high astronomical tidal range ranging from 3 m near the Indian border in the west to as high as 5 m near Sandwip Island at the mouth of Meghna Estuary (meso to macro) (Ciavola et al. 2015), (ii) triangular shape at the head of the Bay of Bengal (the funnelling coastal configuration reduces the width of storm-induced waves and increases the height), (iii) low lying and flat topography of the offshore islands and the coast of Bangladesh (<3 m), (iv) shallow continental shelf, especially in the eastern part of Bangladesh (the intense storms move across shallow shelf seas resulting in the waters get piled-up along the coast) and (v) re-curvature of the tropical cyclone in the Bay of Bengal. Besides, the coasts are situated at right angles in the northern corner of the Bay of Bengal which causes higher storm-induced waves compared to a straight shoreline (Flierl and Robinson 1972).

The tidal ranges in Bangladesh coast show gradual increase from west to east and reach to its maximum at the Meghna Estuary; thereafter, it decreases in south-east direction. Ciavola et al. (2015) have reported that Sandwip Island has a higher tidal range than Chittagong (20–25%), and tidal peaks have a 47.5 m delay. The tidal amplitudes also vary with season. During monsoon, a large volume of terrestrial run-off gets mixed up with the saline water of the Bay, resulting in an increase in the volume of the water, and consequently the tidal amplitude increases. When this high-tide level (October–November) coincides with the storm surge, the impact becomes severe. The triangular shape at the head of the Bay of Bengal helps to funnel the sea water pushed by the wind towards the coast and causes further amplification of the surge. This amplified water level causes extensive flooding while approaching. The shoreline of Bangladesh is characterized by a wide continental shelf, especially off the eastern part of Bangladesh. This wide shelf amplifies the storm surges as the tangential sea-level wind stress field associated with the tropical cyclone pushes the sea water from the deep water side onto the shelf. Being pushed from the south by wind stress, the water has no place to go but upward, which is the storm surge. The phenomena of re-curvature of tropical cyclones developed over the Bay of Bengal are a unique phenomenon which is not fully understood (Fig. 69.10). Under normal situation, the cyclones developed over the Bay of Bengal are supposed to travel from east to west as per the general circulation of the atmosphere but eventually these turn back to north-east.

The storm surges, once generated, are further modified by number of factors, viz., (i) depth of coastal water, (ii) Coriolis effect, (iii) convergence, (iv) tidal ranges, (v)

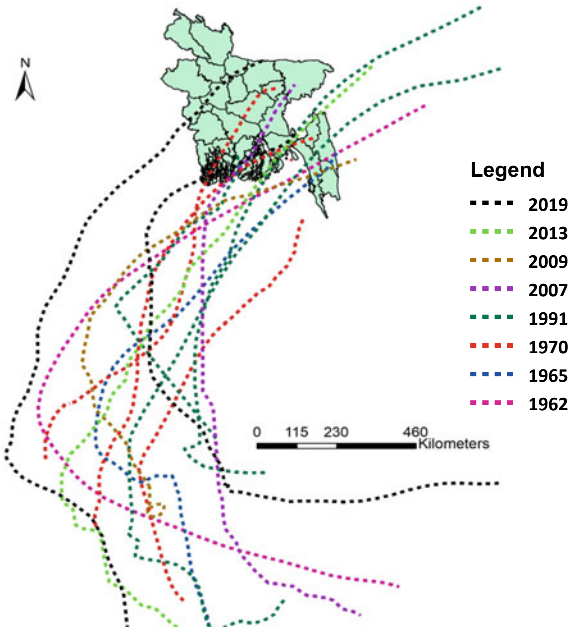

Fig. 69.10 Re-curvature of the cyclone tracks over Bay of Bengal

river, (vi) islands and (vii) cyclone track/route. The amplitude of the surges depends inversely on the depth of water. The Coriolis force occurs due to Earth's rotation. This force acts to the right of the direction of the water motion in the Northern Hemisphere and to the left in the Southern Hemisphere. If the surge is moving northward in the northern Bay of Bengal, it will be deflected towards the east, thereby increasing the surge height along the east coast. The surge is proportional to the convergence which leads to amplification (Proudman 1955). Because of the northward convergence nature of the North Bay of Bengal, surge water is funnelled towards the north leading to height amplification similar to that of shallow bathymetric effect. The braided river system of Lower Meghna Estuary can have a negative effect on surge amplification by allowing deep inland penetration of surges originating in the Bay, which may eventually lead to flood and saline water intrusion. The presence of offshore islands also plays a significant role in surge modification in three different ways: (i) the channels around the islands confine the water within them and compel it to pass through them causing surge amplification, (ii) the islands also act as barrier to impending surge water which may lead to surge amplification and (iii) retard the outflow of surge water back to the Bay after dissipation of the cyclone. Among others, surge height is strongly dependent on the cyclone track. It is the highest to the right direction of the cyclone motion/track. The consequence of all these factors is to produce even a higher positive surge to the right of the cyclone path or point of landfall, whereas the wind on the left being predominantly in the offshore direction drives water away from the coast and produces a negative surge. Negative surges can affect the operation of coastal facilities and ports. Sarker (2019) has shown using MIKE21 Flow Model coupled with the MIKE21 Spectral Wave model that the largest negative surge of up to 1.5 m occurred in the south-eastern coastal water of Bangladesh in the 1991 cyclone.

During the year 1797 to 1991, Bangladesh has been hit by 59 severe cyclones, 32 of which were accompanied by storm surges resulting around 718,000 deaths in the past 50 years (Haque et al. 2012). The deadliest cyclone in Bangladesh was the 1970 'Bhola' cyclone, with a death toll of up to 500,000 (CBC 2008). At least 138,000 people were killed, and as many as 10 million people became homeless during the 1991 cyclones in Bangladesh (NOAA 2008). A total of 14 major cyclones have affected the Bay of Bengal since 1970. Most of the cyclones had landfall over the coastal regions of Cox's Bazar, Patuakhali, Noakhali, Chattogram, Teknaf, Sodadia, Kutubdia Islands and Sundarbans. Cyclones of the pre-monsoon and post-monsoon seasons are the most destructive due to greater instability in the atmospheric and the weak vertical winds. These cyclones generally form over the Andaman sea or south-east of the Bay of Bengal, initially move to west or north-west and then to north and finally to north-east across Bangladesh. The chronology of major cyclones and storm surges in Bangladesh is given by Murty et al. (1986), Khalil (1992), Murty and El-Sabh (1992). Some of the major cyclones that occurred over Bangladesh and the Indian subcontinent are given in Table 69.6.

The 1991 cyclone was the second strongest cyclone affecting the coastal areas of Bangladesh since 1945 (after the 'Bhola' cyclone on 7–13 November 1970) (Sarker 2019). The cyclone developed on 23 April quickly turned into a severe cyclonic

Table 69.6 Some of the major cyclones that affected coastal Bangladesh since 1962

Location and date	Affected area	No of deaths	Remarks	References
Cyclone 26–30 October 1962	Feni-Chittagong area	50,000	Severe cyclonic storm, max wind speed 161 kmph, surge height 2.5 m	Murty et al. (1986)
'Barisal' Cyclone 11–12 May 1965	Barisal-Chittagong coast, landfall between Barisal and Noakhali)	19,279	Cyclonic storm, wind speed 160 kmph, storm surge 3.7–7.6 m	Dhaka Tribune Khan (1995)
'Bhola' Cyclone November 7–13, 1970	Khulna-Chittagong coast, land fall at Hatia	300,000	Severe cyclonic storm, max wind speed 222 kmph, surge height 10.6 m	US Embassy of Bangladesh Dhaka Tribune
'UrirChar'Cyclone 24–25 May 1985	Noakhali-Cox's Bazar coast, landfall at Sandwip	11,069	Severe cyclone, wind speed of 154 kmph, storm surge of 3.0–4.6 m	The Independent Bangladesh Dhaka Tribune
'04B Cyclone' 29-30 November 1988	Sunderbans region	5,708	Severe cyclonic storm, wind speed 162 kmph, storm surge of 4.5 m	The Independent Bangladesh Dhaka Tribune
1991 Cyclone 29 April 1991	Patuakhali-Cox's Bazar coast, landfall at north of Chittagong	138,000	Catastrophic cyclone	The Independent Bangladesh US Embassy of Bangladesh Dhaka Tribune
'Sidr' Cyclone 15 November 2007	Coastal belt of Bangladesh	3363	Cyclonic storm, wind speed of 223 kmph	The Independent Bangladesh Dhaka Tribune
'**Nargis**' Cyclone 8 May 2008	Coastal belt of Bangladesh	3500	Cyclonic storm	US Embassy of Bangladesh
'**Aila**' Cyclone 25 May 2009	Offshore 15 districts of south-western part of Bangladesh	150	Cyclonic storm, wind speed 120 kmph	The Independent Bangladesh Dhaka Tribune
'**Mahasen'** Cyclone 16 May 2013	Chittagong	17	Cyclonic storm, wind speed 85 kmph	The Independent Bangladesh Dhaka Tribune
'Roanu' Cyclone 21 May 2016	Chittagong	26	Cyclonic storm	The Independent Bangladesh Dhaka Tribune
'Mora' Cyclone 28 May 2017	Cox's Bazar	7	Cyclonic storm	The Independent Bangladesh
'Fani' Cyclone 04 May 2019	Coastal belt of Bangladesh (north-east ward), eastern coast of India	14	Cyclone with strongest storm	Business Standard

(continued)

Table 69.6 (continued)

Location and date	Affected area	No of deaths	Remarks	References
'Amphan' Cyclone 21 May 2020	Patuakhali, Satkhira, Pirojpur, Bhola and Barguna	18	Cyclone with strongest storm, wind speed 85 kmph	Bdnews24.com Dhaka Tribune

Table 69.7 Maximum positive surges at selected locations along the shoreline of Bangladesh (Sarker 2019)

Location	Latitude (dd)	Longitude (dd)	Max surge (m)	Time (h) on 29.04.91
Hatia Island	22.46	91.11	4.2	20:00
Sandwip Island	22.55	91.52	5.4	20:15
Chittagong	22.36	91.74	5.4	19:45
Anwara	22.18	91.0	5.1	19:30
Kutubdia Island	21.89	91.89	4.4	19:00
Cox's Bazar	21.42	91.96	2.7	15:45

dd = degree decimal

storm and crossed the Chittagong Port on 30 April with a wind speed of more than 130 kmph. The estimated maximum pressure drop was about 60 mb (Talukdar et al. 1992). The maximum wind speed was more than 235 kmph at Sandwip. The lowering of pressure, in conjunction with the full moon, was sufficient to raise the tidal levels to the highest of the normal range. The storm surge (surge plus tide) was 4–8 m high at different areas resulting in submergence of vast areas of Cox's Bazar, Chittagong, Noakhali and Bhola. The maximum positive surges at selected location along the shoreline of Bangladesh are given in Table 69.7.

The cyclone tracks, developed over the Bay of Bengal, were obtained from IBTrACS to understand the vulnerability of the Bhasan Char Island with respect to the historic cyclone tracks. When the cyclone tracks from 1842 to 2020 were plotted with respect to the newly evolved Bhasan Char Island, it appeared that the island is extremely vulnerable (Fig. 69.11) to the cyclones that develop over the Bay of Bengal. Some of the recent cyclones passed reasonably close to this island including 'Bhola' cyclone (46 km north), Mahesen cyclone (37 km north-west), 1991 cyclone (38 km south-east) and Urir Char cyclone (23 km west). Sarker (2019) had estimated the radius of maximum wind speed from the 1991 cyclone ranging from 18.5 km on 29 April at 12:00 UTC to as high as 63 km on 22 April at 18:00 UTC with corresponding 1-hourly wind speed of 58.03 ms^{-1} and 8.29 ms^{-1}, respectively. From the numerical modelling of the storm surge of 1991, it is obvious that Bhasan Char falls in the radius of maximum wind speed.

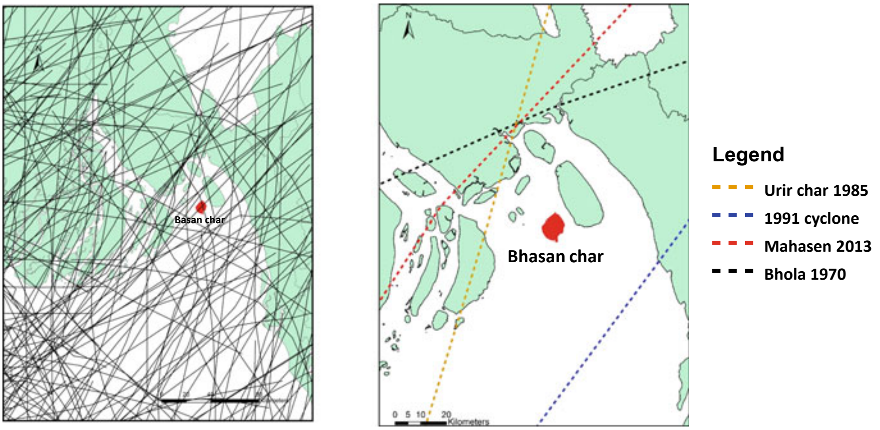

Fig. 69.11 **a** Historic cyclone tracks over Bangladesh, **b** proximity of Bhasan Char with respect to major cyclone tracks

69.5 Storm Surge Model

A tidal surge model is extremely useful to simulate the impact of cyclones on coastal areas and facilities. A number of hydrodynamic numerical models have been developed for storm surge generation and propagation. Numerical models, constructed by Reid and Bodine (1968), Sielecki and Wurtele (1970) and Flather and Heaps (1975), were able to simulate the extent of inundation but not the actual processes of wave propagation, breaking and interaction with the coastal structure. Numerical models are also capable of simulating of storm surges in the coastal areas. Several models were developed for coastal Bangladesh by Das (1972), Jones and Ali (1980), Ghosh et al. (1983), Qayyum (1983), Dube et al. (1985), Flather and Khandaker (1987), Abrol (1987) and Katsura et al. (1992). Most of the models need input as time, elevation of the sea surface, components of depth-mean current, components of the wind stress on the sea surface, components of the bottom stress, atmospheric pressure on the sea surface, the total water depth, the density of the sea water, the acceleration due to gravity and the Coriolis parameter.

A robust and improved model may be useful for designing of coastal and marine structures. Sarker (2019) used MIKE21 Flow Model developed by DHI. He used both the Flow Model and Spectral Wave and tidal model simultaneously in a coupled mode to improve the accuracy of the model prediction. The storm surge model was used for 1991 cyclone to generate wind and pressure fields from cyclone data. The input parameters used were time, track, radius of maximum wind speed, maximum wind speed, central pressure and neutral pressure. Their results also show that the maximum positive surge adjoining to Bhasan Char was between 4.2 and 4.8 m. Similar was the observation (4.3 m) by Deb and Ferreira (2015) for Sandwip Island, but Islam (2015), Flather (1993) and Sarker (2019) have shown slightly higher values for Sandwip Island accounting to > 5.0 m, 5.1 m and 5.4 m, respectively. It is well known (Ciavola et al. 2015) that the tidal ranges in the Bangladesh coast increase from west to east and reache its maximum at the Meghna Estuary. In post-monsoon period due to mixing of large volume of terrestrial run-off, the volume of water increases, resulting in the higher tidal amplitude. When the high-tide level (October–November) coincides with storm surge, the impact could be severe for the newly developed Bhasan Char, the average elevation of which is less than 3 m. The direction of cyclone trajectory also plays an important role by increasing surge height in the east coast (right direction of cyclone motion) due to its eastwards deflection in the North Bay of Bengal. Royal Haskoning DHV (RHDHV) had set up a two-dimensional Regional Tidal Hydrodynamic Model for the Bay of Bengal and its surroundings using the MIKE21 Flow Model FM software of DHI. The model is based on the numerical solution of the two-dimensional shallow water. Model predicted results of 1991 storm surge revealed higher surges of 5.4 m and 5.3 m, respectively, for Sandwip Island and Chittagong. Based upon the model results, the highest surge of approximately 5.4 m was found at Chittagong on 29 April 1991 at 19:45 h where the cyclone made landfall.

69.6 Risk Zone Mapping Using Geospatial Technology

Based upon the landmass dynamics, shoreline change, erosion, topographic deformation, bathymetry, landfall of tropical cyclones, storm surge and tidal height and above all the infrastructure and socio-economic information vulnerability (risk zone), maps can be prepared at cadastral scale for field-level application. Different zones can be identified for various soft and hard measures in a holistic manner to achieve maximum resilience and minimum loss of life and infrastructure. For example, the Multi-Purpose Cyclone Shelter Project (MCSP) in Bangladesh (1993) modelled storm surge along the Bangladesh coast, including flooding along with its depth and duration, with the help of Geographic Information System (GIS) and delineated risk zones. Storm surges height at different wind velocities has been estimated, and corresponding inundation limit from the shoreline has been provided in Table 69.8. In the absence of topographic information, differential interferometric synthetic aperture radar (DlnSAR) technique can be employed along with ground-based observations to record the surface deformation caused by naturally induced surface changes, viz., land subsidence and additional displacement due to anthropogenic pressure. Alternatively, persistent scatterer interferometry (PSI) can be employed which has been demonstrated by Braun et al. (2020) using Sentinel-1 data. One of the major challenge is this process is to establish several stable radar targets across the island for better accuracy of the surface deformation. In this regard, a data repository can be generated based upon the researches carried out in the coastal areas of Bangladesh and also in the islands of the lower Meghna Estuary. This initiative may promote the open science initiative by sharing experiences about obstacles and opportunities of geospatial analyses to tackle current challenges of global change as a response to the call of Braun et al. (2020).

Table 69.8 Typical storm surge inundation characteristics for cyclones of varying strength in Bangladesh

Wind velocity (kmph)	Storm surge height (m)	Limit to inundation (km) from the shoreline
85	1.5	1.0
115	2.5	1.0
135	3.0	1.5
165	3.5	2.0
195	4.8	4.0
225	6.0	4.5
235	6.5	5.0
260	7.8	5.5

Source Appendix: Background Information on the Storm Surge Modelling by Sirajur Rahman Khan, revised by Michiel Damen, ITC

69.7 Discussion

The morphology of the Bhasan Char Island is changing rapidly due to huge river discharge by the Himalayan rivers, tidal effects, re-suspension and frequent cyclone-induced storm surges and flooding. Quantification of the coastal morphological changes was done to better understand the temporal pattern over a span of 17 years (2003–2020). The present study provides insight about how the reformation of the island has happened since its evolution may serve as an important input for land-use planning, conservation management and natural succession. The results show a net gain in land area of about 59.05 km^2 between 2003 and 2020 with an increase of 3.47 $km^2\ yr^{-1}$. It reveals that high volume of sediments from the Himalayan regions is being deposited (Al et al. 2018), and land size is continuously increasing. The sediment source and tidal waves and processes provide the most compelling reasons for the physical changes documented in the islands (Brown and Nicholls, 2015), most notably the expansion of the majority of islands and their locational adjustments. Management of new islands could contribute to the overall land gain of the country as against the projected land submergence due to global warming and sea-level rise in this tidal region. This newly developed Bhasan Char Island has its own significance because it was selected for relocation of around 1,00,000 refugees of the Rohingya minority of Myanmar to reduce the overcrowding of the camps located at Kutupalong and Chittagong regions of Bangladesh. Apart from the landmass dynamics, the vulnerability of the island has also been examined with respect to high-frequency tropical cyclones originated in the Bay of Bengal. The island is located on the trajectory of many deadly cyclones of the past and close to the past landfall locations. Besides, the surge heights are high enough than the mean elevation of the island (< 3 m from mean sea level), which may lead to extensive flooding if there is coincidence of spring tide and cyclone-induced storm surges. The landmass of recent aggradation is mostly devoid of vegetation as is evidenced by the NDVI images, except for some small patches in the island. Based on the present study, the key recommendations are as follows:

(a) Periodic operational monitoring system of the coastal morphological changes in the Meghna Estuary and Bangladesh coast using geo-information technology for optimum land-use planning.
(b) Land surface deformation using differential interferometry or persistent scatterer interferometry study to understand the natural subsidence and anthropogenic impact on the island. Also addressing the deformation regime and role of sea-level rise.
(c) A robust and improved storm surge model, preferably coupled model of Flow Model and Spectral Wave and tidal model, for improving the model accuracy and designing of coastal and marine structures.
(d) Development of an operational early warning system for maximizing the efforts currently undertaken at national level.
(e) Identification of the vulnerable areas in terms of erosion, storm surge and cyclone landfall locations for avoiding further settlement in those areas. In addition to this, identification of the safety zones is necessary for evacuation at the time of disaster.
(f) Carrying out a detailed risk assessment from flooding for representative events, mapping which parts of the island are likely to be inundated, the water depth during the inundation and the residence time of the water.
(g) Creation of a repository of spatial and non-spatial data, viz., cyclone wind speed, tide gauge data including storm surge height and extent and duration of flood. Permanent weather observatory will be a reasonable approach towards weather forecasting and advanced disaster warning.
(h) Creating a bio-shield by planting mangroves or soil/sand binding plants in the vulnerable and eroded areas.
(i) Closing the minor channels may help against the force of flood and ebb-tide current in estuarine channels.

69.8 Conclusions

Morphological changes and position of the shoreline of Bhasan Char Island since its evolution (2003) has been analysed using Landsat satellite data over a period of 17 years. The analyses were carried out in four epochs, and the results show significant changes in the area and shoreline under both high-tide and low-tide conditions. Under high-tide condition, the area of the island increased by 498% in 2020 while comparing with 2003 with the rate of 3.47 $km^2\ yr^{-1}$. The physical process of aggradation outperformed (70%) erosion resulting is significant gain in landmass. The process of aggradation was prominent in the south-east direction till 2016, thereafter erosion became prominent in that direction and aggradation took place in the north direction. Study reveals that there is a clockwise shift of the SW-NE axis of the island by about 8 km towards east till 2008 after which it got stabilized. Similar to the landmass, shoreline change was +270% over the study period with average rate of increase of 2.54 km yr^{-1} under high-tide condition. The net increase in length between 2003 and 2020 was 43.23 km. Time series satellite data reveal that if the present rate of aggradation continues, in near future Bhasan Char may join with Swarnadwip and Sandwip Islands to form a single landmass. In all the epochs, the landmass gain was positive with minimum gain in 2003–2010 and maximum in 2010–2015. For the entire study period, the rate of land loss was only 0.06 km^2 yr^{-1}, which is about 70 times less than the rate of accretion. The vegetation condition of the island was assessed using NDVI in which the mean NDVI values reached to maximum (>0.16) in 2013 and thereafter a decrease continued till 2018. After 2018, the NDVI values again started increasing which demonstrates the natural succession as well as plantation.

The study demonstrates the applicability of RS and GIS techniques for monitoring the landmass and shorelines of newly evolved island such as Bhasan Char. The findings of this study could be of useful in the informed decision-making by the policy-makers and planners working in the area of island land-use planning and ecological restoration including resettlement and management of ecosystem services. Based upon the study, several recommendations have been suggested using geo-informatics, advanced warning system and ground control measures.

Historic cyclone events were analysed to examine the vulnerability of the Bhasan Char Island in respect to frequency of cyclones, storm track and surge height. The low elevation (<3 m) of the Bhasan Char Island coupled with high tide and storm surge may have severe impact on the island. A GIS-based risk zone mapping can be made ready using multi-criteria analysis to take various measures at short, medium and longer timescales. The coupled storm surge model along with flood inundation model can serve as a useful risk zoning to facilitate evacuation and relief management.

References

Abdullah HM, Muraduzzaman M, Islam I et al (2019) Spatiotemporal dynamics of new land development in Bangladesh coast and its potential uses. Remote Sens Appl Soc Environ 14:191–199. https://doi.org/10.1016/j.envc.2020.100001

Abrol V (1987) Application of a linear surge model for the evaluation of storm surges along the coastal waters of Kalpakkam, East Coast of India. Ind J Marine Sci 16:1–4

Al MA, Alam MD, Akhtar A et al (2018) Annual pattern of zooplankton communities and their environmental response in a subtropical maritime channel system in the northern Bay of Bengal,Bangladesh. Acta Oceanolog Sin 37:65–73

Banerjee S (2020) From Cox's Bazar to Bhasan Char: an assessment of Bangladesh's relocation plan for Rohingya refugees [Online], Observer Research Foundation (ORF issue brief 357). Retrieved May 10, 2020, from. https://www.orfonline.org/research/from-coxs-bazar-to-bhasanchar-an-assessment-of-bangladeshs-relocation-plan-forrohingya-refugees-65784

Barua DK (1990) Suspended sediment movement in the estuary of the Ganges-Brahmaputra-Meghna river system. Marine Geol 91:243–253

Barua DK (1997) The active delta of the Ganges-Brahmaputra Rivers: dynamics of its present formations. Mar Geodesy 20(1):1–12

BdNews24: Cyclone Amphan kills 12 in Bangladesh before turning into land depression: https://bdnews24.com/bangladesh/2020/05/21/cyclone-amphan-kills-12-in-bangladeshbeforeturningintolanddepression?fbclid=IwAR3nR8Ep63RtczV5eo59NjZYeHEov2oiOpchz9iA06CO6TgBjY-_N1Hftbk

Brammer H (2014) Bangladesh's dynamic coastal regions and sea-level rise. Coast Risk Manag 1:51–62. https://doi.org/10.1016/j.crm.2013.10.001

Braun A, Hoser T, Blasco Jose Manuel Delgado (2020) Elevation change of Bhasan char measured by persistent scatter interferometry using Sentinel-1 data in a humanitarian context. Eur J Remote Sens. https://doi.org/10.1080/22797254.2020.1789507

Brown S, Nicholls R (2015) Subsidence and human influences in mega deltas: the case of the Ganges–Brahmaputra–Meghna. Sci Total Environ 527:362–374

Business Standard. 14 dead, 63 injured as cyclone 'Fani' hits Bangladesh. Available at: https://www.business-standard.com/article/pti-stories/14-dead-63-injured-as-cyclone-fani-hits-bangladesh-119050400727_1.html

CBC (2008) The world's worst natural disasters Calamities of the 20th and 21st centuries CBC News, May 08, 2008

Ciavola P, Uddin MM, Duo E et al (2015) Vulnerability of the Bangladesh shoreline inundation under cyclone activity: past records and DRR strategies at Sandwip island. In: E-proceedings of the 36th IAHR world congress, the Hague, the Netherlands, 28 June–3 July, 2015

Climate-Data.Org (2019) Bhola Climate

Coleman DJ, Ganju NK, Kirwan ML (2020) Sediment delivery to a tidal marsh platform is minimized by source decoupling and flux convergence. J Geophys Res: Earth Surf 125: e2020JF005558

Das PK (1972) A predictive model for storm surges in the Bay of Bengal. Nature 239:211–213

Datta D, Deb S (2012) Analysis of coastal land use/land cover changes in the Indian Sunderbans using remotely sensed data. Geo-Spatial Inf Sci 15:241–250

Deb M, Ferreira C (2015) Storm surge modelling in the Bay of Bengal, Department of Civil, Environmental & Infrastructure Engineering, Volgenau School of Engineering, George Mason University

Dhaka Tribune, 12 major cyclones from the past, Dhaka Tribune, Available at: https://www.dhakatribune.com/bangladesh/environment/2017/05/30/majorcyclonesbangladesh/?fbclid=IwAR06XP8IyCu0X0gBDSWsMYF7geFoR0nH99-gjEcJvpq2agRUAI39OODTyxk

DHV (2001) Hydro-morphological dynamics of the Meghna Estuary, Meghna Estuary Study, Submitted to Ministry of Water Resources, Bangladesh Water Development Board, by DHV Consultant BV and Associates

Dube SK, Sinha PC, Roy GD (1985) The numerical simulation of storm surges along the Bangladesh coast. Dyn Atmos Oceans 9:121–133

Emran A, Rob MA, Kabir MH et al (2016) Modelingspatio-temporal shoreline and areal dynamics of coastal island using geospatial technique. Model Earth Syst Environ 2(4):1–11. https://doi.org/10.1007/s40808-015-0060-z

Flather RA (1993) A storm surge prediction model for the Northern Bay of Bengal with application to the cyclone disaster in April 1991. J Phys Oceanogr 24:172–190

Flather RA, Heaps NS (1975) Tidal computations for Morecambe Bay, Geophysics. J R Astron Soc 42:489–517

Flather RA, Khandker H (1987) The storm surge problem and possible effects of sea level changes on coastal flooding in the Bay of Bengal. Paper presented at International Workshop on Climatic Change, Sea Level, Severe Tropical Storms and Associated Impacts, UNEP, Norwich, England

Flierl GR, Robinson AR (1972) Deadly surges in the Bay of Bengal: dynamics and storm tide table. Nature 239:213–215

Ghosh SK, Dewan BN, Singh BV (1983) Numerical simulation of storm surge envelops associated with the recent severe cyclones impringing on the east and west coast of India. Mausam 34:399–404

Ghosh MK, Kumar L, Roy C (2015) Monitoring the shoreline change of Hatiya Island in Bangladesh using remote sensing techniques. ISPRS J Photogramm Remote Sens 101:137–144
Goodbred SL, Kuehl SA (2000) The significance of large sediment supply, active tectonism, and eustasy on margin sequence development: late quaternary stratigraphy and evolution of the Ganges-Brahmaputra delta. Sediment Geol 133:227–248. https://doi.org/10.1016/S0037-0738(00)00041-5
Haque U, Hashizume M, Kolivras KN et al (2012) Reduced death rates from cyclones in Bangladesh: what more needs to be done? Bull World Health Organ 90:150–156
Hayes MO (1979) Barrier island morphology as a function of tidal and wave regime. In: Leatherman SP (ed) Symposium on Barrier Islands. Academic Press, New York, pp 1–28
Hori K, Saito Y (2007) Classification, architecture, and evolution of large-river deltas. In: Gupta A (ed) Large rivers: geomorphology and management. Wiley, Chichester, pp 75–96
Hossain I, Mullick AR (2020) Cyclone and Bangladesh: a historical and environmental overview from 1582 to 2020. Int Medical J 25(6):2595–2614
Huete A, Jackson R (1987) Suitability of spectral indices for evaluating vegetation characteristics on arid rangelands. Remote Sens Environ 23:213–218
Islam MS, Rahman MA, Chowdhury TA et al (2019) Geomorphologic change of Bhasan Char island. The new home of Rohingya refugees in the Bay of Bengal, Rohingya-2019. Dhaka, Bangladesh, 28–29 July, 2019
Islam MS (2015) Modelling the effects of cyclonic storm surge and wave action on selected coastal embankments, Ph.D. Thesis, Bangladesh University of Engineering & Technology (BUET), Dhaka
Jakobsen F, Azam M, Mahboob-Ul-Kabir M (2002) Residual flow in the Meghna Estuary on the shoreline of Bangladesh. Estuar Coast Shelf Sci 55:587–597
Jones B, Ali A (1980) The numerical modelling of storm surges in the Bay of Bengal. Q J R Meteorol Soc 106:1–18
Katsura J, Hayashi T, Nishimura H et al (1992) Storm surge and severe wind disaster caused by the 1991 cyclone in Bangladesh, Research Report, No. B-2, Japanese Ministry of Education, Science and Culture
Khan SR (1995) Cyclone hazard in Bangladesh, background information on the storm surge modelling
Kidane D, Alemu B (2015) The effect of upstream land use practices on soil erosion and sedimentation in the Upper Blue Nile Basin. Ethiopia Res J Agric Environ Manage 4:55–56
Knapp KR, Kruk MC, Levinson DH (2010) The 759 international best track archive for climate stewardship (IBTrACS) unifying tropical 760 cyclone data. Bull Amer Meteorol Soc 91:363–376
Mcfeeters SK (1996) The use of the normalized difference water index (ndwi) in the delineation of open water features. Int J Remote Sens 17:1425–1432
Khalil G Md (1992) Cyclones and storm surges in Bangladesh: some mitigative measures. Nat Hazards 6:11–24
Murty TS, El-Sabh MI (1992) Mitigating the effects of storm surges generated by tropical cyclones: proposal, Nat Hazards 6(3):251–273
Murty TS, Flather RA, Henry RF (1986) The storm surge problem in the Bay of Bengal. Prog Oceanog 16:195–233
Nienhuis J, Ashton A, Edmonds D (2020) Global-scale human impact on delta morphology has led to net land area gain. Nature 577:514–518
NOAA (2008) The worst natural Disasters by death toll
Paul BK, Rashid H (2017) Coastal landform changes: coastal erosion, land accretion and subsidence. In: Paul BK, Rashid H (eds) Climatic hazards in coastal Bangladesh. Butterworth-Heinemann, Boston, pp 121–152
Proudman J (1955) The propagation of tide and surge in an estuary. Proc R Soc Lond A 231:8–24
PSMSL (Permanent Service for Mean Sea Level). Available from: http://www.psmsl/data/obtaining

Qayyum MF (1983) Prediction of storm surges for Bangladesh coasts b empirical method: results and discussions. Presented at the WMO-ESCAP Panel on Tropical Cyclones, Dhaka, 22–29 March, 1983, p 12

Rahman M, Dustegir M, Karim R (2018) Recent sediment flux to the Ganges-Brahmaputra-Meghna delta system. Sci Total Environ 643:1054–1064

Reid RO, Bodine BR (1968) Numerical model for storm surges in Galveston Bay. J Waterway Harbour Div 94(WWI):33–57

Sarker MA (2019) Numerical modelling of storm surge from the 1991 cyclone in the Bay of Bengal (Bangladesh) by Royal Haskoning DHV. J Environ Sci Allied Res 2019:109–116

Sielecki A, Wurtele MG (1970) The numerical integration of the nonlinear shallow water equations with sloping boundaries. J Comput Physics 6:219–236

Sokolewicz M, Zhang G, Louter T (2007) Plan form development of the Meghna estuary in Bangladesh. In: Dohmen-Janssen CM, Hulscher SJMH (eds) River, coastal and estuarine morphodynamics: RCEM 2007. Taylor and Francis Group, London, pp 129–135

Talukdar J, Roy GD, Ahmed M (1992) Living with cyclone, community development library, Dhaka, pp 86–102

The Independent, Major cyclones in recent history, Available at: http://m.theindependentbd.com/post/223142?fbclid=IwAR0BDtScrr2pusOKxl8fKhK4SqX2jTG8VXB38dC3uUCbju6sOXhghc2X-Bg

Uddin K, Abdul Matin M, Maharjan S (2018). Assessment of land cover change and its impact on changes in soil erosion risk in Nepal. Sustainability 10(12):4715. https://doi.org/10.3390/su10124715

Uddin, K, Khanal N, Chaudhary S et al (2020) Coastal morphological changes: assessing long-term ecological transformation across the northern Bay of Bengal. Environ Challenges 1. https://doi.org/10.1016/j.envc.2020.100001

US Embassy of Bangladesh: https://bd.usembassy.gov/uscitizenservices/localresourcesofuscitizens/livinginbangladesh/tropicalcyclones/?fbclid=IwAR27RDS-9Us57c9CWpyveYmMXJV5eisNeCkSIGaEkNRjDZAL-4_Q4XdzIRE

Xu H (2006) Modification of normalized difference water index (NDWI) to enhance open water features in remotely sensed imagery. Int J Remote Sens 27:3025–3033

Chapter 70
Time Series Analysis of Climate Variables for Baitarini River Basin of Odisha

Ranu Rani Sethi, S. K. Jena, and D. K. Panda

Abstract Time series analysis, modelling, and forecasting are necessarily becoming the part of management strategies in any river basin. Baitarini River is one of the east flowing rivers of India, which has the drainage area of 14,218 km^2 in two States of Jharkhand and Odisha. Major portion, i.e., nearly 13,482 km^2 areas lie in Odisha covering 42 blocks of eight districts. Water stress during post-monsoon and summer season is the major issue in this river basin. In this paper, time series rainfall analysis for 119 years (1901–2020) was carried out for daily, monthly, seasonal, and annual scales. The average annual, monsoon, post-monsoon, winter, and summer season rainfall were 1416.7 mm, 1093.95 mm, 152.53 mm, 37.95 mm, and 132.26 mm, respectively, for the basin. Statistical parameters (minimum, maximum, mean, standard deviation, coefficient of variation, skewness, and kurtosis) for annual, monsoon, post-monsoon, winter, and summer season rainfall were calculated for each of the location. Temperature variation (1901–2002) of maximum, minimum, and mean temperature was carried out for the basin. The nonparametric Mann–Kendall and Sen's methods were used to determine whether there was a positive or negative trend in rainfall, temperature data with their statistical significance. For the study area, increasing trend in temperature and decreasing trend in rainfall pattern was observed throughout the basin. Hence, hydrological analysis is needed for water conservation measures within the river basin.

Keywords Time series · Baitarini river basin · Mann–Kendall test · Rainfall analysis · Temperature

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70.1 Introduction

The major river basins of the world play a big role in supporting more than 70% of the global population. The hydrological response of any basin is dependent on various climatic variables, in particular temperature and rainfall. Global warming is likely to have significant impacts on the hydrological cycle, which in turn will affect water resources systems (IPCC 2001; Kundzewicz et al. 2008). The dynamic structure of climate is mainly governed by changes in rainfall and temperature. Determining the trends and its magnitude of variations due to climatic changes at the basin scale would provide useful information for the planning, development, and management of water resources. Rainfall being the major source of water in both surface and groundwater resources, agricultural planning is highly dependent on variation of rainfall in different season. In India, more than 70% rainfall is received during monsoon season and in rest of the months water availability is highly unpredictable. Similarly, temperature plays a major role in greenhouse gases in atmosphere. Study showed that anthropogenic emission of various gases has increased considerably since the Industrial Revolution (1750 onward), with an increase of 70% between 1970 and 2004 (IPCC 2007). Implications of climate change on Indian water resources were discussed by Lal (2001). Gosain et al. (2006) quantified the impact of climate change on the water resources of Indian River systems. As per The National Commission for Integrated Water Resources Development (NCIWRD), irrigation sector will consume maximum water followed by domestic and industrial sectors in 2025 and 2050 (CWC 2014). Hence, time series analysis, modelling, and forecasting of climatic parameters are necessarily becoming the part of management strategies within any river basin. The present analysis deals with the determination of trend and the magnitude of changes in seasonal and annual rainfall and temperatures over the last century for Baitarani river basin of India.

70.2 Study Site and Datasets

The Baitarini River is one of the east flowing rivers of India, which has the drainage area of 14,218 km^2 in two states of Jharkhand and Odisha. The basin area is located between east longitudes of 85° 10′ to 87° 03′ and between north latitudes of 20° 35′ to 22° 15′. Major portion, i.e., nearly 13,482 km^2 areas, lies in Odisha covering 42 blocks of eight districts, i.e., Balasore, Bhadrak, Jajpur, Kendrapada, Angul, Keonjhar, Mayurbhanj, and Sundergarh. Precipitation is heterogeneously distributed through the year, with an average annual value of 1420 mm. Dry season typically lasts from March to May and a wet season from June to September. The mean annual temperature is 26.4 °C. May is hottest month, whereas December/January is the coldest month. Monthly rainfall data (1901–2020) and temperature (1902–2002) was collected for eight locations within the river basin. Data were organized according to season, i.e. monsoon (June–September), post-monsoon (October–December), winter (January–February), and summer (March to May).

70.3 Methodology

The rainfall and temperature variability were calculated with basic statistical analysis like measure of central tendencies (mean, median, and mode), measure of dispersion (standard deviation), and degree of symmetry in the distribution (skewness, C_S), degree to peak of data (Kurtosis, C_K), and coefficient of variation (CV). Time series analysis was carried out to determine the trend in data series for all season by using R programme. Temperature anomalies with reference to the mean for each location were found out. These anomalies were plotted against time, and trend was examined by fitting the linear regression line. The linear trend value represented by the slope of the simple least-square regression line provided the rate of change in temperature variables. Using the value of the rate of change, the total change over the last century was computed and used in further calculations for the basin scale estimations. To identify trend in the climatic variables with reference to climate change, the Mann–Kendall test (Mann 1945 and Kendall 1975) has been employed by a number of researchers with temperature, precipitation data series. The rank-based nonparametric Mann–Kendall method was applied to the long-term data in this study to detect statistically significant trends. Sen's slope estimator (S), nonparametric method (Sen 1968), was used to estimate the magnitude of trends in the data time series. A positive value of S indicates that there is an increasing trend in the hydrologic time series; negative values indicate a negative trend.

70.4 Results and Discussion

70.4.1 Rainfall Variability

The summary of rainfall statistics (1901–2020) for eight locations (Angul, Bhadrak, Balasore, Jajpur, Kendrapada, Keonjhar, Mayurbhanj, and Sundergarh) within Baitarini river basin is presented in Table 70.1. Out of eight districts, Angul, Sundergarh, Keonjhar, and Mayiurbhanj fall in the upper catchment area of the river basin, and rest Jajpur, Balasore, Bhadrak, and Kendrapada lies in the lower part of the river basin. The mean annual precipitation varied between 702.9 mm and 1812.8 mm in the northwest part of the river basin (Keonjhar). It varied from 775.2 mm to 2211.3 mm in southeast part (Kendrapada). The coefficient of skewness and kurtosis for Keonjhar was 0.85 and 5.19; it was 0.19 and 3.75 for Kendrapada. For time series data to be considered normally distributed, the coefficient of skewness and kurtosis must be equal to 0 and 3, respectively. Therefore, annual rainfall of all locations within

Table 70.1 Summary of rainfall (mm) statistics for different locations in Baitarini river basin: minimum value (Min), maximum value (Max), standard deviation (SD), coefficient of variation (CV), skewness (Cs), and kurtosis (Ck)

	Mean	Median	Min	Max	SD	CV (%)	Cs	Ck
Angul								
Annual	1283.10	1256.10	814.10	2145.10	201.95	15.74	0.88	5.19
Monsoon	1024.50	1015.90	702.90	1812.80	172.09	16.80	0.87	5.73
Post-monsoon	119.49	111.50	10.40	341.20	67.77	56.72	0.86	3.76
Winter	35.16	25.02	0.00	130.19	32.79	93.26	1.19	3.64
Summer	103.88	96.79	6.20	276.35	56.61	54.50	0.66	3.48
Balasore								
Annual	1532.60	1528.60	917.40	2185.90	236.26	15.42	0.27	3.25
Monsoon	1126.50	1164.20	741.80	1894.60	196.89	17.48	0.74	4.09
Post-monsoon	184.30	177.40	10.30	696.50	110.15	59.77	1.47	7.02
Winter	42.01	33.14	0.00	145.10	35.53	84.58	1.02	3.52
Summer	179.84	182.37	21.41	453.64	77.94	43.34	0.26	3.16
Bhadrak								
Annual	1461.40	1451.00	833.60	2185.00	220.07	15.06	0.30	3.75
Monsoon	1082.10	1068.00	681.00	1678.70	172.56	15.95	0.32	3.34
Post-monsoon	191.10	1872.00	14.90	665.30	108.38	56.71	1.34	6.76
Winter	37.89	28.80	0.00	148.44	34.39	90.76	1.23	3.97
Summer	150.25	149.71	16.81	374.96	70.49	46.92	0.48	3.36
Jajpur								
Annual	1435.60	1407.30	843.40	2241.70	231.67	16.14	0.53	3.81
Monsoon	1076.80	1070.00	703.90	1770.40	190.98	17.74	0.53	1.18
Post-monsoon	185.90	179.00	13.20	677.10	105.39	56.69	1.17	6.12
Winter	35.71	25.85	0.00	140.59	34.00	95.21	1.30	3.99
Summer	134.02	134.37	12.52	344.78	64.15	47.87	0.38	3.12
Kendrapada								
Annual	1478.30	1482.10	775.20	2211.30	225.63	15.26	0.19	3.75
Monsoon	1096.70	1085.60	633.30	1657.20	183.58	16.74	0.32	3.21
Post-monsoon	223.90	219.70	13.70	647.00	116.38	51.98	0.81	4.17
Winter	31.77	23.62	0.00	147.09	29.93	94.21	1.32	4.61
Summer	126.01	123.17	20.79	418.00	64.22	50.96	1.00	5.62
Keonjhar								
Annual	1283.90	1256.10	814.10	2145.10	201.53	15.70	0.85	5.19
Monsoon	1030.20	1030.40	702.90	1812.80	176.98	17.18	0.86	5.42
Post-monsoon	115.38	110.17	10.40	314.20	62.42	54.10	0.73	3.64
Winter	35.16	24.96	0.00	130.19	33.18	94.36	1.17	3.56

(continued)

Table 70.1 (continued)

	Mean	Median	Min	Max	SD	CV (%)	Cs	Ck
Summer	107.55	100.44	8.12	345.20	59.64	55.45	0.93	4.53
Mayurbhanj								
Annual	1404.00	1375.30	949.20	2246.20	220.19	15.68	0.86	4.61
Monsoon	1055.60	1023.80	718.20	1713.30	178.96	16.95	0.94	4.28
Post-monsoon	134.06	121.14	11.30	574.80	80.16	59.79	1.78	9.59
Winter	45.92	37.90	0.00	170.82	37.65	81.99	1.10	3.99
Summer	168.37	169.15	15.97	449.83	76.25	45.29	0.48	3.76
Sundergarh								
Annual	1405.30	1375.30	949.20	2246.20	220.19	15.67	0.85	4.52
Monsoon	1059.10	1031.70	718.20	1713.30	179.11	16.91	0.90	4.20
Post-monsoon	133.12	120.81	11.32	574.80	80.83	60.72	1.75	9.39
Winter	45.73	37.59	0.00	170.82	37.63	82.29	1.11	4.02
Summer	167.28	169.15	15.97	378.00	73.05	43.67	0.18	2.75

the river basin is positively skewed and not normally distributed. The coefficient of variation, the measure of dispersion around the mean, was 15.7 and 15.26 for annual rainfall of Keonjhar and Kendrapada, respectively. The coefficient of variation is lowest (15.06–16.16) in annual rainfall followed by monsoon, summer, and post-monsoon. The coefficient of variation for winter rainfall in almost all location was more than 90%, which indicated the greater the level of dispersion around the mean. This indicates higher degree of uncertainty in winter season throughout the basin.

The mean annual temperature varied between 19.8 and 30.9 °C in Keonjhar. It varied from 21.9 to 30.95 °C in Kendrapada. The coefficient of skewness and kurtosis for Keonjhar was −0.36 and 3.7; it was −0.37 and 3.62 for Kendrapada. For all locations, mean annual temperature is negatively skewed for annual, monsoon, and summer season and positively skewed for post-monsoon and winter season. The coefficient of variation for all season for all location varied between 1.35 and 4.95% only (Table 70.2).

70.4.2 Temperature Anomaly

The anomalies of temperature variables and their trends were determined for all locations. The mean annual temperature variations for Keonjhar and Kendrapada are shown in Fig. 70.1. The trend showed that from 1900 to 1950 the trend was negative, i.e., mean temperature over century was more where as after 1950 there is an increase in temperature over mean. Hence, the mean temperature will increase over the period of time within the basin as most of the locations showed the same trend.

Table 70.2 Summary of mean temperature (°C) statistics for different locations in Baitarini river basin: minimum value (Min), maximum value (Max), standard deviation (SD), coefficient of variation (CV), skewness (Cs), and kurtosis (Ck)

	Mean	Median	Min	Max	SD	Cv (%)	Cs	Ck
Angul								
Annual	24.90	24.91	23.70	25.80	0.40	1.61	−0.31	3.52
Monsoon	26.85	26.80	25.43	27.91	0.48	1.78	−0.18	3.11
Post-monsoon	21.78	21.79	20.27	23.28	0.66	3.03	0.11	2.54
Winter	20.45	20.45	18.90	22.42	0.68	3.33	0.08	2.87
Summer	28.39	28.50	26.19	30.35	0.71	2.51	−0.55	3.61
Balasore								
Annual	20.09	20.07	19.24	20.99	0.37	1.85	−0.07	2.77
Monsoon	24.42	24.46	23.06	25.45	0.46	1.90	−0.24	3.08
Post-monsoon	16.19	16.08	14.41	18.63	0.76	4.71	0.62	3.80
Winter	13.46	13.44	11.86	15.07	0.67	4.96	0.09	2.59
Summer	22.62	22.61	20.79	24.61	0.67	2.98	−0.12	3.27
Bhadrak								
Annual	27.36	27.38	26.32	28.24	0.37	1.35	−0.27	3.33
Monsoon	29.24	29.25	27.95	30.16	0.40	1.38	−0.30	3.37
Post-monsoon	24.70	24.77	23.40	25.89	0.59	2.39	0.41	2.36
Winter	23.20	23.25	21.85	25.13	0.63	2.72	0.11	3.04
Summer	30.28	30.37	28.04	32.13	0.68	2.26	−0.60	3.72
Jajpur								
Annual	27.17	27.20	25.93	28.06	0.40	1.46	−0.43	3.69
Monsoon	29.03	29.05	27.68	30.01	0.44	1.51	−0.33	3.39
Post-monsoon	24.46	24.52	23.04	25.81	0.62	2.55	0.01	2.45
Winter	23.01	23.03	21.43	25.00	0.67	2.91	0.03	3.05
Summer	30.18	30.25	27.89	32.14	0.72	2.38	−0.65	3.87
Kendrapada								
Annual	27.23	27.24	26.05	28.07	0.38	1.40	−0.37	3.62
Monsoon	29.14	29.14	27.82	30.07	0.41	1.42	−0.35	3.53
Post-monsoon	24.95	25.02	23.63	26.25	0.60	2.39	−0.01	2.46
Winter	23.26	23.28	21.72	25.20	0.64	2.75	−0.01	3.17
Summer	29.61	29.72	27.49	31.39	0.68	2.29	−0.66	3.85
Keonjhar								
Annual	26.29	26.31	25.20	27.27	0.38	1.45	−0.36	3.70
Monsoon	28.31	28.29	26.84	29.29	0.46	1.61	−0.32	3.43
Post-monsoon	22.87	22.89	21.36	24.26	0.63	2.76	0.11	2.51
Winter	21.45	21.49	20.16	23.11	0.65	3.01	0.07	2.60

(continued)

Table 70.2 (continued)

	Mean	Median	Min	Max	SD	Cv (%)	Cs	Ck
Summer	30.22	30.32	27.87	32.23	0.73	2.41	−0.53	3.66
Mayurbhanj								
Annual	25.75	25.78	24.64	26.75	0.35	1.35	−0.23	3.63
Monsoon	27.94	27.93	26.61	28.78	0.40	1.43	−0.29	3.54
Post-monsoon	22.39	22.36	21.10	23.75	0.60	2.68	0.20	2.52
Winter	20.83	20.84	19.49	22.29	0.60	2.88	0.06	2.45
Summer	29.47	29.56	27.03	31.34	0.73	2.46	−0.52	3.53
Sundergarh								
Annual	26.01	26.05	24.98	27.00	0.36	1.38	−0.07	3.21
Monsoon	28.40	28.39	26.92	29.43	0.48	1.70	−0.23	2.97
Post-monsoon	22.33	22.23	20.83	24.07	0.68	3.05	0.41	2.93
Winter	20.57	20.57	19.15	22.04	0.63	3.05	0.08	2.56
Summer	30.16	30.24	28.17	31.99	0.69	2.30	−0.23	3.00

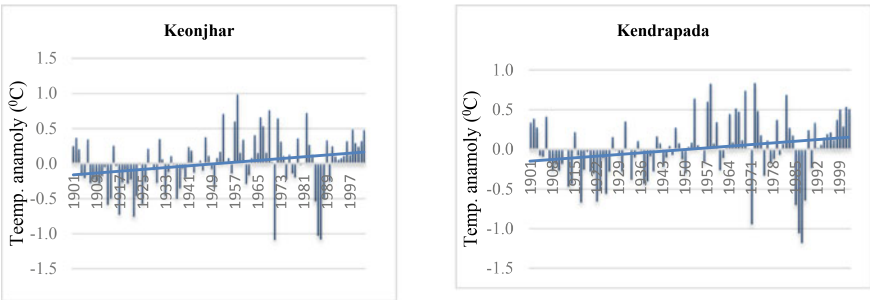

Fig. 70.1 Anomalies in mean annual temperature at Keonjhar and Kendrapada

70.4.3 Mann–Kendall Test (Rainfall)

Data pertaining to trend and slope of rainfall and temperature in all eight districts has been calculated, and results on seasonal and annual basis are presented in Table 70.3. It showed that increasing trend was observed for annual, monsoon, post-monsoon, and summer rainfall in all the districts except Angul district. Decreasing trend (slope 0.6) in summer season was observed for Angul district. For all the stations, winter rainfall was in decreasing trend over the past 100 years. The temperature data showed that most of the locations the temperature is in increasing trend. Most of the locations within Baitarini river basin show increasing trend in mean annual temperature at 90% significance (Table 70.4).

Table 70.3 Mann–Kendall test trend statistics (z) and Sen's slope (rainfall analysis)

		Z	Sen's slope	*p*	Tau
Angul	Annual	1.0680 ↑	0.0470	0.0285**	0.0662
	Monsoon	0.0215 ↑	0.0070	0.0820***	0.0009
	Post-monsoon	1.1499 ↑	0.0208	0.0250**	0.0071
	Winter	−1.1295 ↓	−0.0060	0.0258**	−0.0069
	Summer	−0.0265 ↓	−0.0070	0.0790***	−0.0067
Balasore	Annual	2.5100 ↑	1.5750	0.0012**	0.0150
	Monsoon	1.6760 ↑	0.0756	0.0093*	0.0103
	Post-monsoon	1.8100 ↑	0.0490	0.00699*	0.0112
	Winter	−0.085 ↓	−0.0050	0.0390**	−0.0520
	Summer	0.0755 ↑	−0.0190	0.0450**	0.0040
Bhadrak	Annual	1.6670 ↑	0.0946	0.00954*	0.0100
	Monsoon	0.0700 ↑	0.0304	0.0480**	0.0040
	Post-monsoon	1.5500 ↑	0.0400	0.0110**	0.0090
	Winter	−1.2800 ↓	−0.0080	0.01984**	−0.0070
	Summer	1.5490 ↑	0.0270	0.0120**	0.0090
Jajpur	Annual	2.8550 ↑	1.6170	0.000429*	0.0170
	Monsoon	1.9750 ↑	1.0527	0.0048*	0.0122
	Post-monsoon	1.2400 ↑	0.0340	0.0230**	0.0070
	Winter	−1.2000 ↓	−0.0050	0.0220**	−0.0070
	Summer	1.8400 ↑	0.0330	0.00645*	0.0114
Kendrapada	Annual	2.7000 ↑	1.5900	0.00069*	0.0166
	Monsoon	1.6220 ↑	0.0820	0.0106**	0.0100
	Post-monsoon	1.8570 ↑	0.0552	0.0060*	0.0114
	Winter	−2.0480 ↓	−0.0106	0.0040*	−0.0120
	Summer	1.4530 ↑	0.0230	0.0140**	0.0090
Keonjhar	Annual	1.2130 ↑	0.0560	0.0220**	0.0070
	Monsoon	0.0669 ↑	0.0262	0.0500**	0.0040
	Post-monsoon	0.0480 ↑	0.0075	0.0620***	0.0020
	Winter	−1.3260 ↓	−0.0074	0.0180**	−0.0082
	Summer	0.0650 ↑	0.0100	0.0510***	0.0040
Mayurbhanj	Annual	1.8700 ↑	1.0300	0.00613*	0.0115
	Monsoon	0.0655 ↑	0.0242	0.0512***	0.0040
	Post-monsoon	1.4940 ↑	0.0275	0.0134**	0.0090
	Winter	−1.7620 ↓	−0.0149	0.0077*	−0.0100
	Summer	1.9575 ↑	0.0380	0.00502*	0.0120
Sundergarh	Annual	1.9500 ↑	1.0800	0.0050*	0.0068

(continued)

Table 70.3 (continued)

		Z	Sen's slope	*p*	Tau
	Monsoon	1.1000 ↑	0.0480	0.0061*	−0.0110
	Post-monsoon	1.2100 ↑	0.0220	0.0220**	0.0070
	Winter	−1.8600 ↓	−0.0157	0.0061*	−0.0155
	Summer	1.9400 ↑	0.0380	0.0051*	0.0662

All values are significant at (*** 10%), (**5%), and (*1%) level of significance

70.5 Conclusions

Rainfall analysis for eight districts within Baitarani River (Odisha) for a period of 119 years (1901–2020) showed overall positive trend in annual, monsoon, and post-monsoon rainfall, but there are variations in terms of winter and summer season rainfall which indicated higher degree of uncertainty in rainfall distribution. The trend in rainfall data on annual, seasonal, and monthly basis is examined through Mann–Kendall test and Sen's estimator of slope. Mean annual, monsoon rainfall is decreasing over 100 years, whereas post-monsoon rainfall is increasing in Sundergarh, Jajpur, and Bhadrak stations. In winter season, there is increase in mean rainfall in Myurbhanj, whereas increase in mean rainfall was observed in summer season for Sundergarh location. Rest other areas there is decrease in mean winter rainfall over last 100 years. The majorities of locations within Baitarini river basin show increasing trend in mean annual temperature. Temperature analysis for all location within the river basin showed a positive trend and statistical significance. Furthermore, the study showed that both the Mann–Kendall trend test and Sen's slope estimator reveal that there is a tendency of temperature increase in annual, monsoon, and winter season in the study area. In few locations, there is decrease in temperature in post-monsoon and summer season. The similar trend was observed by Prabhakar et al. (2018). Thus, the increasing trend of temperature and decrease in rainfall pattern can lead to plan and develop appropriate water conservation and management options for sustainable agriculture in the river basin.

Table 70.4 Mann–Kendall test trend statistics (z) and Sen's slope (temperature analysis)

		Z	Sen's slope	*p*	Tau
Angul	Annual	3.44 ↑	0.0044	0.0001*	0.0230
	Monsoon	0.063 ↑	0.0011	0.0520***	0.0431
	Post-monsoon	4.29 ↑	0.0098	0.0000*	0.0288
	Winter	3.24 ↑	0.0075	0.0012*	0.2180
	Summer	−0.015 ↓	−0.0003	0.0870***	−0.1040
Balasore	Annual	3.92 ↑	0.0050	0.0001*	0.0263
	Monsoon	1.22 ↑	0.0015	0.02200**	0.0820
	Post-monsoon	4.69 ↑	0.0102	0.0000*	0.3150
	Winter	3.013 ↑	0.0073	0.0025*	0.2020
	Summer	0.659 ↑	0.0015	0.05090***	0.0440
Bhadrak	Annual	3.687 ↑	0.0042	0.0002*	0.2470
	Monsoon	1.14 ↑	0.0016	0.02530**	0.0768
	Post-monsoon	4.442 ↑	0.0091	0.0000*	0.2960
	Winter	3.36 ↑	0.0070	0.0008*	0.2250
	Summer	0.112 ↑	0.0003	0.09102***	0.0078
Jajpur	Annual	3.42 ↑	0.0044	0.0006*	0.2300
	Monsoon	1.015 ↑	0.0077	0.03100**	0.0680
	Post-monsoon	4.224 ↑	0.0090	0.0000*	0.2830
	Winter	3.438 ↑	−0.0073	0.0006*	0.2310
	Summer	−0.216 ↓	−0.0005	0.08280***	−0.0140
Kendrapada	Annual	3.49 ↑	0.0040	0.0005*	0.2340
	Monsoon	1.07 ↑	0.0015	0.02830**	0.0722
	Post-monsoon	4.16 ↑	0.0084	0.0000*	0.2790
	Winter	3.4 ↑	0.0069	0.0007*	0.2280
	Summer	0.112 ↑	0.0003	0.09102***	0.0078
Keonjhar	Annual	3.46 ↑	0.0042	0.0005*	0.0230
	Monsoon	0.058 ↑	0.0010	0.0557***	0.0390
	Post-monsoon	4.57 ↑	0.0010	0.0000*	0.0307
	Winter	3.417 ↑	0.0075	0.0006*	0.0229
	Summer	−0.048 ↓	−0.0011	0.0629***	−0.0326
Mayurbhanj	Annual	3.76 ↑	0.0042	0.0002*	0.2520
	Monsoon	0.754 ↑	0.0011	0.04500**	0.0508
	Post-monsoon	5.05 ↑	0.0103	0.0000*	0.3390
	Winter	3.501 ↑	0.0011	0.0005*	0.2350
	Summer	−0.393 ↓	0.0103	0.06940***	−0.0260
Sundergarh	Annual	3.92 ↑	0.0047	0.0001*	0.2630

(continued)

Table 70.4 (continued)

		Z	Sen's slope	*p*	Tau
	Monsoon	−0.103 ↓	−0.0001	0.09190***	−0.0065
	Post-monsoon	5.26 ↑	0.0116	0.0000*	0.3530
	Winter	3.09 ↑	0.0067	0.0019**	0.2080
	Summer	0.17 ↑	0.0005	0.08640***	0.0116

All values are significant at (*** 10%), (**5%), and (*1%) level of significance

References

CWC (Central Water Commission) (2014) Guidelines for improving water use efficiency in irrigation, domestic and industrial sector. Performance Overview & Management Improvement Organization, Central Water Commission, Ministry of Water Resources, Government of India. http://nwm.gov.in/sites/default/files/Final%20Guideline%20Wateruse.pdf

Gosain AK, Rao S, Basuray D (2006) Climate change impact assessment on hydrology of Indian river basins. Curr Sci 90:346–353

IPCC (Intergovernmental Panel on Climate Change) (2001) Climate change—the scientific basis. In: Houghton JT, Ding Y, Griggs DJ (eds). Cambridge University Press, UK

IPCC (2007) Summary for policymakers. In: Metz B, Davidson OR, Bosch PR et al (eds) Climate change 2007: mitigation. Cambridge University Press, Cambridge, UK

Kendall MG (1975) Rank correlation methods. Griffin, London

Kundzewicz ZW, Mata LJ, Arnell NW et al (2008) The implication of projected climate change for freshwater resources and their management. Hydrol Sci J 52(1):3–9

Lal M (2001) Climatic change—implications for India's water resources. J Indian Water Resour Soc 21:101–119

Mann HB (1945) Nonparametric tests against trend. Econometrica 13:245–259

Prabhakar AK, Singh KK, Lohani AK (2018) Spatial and temporal rainfall trends and its variability analysis over Champua sub-watershed of Baitarani River basin of Odisha. J Indian Water Resour Soc 38(1):39–46

Sen PK (1968) Estimates of the regression coefficient based on Kendall's tau. J Am Stat Assoc 63:1379–1389

Chapter 71
Animal Shelter Designs and Construction in Tropical Cyclone Prone Coastal Areas as Disaster Management Strategies for Livestock

Dilip Kumar Mandal, S. K. Swain, A. Debbarma, S. Rai, C. Bhakat, S. K. Das, and M. K. Ghosh

Abstract In coastal areas of tropical countries, cyclone is one of the most common natural hazards that cause damages to human settlement, livestock, agriculture and ecosystem. Every year globally several million people are affected by tropical cyclones. Information on the extent of cyclonic damage to livestock houses solely due to construction practices and faulty shed designs is very less. This paper summarizes the improvement in animal shelters' construction practices, modification of designs, orientation of farmstead buildings, choice of better quality materials for livestock house construction, landscaping of livestock farm and farmers' house which can reduce the degree of damages in livestock houses of coastal areas due to cyclone. The shape and dimensions of animal houses, roofing materials, roof design and slope of the roof are very important concerns to withstand high wind speed. Foundation of buildings of animal house, walls, ventilation and other different structural elements need special attention to reduce the risk of structural damages and in case, damages happen that could be repaired with minimum expenditure to make usable by shortest possible time. In tropical cyclone-prone areas double slope roof with an open ridge

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is the most suitable design for loose housing system animal shelter, whereas for close housing system Pyramidal roofing design is the most suitable option. Scientific construction of animal shelters and suitable modification of existing designs can minimize collateral losses of animal owners of coastal areas and a few related livestock management strategies should be undertaken to mitigate disasters owing to the cyclone.

Keywords Animal shelter · Disaster management · House design · Livestock · Tropical cyclone

71.1 Introduction

Livestock is a very important sector in rural economy that contributes food, wealth, input for crop production, gainful rural employment opportunity round the year, steady income, insurance, readily en-cashable savings or investments for the poor households and a mean of social and economic livelihood security through various ways in different production systems. Rearing of livestock is an integral part of mixed farming systems, contributes to on-farm diversification and intensification, which help poor households in poverty alleviation. The distribution and importance of livestock, depending upon contribution, vary widely among agro-ecological regions and it requires region-specific interventions based on resource endowments of that region keeping in mind the challenges, opportunities and geo-morphology of the area.

Indian subcontinent is one of the worst cyclone-affected areas of the world. The whole of the eastern coast and upper part of western coast, particularly Maharashtra and Gujarat coast is the most vulnerable to tropical cyclones. Cyclones form more in Bay of Bengal as compared to Arabian Sea and the ratio of cyclones hitting east and west coast is 80:20. The coastal area of India is about 8% of the total geographical area, 6% of net cropped area, 8% of gross cropped area, clasps 8% of total livestock and supports livelihood of 13% human population (Kumar and Singh 2008). Tropical cyclones in North Indian Ocean have two distinct seasonal occurrences, one in May–June and another at September and October, the post-monsoon usually more severe than monsoon. Every year, about 5–6 tropical cyclones are formed in the Bay of Bengal and the Arabian Sea, 2–3 may be severe. A list of some tropical cyclones occurred in last few decades in the Asia pacific regions are given in Table 71.1. These cyclones, depending on severity, cause moderate to severe damages to human habitat, buildings, infrastructures like road, electricity supply; crops, agricultural fields, forest, pasture land and livestock. The coastal region cattle are dominant livestock species followed by sheep, goat and buffalo; pigs are least in number. Loss of livestock due to cyclone is very common and farmers incur a huge loss. Collateral losses of livestock inhabitation are also a serious setback to farmers' economy, which requires reconstruction, repair and renovation to make it suitable for livestock rearing. A destructive cyclone leads to huge storm surges, high-speed

Table 71.1 List of some devastating cyclones in the Asia–Pacific regions

Year	Name	Countries affected
1970 (3rd–13th Nov)	Cyclone Bhola	India, East Pakistan
1979 (4th–24th Oct)	Typhoon Tip	Japan, Philippines, Alaska, Korea, China, Russia
1991 (24th–30th Apr)	Bangladesh cyclone	Bangladesh, Myanmar
1999 (25th Oct–3rd Nov)	Odisha cyclone	India, Thailand, Bangladesh, Myanmar
2001 (26th Dec–1st Jan)	Tropical storm Vamei	Singapore, Indonesia, Malaysia
2003 (1st–8th Apr)	Cyclone Inigo	Australia, Indonesia
2004 (1st–18th Mar)	Cyclone Gafilo	Madagascar
2007 (1st–7th Jun)	Cyclone Gonu	Iran, Pakistan, UAE, Oman
2007 (10th–16th Nov)	Cyclone Sidr	India, Bangladesh
2008 (25th Apr–4th may)	Cyclone Nargis	Bangladesh, Myanmar, Sri Lanka
2009 (4th–11th Nov)	Cyclone Phyan	India, Pakistan, Sri Lanka
2010 (11th–24th Oct)	Typhoon Megi	China, Hong Kong, Philippines, Taiwan, Macao
2013 (5th–14th Oct)	Cyclone Phailin	India, Thailand, Myanmar, Nepal
2013 (3rd–11th Nov)	Typhoon Haiyan	Philippines, Vietnam, Hong Kong, Taiwan
2014 (7th–14th Oct)	Cyclone Hudhud	Nepal, India
2016 (7th Feb–3rd Mar)	Cyclone Winston	Fiji, Vanuatu, Tonga, Queensland
2017 (29th Nov–6th Dec)	Cyclone Ockhi	Maldives, Sri Lanka, India
2018 (31st Dec–6th Jan)	Tropical storm Pabuk	Vietnam, Thailand, Myanmar
2019 (13th–21st Mar)	Cyclone Idai	Zimbawe, Malawi
2019 (26th Apr–5th May)	Cyclone Fani	India, Bangladesh, Sri Lanka
2019 (24th Oct–3rd Nov)	Cyclone Kyarr	UAE, Oman, Somalia
2019 (10th–17th Jun)	Cyclone Vayu	India, Pakistan, Maldives, Oman
2019 (22nd–25th Sep)	Cyclone Hikaa	India, Oman
2019 (5th–12th Nov)	Cyclone Bulbul	Bangladesh, India
2019 (4th–20th Oct)	Typhoon Hagibis	Japan, Russia, Alaska
2020 (11th–18th Sep)	Hurricane Sally	US, Cuba, The Bahamas
2020 (1st–4th Jun)	Cyclone Nisarga	India
2020 (28th Oct–6th Nov)	Typhoon Goni	Vietnam, Philippines, Cambodia, Laos
2020 (23rd–27th Nov)	Cyclone Nivar	India
2020 (16th–21st May)	Cyclone Amphan	India, Bangladesh, Sri Lanka, Bhutan

wind gusts and under these actions buildings designed incorrectly will not perform well and surrenders (Keote et al. 2015). Thus, livestock shelters design, foundation, orientation, structural elements like roof, frame, walls, etc. need special attention, so that those can withstand the severity of cyclones in the coastal area, nonetheless, damages that occur are minimum and repairable with less expenditure.

71.2 Animal Shelter Construction in Cyclone Prone Areas

The coastal areas of India possess around 8% of total livestock and a very wide variety of livestock genetic resources. Specified animal breeds of livestock that are predominant in coastal areas are given in Table 71.2. The livestock resources are

Table 71.2 Indigenous livestock genetic resources at coastal areas of India

State/UTs	Coastal Districts	Indigenous Livestock breeds
Gujarat	Ahmedabad, Amreli, Anand, Bharuch, Bhavnagar, Jamnagar, Junagadh, Kachchh, Navsari, Porbandar, Devbhumi Dwaraka, Surat, Girsomnath, Valsad	Cattle: Gir, Tharparkar, Kankrej Buffalo: Surti Sheep: Patanwadi Goat: Mehsana, Gohilwadi, Surti, Kutchi/Kathiawari
Maharashtra	Palghar, Mumbai sub-urban, Mumbai, Raigarh, Ratnagiri, Sindhudurg, Thane	Cattle: Dangi
Goa	North Goa, South Goa	Cattle: Konkan Kapila, Shweta Kapila Pig: Agonda Goan
Karnataka	Dakshin Kannada, Udupi, Uttar Kannada	Cattle: Malnad Gidda
Kerala	Alappuzha, Ernakulam, Kannur, Kasaragod, Kollam, Kozhikode, Malappuram, Thiruvananthapuram, Thrissur	Cattle: Vechur Goat: Tellicherry
Tamilnadu	Chennai, Cuddalore, Kancheepuram, Kanniakumari, Nagapattinam, Pudukkottai, Ramanathapuram, Thanjavur, Thiruvallur, Thoothukudi, Tirunelveli Kattabo, Villupuram	Cattle: Umblacherry Sheep: Kilakarsal, Ramnad White, Keezhakaraisal, Madras Red/ Chennai Red Goat: Kanniaadu, Kodiaadu
Andhra Pradesh	East Godavari, Guntur, Krishna, Nellore, Prakasam, Srikakulam, Vishakhapatnam,Vizianagaram, West Godavari	Cattle: Ongole Sheep: Nellore
Odisha	Baleshwar, Bhadrak, Jagatsinghpur, Kendrapara, Puri, Khordha, Ganjam	Cattle: Ghumusari Buffalo: Chilika Sheep: Kendrapara, Ganjam
West Bengal	Purba Medinipur, South 24 Parganas, North 24 Parganas	Sheep: Garole Goat: Black Bengal
Andaman and Nicobar	North and Middle Andaman, Nicobar, South Andaman	Cattle: Jangli Gai, Trinket Goat: Barren, Teressa, Andaman, Malabari goat Pig: Nicobari, Andaman wild pig Poultry: Brown/Black/White Nicobari, Naked Neck, Frizzle fowl

very important supplementary to the livelihood of farmers residing in coastal areas. Livestock housing is one of the essential components of scientific animal rearing for better productivity and profitability. Generally, animal shelters of unorganized sector are non-engineered constructions done by farmers based on their traditional knowledge and experience. Main objectives remain to serve the purpose of keeping animals only by least possible cost, using cheapest and easily available materials. Most of the farmers cannot afford more prices and able ones are unwilling to afford money for construction of better livestock houses due to multifarious socio-economic reasons depending upon their conditions, returns and individual mind set. However, some minimum standards for the designs, constructions and durability performance need to be considered so that animal houses can withstand the pressure of wind speed, minimize losses, reduce livestock sufferings and death. Some of the important considerations are discussed below.

71.2.1 Construction of Roofing Structures

Roof is the most vital structure of animal shed that protects animal from direct sunlight, rain, hailstorm, due, etc. People use locally available materials of wide range such as dry leaves, paddy straw, asbestos, tin sheet, wood, tiles and seldom reinforced cement concrete (RCC). However, choices of roofing designs have some roles to play. Capacity to withstand cyclone thrust and wind gusts vary significantly with roofing designs and types (Table 71.3). Wind loads on structure are due to turbulence generated between the structure and the incoming wind force which eventually fluctuate with varied wind speed.

RCC roof is very strong, plain on top surface with slope towards sides and best choice, if affordable. For other kinds of roofing materials choice of roof designs have some roles to play. For example:

i. **Gable-ended roof/ couple-closed roof:** Described in Fig. 71.1, two roofs are attached to central ridge. In such designs, storm hits the wall and very low-pressure zone created above rooftop, which cause high lift of roof. Therefore, Gable-ended roof for animal house should be avoided in coastal cyclone-prone areas.

Table 71.3 Wind withstanding capacities of different types of roofs

Roof type	Wind speed (km hr^{-1})
Conventional gable roof	136.8
Improved gable roof	180.0
Improved hip roof	219.6
Asbestos sheet roof	259.2
Engineered building	288.0

Source Krishna (2002)

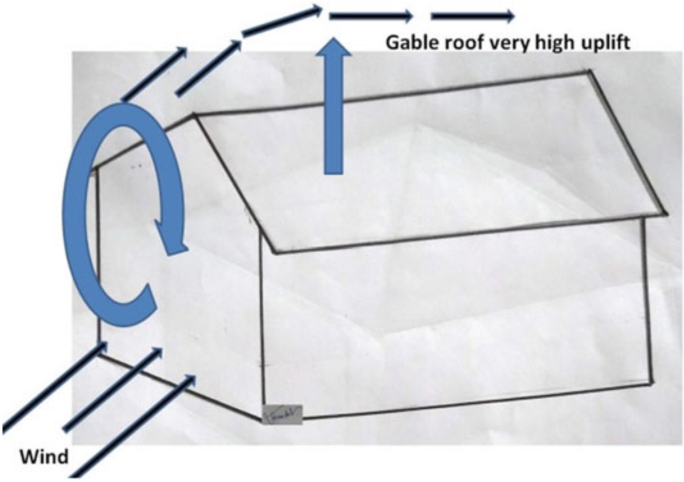

Fig. 71.1 Gable-ended or couple closed roof

ii. **Hip roof**: This type of roof looks trapezium-like (Fig. 71.2). Winds after hitting wall push the hip end then take a gradual slope. Thus, creation of low-pressure zone over roof is lesser as compared to Gable-ended roof. Hence, in this type of roofing design there is low uplift and it is better than Gable-ended roof.

iii. **Pyramidal roof**: Pyramidal roof can be created over a square-shaped house. After collision on the wall wind takes a smooth slope over the roof and passes across the vertex of the pyramid. Thus, the roof get lowest uplift in this design and most suitable for animal house (including residential house) in tropical cyclone-prone areas. As the pyramid roof structure each above the square-shaped house, protective capacity is similar at all four sides and immune to direction of cyclone path (Fig. 71.3).

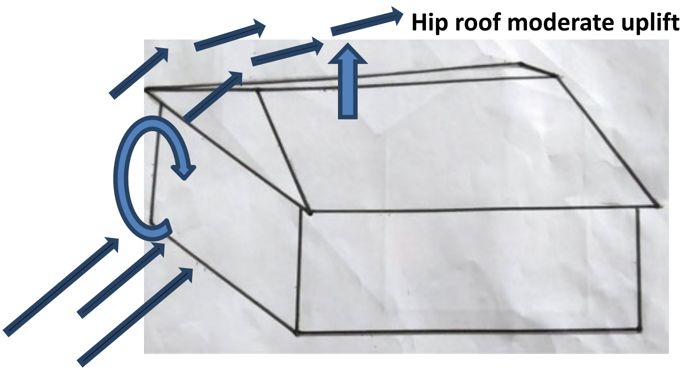

Fig. 71.2 Hip roof

iv. **Double slope roof with open ridge:** Basic design of such roof is given in Fig. 71.4. It is very suitable for loose housing system with animal shelters. Front and back wall heights are comparative less. There is open space (1–1.5 ft) between central and side roof. There is no or less chance to roof uplift in this design because of through passage of wind. At Eastern Regional Station of ICAR-National Dairy Research Institute, Kalyani a very low-cost double slope roof with open ridge ventilated thatched roof was installed. The structure sustained without any damage during the cyclone *Amphan* (20th May 2020) that had wind speed of 90–110 km hr^{-1}.

In tropical cyclone-prone areas double slope roof with open ridge (Fig. 71.4.) is the most suitable design for loose housing system animal shelter, whereas for close housing system Pyramidal roofing design (Fig. 71.3) is the most suitable option. In tropical countries, loose housing system is the most comfortable and cheap animal sheltering system. However, if farmers want to construct house for night shelter only or for any other purpose, close housing system is followed with pyramidal roof in coastal tropical areas.

The double slope roof with open ridge (Fig. 71.4.) design loose housing system animal shelter had added advantage over traditional single slope roof asbestos shed in terms of more comfortable micro-climate for animals, natural cooling effect, better milk production and comfort (Table 71.4) of lactating dairy cows (Mandal et al. 2021; Kumar et al. 2020).

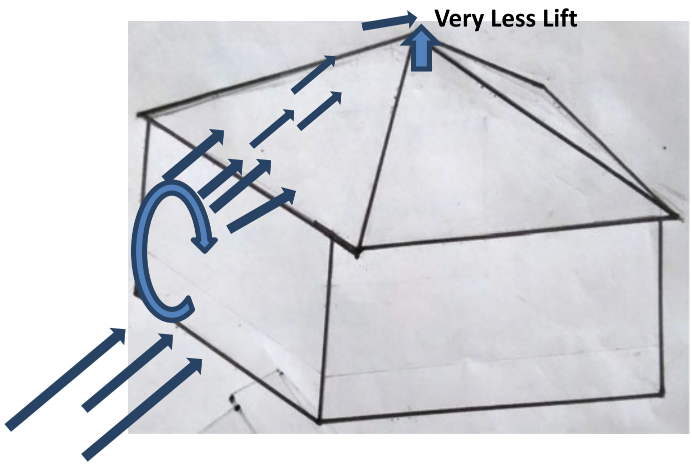

Fig. 71.3 Pyramidal roof

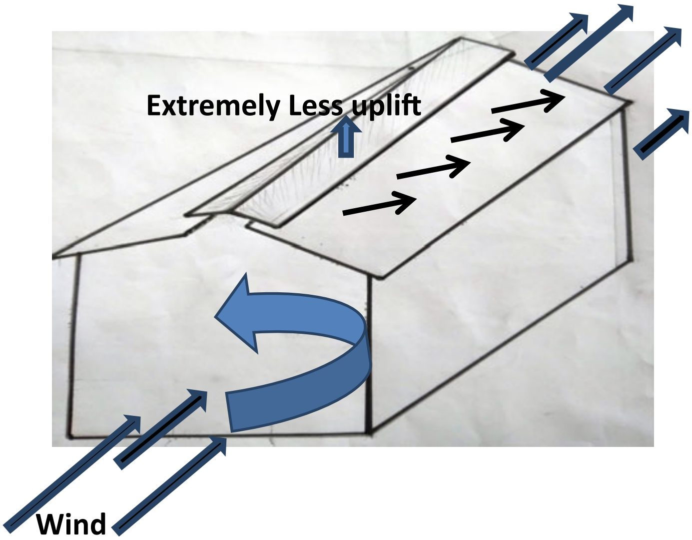

Fig. 71.4 Double slope roof with ridge ventilation

Table 71.4 Performance of cows in double slope roof with open ridge thatch roof shed (T1) vs single slope asbestos roof shed (T2)

Parameters	Double slope roof with open ridge thatch roof shed (T1)	Traditional single slope asbestos roof shed (T2)
Micro-environment parameters inside the sheds		
Morning air temperature (ºC)	$27.71^{a} \pm 0.27$	$29.12^{b} \pm 0.27$
Morning Humidity (%)	$64.36^{a} \pm 0.25$	$66.26^{b} \pm 0.26$
Afternoon air temperature (ºC)	$30.20^{a} \pm 0.24$	$32.00^{b} \pm 0.26$
Afternoon Humidity (%)	$63.04^{a} \pm 0.33$	$64.64^{b} \pm 0.39$
Milk production parameters		
Morning Milk yield (Kg) /day **	$5.29^{a} \pm 0.02$	$4.95^{b} \pm 0.02$
Evening Milk yield (Kg) /day**	$2.70^{a} \pm 0.01$	$2.53^{b} \pm 0.01$
Total milk yield (Kg) / day **	$7.99^{a} \pm 0.03$	$7.47^{b} \pm 0.03$
Monthly milk yield (Kg)**	$241.90^{a} \pm 5.48$	$223.25^{b} \pm 5.73$
Milking behaviour & cow comfort[#]		
No of Stepping / milking	1.26 ± 0.06^{a}	1.47 ± 0.07^{b}
Milking Duration(seconds)	235.92 ± 5.97	222.76 ± 6.68
Milk Flow Rate (g/minute)	954.44 ± 21.11	924.82 ± 23.63

[#]Kumar et al. (2020); Mandal et al. (2021)
[a,b]means with different superscripts differ significantly ($P < 0.01$).

71.2.1.1 Pitch Angle of the Roof

Pitch angle indicates the slope of the roof with the horizontal. It is the angle that is created as the rafter leaves the sealing joint. While installing the roof, the pitch angle should be kept between 12–35° depending upon rainfall, climatic condition, and roofing material. However, in no case roof pitch angle should exceed 45°. Sastry and Thomas (2015) recommended pitch angle in different types of roofing materials for construction of animal shelter as follows: Thatched roof 35°, tiled roof 25–30° and sheet roof 12–18°. In heavy rainfall areas, roof pitch should be kept steeper. Experimental wind tunnel testing (wind turbulence 7 m s^{-1}) of low-rise building models in South Pacific region with flat, gabled and hip roof configurations indicated that the 45° pitch angled gabled and hip building models performed better than flat roof under the same wind conditions; between gabled and hip roof, hip roof was better (Prasad et al. 2009).

71.2.1.2 Eaves of Roof

Eaves refer to the outdoor ends or overhangs of the roof from side wall or last purlins. It prevents entry of sunshine, rainwater, and wetting of walls. But lengthy verge or overhangs are more prone to damage by cyclone storms because it catches upward wind pressure and facilitates uplift of roof. Thus, verge (eaves) should not be more than 18 inches in animal house of tropical coastal areas.

71.2.1.3 Construction of Roof Truss

Choice of roof truss type depends upon width of animal house. Incase width is more than 6 m; King post truss should be installed (Fig. 71.5). The central ridge should be properly secured by using gussets, collar ties, and metal straps. If the frames are made by iron pipe, joint angles should be supported by metal straps of L clamps to make it stronger (Fig. 71.6). The horizontal bars parallel to central ridge are called purlins. While fixing roofing materials with screws, drive the screw at least 5 cm (2 inches) inside the purlins. In case, patio and verandahs are to be constructed it is better to create separate truss than to use extended version of main roof truss.

71.3 Foundation of Animal House Structure

In coastal areas, human residential buildings need very strong foundation. For animal shelter structures that much robust foundation may not be necessary because of their low-rise structures and practically being not affordable by farmers. However, it should be strong enough to withstand storms and inundation of salty water which follows the cyclone. Depth of foundation depends upon the soil type and quality. Post rising from

Fig. 71.5 King post truss with gussets

Fig. 71.6 Iron frame with metal strap-L clamp

foundation should be embedded into the ground at 2.5 ft depth. Provisions of knee bracings make foundation stronger. Quality of foundation could not be compromised because it is the base on which the building stands upon.

71.3.1 Doors and Windows

Loose house animal shed does not require any doors and windows, but required gates for movement of animals and workers. In close house shelter for other ancillary structures (e.g., milking parlour, ration room, store room, dispensary cum office room, etc.) require doors and windows fittings according to need like passage, light, ventilation, etc. These unavoidable openings are the most vulnerable areas where stresses concentrate because high-speed winds enter through small openings making non-uniform distribution of pressure (wind), vibration of structures of the shed/house. Thus some precautionary measures need to be taken during construction of walls and fixtures. Total sum of length of opening should be less than half the width of the structures. Door's frame should have 6 holdfast and window frames 4 holdfast of 9 in long for proper anchoring with walls. For doors 2 braces diagonally between stiles, first one between top and middle rail and the second one between middle and bottom rail should be given to make it strong. Every door and window should have easily openable window locks, shutter catch, etc. made of strong iron or wood. The criteria should be strength not the beautification or other cosmetic values that cause unwanted expenditure. If a door of 6 ft height is to be fixed on wall at one corner, fix it at least one foot (1/6th of length) away from corner for proper protection of walls as well as fixture (windows/doors). Doors and windows should have counter opening (doors/windows) exactly at opposite side for cross ventilation and making balance of pressure between wind ward and leeward sides.

71.3.2 Walls

Walls bear the stress of cyclone momentum across their entire length and breadth. Walls support the roof structure, fixtures like doors, windows, etc. This structure gives an enclosure to the house and bears the stress and strain both from windward and leeward sides. In loose housing system, animal shelters do not require full wall construction. Only 1.5 m (5ft) wall height is sufficient to work as boundary walls for livestock enclosure. However, in close housing system, full wall construction would be necessary. Wall should be constructed from foundation at least 45 cm (1.5 ft) depth from ground. For structures of more wall height (close housing/ ancillary structures) base should lay on concrete bed, however, for boundary walls (loose house system) well compact ground soil/ grouted broken brick base could be used. Reinforcing with vertical concrete band/column at 10ft. intervals would be required for long and high walls; however, for boundary walls brick pillars (2 brick thick- 10 in $\times$ 10 in) at 10 ft intervals provide strength to walls. Structures that rest on walls (e.g., roof, post, window, doors, etc.) should be properly braced and anchored to withstand wind surge, storm gusts and squalls. Undesirable opening of walls, particularly at corners must be closed to ensure proper strength of wall. In human residential buildings of more height, long walls are supported by buttresses to prevent collapse; however, in some ancillary structure like godowns, dry fodder storage buildings (high and long walls) of animal farm might be supported by buttresses in tropical cyclone-prone coastal areas.

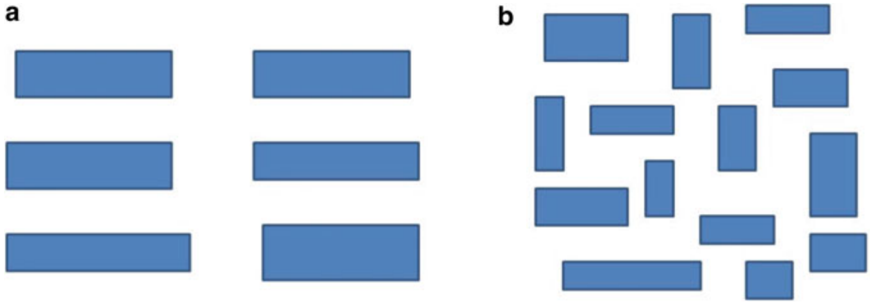

Fig. 71.7 **a** Row wise orientation of buildings, **b** Zig-zag orientation of buildings

71.4 Building Orientation, Landscaping of Farmstead and Other Miscellaneous Requirements

Orientation of buildings is applicable for large livestock farms located at coastal areas (not for individual/small farm) where several sheds, animal shelters, ancillary structures, residential houses of workers, etc. are installed at one place. Impact of cyclone could be reduced to by zig-zag orientation of buildings (Fig. 71.7a, b). Row houses provide wind tunnel, whereas zig-zag patterns act as speed breakers. However, structures at windward side should be stronger because gusts of wind first hit the outermost settlements than those located inside the farmstead.

Similarly planting of trees in zig-zag patterns at the outskirt of farm (especially at seaside/windward side) first few rows (2–3) small size plant, then medium size plants and large size plants (1–2 rows) close (but safe distance) to animal shelter can work as speed breaker.

Livestock houses built on stilts or raised earth mounds are more protected from high-speed winds as compared to ground label constructions. However, cost effectiveness of animal houses built on stilts need to be tested. Ground-level constructions have high risk of inundation that often follows cyclone in coastal area when high-rise sea water influx into land area.

Farm houses located at valley are more protected if location of hillocks is at windward side. Hence, lands of leeward side are the preferable site of construction and selection to establish new livestock farm in coastal area, which depends upon availability, land price and other economic factors.

71.5 Conclusions

Cyclone is an inevitable phenomena in tropical coastal areas. We cannot stop arousal of cyclone; with the advent of modern technology we can attempt to modify cyclones to change its path, intensity, precipitation type by incurring huge expenditure (Cloud seeding, soot dropping). Prediction of landfall of cyclone has improved reasonably and it helped us taking steps like evacuation, shifting, logistic arrangement, etc. for reduction of losses of life and property. It is very difficult to predict damages done by cyclone, however, experiences of previous cyclone give an insight about designs of structure to be installed that at least are able to withstand storm, minimize the extent of damage and loss of property. This paper summarizes some of the important building design requirements for construction of animal shelters that can withstand storm surges and minimize structural damage, loss of property and livestock, etc.

References

Keote SA, Kumar D, Singh R (2015) Construction of low rise buildings in cyclone prone areas and modification of cyclone. J Energy Power Sources 2(7):247–252

Krishna P (2002) Wind disasters in the Indian region and the mitigation efforts. NCWE p 40–49, 2002

Kumar A, Singh DK (2008) Livestock production systems in India: an appraisal across agro-ecological regions. Indian J Agric Econ 63(4):577–597

Kumar A, Mandal DK, Mandal A et al (2020) Effects of loose housing designs on expressions of milking parlour behaviours and milk yield of crossbred jersey cows. J Anim Res 10(2):315–323

Mandal DK, Mandal A, Bhakat C et al (2021) Effect of stress amelioration through open-ridge ventilated thatched roof housing on production and reproduction performance of crossbred Jersey cows. Trop Anim Health pro 8(4):272–280. https://doi.org/10.5455/ijlr.20171012061118

Prasad D, Uliate T, Ahmed MR (2009) Wind loads on low-rise building models with different roof configurations. Int J Fluid Mech Res 36(3):231–242

Sastry NSR, Thomas CK (2015) Livestock production management. Kalyani Publishers, Ludhiana, Punjab, India

Part V
Socio-economic Issues and Value Chain Analysis

Chapter 72
Value Chain Analysis of the Marine Ornamental Reef Fishery in Trincomalee, Eastern Sri Lanka

M. S. V. H. Priyashadi, K. H. M. A. Deepananda, and U. A. D. Jayasinghe

Abstract Marine ornamental fishery began in the 1930s in Sri Lanka has developed into a multi-million-dollar industry at present. This study was carried out from February 2019 to February 2021 focusing on marine aquarium fishing communities in Trincomalee, eastern Sri Lanka, to analyze the value chain of marine ornamental reef fishery. Stakeholders were identified through the snowball sampling technique. Data were collected through semi-structured interviews, focus group discussions and participant observations. The market chain of marine reef fishery in Trincomalee consisted of approximately 600 fishers, 11 middlemen and 21 exporters. Two local aquaria played a minor role in the market chain by purchasing 2% of the total fish collection from middlemen. Government authorities & non-governmental organizations, equipment & other service suppliers and supporters were key components in the input flow. The price of fish and invertebrates increased by ten times through the production flow from fishers to exporters. The study indicated that the price determination process for species through the production flow should be modified to get a considerably higher profit for the fishers.

Keywords Divers · Exporters · Input suppliers · Ornamental reef fishery · Stakeholders · Value chain analysis

72.1 Introduction

Coral reefs that represent less than 0.1% of the world's ocean area (Spalding et al. 2001; Biondo 2017) are the most biologically rich and productive ecosystems on the

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earth. Approximately, 4000 species of fish, 800 species of reef-building corals, and 500 species of invertebrates other than corals are associated with the coral ecosystem (Biondo 2017; Wabnitz et al. 2003). About 10% of commercially important fishes worldwide are coral reef fishes (Zhang et al. 2020).

Marine ornamental reef fishery developed as a large scale multimillion-dollar industry contributing to the global economy, after the 1970s (Wood 2001). Currently, 48 fish exporting countries and 38 fish importing countries involve in the marine ornamental fish industry (Biondo and Burki 2020). Indonesia, USA, Philippines, Sri Lanka, and Maldives are the top five marine ornamental fish exporters (Biondo and Burki 2019). Ornamental reef fish trade in Sri Lanka was not expanded up to a commercial level until the 1950s, even though it had been initiated in the 1930s (Wood 2001; Bruckner 2005). Coastline of Sri Lanka, which is approximately 1585 km long, is rich with fringing coral reefs and offshore bar reefs (Rajasuriya et al. 2005). Collecting marine ornamental reef fish can be observed throughout the coast except in the northern region (Rajasuriya 2008). The collected coral reef fish are traded at the export market, and the estimated value of the fishery in 2008 was 3–5 million US$ (Rajasuriya 2008). Marine ornamental fishery contributes to providing livelihoods for people, and therefore, fish stocks are being depleted in the absence of proper management. Thus, issues of the marine ornamental reef fishery should be identified to acquire maximum benefits while ensuring the sustainability of the coral reef ecosystems (Manejar and Guiehem 2018).

Value chain (Porter 1985), describes the full range of activities that are required to bring a product or service from conception through different phases of production (involving a combination of physical transformation and the input of various producer services), delivery to final consumers, and final disposal after use (Kaplinsky and Morris 2001). Identification of key stakeholders and market chain is appropriate for addressing the challenges of an industry (Manejar and Guiehem 2018). Studies are scarce to date to characterize the value chain of the marine ornamental reef fishery and describe the input & production flow and key actors in Trincomalee, which is considered as a hotspot for this fishery in Sri Lanka (NARA 2008). Therefore, the present study aimed to identify the value chain, characterize the role of different actors along the value chain, and assess the performance of the value chain with an emphasis to Trincomalee district, Sri Lanka.

72.2 Materials and Methods

The study was carried out among marine ornamental reef fisher communities engaged in fishing in the reefs located at Pulmodai, Coral Island, Dutch Bay, Kuchchaweli, Back Bay, Foul Point, Coral Cove and Sampur in Trincomalee district of Sri Lanka over two-year period starting from February 2019. Survey questionnaires were developed to characterize the principal actors along the value chain. Different principal actors were identified using snowballing sampling technique (Biernacki and Waldorf 1981; Deepananda et al. 2015). Furthermore, the current status of marine ornamental reef fishery was ascertained. Primary data were collected through semi-structured interviews, focus group discussions and participant observations (Deepananda et al. 2016a) from 90 reef fishers. Key informant interviews (Manejar and Guiehem 2018) and informal discussions were carried out with middlemen ($n = 6$), exporters ($n = 9$), District Fisheries Officers (DFOs) of the Department of Fisheries and Aquatic Resource ($n = 2$), subject officers of Sri Lanka Navy ($n = 4$), drivers ($n = 6$), accountants ($n = 4$) and other supporters ($n = 5$). All the interviews with fishers and focus group discussions were carried out in the native language of the interviewee at the fish landing sites or their relevant workplaces. Key informant interviews with government officers were carried out at a scheduled time of the day with granted permission from higher officials. Prior to the interviews and discussions, the objectives of the study were explained well for respondents. The supply chain and production chain were evaluated, and the quantity of fish was gathered at each operational component along the production chain. Also, the selling price of the fish and invertebrates were gathered from the records of accountants at each level.

72.3 Results

72.3.1 Stakeholders of the Marine Ornamental Reef Fishery

Fish collectors, middlemen, and exporters were the main operational components of the marine ornamental reef fishery in Trincomalee, Sri Lanka. The value chain consisted of approximately 600 fishers, 11 local buyers, 21 exporters, and 2 local aquaria. Fishers collected fish and invertebrates from the wild, and middlemen were the actors between fishers and exporters. Final destination of the collected fish was decided by exporting companies, one of which was located within Trincomalee while the rest were located throughout the western province mainly due to close proximity to the international airport. In addition, input suppliers, supporters, regulatory authorities and support staff were the key components of the value chain. The production and input flow of the value chain of marine ornamental reef fishery in Trincomalee is depicted in Fig. 72.1.

‘Fish-to-order’ concept is employed in ornamental reef fishery in Trincomalee. Middlemen nominate fish to be caught by fishers in par with the orders from exporters. The daily excess catch is stored in aerated glass, concrete or fibreglass tanks until the next order for that species. Often, the monetary loss of post-harvest damages is shouldered by the middlemen except for non-ordered fish. The vast majority of fish & invertebrates (98%) are sold to the exporters, while the rest (2%) is sold to the local aquaria.

The reefs were located approximately 1–3 km away from the coastline therefore, fishers used vessels for fishing at reefs, which was done by diving up to 24 m depth. Fiberglass Reinforced Plastic boats with outboard motor (OFRP) and canoes were the fishing vessels used. Of the two types, the most popular fishing vessel

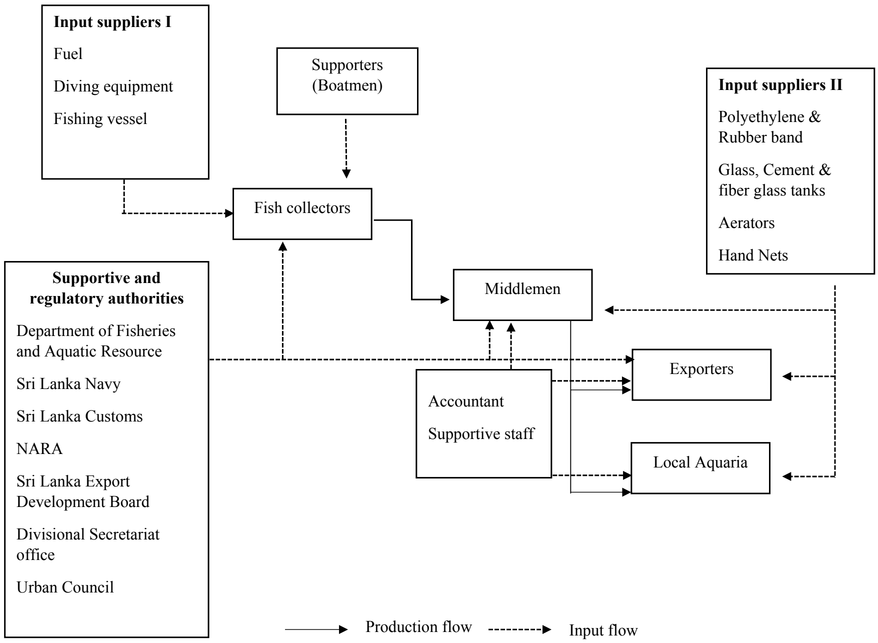

Fig. 72.1 The flow of production, input and supportive services in marine ornamental reef fishery in Trincomalee, eastern Sri Lanka

was OFRP run with kerosene oil or petrol, which were provided by the middlemen. Diving equipment; goggles, snorkel, Buoyancy Control Device (BCD), regulators, oxygen cylinders were integral components in fishing. All fishers possessed their own diving equipment and accessories except oxygen cylinders. Thus, sellers of the diving equipment played a key role in the value chain. Fishers collected fish associating reefs using several types of fishing gears, including hand net and moxy net. Collected fish were kept in polyethylene/ plastic bags at the reefs and then transferred to storage containers in the boat. Rubber bands, polythene bags, styrofoam or plastic storage containers which were essential for packing fish and transport to the destination, as well as, glass tanks, aerators and hand nets which were used for storing excess fish until selling, and fish handling were provided by suppliers. Live fish harvest was sold to local buyers viz., middlemen.

Water quality maintenance in fish storage containers and all mechanical operations of the fishing vessels were assigned to the boatmen. On arrival to the shore, all the equipment were shouldered to the storeroom of the diving centre by the boatman. Accountants managed all financial aspects throughout the production flow and input flow and were involved in calculating and distributing salaries to all the employees. Other supportive staff involved in counting fish in the production flow, maintaining the water quality of fish storage tanks, and packing fish for transport. The role of the supportive and regulating authorities are given in Table 72.1.

Table 72.1 Key roles and responsibilities of supportive and regulating authorities in marine ornamental reef fishery in Trincomalee, Sri Lanka

Authority	Role and responsibilities
Department of Fisheries and Aquatic Resource	Registering fishing vessels Issuing Scuba License and permits to snorkelers Declaring the restricted and prohibited fish & invertebrate species Issuing permits for exporting restricted fish & invertebrate species Issuing permits for fish export companies Regulating the maintenance operations of the export companies Monitoring fishing vessels for illegal fishing gears
Sri Lanka Navy	Check the permits of divers & fishing vessels Monitoring use of illegal fishing gears, and inspecting fish harvest
National Aquatic Resource Research and Development Agency (NARA)	Conducting awareness programme and researching on coral reef and environment
Sri Lanka Customs	Monitoring illegal activities in fish exports
Sri Lanka Export Development Board	Registering the fish exporting companies, issuing a registration number
Divisional Secretariat office	Registering the local fish collecting centres
Urban Council	Estimating tax for local fish collecting centres

72.3.2 *Price Variation of Fish and Invertebrates Through the Production Flow*

The price of the fish and invertebrates varied with species along with the production flow. The price at the fish collectors ranged between 10 and 12,000 Sri Lankan Rupees (LKR) per individual. Price variation through the production flow was conspicuously higher (Table 72.2).

72.4 Discussion

Being the key stakeholders of the industry, fish collectors, middlemen and exporters, the main operational components of the marine ornamental reef fishery in Trincomalee link with input suppliers and supportive services to form the value chain. Key findings of the present work on value chain are in agreement with the findings of Manejar and Guiehem (2018), Ferse et al. (2012) and Madduppa et al. (2014). However, some other studies have documented disagreements with the present findings in the production flow. The present study unfolds that individual fish collectors

Table 72.2 Price variation of fish and invertebrates valued over 400 LKR at fishers to exporters through the production flow of the marine ornamental reef fishery, eastern Sri Lanka

Common name	Scientific name	Price per individual (LKR)[a]		
		Fishers	Middlemen	Exporters
Fish				
Spotted unicorn fish	*Naso brevirostris*	400	500	4541
Blue-spotted puffer	*Arothron caeruleopunctatus*	400	500	3654
Blue-spotted ribbontail ray	*Taeniura lymma*	400	450	19,001
Emperor angel	*Pomacanthus imperator*	400	500	4918
Zebra eel	*Gymnomuraena zebra*	400	500	2375
Banded snake eel	*Myrichthys colubrinus*	450	500	1090
Harlequin ghost pipe fish	*Solenostomus paradoxus*	500	550	7451
Black snapper	*Macolor niger*	900	1200	8053
Palette surgeon fish	*Paracanthurus hepatus*	1000	1200	14,903
Ribbon eel	*Rhinomuraena quaesita*	1000	1500	7405
Honeycomb moray	*Gymnothorax favagineus*	1000	1500	8383
Guineafowl puffer	*Arothron meleagris*	1000	1200	5775
Long nose hawk fish	*Oxycirrhites typus*	1200	1500	11,175
Striped frog fish	*Antennarius striatus*	1800	3000	22,352
Clown trigger fish	*Balistoides conspicillum*	2000	2500	8103
Blue and yellow grouper	*Epinephelus flavocaeruleus*	2500	3000	9321
Blackspotted puffer	*Arothron nigropunctatus*	4000	4500	9500
Freckled frogfish	*Antennarius coccineus*	5000	6000	10,250
Painted frogfish	*Antennarius pictus*	7000	8000	11,175
Invertebrates				
Bullseye pistol shrimp	*Alpheus soror*	400	500	1313
Red fire shrimp	*Lysmata debelius*	425	700	2459
Pacific cleaner shrimp	*Lysmata amboinensis*	500	600	1887
Golden coral shrimp	*Stenopus scutellatus*	500	700	6900
White sand anemone	*Heteractis malu*	600	800	1956
Bicolor branching hammer coral	*Euphyllia paraancora*	1500	2000	4560
Green bubble tip anemone	*Entacmaea quadricolor*	3500	4000	8612
Haddon's sea anemone	*Stichodactyla haddoni*	5000	6000	11,177
Gigantic sea anemone	*Stichodactyla gigantea*	12,000	14,000	18,632

[a] 1 USD = 200 LKR in March 2021

connect with the middlemen, albeit studies in Southwest Sulawesi, Indonesia documented that group of fishers deals with the middlemen (Madduppa et al. 2014), due to the presence of several types of middlemen/patrons, such as transport middlemen, big patron, and small/fishing patrons. Of them, fishing patrons have linked to the export companies through an intermediary, while other middlemen/patrons directly connect with the export companies (Ferse et al. 2012). However, key actors of marine ornamental reef fishery in Trincomalee, Sri Lanka, and Sulawesi, Indonesia deal with the exporters through middlemen, and in the contrary, fish collectors in Philippines sell their harvest directly to the exporters (Manejar and Guiehem 2018). In Sri Lanka and the Philippines, fish collectors do not shoulder the responsibility for fish postharvest damages and mortalities after selling the harvest to the middlemen who bear those economic losses in such circumstances (Manejar and Guiehem 2018). However, the fish-to-order concept tends the fish collectors to shoulder the postharvest mortalities of the non-ordered fish in Trincomalee fishery. Licence for fishers and economic losses due to postharvest damages and mortalities in Indonesia are borne by the exporters (Ferse et al. 2012). The price of the fish and invertebrates vary with species due to varying demand, and some invertebrates are valued for a higher price. Also, the price changes through the production flow in the value chain are conspicuous, and the profit gained by middlemen and exporters are several folds higher than fishers. Key actors are assigned specific roles in input flow, and supporting and regulatory authorities are vital in this context. The role of the input suppliers are noteworthy and, regulatory authorities i.e., government entities are compulsorily responsible for managing fishing activities for which community participation is minimum. To sustain the marine ornamental reef fisheries in long run, community participation should be further strengthened in managing fishery resources as it has been proven in some small-scale coastal fisheries in Sri Lanka (Deepananda et al. 2016a, b).

72.5 Conclusions

Sri Lanka plays a major role in the global marine ornamental fish trade, becoming one of the top five exporting countries. Fish collectors, middlemen and exporters are the key actors in the production flow, and equipment & other accessory suppliers, supporters and government & non-governmental authorities are the active participators in the input flow. Government authorities regulate the fishery by implementing rules and regulations. Although there is government intervention, transparency in determining selling price is negligible. Thus, exporters acquire higher prices as much as 10 times higher than the price for fishers. The study indicated the long chain between the fishers and the exporters results in a lower selling price at the level of fishers.

References

Biernacki P, Waldorf D (1981) Snowball sampling - problems and techniques of chain referral sampling. Sociol Methods Res 10(2):141–163

Biondo MV, Burki RP (2020) A systematic review of the ornamental fish trade with emphasis on coral reef fishes-an impossible task. Animals 10(11):1–21. https://doi.org/10.3390/ani10112014

Biondo MV (2017) Quantifying the trade in marine ornamental fishes into Switzerland and an estimation of imports from the European Union. Glob Ecol Conserv 11:95–105. https://doi.org/10.1016/j.gecco.2017.05.006

Biondo MV, Burki RP (2019) Monitoring the trade in marine ornamental fishes through the European trade control and expert system TRACES: challenges and possibilities. Marine Policy 108https://doi.org/10.1016/j.marpol.2019.103620

Bruckner AW (2005) The importance of the marine ornamental reef fish trade in the wider Caribbean. Rev Biol Trop 53:127–137

Deepananda KHMA, Amarasinghe US, Jayasinghe-Mudalige UK (2015) Indigenous knowledge in the beach seine fisheries in Sri Lanka: an indispensable factor in community-based fisheries management. Mar Policy 57:69–77. https://doi.org/10.1016/j.marpol.2015.03.028

Deepananda KHMA, Amarasinghe US, Jayasinghe-Mudalige UK (2016) Neither bust nor boom: institutional robustness in the beach seine fishery of southern Sri Lanka. Ocean Coast Manag 128:61–73. https://doi.org/10.1016/j.ocecoaman.2016.04.020

Deepananda AKHM, Amarasinghe US, Jayasinghe-Mudalige UK et al (2016) Stilt fisher knowledge in southern Sri Lanka as an expert system: a strategy towards co-management. Fish Res 174:288–297. https://doi.org/10.1016/j.fishres.2015.10.028

Ferse SCA, Knittweis L, Krause G et al (2012) Livelihoods of ornamental coral fishermen in South Sulawesi/Indonesia: implications for management. Coast Manag 40(5):525–555. https://doi.org/10.1080/08920753.2012.694801

Kaplinsky R, Morris M (2001) A handbook for value chain research. Institute of Development Studies, University of Sussex and School of Development Studies. https://www.researchgate.net/publication/42791981_A_Handbook_for_Value_Chain_Research. Accessed 12 Mar 2021

Madduppa HH, Juterzenka KV, Syakir M et al (2014) Socio-economy of marine ornamental fishery and its impact on the population structure of the clown anemone fish *Amphiprion ocellaris* and its host anemones in Spermonde Archipelago, Indonesia. Ocean Coast Manag 100:41–50. https://doi.org/10.1016/j.ocecoaman.2014.07.013

Muyot FB, Mutia MTM, Manejar AJA et al (2018) Value chain analysis of marine ornamental fish industry in the Philippines. Philipp J Fish 25(2):57–74. https://doi.org/10.31398/tpjf/25.2.2018A0005

NARA (2008) The survey of the marine aquarium fishery Batticoloa and Ampara Districts, Sri Lanka. http://www.nara.ac.lk/wp-content/uploads/2017/09/AQ-fishery-report-of-the-East-Coast-2008.pdf. Accessed 2 Apr 2021

Porter ME (1985) Competetive advantage, creating and sustaining superior performance. The Free Press, New York

Rajasuriya A (2008) Status of the marine aquarium fishery in the bar reef marine sanctuary, Puttalam District. CENARA reports: marine aquarium fishery, northwestern coast, 2008, (November). http://www.nara.ac.lk/wp-content/uploads/2017/09/Status-of-the-Marine-Aquarium-Fishery-in-the-Bar-Reef-Marine-Sanctuary-Puttalam-District-1.pdf

Rajasuriya A, Perera N, Fernando M (2005) Status of coral reefs in Trincomalee, Sri Lanka. In: Souter D, Linden O (ed) Coral reef degradation in the Indian Ocean (CORDIO), Status report 2005, University of Kalmar, Sweden, pp 97–103. http://www.cordioea.org/storage/status-reports-full/CORDIOStatusReport2005.pdf#page=95. Accessed 3 Mar 2021

Spalding MD, Ravilious C, Green EP (2001) World atlas of coral reefs, 1st edn. University of Califonia Press, Berkeley, California

Wabnitz CCC, Taylor ML, Razak T (2003) From Ocean to aquara: the global trade in marine ornamental species. UNEP-WCMC, Cambridge, UK. https://www.researchgate.net/publication/

265496427_From_Ocean_to_Aquarium_The_Global_Trade_in_Marine_Ornamental_Species. Accessed 27 Feb 2021

Wood E (2001) Collection of coral reef fish for aquaria: global trade, conservation issues and management strategies. Marine Conservation Society, UK. https://www.researchgate.net/publication/241193889_Collection_of_Coral_Reef_Fish_for_Aquaria_Global_Trade_Conservation_Issues_and_Management_Strategies. Accessed 27 Mar 2021

Zhang R, Yu K, Li A et al (2020) Antibiotics in coral reef fishes from the South China sea: occurrence, distribution, bioaccumulation, and dietary exposure risk to human. Sci Total Environ 704. https://doi.org/10.1016/j.scitotenv.2019.135288

Chapter 73
Strengthening Agricultural and Allied Value Chains for Income and Livelihood Security in Coastal Economies of India

Shinoj Parappurathu

Abstract Coastal zones of India are the most fragile, yet dynamic and productive ecosystems that support a variety of agricultural and allied enterprises, thereby providing livelihoods to millions of smallholder producers. Traditional value chains associated with coastal primary production systems are characterized by a high amount of inefficiency, disconnect between producers and consumers, fragmented market channels, poor infrastructure and policy distortions. Given the rapid changes in agri-food market environment in the country post-globalization, it is imperative to develop well-functioning value chains fully equipped to meet the emerging consumer needs encompassing product quality, certification, branding, packaging and traceability. In this backdrop, this chapter presents a comprehensive set of strategies and options, with emphasis on technological and policy interventions, needed to strengthen the agri-food value chains in the coastal zones of India.

Keywords Agri-food markets · Coastal ecosystem · India · Value chains

73.1 Introduction

India's coastal economy supports a significant number of predominantly rural, smallholder households which depend on a diverse set of primary activities comprising of crop and animal husbandry, capture and culture fisheries, forestry, integrated farming, post-harvest processing and value addition and other value chain-related activities for their basic sustenance. A considerable part of agricultural production in coastal zone happens in homestead farms which are mostly mixed farming systems. Intensification of cropping system, as well as diversification to high-value crops, allied enterprises including livestock, aquaculture and fishery, has been a major driver that sustained agriculture in India including the coastal zones (Birthal et al. 2007; Joshi et al. 2006). Agricultural diversification in general has shown a small-farm bias and had significant impacts on income augmentation and distribution, poverty alleviation, besides enhancing the resilience of farmers to shocks (Birthal and Hazrana 2019; Birthal et al. 2015). Capture fisheries, which is the lifeline for close to 4

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million coastal dwellers have been driven mostly by mechanization of fishing crafts, advancement in propulsion systems, innovations in gears and better mechanisms for fish finding and harvesting (Kurien 1985; Salagrama 2004). In recent times, coastal aquaculture and mariculture have experienced a great spurt owing to technological innovations as well as initiatives on the part of the government, private entrepreneurs as well as civil society organizations (Bavinck and Johnson 2008; Jadhav 2018; Gopalakrishnan et al. 2017; Parappurathu et al. 2017). Notwithstanding these, several regions in the coastal continuum still remain cut off from the mainstream development process with umpteen challenges acting as speed-breakers in the way of their continuous development. Lately, these ecosystems are particularly exposed to climate change and associated extreme weather events that deepen the vulnerability of production systems and economic processes (Roxy et al. 2017; Rohit et al. 2018; Dineshbabu et al. 2020). The occurrence of tropical cyclones in quick succession year after year causes crop loss and destruction of fishing vessels and other coastal structures, thereby resulting in significant hardships to the affected people (NCRMP 2020). Apart from these, there are problems related to submergence, saltwater intrusion, destruction of fragile wetlands and mangrove habitats due to the expansion of non-agricultural and industrial activities (Mandal et al. 2020; George et al. 2018).

Sustainable development of smallholder dominant coastal livelihood systems requires efficient and cost-effective farm production, competitive markets, well-functioning value chains, transparent management and governance regimes as well as dynamic policies that are sensitive to the changing national and global environments (Meyer 2007; Chand 2012; Mani and Joshi 2017). Continuous technological innovations not only in production processes but also in the realms of institutions and governance are indispensable to maintain efficient functioning of market value chains and in turn ensure income and livelihood security of the dependent population (Trienekens 2011). Development of business models involving promising enterprises and strengthening the associated value chains can play a significant role in ensuring steady employment and income for the coastal workforce. Widening the avenues for trade and enhancing the international competitiveness of farm products is another sensible option to maintain the vibrancy in agri-business. Considering the above aspects, this chapter presents a broad overview of coastal agriculture and the complex set of value chain networks and interactions therein. Further, a comprehensive set of strategies and options with emphasis on technological and policy interventions needed to improve the efficiency of agricultural, livestock and fishery value chains in the coastal zones of India is presented.

73.2 Agricultural Value Chains in India: An Overview

Value chains play an integral role in taking the agricultural products from primary producers to the ultimate consumer, connecting the various market functionaries in the process and simultaneously adding value at each node to maximize the net revenue. It can be described as organized links across groups of producers, traders, processors and service providers including non-governmental organizations (NGOs) that join together to improve productivity and the value added from their activities (ADB 2013). Market efficiency associated with farm products depends to a considerable extent on the length of the supply chain, number of market intermediaries, linkages with the input markets, logistics associated with upstream and downstream movement of the product, and the overall fashion in which value chains are organized so that 'value addition' and 'value creation' take place for the benefit of stakeholders involved. Not only the factors of production but technology, market information systems and management constitutes the key determinants of performance of agricultural value chains (FAO 2014). Based on their organization, value chains could be broadly classified as (i) producer-driven, (ii) buyer-driven, (iii) facilitator-driven and (iv) integrated (Miller 2012) (Table 73.1).

Traditional value chains of farm products in India are rather long with at least four intermediaries between producers and consumers with relatively high price spread and with little or limited value addition made on the primary produce. These value chains, particularly those of the cereals, pulses and oilseeds are characterized by a high amount of inefficiency, disconnect between prices received by producers and prices paid by consumers, fragmented market channels, poor infrastructure and policy distortions (Chand 2012). Relatively, value chains of perishables such as milk and its products, broilers, eggs, fruits and vegetables are better developed due to the presence of well-organized co-operative organizations, multi-national companies and farmer producer companies. Agricultural marketing in India is governed to a great extent by the public sector through government policies, market regulations and institutions. State intervention in the functioning of agricultural markets is effected through

Table 73.1 Typical organizational models of smallholder value chains in developing countries

Business model	Drivers	Rationale
Producer-driven	• Small-scale producers, especially when formed into groups such as associations or co-operatives • Large farmers	• Access to new markets • Obtain higher market prices • Stabilize and secure market positions
Buyer-driven	• Processors • Exporters • Traders • Retailers	• Assure supply • Increase supply volumes • Serve niche markets and consumer preferences
Facilitator-driven	• NGOs • National and local governments	• Make markets work for the poor • Facilitate regional and local development
Integrated	• Lead firms • Super markets • Multinationals	• New and higher value markets • Low prices for good quality • Market monopolies

Source Miller (2012)

several means, first, by placing a policy and regulatory framework for smooth functioning of markets (mainly through Agricultural Produce Marketing Committee Act (APMC Act) of the respective state governments); second, by providing the physical and institutional infrastructure; third, by price administration and public distribution and fourth, by open market operations (Chand 2006; Bhalla 2007). These interventions are meant to act as incentives for the marketing system to become more efficient and better serve the market functionaries including producers, market intermediaries and consumers in terms of reasonable prices and steady income. However, despite having an elaborate set of institutional and policy instruments in place, agri-food markets in the country remain fragmented with high logistics costs to the tune of 15%. The efficiency, inclusiveness and sustainability of agricultural value chains seem to be significantly affected by the limited scale of individual smallholder producers, infrastructure and communication bottlenecks in rural areas, excessive presence of middlemen, some following unscrupulous trading practices, low level of post-harvest value addition and processing, declining export competitiveness of farm products in global markets, low private capital formation in the farm value chain segment as well as excessive dependence of farmers on the support price system (Chand 2020). Though market reforms were initiated through the model APMC Act, 2003 followed by its subsequent variants such as model Agricultural Produce and Livestock Marketing (Promotion and Facilitation) Act, 2017 and Contract Farming Act, 2018, these did not translate into perceivable results. Notwithstanding this, in recent years, several organized retail marketing chains owned by the large private corporate players have emerged in the agri-marketing sector in India. They have retail outlets in the form of super markets, hyper markets, convenience stores, etc., that deal with cereals and pulses, fruits and vegetables, fish, meat, milk and several other agricultural commodities. In general, they procure farm products directly from the farmers and in certain cases, from the wholesale markets. Several corporate agri-business entities dealing with fresh and processed farm products have also been found to utilize the opportunities thrown open by the contract farming over the past two decades. The activity of traders and middlemen has been observed to be lower in these modern supply chains, thus increasing producer prices and marketing efficiency (Chandra et al. 2020). In 2020, the government of India passed three laws (the new farm laws)viz., (i) Farmers' Produce Trade and Commerce (Promotion and Facilitation) Act 2020; (ii) Farmers' Empowerment and Protection Agreement on Price Assurance and Farm Services Act 2020 and (iii) Essential Commodities (Amendment) Act 2020 in an effort to further reform the agri-market system. These acts have multiple objectives such as enhancing the freedom of farmers to sell their produce anywhere in the country, to promote e-commerce, to enhance fairness and transparency in trade deals, minimize market intermediation, increase enterprise diversification, upscale private capital formation and competition, reduce excessive dependence of farmers on the support prices and so on (Chand 2020). On the other hand, a significant section of farmers has expressed their strong opposition to the legislation through massive public agitations and rallies citing a number of possible adverse impacts. Given the high level of uncertainty in their implementation, the future course taken by the new farm laws is yet to unfold completely.

73.3 Agriculture-based Livelihood Systems in Coastal Zones

Coastal zones of India are spread across nine maritime states and four union territories and are the most fragile, dynamic and productive ecosystems that support rich floral and faunal biodiversity. The diverse habitats supported by the coastal zones include mangroves, coral reefs, seagrasses, salt marshes, estuaries, lagoons, sand dunes and mudflats which are characterized by distinct biotic and abiotic processes (ISRO 2011). Because of their geographic, edaphic and climatic peculiarities, the coastal inhabitants draw their livelihood from a variety of agricultural and allied production systems which include the homestead production systems (HPS) that support a plethora of field and horticultural crops besides poultry and livestock, rice-based wetland farming systems, millet-based farms in rainfed drylands, submerged wetland systems that integrate paddy along with fish and duck in below sea level areas, backwaters and estuaries that support a variety of fishery activities and so on (See Table 73.A1 in annexure for an overview of land allocation for cropping in the coastal districts). Besides this, close to 4 million fisherfolk depend on marine fishing, fish seed collection, coastal aquaculture, mariculture and other allied activities for their daily sustenance. Traditionally, marine fishing in India is carried out by members of particular fishing communities who reside along the coasts and is distinct from the mainstream agrarian communities. As per the Marine Fisheries Census, 2016, there were 3477 fishing villages with a total of 893.3 thousand fisher families, of which 818.5 thousand (92%) were traditional fisher families (Table 73.A2). The total population of fisherfolk is estimated to be 3774 thousand, of which 1528.4 thousand were employed, mainly in capture fisheries, coastal aquaculture and allied activities in 2016 (Parappurathu et al. 2020).

73.4 Coastal Agricultural Value Chains

It is challenging to evolve efficient, inclusive and sustainable value chains in coastal zones of India where primary producers are predominantly smallholders, mainly associated with homestead production systems. As indicated earlier, traditional farm produce value chains in these regions are fragmented with large number of intermediaries and are increasingly getting less oriented to the requirements of evolving modern markets. It is imperative to develop well-functioning value chains which are fully equipped to meet the emerging consumer needs encompassing product quality, certification, branding, packaging, and traceability. In this context, depending on the farm produce concerned, the sensibilities of not only the domestic consumers, but those of the international markets also need due recognition. Furthermore, the changing global order with regard to trade rules, market access, safety and quality considerations as well as intellectual property-related matters also need attention. Achieving these objectives, therefore, require well-knit systems in place for input delivery and management, farm gate procurement, produce aggregation, transportation, grading, storage/warehousing, value addition, marketing, data management and networking. Innovative, technology-driven and policy-oriented interventions in the realms of land, labour, capital and management are of utmost importance to enable such a transition.

73.5 Interventions for Efficiency Enhancement

In this section, a comprehensive set of possible interventions at different levels of agri-produce value chains in coastal zones is discussed. For simplicity and clarity, the overall value chain is divided into three value subsystems, viz., (i) input market system, (ii) primary produce market system and (iii) value added product market system. Figure 73.1 provides an illustration of a representative agri-produce value chain where interventions in the realms of input delivery (seed, feed, farm implements, labour, credit, etc.), primary produce marketing and value added produce marketing are depicted. Detailed accounts on each specific intervention suggested along with enabling factors are presented in Table 73.2.

The interventions discussed in Table 73.2 are broadly indicative, cutting across the domains of inputs/products and would hold good irrespective of the sector in question (field/horticulture/livestock/poultry/fishery). Some of the successful examples of agri-food value chain integration in the country include AMUL, based in Gujarat, dealing with dairy products; MDFVL (formerly SAFAL) based in Delhi dealing with dairy products, fruits and vegetables; HOPCOMS and VFPCK dealing with fruits and vegetables based in Karnataka and Kerala, respectively; Suguna foods dealing with

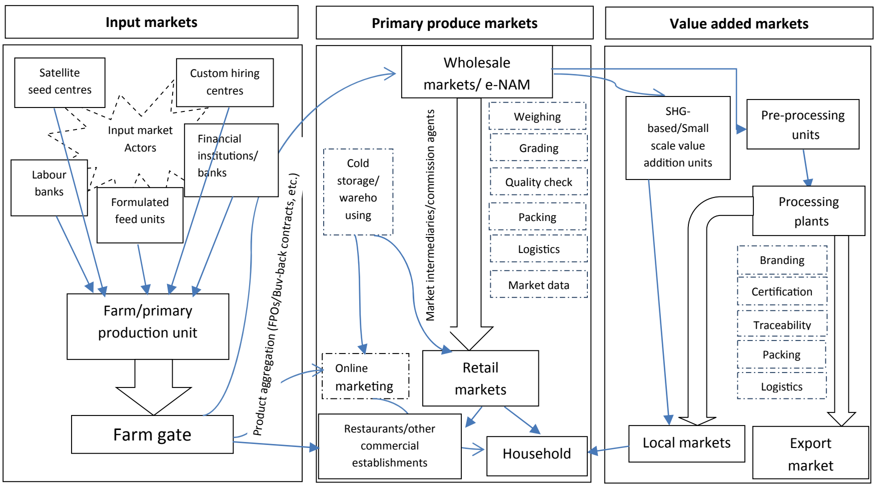

Fig. 73.1 Value chain subsystems of farm produce with interventions: an illustration

Table 73.2 Value chain interventions for efficiency enhancement in coastal zones of India

Domains where applicable	Value chain intervention	Enabling factors required
Input supply chains of crops/livestock/fishery production systems	Establishment of satellite seed production centres for enhancing the supply of certified /improved seeds of promising crop varieties and fish species	A viable technology incubation policy at the state level; Equipping front line extension agencies to train prospective entrepreneurs and facilitate business incubation of seed production/multiplication units. In fisheries sector, public sector broodstock development units and private / PPP for hatchery production of fish seeds may be encouraged
	Establishment of custom hiring centres of farm machinery at local level to enhance affordable access of smallholders to such services	Ensuring timely extension of technological advancements related to farm machinery through a network of research /extension institutions; state support/credit facilities for initial establishment
	Formation of labour banks at local level to better co-ordinate timely supply of labour services	A labour policy at state level; provision of ICT tools and applications to facilitate information management and networking; support from local self-government bodies for efficient implementation
	Improving financial inclusion in disconnected areas; enhancing access of farmers / fishers to Kisan Credit Cards (KCC)	Policy and budgetary support to enhance financial inclusion in coastal areas; monitoring at all levels to ensure best use of credit for primary production related activities; interest subvention schemes wherever necessary; awareness campaigns to enhance adoption of KCC by beneficiaries
	Enhancing the supply of good quality formulated/functional feeds to animal and fish farms at affordable prices	Enactment of feed laws at state level to ensure quality as well as regulation of imports. Strict control on the use of juvenile fish for fish meal production

(continued)

Table 73.2 (continued)

Domains where applicable	Value chain intervention	Enabling factors required
	Facilitate leasing on transparent conditions for optimal utilization of productive lands and water bodies	Enacting leasing laws following the Model Land Lease Law proposed by NITI Aayog; Framing a leasing policy and subsequent laws to allow leasing of water bodies for promotion of mariculture
Value chains of farm products in primary forms	Promotion of contract farming in crops/livestock/aquaculture for assured market opportunities	Enactment of contract farming laws at state level to regulate activities of the parties involved and to minimize misuse; technical and logistical support from public agri-business entities; a strong grievance redressal system in place
	Establishment of electronic auction/marketing for suitable farm products including fish	Extending e-NAM to less connected coastal markets; extending technical and logistical support through research /extension institutions/agencies
	Promotion of Farmer Producer Organizations (FPOs) in agri/livestock/ fisheries for better integration amongst producers	Technical and logistic support from public financial institutions (NCDC/NABARD), apex co-operative bodies, local self-governments, research/frontline extension agencies, etc.
	Strengthening wholesale and retail market infrastructure with emphasis on grading, weighing, packaging, cold chain, warehousing, adulteration check facilities, market data networks, etc.	Specialized schemes for infrastructure development with credit support; replicating successful PPP models in potential areas; reorganizing primary market management committees, wherever necessary, with greater community participation

(continued)

Table 73.2 (continued)

Domains where applicable	Value chain intervention	Enabling factors required
Extended value chains of value added products	Emphasis on good agriculture practices (GAP)/ good manufacturing practices (GMP) in all farms/processing/value addition units to ensure product quality	Greater policy focus for entrepreneurship development by utilizing latest innovations in food processing, bioprospecting, product certification, packaging, etc.; Identification of niche products in each coastal area and develop specialized schemes to capitalize their value addition potentials; developing a network of value addition incubation centres with technical support from research institutions/ universities/ front line extension agencies to promote start-ups of promising agro-based products; special credit delivery schemes, interest subvention programmes, etc., to encourage start-ups in agro/food processing
	Specialized schemes to encourage small-scale processing units to adopt quality certification and branding to enhance product quality and value	
	Adopting a zero-waste approach and encourage adoption of latest developments in packaging (vacuum packaging (VP), modified atmosphere packaging (MAP), etc.)	
	Developing traceability systems in high-value product chains, especially of exported products	
	Encouraging extraction and use of secondary by-products (collagen/ gelatin/ pectin/ chitin/ chitosan, etc.) from farm/ animal/ fish products and other discards	

Source Sen et al. (2014); Parappurathu et al. (2017); Dey (2018); GoI (2018); GoI (2019); ICAR (2019) broilers, poultry feed and vaccines, based in Tamil Nadu; Matsyafed and BENFISH dealing with fresh fish and fish products in Kerala and West Bengal, respectively. Some corporate/multi-national companies who own well-established value chain models in agri-business include Nestle, ITC, PepsiCo, Reliance Fresh, Heritage foods, Mahagrapes and Namdharis. Most of these establishments have followed successful models of organizing small-scale producers either through co-operatives or SHGs, or achieve product aggregation through contract farming arrangements. They are also excellent examples of success in farm-level input delivery and extension, value addition, brand building, product certification and marketing (Mani and Joshi 2017; Birthal et al. 2017). In recent times, a number of small-scale farmer producer companies (FPCs) have emerged triumphant in developing popular agri-food product brands. There is immense potential in upscaling the activities of FPCs in the coastal zones of India, particularly in emerging enterprises such as mariculture, seaweed farming, mussel and oyster culture, shrimp culture, etc. Entrepreneurial efforts focussing on value added secondary products, ready-to-eat foods, and nutraceuticals also hold promising future potential in coastal zones.

73.6 Conclusions

Ensuring the vibrancy of value chains associated with farm products is critical in achieving sustainable and inclusive development of smallholder-dominant coastal agricultural livelihood systems in India. Value chain approach has immense potential in improving the competitiveness and smallholders' access to markets, enhancing efficiency of market transactions, ensuring quick transmission of price signals, bridging the disconnect between various categories of market actors and intermediaries, besides minimizing supply and market risks. This chapter presents a broad overview of the agriculture-based livelihood systems in coastal zones of India and goes on to throw key insights into the workings of agri-food value chains associated with diverse production systems ranging from homesteads to wetlands, backwaters and estuaries that support a variety of agriculture and allied activities. Furthermore, a comprehensive set of possible interventions at different levels of agri-produce value chains is discussed with special reference to input delivery (seed, feed, farm implements, labour, credit, etc.), primary produce marketing as well as value added produce marketing. These interventions are identified based on a comprehensive review and are proven to have promising potential in enhancing the efficiency of value chains cutting across sectors (field/ horticulture/ livestock/ poultry/ fishery), market formats and product types. The future development of coastal agriculture and associated livelihoods would depend considerably on how the product value chains emanating from diverse production systems are effectively managed by consolidating technological innovations, institutional reforms as well as policy changes.

Annexures See Tables 73.A1, 73.A2

Table 73.A1 Cropping profile of coastal districts/states in India, 2018–19

Coastal state /UT	Coastal districts				State/UT			
	GCA ('000 ha)	CI (%)	Irrigated area (%)	Area under food crops (%)	GCA ('000 ha)	CI (%)	Irrigated area (%)	Area under food crops (%)
A&N islands#	16.5	112.4	0.72	83.1	16.5	112.4	0.72	83.1
Andhra Pradesh	4697.7	128.0	60.9	80.0	7296.6	120.6	49.8	71.1
Dadar & Nagar Haveli*	23.2	124.0	33.3	95.6	23.2	124.0	33.3	95.6
Daman & Diu*	2.8	102.8	0.75	98.3	2.8	102.8	0.75	98.3
Goa	149.8	117.4	22.6	81.6	149.8	117.4	22.6	81.6
Gujarat	NA	NA	NA	NA	11,994.4	116.4	49.3	46.2
Karnataka*	388.7	109.2	39.5	NA	11,993.6	121.2	30.3	76.6
Kerala	1550.4	122.5	20.3	34.8	2571.1	126.4	20.0	36.8
Lakshadweep*	2.3	107.2	0.0	4.6	2.3	107.2	0.0	4.6
Maharashtra	NA	NA	NA	NA	16,910.4	141.6	19.5	61.2
Odisha	1220.2	120.6	44.3	99.6	4526.9	113.0	29.0	98.4
Puducherry	26.7	174.5	84.6	81.7	26.7	174.5	84.6	81.7
Tamil Nadu*	2635.9	133.1	65.7	82.4	5729.5	123.5	57.2	76.3
West Bengal	1633.1	167.5	NA	88.7	9959.5	189.9	65.7	82.3

Source GoI (2019); Note: * data pertain to the year 2017–18; # data pertain to 2009–10

Table 73.A2 Profile of fishing villages of coastal states /UTs in India, 2016

Coastal state /UT	Fishing villages (No.)	Fish landing centres (No.)	Fisher households (No.)	Households below poverty line (%)	Total fisher population ('000)	Fishing crafts (No.)
A&N islands	169	57	5,944	24.6	26.5	-
Andhra Pradesh	533	234	1,55,062	97.1	517.4	20,219
Daman & Diu	12	8	3,163	0.6	15.8	1,992
Goa	41	32	2,986	21.7	12.6	1,982
Gujarat	280	107	67,610	28.2	355.0	27,642
Karnataka	162	84	32,479	84.1	158.0	11,884
Kerala	220	174	1,21,637	59.6	563.9	21,684
Lakshadweep	10	37	4,163	28.1	27.9	-
Maharashtra	526	155	87,717	31.2	364.9	15,520
Odisha	739	55	1,15,228	42.2	517.6	8,682
Puducherry	39	22	14,347	90.3	50.3	2,319
Tamil Nadu	575	349	2,01,855	90.9	795.7	43,355
West Bengal	171	49	81,067	68.2	368.8	11,054
India	3477	1363	8,93,258	67.2	3774.6	1,66,333

Source CMFRI-DoF (2020)

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References

ADB (2013) Agricultural value chains for development: learning lessons, Asian Development Bank, Manila, Phillippines

Bavinck M, Johnson D (2008) Handling the legacy of blue revolution in India - social justice and small-scale fisheries in a negative growth scenario. Am Fish Soc Symp 49:585–599

Bhalla GS (2007) Indian agriculture since independence. National Book Trust, New Delhi, India

Birthal PS, Hazrana J (2019) Crop diversification and resilience of agriculture to climatic shocks: evidence from India. Agric Syst 173:345–354

Birthal PS, Roy D, Negi DS (2015) Assessing the impact of crop diversification on farm poverty in India. World Dev 72:70–92

Birthal PS, Chand R, Joshi PK et al (2017) Formal versus informal: efficiency, inclusiveness and financing of dairy value chains in Indian Punjab. J Rural Stud 54(2):288–303

Birthal PS, Joshi PK, Roy D et al (2007) Diversification of Indian agriculture towards high value crops: the role of smallholders. IFPRI discussion paper 00727, International Food Policy Research Institute, Washington, D.C.

Chand R (2012) Development policies and agricultural markets, Review of Rural Affairs. Econ Polit Wkly 47(52):53–63

Chand R (2006) Agricultural markets in India: implications for competition. In: Pradeep S. Mehta (Ed.) Towards a functional competition policy in India: an overview, CUTS International, Jaipur, India

Chand R (2020) New farm acts: understanding the implications. NITI Aayog, Government of India.

Chandra SRN, Sutradhar R, Reardon T et al (2020) Supermarket procurement and farmgate prices in India. World Dev 134:105034.

CMFRI-DoF (2020) Marine fisheries census 2016-India, Central Marine Fisheries Research Institute, Indian Council of Agricultural Research, Ministry of Agriculture and Farmer' Welfare; Department of Fisheries, Ministry of Fisheries, Animal Husbandry and Dairying, Government of India.

Dey K (2018) Farmer producer companies in India: determinants of performance and viability. Econ Polit Wkly 43(35):44–52

Dineshbabu AP, Zacharia PU, Sujitha T et al (2020) Assessment of stock vulnerability of Indian marine fishes to past changes in climate and options for adaptation. Clim Res 79:175–192

FAO (2014) Value chain dynamics and the small-scale sector: policy recommendations for small-scale fisheries and aquaculture trade, FAO Fisheries and Aquaculture Paper No. 581, Food and Agriculture Organization of the United Nations, Rome, Italy.

George G, Krishnan P, Mini KG et al (2018) Structure and regeneration status of mangrove patches along the estuarine and coastal stretches of Kerala, India. J for Res 30:507–518

GoI (2018) Report of the committee on doubling farmers' income. volume XIV. Ministry of Agriculture and Farmers' Welfare, Government of India, New Delhi

GoI (2019) Report of blue economy working group-3 on fisheries aquaculture and fish processing submitted to the Economic Advisory Council to the Prime Minister, Government of India New Delhi

Gopalakrishnan A, Ignatius B, George G (2017) India's largest fisheries research body turns 70-CMFRI's legacy and few recent achievements. Fish Chimes 37(1):38–43

ICAR (2019) State specific strategies for doubling farmers income - 2022. Indian Council of Agricultural Research, Department of Agricultural Research and Education, New Delhi, India

ISRO (2011) Coastal zone of India. Space Applications Centre, Indian Space Research Organization, Ahmedabad, Gujarat, India

Jadhav A (2018) Undefining small-scale fisheries in India: challenging simplifications and highlighting diversity and value. In: Johnson DS, Acott TG, Stacey N et al. (eds) Social well-being and the values of small-scale fisheries, MARE publication series 17, Springer International Publishing, AG, Switzerland

Joshi PK, Birthal PS, Minot N (2006) Sources of agricultural growth in India: role of diversification towards high value crops. MTID discussion paper 98, International Food Policy Research Institute, Washington, D.C.

Kurien J (1985) Technical assistance projects and socio-economic change: Norwegian intervention in Kerala's fisheries development. Econ Polit Wkly 20(25/26):A70–A88

Mandal S, Maji B, Sarangi SK et al (2020) Economics of cropping systems intensification for smallholder farmers in coastal salt-affected areas in West Bengal: options, challenges, and determinants. Decision 47(1):19–33

Mani G, Joshi PK (2017) Financing agricultural value chains: an overview of issues, lessons learnt, and policy implications. In: Mani G, Joshi PK, Ashok MV (eds) Financing agricultural value chains in India, India studies in business economics, Springer Nature, Singapore.

Meyer RL (2007) Analysing and financing value chains: Cutting edge developments in value chain analysis. Paper presented at the 3rd African microfinance conference: new options for rural and urban Africa, Kampala, Uganda, 20–23 August 2007

Miller C (2012) Agricultural value chain finance strategy and design. Technical note, International Fund for Agricultural Development (IFAD), Rome, Italy

NCRMP (National Cyclone Mitigation Project) (2020). Website of national cyclone risk mitigation project. https://ncrmp.gov.in/cyclones-their-impact-in-india/. Accessed 25 June 2020

Parappurathu S, George G, Narayanakumar R et al (2017) Priorities and strategies to boost incomes of marine fisher folk in India, Agric Econ Res Rev 30(Conference Issue):205–216.

Parappurathu S, Gopalakrishnan A, Jena JK (2020) Demographic change in marine fishing communities in India. In: Siar SV, Kusakabe K (eds) Demographic change in Asian fishing communities - drivers, outcomes and potential impacts, FAO, Bangkok, Thailand. https://doi.org/10.4060/cb1752en

Rohit P, Sivadas M, Abdussamad EM et al (2018) Enigmatic Indian oil sardine: an insight. CMFRI special publication 130, ICAR-Central Marine Fisheries Research Institute, Kochi, Kerala, India

Roxy MK, Ghosh S, Pathak A et al (2018) A threefold rise in widespread extreme rain events over central India. Nat Commun 8:708

Salagrama V (2004) Policy research: implications for liberalization of fish trade for developing countries - a case study for India. Project PR 26109, Food and Agriculture Organization of the United Nations, Rome, Italy

Sen HS, Ghorai D, Karmakar PG et al (2014) Value addition to farm produce under changing contexts in India: a sine qua non for resuscitating Indian agriculture. Indian J Agric Sci 84(11):1295–1302

Trienekens JH (2011) Agricultural value chains in developing countries, a framework analysis. Int Food Agribus Manag Rev 14(2):52–82

Chapter 74
Analysis of Seaweed Value Chain to Improve Coastal Livelihood and Blue Economy of Bangladesh

M. I. Hossain, T. K. Ghose, and M. E. A. Begum

Abstract Seaweed culture in Bangladesh door to blue economy of Bangladesh by significant contribution toward eradication of poverty, improving to food and nutrition security, mitigation, and adaptation of climate change and generation of sustainable and inclusive livelihoods of coastal communities. Almost 3 crores people in 19 coastal districts largely depend on the sea. A shortfall in protein supply from capture fisheries has emphasized the Bangladesh government to focus on alternative cheap sources of protein like seaweed which is not well studied. Thus, this study analyzed the seaweed value chain sector of Bangladesh using primary and secondary data. Primary data were collected from 33 seaweed farmers and 15 different market actors by using pre-tested questionnaires. Fieldwork was conducted between December 10–30 2020 among seaweed stakeholders involved in the value chain using mixed methods approach—in depth interviews with key informants, focus group discussions, household surveys, and personal observation. Seaweed was sold in two forms: dried seaweed to be used as raw materials in carrageenan processing (approximately 88% of total harvest) and fresh seaweed to be used as a source of seedlings (approximately 12% of total harvest). The value chain map ended with carrageenan form, which is started from farmers and reached to the local tribal consumers and some portion is exported to international markets. The price of dried seaweed varied according to a combination of seaweed quality, the strength of farmer's relationships with intermediaries and processors and in response to demand from the carrageenan industry. The prices obtained by farmers for dried seaweed and carrageenan remained low, BDT 80, and BDT 1280 per kg, respectively. The intermediaries in the seaweed business were limited as the consumers are not aware about the benefits of seaweed.

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The value chain analysis was a useful tool to identify and map the market, with the results providing a better understanding of the seaweed sector, which could be helpful in supporting further development of this sub-sector. Seaweed, if systematically cultured, explored, and marketed, could emerge as a vital agricultural product for coastal communities, be consumed as dishes and used in the pharmaceutical and cosmetic industries and contribute to the livelihood improvement and blue economy of Bangladesh.

Keywords Seaweed · Value chain analysis · Coastal region · Bangladesh

74.1 Introduction

In the face of climate change, global and financial instability, and increasing competition for natural resources, the world faces one of the most significant problems of the twenty-first century: how to feed 9 billion people by 2050. These various challenges necessitate a coordinated response and a rapid shift in the global economy toward a more competitive, equitable, and resource-efficient direction. Blue economy can be the way to feed the inhabitants and use the resource efficiently for economic growth, improve livelihoods and jobs and ocean environment (World Bank 2017; Bhuyan et at. 2019). The ocean is considered as the life blood of the earth which absorbs carbon dioxide (CO_2), release oxygen (O_2), recycle nutrients, and regulate climate and temperature (Yousaf et al. 2016; Bristow et al. 2017).

The world economy is about US$ 88 trillion where 24 trillion comes from the sea. In Bangladesh, 81% of resources are existing from the ocean remaining 19% are from the land. More than 500 varieties of fish found in the Bay of Bengal and 8 million tons of fish are available where only 0.7 million tons of fish is captured every year (Alam 2019, BBS 2011). The latest ruling by the International Tribunal for the Law of the Sea (ITLOS) and the International Arbitration Tribunal on the maritime border disputes between Myanmar and India lawfully resolve Bangladesh's EEZ up to 200 nautical miles from the baseline, which covers 118,813 km^2 of maritime waters. The newly opened blue economy development window has the potential to dramatically contribute to Bangladesh's socioeconomic development as a growth engine during the 7th plan era (seventh five year plan 2016–2020).

Seaweed, a marine alga that is listed as an aquatic plant, has the capacity to contribute US$ 0.7 million to Bangladesh's blue economy (Hossain et al. 2021). Red (Rhodophyta), brown (Phaeophyta), and green (Chlorophyta) are the most common colors found in seaweeds (Ghose and Hossain 2020). Seaweed is enriched with protein, carbohydrates, beta-carotene, minerals, vitamins, essential amino acids, etc. Recently, seaweed experienced significant growth and demand in the Bangladesh market as well as foreign market due to its food and medicinal values including expended use in pharmaceutical, cosmetic, and chemical industries. Popularity of seaweed is also increasing in this COVID-19 situation due to its medicinal value and improvement of immunity of human health. Most importantly, World Health

Organization (WHO) has enlisted seaweed in the top ten nutritious supplementary foods and medicinal herbs. Seaweed can easily cure and prevent nutrition deficiency as well fatal cancer. It is also effective for various digestive problems, diabetics, fat reducing, thyroid gland problems, breast and intestine cancer, minerals deficiency, high blood pressure and stress, and heart diseases. While solving the problem of food and nutrition security of the increasing population of Bangladesh, seaweed can also open up a new business horizon for the country.

Bangladesh is home to 133 different types of seaweed, eight of which are commercially important. Despite having a 710-km coastline and a 25,000-km^2 coastal region with sandy and muddy beaches, estuaries, and mangrove swamps, Bangladesh is still lagging behind in terms of commercial seaweed production and market penetration (Siddiqui et al. 2019). About 1500 tons of seaweed are extracted in a year from St. Martin's Island without damaging environment (Sarkar 1992). Extrapolation of seaweed production shows that a 5000 km^2 farming area in Bangladesh could yield over 50 million tons of seaweeds (dry weight) by 2050 if growth rates of double, fifth, and one-fourth per year are maintained (Hossain et al. 2021).

It is clear that the seaweed industry has enormous promise, both now and in future, and that it will take on the burden of improving the wellbeing of coastal populations. However, owing to socioeconomic and technical limitations, Bangladesh's seaweed industry is still in its early stages and is not widely used. As a result, the Bangladesh government expects seaweed aquaculture to play an increasingly important role in ensuring food security, reducing pressure from capture fisheries, generating foreign exchange revenue, providing jobs, expanding alternative livelihoods, and developing industry and industrial investment opportunities. Furthermore, rising demand for seaweed and its derivatives provides Bangladesh with an ability to strengthen its status as a major global supplier. So, this study analyzed the seaweed value chain sector of Bangladesh with the objective to focus on its governance, economic, environmental, technological, and socio-cultural dimensions.

74.2 Value Chain Analytical Framework

A value chain describes the full range of activities that are essential to bring a product or service from conception, through different phases of production, transfer to consumers, and final disposal after use (Kaplinsky and Morris 2001). In the seaweed value chain, it is useful to assess the commercial viability (Neish 2008, 2013; Andriesse and Lee 2017; Ferdinandus et al. 2017; Mulyati and Geldermann 2017). A value chain analysis may be internal to a firm, when its aim is to identify which activities are the most valuable and which ones could be improved. The objective of carrying out value chain analysis is to identify the points where the product may be inefficiently passed on and the producer may be losing an opportunity to maximize market uptake. Thus, value chain analysis of seaweed will identify the opportunities and constraints for improvement for ensuring higher income of the farmers.

74.3 Materials and Method

74.3.1 Study Area

The area for the study was southeast Bangladesh mainly Cox's Bazar district where seaweed can be harvested naturally also cultivated. Teknef, Ukhiya, and Cox's Bazar sadar upazilas of Cox's Bazar district were purposively selected as the location advantage of cultivation of seaweed (Fig. 74.1).

Cox's Bazar is one of 64 districts of Bangladesh located 150 kms south of Chattogram with area of 2,491.86 km^2 (962.11 sq miles), with the world's longest natural sea beaches (120 kms long including mud flats). Cox's Bazar is considered one of the "lagging behind" districts of Bangladesh with the national average for development indicators, with approximately 33% of the population living below the poverty line compared to the national average of 31.5% (World Bank 2016). Around 32.2% of households in the district have access to electricity which is lower than the national average of 56.5% (World Bank, 2016), and about 11.8% of households do not have access to sanitary facilities and practice open excretion, compared to the national average of 7.7% (World Bank 2016). Approximately, 78.5% of Cox's Bazar is considered as rural, and most communities live in remote areas without

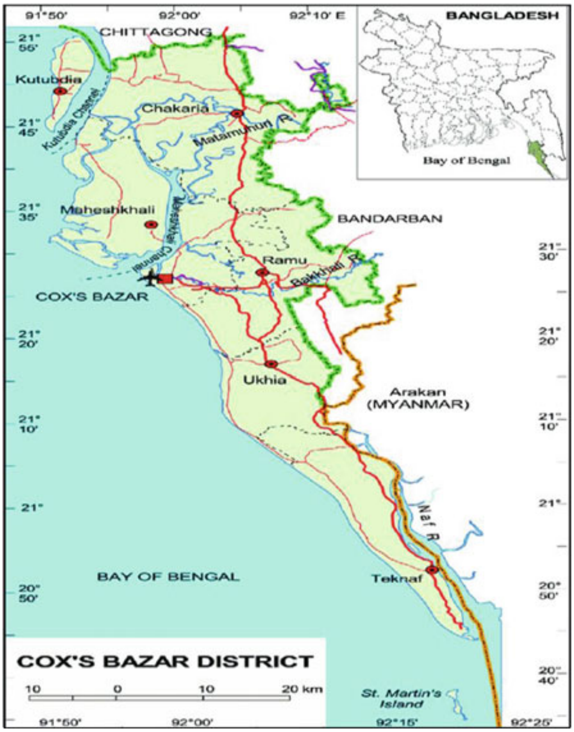

Fig. 74.1 Map of the study area

basic amenities (World Bank 2016). The district also has underprivileged food security and nutritional status, with most of the inhabitants dependent on daily wages and government social safety nets are insufficient (District Development Plan for Cox's Bazar—Phase 1 2019). Like other coastal areas in Bangladesh, the incidence of natural disasters and impact of climate change hampers significant development progress. Cox's Bazar is diverse linguistically, ethnically, and religiously. In additional to Bangla, people in Cox's Bazar district speak Chittagonian, which is to some extent similar to Rohingya. Around 90% population of this district belongs to Muslim and the area is considered socially, culturally, and religiously old-fashioned compared to the rest of Bangladesh. The second most practiced religion is Hinduism (4% average), followed by Buddhism (2% average) (Bangladesh Population Census 2011). The upazilas bordering the Chattogram Hill Tracts (CHT) are home to larger minority communities, most of whom are not Muslim. Since the 1970s, Cox's Bazar District has received multiple surfs of Rohingya refugees from Myanmar, with the largest influx inward in 2017. Between August 2017 and December 2018, 745,000 Rohingya refugees arrived Bangladesh through Cox's Bazar. By 31 December 2019, Teknaf and Ukhiya hosted an estimated 860,000 Rohingya in densely populated camps. The rapid increase in the refugee population had a massive impact on the local communities (JRP 2020). The consequential population density, coupled with the lack of supportable alternatives to meet the basic needs of refugees and the underlying poverty and vulnerability of the Bangladeshi population in the area, has put additional pressure on the environment, such as deforestation, depleting water resources, destruction of social forestry, and road congestion.

74.3.2 Data Collection and Analysis

Purposive sampling technique was used for selection of the study area. Farmers and market actors were selected snowball sampling technique. Both primary and secondary data were used in this study. Secondary data were collected from different reports, articles, books, government statistics, FAO, and Web searching. Primary data were collected from farmers, market actors, and government official. The data obtained to understand the VCA of seaweed production in Bangladesh came from stakeholders, personal observation, and secondary sources. The stakeholders included 5 key informant interviews (KIs), 2 focus group discussion (FGDs), 33 household survey (HHSs) questionnaire respondents, and 15 different market actors. The KIs were conducted with government officials, nongovernmental organization (NGO) representatives, community leaders and private companies, selected using nonprobability sampling through the snowball method. The FGDs and HHS were conducted in Cox's Bazar sadar upazila, Teknaf, Ukhiya, and Saint Martin Island. The FGDs were conducted based on whether the communities included either cooperative or individual farmers. Fieldwork was conducted between December 10 to 30 2020.

The qualitative data obtained from transcripts of KIs, FGDs, and personal observations were coded into themes. Themes were analyzed for connections between data, concepts, and theories. The quantitative data obtained from the HHSs were processed and analyzed as descriptive statistics using the Statistical Package for the Social Sciences (SPSS) version 21.

74.4 Results and Discussion

74.4.1 Seaweed Production

In 2007, the world seaweed production of was about 15 million tons. It reached approximately 29 million tons in 2016, with a 97% increase each year. The market value of the seaweed industry also increased proportionately with its production, rising from US$ 6.08 billion to US$ 11.45 billion. Asia is the market leader of seaweed industry, sharing 99% of the global seaweed production. Total worldwide seaweed production was 28.85 million tons in 2016 and 28.68 million tons of that came from Asia. A lion share of seaweed production in Asia comes from China, Indonesia, the Philippines, Korea, Japan, and India. Between 2007 and 2020, these countries have made significant progress in seaweed production.

Bangladesh is still lagging behind and not able to capture the opportunities, although country has an abundance of seaweed species, a coastal zone of 480 km coastline, and 25,000 km^2 of coastal area with favorable environmental conditions for seaweed production. Bangladesh can also earn a great deal of foreign exchange by exporting of seaweed as well can able to meet food and nutritional security.

One of the major constriants for cultivating and promoting seaweed farming in the coastal areas is the extremely low price in the farmgate. The production cost of seaweed in Bangladesh is about BDT (Bangladesh Taka) 150 kg^{-1} but the farmgate price is about BDT 350 kg^{-1} which is comparatively low. According to the Agricultural Information Service (AIS) of the Bangladesh government, the international price for Bangladeshi seaweed in the global market is US$ 16 kg^{-1} (BDT 1280 kg^{-1}). Sometime seaweed export price is varied from US$ 9–16 which is around BDT 783-1393 (Table 74.1).

Since 2008, Falcon International Ltd. started its business initiative with development of seaweed commercially. Presently, Falcon is producing red seaweed, brown

Table 74.1 Export of seaweed from Bangladesh

Particulars	Volume of exports (kg)						
	2014	2015	2016	2017	2018	2019	2020
Exports (kg)	200	–	199,625	90,547	52,718	1547	1099
Export price (US$ kg^{-1})	9	–	9	10	10	10	10

Table 74.2 Production of seaweed in Bangladesh

Particulars	Red seaweed			Brown seaweed			Green seaweed		
	2018	2019	2020	2018	2019	2020	2018	2019	2020
Production (kg)	53,718	38,502	16,308	1000	838	22,415	7,907,700	232,050	51,695,700
Production cost (BDT kg^{-1})	150	150	150	150	150	150	150	150	150
Sales price (BDT kg^{-1})	350	350	350	350	350	350	350	350	350

seaweed, green seaweed, green mussel, and oyster. The Table 74.2 shows that total volume of red seaweed decreased but production and sales of brown and green seaweed increased. Particularly, production of brown seaweed increased about 22 times where green seaweed about 5.5 times. It also observed that production of seaweed fluctuates. Already Falcon International trained about 1000 farmers and expended market to Korea, China, and Japan.

74.4.2 Farming Activities

Seaweeds in Bangladesh are produced in two ways: naturally harvested and culture. Naturally, harvested seaweeds are collected by the farmers from the coastline, then wash, dry, cool and store, and sells to the market (Fig. 74.2). On the other hand, for culture seaweed, farmers use/procure seedlings as the beginning of farming cycle from trusted suppliers/sellers. When transporting from suppliers to the farmers, essential measures should be taken for protecting seedlings and the seedlings are covered with plastic sheets and wetted with seawater every 15 min. Just after reaching the farm site, the seedlings are quickly placed in seawater so and are "planted" by tying to longlines so that seedlings remain alive and start vegetative growth. These activities are done by often by the farmers and their wives and children. Here, planting activity means tying of seedlings with longlines. Tying of the seedlings to the long lines are done under the scorching sun.

Harvesting of seaweed is done after 6 to 8 weeks of cultivation. During harvest time, majority farmers harvest the whole seaweed by untying lines or cutting the raffia tie-tie from longlines. Then, harvested seaweeds are transported in farmers dying yard which may be made of a stilt house or wooden frame drying platform. Here, the farmers grade the seaweed (known as culling) either to be dried and package them for sale or to be used as seedling material for the next cycle.

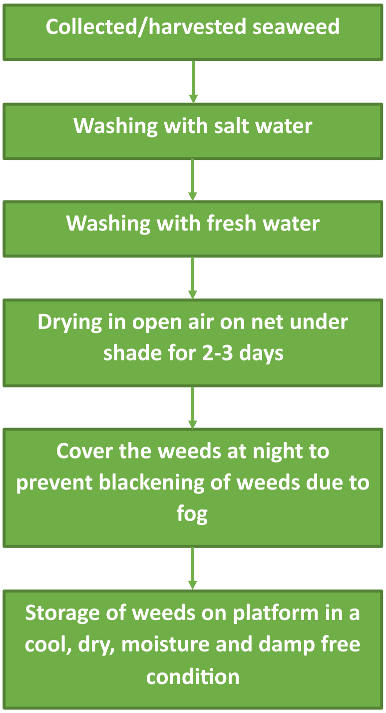

Fig. 74.2 Seaweed farming and postharvest treatment

74.4.3 Postharvest Treatment

Natural drying of harvested seaweeds requires good weather and sun shine for about 2–3 days. The commonly used drying methods are spreading the fresh seaweed across concrete slabs or wooden platforms and hanging using elevated drying racks and bamboo racks. The seaweeds are evenly spread and repeatedly turned over to expose all angles of the thalli to the sun. The farmers assess the moisture content through eye observation by squeezing the seaweed. The acceptable moisture content lies between 30 and 38% that are preferable to sell. The capacity to achieve this moisture content is influenced by active sunshine, species, location, and the frequency with which farmers turn the seaweed during drying. Well-dried seaweed is heavily covered with crystallized sea salt for preventing spoilage of the carrageenan and this prolongs storage duration by up to 2 years.

74.4.4 Marketing System

Seaweed was sold in two forms. Firstly, dried form which is used as raw materials in carrageenan processing industry. Approximately, 55% of the total harvested seaweeds sold in this way. Secondly, in fresh form, which is used as a source of

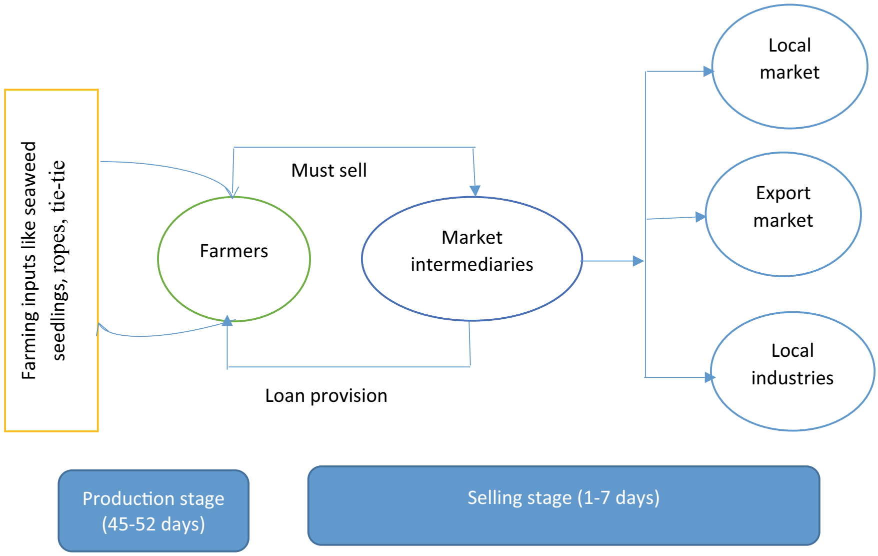

Fig. 74.3 The value chain map and relationship between seaweed intermediaries and farmers

seedlings for the next production cycle and local consumption by tribal people and other inhabitants. Rest of the amount of seaweeds are sold like this form. All farmers sold their seaweed to intermediaries in local markets or sometimes at their farm-yard if production volume is large. Sometimes, farmers themselves consume certain percentage of seaweeds. Those farmers sell seaweed through intermediaries, and sometimes they take loan in advance. In this case, farmers have to sell total harvested amount to the intermediaries. This type of intermediaries has established and exercise market power and determines price. Intermediaries, sometimes, sell seaweed in the local markets but the amount is low. These intermediaries especially sell the seaweeds in super markets, bacarries, cosmetics, or other pharmaceuticals industries. Strong network and relationship are maintained by farmers and intermediaries and for that they allowed the farmers to obtain informal credit services either as cash or through the direct supply of farming inputs such as ropes, tie-tie, and seedlings (Fig. 74.3). The prices obtained by farmers for dried seaweed and carrageenan remained low, BDT 80, and BDT 1280 kg^{-1}, respectively.

74.5 Conclusions and Policy Recommendation

The price of seaweed is volatile. The farmers do not sell directly to the processors and are forced to rely on intermediaries. The weak negotiating position of the farmers due to taking advance loan in the value chain serves to disseminate their low-income status. There was low trust in relationships between processors, intermediaries, and farmers on seaweed quality.

A well structure market system is greatly needed for seaweed farmers so that they can get the actual market price of their products which will ensure continued production of seaweed. It is the right time for the Bangladesh government, NGOs, and private companies to work together and establish seaweed farming as a sustainable eco-friendly industry in order to ensure food and nutrition security for increasing population, and improve the livelihoods of the coastal communities. Finally, the super shop, pharmaceutical and cosmetic companies, and model pharmacies may be a good market source and chain for scaling up the seaweed products in Bangladesh.

References

Alam MK (2019) Blue economy-development of sea resources for Bangladesh. Ministry of Foreign Affairs, Dhaka, Bangladesh. https://mofa.gov.bd/site/page/8c5b2a3f-9873-4f27-8761-2737db83c2ec/OCEAN/BLUE-ECONOMY--FOR-BANGLADESH. Accessed 12 July 2021

Andriesse E, Lee Z (2017) Viable insertion in agribusiness value chains? Seaweed farming after typhoon Yolanda (Haiyan) in Iloilo Province, the Philippines. Singapore J Trop Geogr 38:25–40

BBS (Bangladesh Bureau of Statistics) (2011) Population census. Statistics and Informatics Division, Ministry of Planning, Peoples Republic of Bangladesh

Bhuyan MS, Sharif ASM, Islam MS (2018) Blue economy in Bangladesh: next resources exist. Mod Approaches Oeanogr Petrochem Sci 2(1):1–4

Bristow LA, Mohr W, Shmerkamp S et al (2017) Nutrients that limit growth in the ocean. Curr Biol 27(11):474–478

District development plan for Cox's Bazar (2019) District development plan for Cox's Bazar—phase i, volume i. Government of the People Republic of Bangladesh and United Nations. https://fscluster.org/rohingya_crisis/document/coxs-bazar-district-development-plan. Accessed 12 May 2021

Ferdinandus SJ, Risambessy A, Sormin RBD (2017) Strategy for increasing added value by seaweed processing and marketing business (a case study in west Maluku Tenggara Regency-Indonesia). Man India 97:439–447

Ghose TK, Hossain MI (2020) Socioeconomic factors affecting profitability of seaweed culture in Saint Martin Island of Bangladesh. Progress Agric 31(3):227–234

Hossain MS, Sharifuzzaman SM, Nobi MN et al (2021) Seaweeds farming for sustainable development goals and blue economy in Bangladesh. Mar Policy 128. https://doi.org/10.1016/j.marpol.2021.104469

JRP (2020) Joint response plan for rohingya humanitarian crisis. www.humanitarianresponse.info/en/operations/bangladesh. Accessed 12 May 2021

Kaplinsky R, Morris M (2001) A handbook for value chain research. Int Dev

Mulyati H, Geldermann J (2017) Managing risks in the Indonesian seaweed supply chain. Clean Technol Environ Policy 19:175–189

Neish IC (2008) Structure and development of tropical red seaweed value chains with focus on the red algal Galactan seaplants (RAGS), SEAPlant.net Monograph No. HB2A 0808 V1

Neish IC (2013) Socio-economic dimensions of seaweed farming in Indonesia—full version. Monograph No. SATOUMI_SED_20SEP13

Sarker MN (1992) Studies on the red seaweeds in Bangladesh. In: Regional workshop on the research centre.Taxonomy, ecology and processing of commercially important red seaweeds, held at Kasetsart University in Bangkok, Thailand, Organized by FAO/NACA and France Govt

Seventh Five Year Plan (2016–2020) General economics division (GED), Planning Commission, Government of the People's Republic of Bangladesh
Siddiqui AAM, Kashem MA, Mondal MAI et al (2019) Commercially important seaweed cultivation and its potentials for the coastal areas of Cox's bazar Bangladesh. Int J Fish Aquat Sci 7(5):463–470
World Bank (2016) Bangladesh—towards accelerated, inclusive and sustainable growth: opportunities and challenges, vol 2. World Bank, Washington DC
World Bank (2017) The potential of the blue economy increasing long-term benefits of the sustainable use of marine resources for small island developing states and coastal least developed countries. In: International bank for reconstruction and development/the world bank. 1818 H Street NW, Washington DC
Yousaf B, Liu G, Wang R et al (2016) Investigating the biochar effects on c-mineralization and sequestration of carbon in soil compared with conventional amendments using stable isotope (δ13c) approach. GCB Bioenergy 9(6):1085–1099

Chapter 75
Decision Support System: An Essentiality for Micro Planning in Coastal Agro-Ecosystem

Sankar Kumar Acharya and Riti Chatterjee

Abstract Unlike other parts of the globe, small and marginal farmers in India have to confront with uncertainty and chaos. These uncertainties are relating weather, market, livelihood, productivity and functional knowledge in agriculture. These are more conspicuous for a coastal ecosystem of Bengal. The brunt of climate change, sea level rise, ingress of salinity, punitive poverty, migration and up-scaling conflict between wild life and human interest have made the entire scenario more complex and polymorphic in nature. So, making and taking decisions are so complex here. When crop yield is better, market price is poor; when everything sets to big success, cyclonic storms wash away everything. For this zone, we need application of decision support system, both in participatory and non-participatory manners. The proposed DSS comprises not only of ephemeral decision-making for farmers; it would empower them in predicting and projecting for a mid to long-term perspectives. The community-based knowledge management, micro-level brain storming, application of DSS, knowledge kiosk, local-level market informant are of innovative interventions for dealing with uncertainty and unpredictability character of coastal agro-ecosystem.

Keywords Decision support systems · Knowledge-based systems · Online analytical processing · Executive information systems

75.1 Introduction

The farmers and farming in India are becoming increasingly vulnerable to huge pool of uncertainty factors consisting of weather, market, technology, input delivery, quality management and skill availability. The marginalization of land resources

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and its fragmentations, increasing intensity and velocity of cyclonic storms, sea-level rising at an ever increasing scale, erosion of mangroves, fragile and uncertain economy of more than 80% of rural people are making life of coastal agro-ecosystem of West Bengal more uncertain, complex and difficult. They need a strong decision support system which would help them extract the best choice out of a basket of choices. That can encompass crop-fish-livestock, forest resource towards attaining a sustainable eco-friendly livelihood. In this era of emerging technologies in data science, knowledge engineering can cater excellent possibilities in monitoring water quality, location-specific technologies, farm-level decision-making, or land evaluation processes. The application phase will be started from scaling-up of the representative areas of the development phase to implementation in any unknown scenarios. Hence, the application phase that was previously accomplished manually now will be computer-assisted.

Here, linkage of integrated databases, computerized programs, and spatialization tools have to be involved in construction of decision support systems (DSSs) will be involved (De la Rosa and Van Diepen 2002). DSS is mainly computerized technology that is used to support complex approaches of decision-making and problem solving (Shim et al. 2002). If one wants to apply this DSS in the situations of coastal ecosystem, first, the marine, wetland, estuarine and coastal systems are to be studied (Sorensen and McCreary 1990; Clark 1992).

Coastal ecosystems are characterized by some vulnerable ecosystems like mangroves, seagrass beds and coral reefs; human system interacts with the ecosystems by the means of fishing, tourism, recreation, residential or industrial activities. Because of these activities, decision-makers have to face the issues of rapid population growth, increasing pressure on tourism, depletion of the fish stocks because of overexploitation and fragile personnel and financial capacity to manage natural resources (Wilkinson 1993; IUCN 1993; Bryant et al. 1998; Cicin-Sain and Knecht 1998). Hence, for effective decision-making for the coastal agro-ecosystem, multiple decision-makers from different disciplines must be involved to understand and cope with the complexity arisen from the issues (Sorensen and McCreary 1990; Bijlsma et al. 1993; Bower et al. 1994; Cicin-Sain and Knecht 1998). Besides, in a decision-making environment, decision-makers ought to make their view broaden and add the impacts of the decisions made on other stakeholder groups and socio-economic sectors. And DSSs are developed with the belief that they are capable of improving inter-relationships between ecological and socio-economic factors (Te'eni and Ginzberg 1991; Fabbri 1998).

Knowledge-based systems used synonymously as decision support system, which refers to formalize knowledge to make it amenable to mechanized reasoning. Different kinds of information systems have been developed for executing different operations based on the need of the particular business. Transaction process system (TPS) is functioning in operational level to process vast amounts of data for the last 20 years, for the organizations, while office automation system (OAS) supports data workers and knowledge work system (KWS) operates to help professional workers. There are two higher-level systems, viz., management information system (MIS) and

DSS. While, expert system (ES) makes use of the expertise of the decision-makers to solve specific and unstructured problems.

At the strategic level of management, there will be executive support system (ESS), group decision support system (GDSS) and the more generally described computer-supported collaborative work (CSCW) systems to support group-level decision-making of a semi-structured or unstructured decision. The history of such systems begins in the mid-1960s. Different people perceive the field of DSS from different viewpoints and report the details of what happened and what was important (Arnott and Pervan 2005; Eom and Lee 1990; McCosh and Correa-Perez 2006; Power 2003, 2004a; Silver 1991).

Today, one is able to organize the history of DSS into the five broad DSS categories (2001; 2002; 2004b), viz., communication-driven, data-driven, document-driven, knowledge-driven and model-driven DSS. Classic decision support system design constitutes the components for (i) furnishing database management capabilities, (ii) powerful modelling functions and (iii) simple user interface (Shim et al. 2002).

The problem starts on the point where the decision support system within the e-government components is and how to utilize the DSS into e-government. However, there is no explicit e-government framework that can include DSS into its components. Hence, the proposed framework is used to solve this problem. Thus, the aim of DSS is to utilize its components to help decision-makers within the e-government.

75.2 DSS and Managing Decision

- Sensitization of the concept of decision support system (DSS),
- Analysis of the methodology of DSS,
- Identification of the area of DSS application,
- Issues and challenges faced by DSS,
- The present status of DSS application in agriculture and allied sectors,
- Delineation of application of DSS in coastal agro-ecosystem.

75.3 What is Decision Support System (DSS)? and How Does it Work?

A decision support system (DSS) is a computer-based information system that supports business or organizational decision-making activities.

DSSs serve the management, operations and planning sections of an organization and help to make decisions.

75.3.1 DSS: Concepts

The concept of decision support system (DSS) emerged in the 1970s following developments in IT which allowed the interactive use of computer technology. The DSS concept reflected dissatisfaction with previous inflexible modelling approaches which did not allow management intervention in problem solving. DSS includes knowledge-based systems.

An ideally designed DSS is an interactive software-based system that intends to help decision-makers in compiling information from a combination of raw data, documents, personal knowledge or business models. Information that a decision support application gathers and presents are on: (i) inventories of information assets, (ii) comparative sales figures and (iii) projected revenue figures. Historical and common data are also used in DSS to help executives in making better decision.

DSS is a type of computerized information system that supports decision-making activities. DSS is mainly an interactive computer-based system and subsystem intends to help decision-makers in utilizing communications technologies, data, documents, knowledge, even models to successfully conduct decision process-oriented task. The DSS mechanism produces output in the form of periodic report or as the results of some mathematical simulations. However, it is quite difficult to segregate which are completely structured or unstructured while the majorities are semi-structured.

This means that the DSS is aimed at the area where most semi-structured decision is needed to be made (Fig. 75.1).

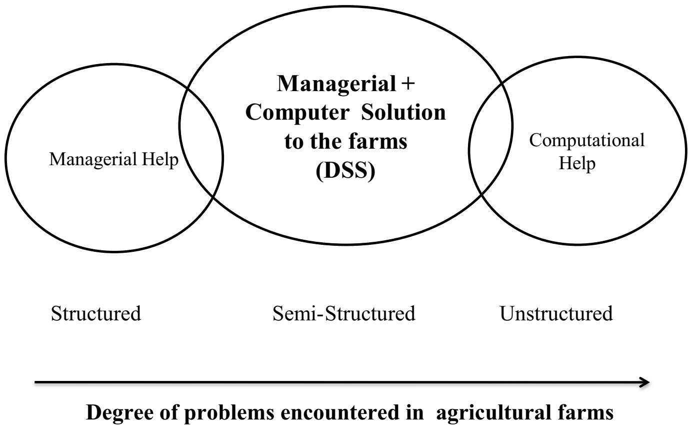

Fig. 75.1 The DSS focuses on semi-structured problems (adapted from Raymond, 1966)

75.3.2 Characteristics of DSS

The characteristics of the DSS are as follows:

- DSS mainly focuses on analysing situations rather than providing right information from various types of reports.
- DSS is individual-specific. Each decision-makers can amalgamate their own perceptions about the problem and then analyse the effect.
- DSS does not impose its outcomes on the part of decision-maker. It is effective in catering assistance to solve semi-structured problems at each and every levels, viz., first line, middle-level and top-level management.
- DSS needs an effective database management system. DSS helps decision-makers to carry out 'what- if' analysis.

75.4 DSS and Coastal Ecosystem of Bengal

Unlike other agro-ecological zones of Bengal, viz., Hill, Terai, Old Alluvial, New Alluvial, Red and Laterite, Saline and coastal zone is much vulnerable to the brunt of climate change and production uncertainty. The intensity of cyclones is escalating more than 20% over past two decades and sea-level rising is at 30% higher than predicted two decades back. Some islands have already been vanished from Sundarbans biosphere leaving huge loss of natural resources and threats behind. Aila (2009), Fani (2019), Amphan (2020) and Yaas (2021) are the cyclones in their quickest succession to inflict huge losses of crop, life, biodiversity and habitats. These are having both the slow on set and rapid onset disastrous impact.

Thousands of fishermen in these areas are regularly venturing into Bay of Bengal to sustain their livelihoods across the undulations of nature and weather. So, the farmers, fishermen, livestock raisers, honey, shrimp, crab collectors deep in forest and marine ecosystem and daily wage earners need constant support and forecasting from weather intelligence for their survival. This will help take decisions as to whether they should venture into sea or forest, sow the crop or schedule the harvest, go out for earning wages or opting for a home captivity.

There are both long-term and short-term need for processed, catalogued, effective information basket, both in participatory and non-participatory modes at micro-level, to equip them with cloud of participatory decision-making.

There is a need to transform classical farmers into resource, climate and information managers. The regular, truthful, sufficient data uploading and subsequent inventorization will go a long way to make time-framed and targeted decisions across time and space.

75.4.1 DSS: Functions and Benefits

That said, even if DSS does not necessarily result in quantifiable, tangible benefits, they do provide identifiable ones. The following list is derived from about 30 DSS studies. Only benefits mentioned in at least five case studies are included. A few typical illustrations or quotes are given for each category on the list: (i) increase in number of alternatives examined, (ii) better understanding of the business, (iii) fast response to unexpected situations, (iv) ability to carry out ad hoc analysis, (v) new insights and learning, (vi) improved communication, (vii) control, (viii) cost savings, (ix) better decisions, (x) more effective teamwork, (xi) time savings and (xii) making better use of data resource. These categories add up to a concept of productivity.

It is these often qualitative aspects of effectiveness that managers value. The operating assumption of decision support is that improving communication, flexibility, learning and responsiveness leads to better decision-making.

75.4.2 Farming with DSS

The model will help the farmers in increasing their productivity by raising the yield per hectare in food grains: thus, leading to their economic growth. This system has been developed to keep track of farmers all type of information related to crops.

Certain applications that are successfully developed using this database are:

- Farmers can manage their cash flow through the DSS system in a more predictable and efficient way. It is a more common problem with the farmers to manage the cash received at time of harvesting the crop.
- They can avail full benefit of their cash management by co-relating it with the loans and advances.
- The administrator can add information to the database without stopping the application.
- If implemented at village, district and state-level, the model will provide valuable information to other agencies and panchayats in particular.

Growing population and demands for improved watershed management; there is an obvious need to implement sustainable resource use that best serves the communities and the nation. To satisfy this need, the DSS is developed to aid decision-makers and various stakeholders in identifying and assessing options for resource uses. The DSS applies an integrative approach, combining biophysical data, perceptions and socioeconomic conditions of the farmers in the given area.

The DSS attempts to stimulate the farmer's behaviour in selecting farming systems given relevant constraints and then aggregating up to the node. Application of ecosystem services in spatial planning and land-use policies are still remained quite challenging (Grêt-Regamey et al. 2017). However, decision support tools are a

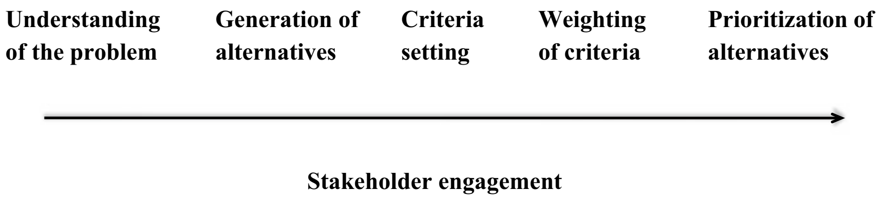

Fig. 75.2 Workflow through decision support system (adapted from Langemeyer et al. 2016)

potential option to implement ecosystem services, that is, to promote their use by decision-makers (Potschin and Haines-Young 2013).

Hence, a large number of database queries can be generated according to crop, water availability and requirement, socio-economic constraints and so on. Design and development of this database is purely based on relation database management system model, so the large volume of queries can be easily handled. DSS with all the ready information help the farmers in a very useful manner. The farmers can get all the information at just at click of the mouse using only few steps (Fig. 75.2), and they need not to travel to agricultural universities for that.

75.4.3 DSS for Agro-Technology Transfer

The decision support system for agro-technology transfer (DSSAT) is a software package that integrates the effects of soil, crop, weather and management segments that permits the users to ask ‘what-if’ questions and simulate the results in minutes on a desktop computer. It has been in use for more than 15 years by researchers in over 100 countries.

DSSAT helps users with the information that is able to rapidly appraise new crops, products and practices where, the release of DSSAT Version 4 has incorporated models of 27 different crops with various new tools that are able to facilitate the creation and management of experimental, soil and weather data files. It also encompasses improved application programs for seasonal and sequence analyses that assess the economic risks and environmental impacts related to irrigation, fertilizer and nutrient management, climate change effect, soil carbon sequestration, climate variability and precision farm management.

75.4.4 Minimum Data

The minimum dataset (MDS) refers to a minimum set of data need to run the crop models and validate the outputs. Validation requires: (i) site weather data for the duration of the growing season, (ii) site soil data and (iii) management and observed data from an experiment.

(i) MDS weather data: The required minimum weather data includes: latitude and longitude of the weather station, daily values regarding incoming solar radiation (MJ m^{-2} day^{-1}), daily maximum and minimum air temperature (ºC) and rainfall (mm). Accessory datasets, such as daily dry and wet bulb temperatures and wind speed are optional. The period of weather records for validation must, at a minimum, cover the duration of the experiment and preferably should begin a few weeks before planting and continue a few weeks after harvest so that 'what-if' type analyses may be performed as desirable.

(ii) MDS soil data: Desired soil data includes soil classification (e.g. USDA/NRCS), surface slope, soil colour, permeability and drainage class. Soil profile data by soil horizons include: upper and lower horizon depths (cm), percentage sand, silt, clay content, 1/3 bar bulk density, organic carbon, pH in water, aluminium saturation and Information on abundance of roots.

(iii) Management and experiment/observed data: Management data embraces information on date of sowing, planting density, row spacing, planting depth, crop variety, irrigation schedule and fertilizer management practices. This data are required for both validation of models and strategy evaluation. Along with the site soil and weather data, experimental data covers crop growth data, on-farm soil water and fertility measurements for model validation.

75.3.7.1 System requirements (i) Personal Computer running MS-Windows, (ii) Pentium2 with 128 MB RAM minimal, (iii) Pentium4 with 512 MB RAM recommended, (iv) CD-ROM Drive, (v) Hard Disk Space requirement 300 MB of free space.

75.3.7.2 Components The cropping system model (CSM) released with DSSAT Version 4 represents a major departure from previously released crop models in DSSAT, not in function, but in design.

The computer source code for the model was restructured into a modular format in which components get separated along lines of scientific discipline and are structured to allow easier replacement or addition of various modules. CSM now incorporates all crops into the modules using a single soil module and a single weather module. The new CSM now contains models of 17 crops derived from the old DSSAT CROPGRO and CERES models. The major modules are: (i) land module, (ii) management module, (iii) soil module—a soil water balance sub-module and two soil nitrogen/organic matter modules, (iv) weather module—reads or generates daily weather data, (v) soil–plant–atmosphere module—deals with competition for light and water among the soil, plants and atmosphere, (vi) CROPGRO plant growth module: a. grain legumes—soybean, peanut, dry bean, chickpea, cowpea, velvet bean, and faba bean, b. vegetables—pepper, cabbage, tomato, c. grasses—bahia, brachiaria.

75.4.5 Development and Adoption: The Issues

Although these systems seem to have many benefits to producers, they have not widely been taken up (Wilde 1994; Lynch et al. 2000). Cox (1996), Campbell (1999), and Lynch et al. (2000) have studied reasons why the adoption of DSS is still low and other existing intelligent support systems within agriculture.

Some of the reasons they suggest are as follows: (i) limited computer ownership among producers, (ii) lack of field testing, (iii) no end user input preceding and during development of the DSS, (iv) DSS complexity and possibly considerable data input, (v) no reason seen for changing current management methods, (vi) distrust for the output of a DSS because producers do not understand the underlying theories of the models, (vii) mismatch of the DSS output with the decision-making style of the producer because the producer's conceptual models are excluded, and unclear definition of the beneficiaries (e.g. scientists, primary producers and technology transfer agents) and (viii) availability of back up and software.

75.4.6 Ease of Use

Few features of the DSS may affect its adoption (i.e. that DSS are not useful to the user and are not easy to use). While, perceived ease of use and perceived usefulness of DSS has been discussed by Keil et al. (1995). He said that software that possess low rating in ease-of-use and dull in usefulness can be rejected. Software that is high in ease-of use and low in usefulness is termed as 'toys'. Users may accept this software initially, but there is little chance of lasting experience. Software that is low in ease of use but high in usefulness can be called 'power users', it is very competent computer users.

However, most users avoid this type of software as the time and effort required to learn how to use it outweighs the potential benefits. The aim is to develop software that rates high in ease of use and high in usefulness.

75.4.7 Information Flow and Execution in Extension System

The information flow in extension system is either two ways or multi-ways, from source of innovation to application, from farmers to research stations in the form of feedback. It takes multi-ways when a score of actors play in parallel or series connections.

The technology generators, the technology carriers, middle lever interpreters, the input dealers and credit providers and socio-political opinion leaders are framing and forming a cross-cultural information network. This has made the journey from data to decision more meandering and spiral. Sometimes, it may so happen that

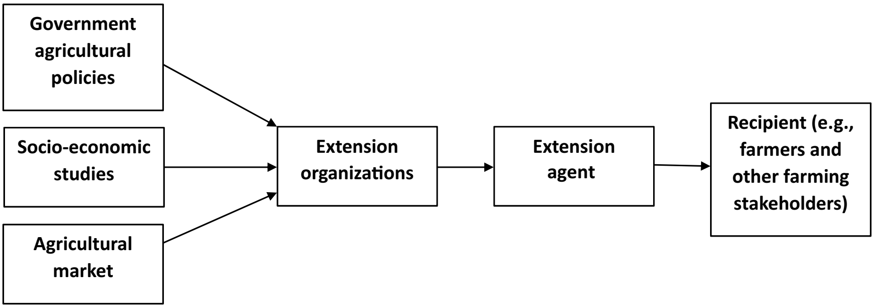

Fig. 75.3 Information flow mechanism in extension functionary

commodity reaches the farmers' field while do how is missing; on the contrary, do how is imparted by this time do what is missing. These all are a barrier to effective decision-making at micro-level reality (Fig. 75.3).

From the flow chart, it is obvious that information flow in the present extension system has been mostly unidirectional and not well synchronized with different anatomy of information management. Feedbacks are not finding a conveyor belt and lateral contributors are somehow missing.

75.3.9.1 Sitemap

Sitemap gives us the complete description of how the control flows through the site. The main page that links to all the pages is called the Home Page. This page shows the introduction about the farm entrepreneur system, the objective of the system and the principles of activity.

75.3.9.2 Information retrieval system

The main advantage of this model to the farmer is that they can retrieve the dynamic information for their farm management decisions. DSS framework being an agent for the driving force behind the changes in highland resource uses; the farm or household is considered to be the centre of this analysis. The decisions on agricultural land and water uses are made in response to resource endowments, economic conditions and socio-cultural norms of the household or communities.

75.3.9.3 Resource Management Unit

Farms or households are classified into different types called resource management units or RMU.

75.3.9.4 Modelling at the Node Level

The term node is defined, conceptually, as 'water balance unit'. Its implication depends much on the aspect from which a node is looked at. From hydrological view point, a node represents a village and a network of nodes. Hence, each node has a physical domain, which has to conform to that of the village it represents. Within this physical domain exist other biophysical attributes such as soil type and climate type.

From a socio-economic viewpoint, the characteristics of farm households, alternative land use options, farmers' priorities and obstacles depicted by resource management units may differ from node to node. Here, different set of socio-economic factors influence the decisions on how the farmers should manage their available resources to fetch optimal level of production. From the modelling viewpoint, nodes have major role in the whole decision support system. The main outputs from modelling process, although initialized at farm level, are reflecting relation between human and resource availability at the node level.

75.3.9.5 Outputs, Outcomes and Implications

The simulation system gives the output on the land and water allocation that has the potential to maximize gross margin for the communities and farm entrepreneur within the specified node by taking into consideration the biophysical and socio-economic constraints pertaining to the study area. Hence, the effects of a partial change in the land uses, prices, investment, labour and capital requirements can be easily computed, and the results can be represented both at the non-aggregated RMU (household) level and the aggregated level (node or village).

The economic and environmental trade-offs of various plans can be determined for improving welfare. Here are certain applications that are successfully developed using the following databases:

- Farmers can be able to manage their cash flow through the DSS system in a more predictable and efficient way than ever. As it is found to be a more common problem with the farmers to manage the cash they receive at time of crop harvesting.
- Additionally, they can avail full benefit of their cash management by co-relating it with the loans and advances.
- The administrator can add information to the database without abolishing the application.
- If the programme gets implemented at village, district and state level, the model will provide valuable information to other agencies and panchayats in particular.

Thus, DSS is being applied as an integrative approach, combines biophysical data, perceptions and socioeconomic conditions of the farmers in the study area. DSS attempts to stimulate the farmer's behaviour in selecting farming systems giving relevant constraints and then aggregating up to the node.

75.5 DSS Models Relevant to Coastal Agro-Ecosystem

Computerized modelling techniques as the management tools are getting increased attention as computers have become more user-friendly and accessible at the same time (Parker et al. 1995). And their use in coastal management is increasing by some of the major international organizations. Here, some brief descriptions will be presented below:

- **COSMO** is a simulation model used for the coastal region and **CORONA**, the role play version of COSMO, developed by the Netherlands' Government (Resource Analysis and Delft Hydraulics 1993);
- **ISLAND** model, developed for the United National Environment Programme, Caribbean Unit and presented during the ICM Conference on Small Island Developing States in Barbados, 1994 (Engelen et al. 1993);
- **COMA**, a coastal model for Africa, developed as part of the World Bank's post-UNCED strategy for sustainable environmental development in Sub-Saharan Africa (Westmacott 1995; World Bank 1995);
- **CORAL** developed at Montego Bay in Jamaica for coral reef management and protection with a cost-effectiveness methodology developed by the World Bank (Westmacott and Rijsberman 1995; Huber and Jameson 1998; Gustavson et al. 2000);
- **SIMCOAST** is an expert system for worldwide coastal zones developed in 1995 and jointly funded by ASEAN and the EU (Hogarth 1999);
- **Reef Base** is the global database for coral reefs initiated by the International Centre for Living Aquatic Resources Management (ICLARM) and supported by Reef Check and the Global Coral Reef Monitoring Network (GCRMN) (McManus et al. 1999).

75.6 Decision Support Systems (DSS) Suitable for Coastal Zone Management

A decision support system developed for coastal agro-ecosystem must take into account the interrelations between ecological and socio-economic factors operating in the coastal area. This needs the DSS to deal with the many variables of coastal zones, viz., (i) educational level, (ii) analytical capacity of all the stakeholder groups for developing a balanced management plan, (iii) cooperation among the stakeholder groups, active communication among the stakeholder groups, (iv) economic sources that are critical for both the development as well as conservation, (v) awareness of the impacts of human activities on the ecology and the impact environmental degradation on the human welfare and the economy, (vi) information available on both the economy, environment and their inter-dependence (Westmacott 2001).

These all factors need to be integrated within the DSS developed for coastal regions, with the need to: (i) integrate inter-dependent objectives and views; (ii) take multi-disciplinary subject area; (iii) handle limited data and information, found among the different stakeholders.

Then only, the DSS for coastal agro-ecosystem will be able to play the following roles:

Firstly, it will be able to conglomerate data and information from the different stakeholder groups that may generally do not share their information. Secondly, it will provide a facilitative role among various stakeholder groups enabling discussion. Thirdly, it can play an educational role for others elucidating the interactions and impacts among different coastal factors and ecology. Therefore, it can assist decision-making in coastal ecosystem.

75.7 Future Scope

The scope for future research are-

- The Farm Entrepreneur System can be made more useful for the farmers by converting the language of the system to the local language,
- Further, development of the economic model is required to address more complicated resource management patterns effectively,
- Market information relating to prices of the crop, particularly if quoted higher than the maximum support price offered by the government,
- Information transfer to the farmers can be increased substantially by providing email, news groups, messenger services, online chatting and discussion groups,
- Voice support in local language can be provided for illiterate or semi-literate farmers.

75.8 Conclusions

Decision support systems research and development will continue to exploit any new technology developments and will benefit from progress in very large databases, artificial intelligence, human–computer interaction, simulation and optimization, software engineering, telecommunications and from more basic research on behavioural topics like organizational decision making, planning, behavioural decision theory and organizational behaviour.

This knowledge-driven DSS covers broader domains. While current researchers must remember that DSS pioneers came from a wide range of backgrounds and witnessed many obstacles that they successfully overcame to demonstrate the value of using computers, information technologies and decision support software to enhance and in some situations help to improve decision-making.

The DSS pioneers created this specific streams of technology, research and development that serve as the foundation pathway for maximum of today's interest in building, handling and studying computerized DSS. Hence, the legacy of those DSS pioneers must be preserved. The association with e-governance is very important for government to interact with people and business transactions. E-government programmes offer a huge potential to find innovative ways to satisfy the needs of people. This can be helpful to the farmers as well. Hence, the progress of new technologies permits electronic services to be applied in e-government. Thus, DSS must be integrated with e-government managerial systems. DSS is a very helpful tool for all e-government enterprises.

References

Alavi M, Joachimsthaler EA (1992) Revisiting DSS implementation research: a meta-analysis of the literature and suggestions for researchers. MIS Quart 16(1):95–116

Alter SL (1977) Why is man-computer interaction important for decision support systems? Interfaces 7(2):109–115

Alter SL (1980) Decision support systems: current practice and continuing challenge. Addison-Wesley, Reading, MA, USA

Alter SL (1975) A study of computer aided decision making in organizations. PhD dissertation, MIT, Cambridge, MA, United States

Armstrong MP, Densham PJ, Rushton G (1986) Architecture for a microcomputer based spatial decision support system. The second international symposium on spatial data handling, International Geographics Union, Seattle, Washington, USA, 5–10 July 1986, p 120–131

Arnott D, Pervan G (2005) A critical analysis of decision support systems research. J Inf Technol 20(2):67–87

Baskerville R, Myers M (2002) Information systems as a reference discipline. MIS Quart 26(1):1–14

Berners-Lee T (2007) The world wide web: past, present and future. http://www.w3.org/People/Berners-Lee/1996/ppf.html. Accessed 5 March 2007

Bhargava HK, Krishnan R, Müller R (1997) Decision support on demand: emerging electronic markets for decision technologies. Decis Support Syst 19(3):193–214

Bhargava H, Power D J (2001) Decision support systems and web technologies: a status report. In: Proceedings of the Americas conference on information systems, Boston, MA, USA

Bijlsma L, Crawford M, Ehler C et al (1993) World coast conference report World Coast Conference, Ministry of Transport, Public Works and Water Management, Noordwijk, the Netherlands and National Institute for Coastal and Marine Management, Coastal Zone Management Centre, p 115

Bonczek RH, Holsapple CW, Whinston AB (1981) Foundations of decision support systems. Academic Press, New York

Bower BT, Ehler CN, Basta DJ (1994) A framework for planning for integrated coastal zone management. National oceanographic and atmospheric administration (NOAA), Washington DC

Bryant D, Burke L, McManus J et al (1998). Reefs at risk. a map-based indicator of threats to the world's coral reefs. World Resources Institute, Washington

Cicin-Sain B, Knetch RW (1998) Integrated coastal and ocean management: concepts and practices. Island Press, Washington DC and Covelo CA

Clark J R (1992) Integrated management of coastal zones. Technical report 327. FAO, Rome, Italy

Davis G (1974) Management information systems: conceptual foundations, structure, and development. McGraw-Hill Inc., New York

De la Rosa D, Anaya-Romero M, Diaz-Pereira E et al (2009) Soil specific agroecological strategies for sustainable land use. a case study by using MicroLEIS DSS in Sevilla province (Spain). Land Use Policy 26:1055–1065

Engelen G, White R, Uljee I et al (1993) Vulnerability assessment of low-lying coastal areas and small islands to climate change and sea level rise. Report to the United Nations Environment Programme, Caribbean Regional Co-ordinating Unit, Kingston, Jamaica (905000/9379), Research Institute Knowledge Systems (RIKS), Maastrict

Eom HB, Lee SM (1990) A survey of decision support system applications (1971-April 1988). Interfaces 20(3):65–79

Fabbri KP (1998) A methodology for supporting decision making in integrated coastal zone management. Ocean Coast Manag 39:51–62
Grêt-Regamey A, Sirén E, Brunner SH (2017) Review of decision support tools to operationalize the ecosystem services concept. Ecosyst Serv 26:306–315. https://doi.org/10.1016/j.ecoser.2016.10.012
Gustavson K, Huber RM, Ruitenbeek J (2000) Integrated coastal zone management of coral reefs: decision support modeling. The World Bank, Washington DC
Hogarth AN (1999) SIMCOAST. Coastnet 4:6
Huber RM, Jameson SC (1998) CORAL: a least-cost management decision support model for coral reef ecosystems. Intercoast Netw 32(Fall):20–21
IUCN (1993) Reefs at Risk. IUCN Marine Coastal Areas Programme
Langemeyer J, Gómez-Baggethun E, Haase D et al (2016) Bridging the gap between ecosystem service assessments and land-use planning through multi-criteria decision analysis (MCDA). Environ Sci Policy 62:45–56. Doi:https://doi.org/10.1016/j.envsci.2016.02.013
McCosh AM, Correa-Perez BA (2006) The optimization of what? In: Gupta J, Forgionne G, Mora M (eds) Intelligent decision-making support systems: foundations, applications and challenges. Springer-Verlag, pp 475–494
McManus J, Vergara S, Reyes K (1999) Reef Base 3.0. Intercoast Network Spring:19–21
Parker M, Thompson JG, Reynolds RR et al (1995) Use and misuse of complex models: examples from water demand management. Water Resour Bull 31:257–263
Potschin M, Haines-Young R (2013) Landscapes, sustainability and the place-based analysis of ecosystem services. Landsc Ecol 28(6):1053–1065. https://doi.org/10.1007/s10980-012-9756-x
Power DJ (2004b) Specifying an expanded framework for classifying and describing decision support systems. Commun Assoc Inf Syst 13(13):158–166
Power DJ (2001) Supporting decision-makers: an expanded framework. In: Harriger A (ed) e-Proceedings informing science conference, Krakow, Poland, 19–22 June 2001, p 431–436. http://proceedings.informingscience.org/IS2001Proceedings/pdf/PowerEBKSupp.pdf
Power DJ (2002) Decision support systems: concepts and resources for managers. Faculty Book Gallery, p 67
Power DJ (2003) A brief history of decision support systems. DSS Resources.COM, World Wide Web, URL DSSResources.COM/history/dsshistory2.8.html, version 2.8, 31 May 2003
Power DJ (2004a). Decision support systems: from the past to the future. In: Proceedings of the 2004 Americas conference on information systems, New York, NY, 6–8 August 2004, p 2025–2031
Raymond RC (1966) Use of the time-sharing computer in business planning and budgeting. Manage Sci 12(8):B363-381
Shim JP, Warkentin M, Courtney JF et al (2002) Past, present and future of decision support technology. Decis Support Syst 33:111–126
Silver MS (1991) Systems that support decision makers: description and analysis. John Wiley and Sons, New York
Sorensen JC, McCreary ST (1990) Institutional arrangements for managing coastal resources and environments. National Parks Service, US Department of Interior, Washington DC
Urban GL (1967) SPRINTER: A tool for new products decision makers. Ind Manag Rev 8(2):43–54
Westmacott S (2001) Developing decision support systems for integrated coastal management in the tropics: is the ICM decision-making environment too complex for the development of a useable and useful DSS? J Environ Manage 62:55–74. https://doi.org/10.1006/jema.2001.0420
Westmacott S, Rijsberman F (2000) Cost effectiveness analysis of coral reef management and protection: a case study of the Republic of the Maldives. In: Gustavson K, Huber RM, Ruitenbeek J (eds) Integrated coastal zone management of coral reefs: decision support modelling. The World Bank, Washington, DC, pp 67–82
Westmacott S (1995) Decision support in coastal zone management. MSc Thesis. International Institute for Hydraulic and Environmental Engineering (IHE) and Resource Analysis, Delft, the Netherlands

Wilkinson C R (1993) Coral reefs of the world are facing widespread devastation: can we prevent this through sustainable management practices. In Richmond RH (ed) Proceedings of the 7th international coral reef symposium, vol 1. University of Guam Press, UOG Station, Guam, p 11–21
World Bank (1995) Africa: a framework for integrated coastal zone management. The World Bank, Washington DC

Chapter 76
Soil Salinity Effects on Traditional Agricultural Practices in Three Coastal Rural Villages of Indian Sundarban, West Bengal

Aminul Haque Mistry

Abstract Soil salinity enables risks livelihood in densely populated tropical deltas, which is likely to have a negative effect on the human and ecological sustainability of the area and beyond. The farming community in Indian Surdarban is dominated by poor, marginal cultivators and landless people. This study is an attempt to analyse the adaptation strategies undertaken by people with the rise in soil salinity. The community perceptions about the adaptation strategies have been captured through a survey of three selected villages—Gopalganj, Dakshin Garankati and Kaikhali—in the Kultali block. Both focus group discussion and in-depth interviews were helping us to know the changes in farming strategies. A total of 204 households have been surveyed (80 households in Gopalganj, 64 households in Kaikhali and 60 households in Dakshin Garankati) in 2016. Salinity is a severe problem which is not only reducing agricultural potential but also creating an effect on the livelihood strategies of farmers. A higher level of soil salinity has adversely affected the cultivation of indigenous rice varieties and there has been a shift towards HYV-salt tolerant varieties and practicing too. A part of such cultivable land has been replaced with bitter gourd and chilli cultivation, crops that can sustain in soil with a higher pH. Farmers were switching from single paddy to double paddy cultivation and have become more dependent on irrigation. Land shaping of cultivable plots has also been adopted as a coping strategy to minimize the effects of soil salinity. Those people who were not able to cope up with livelihood security challenges have changed their occupation profile and forcefully migrated to seek job opportunities in urban areas.

Keywords Adaptation · Livelihood · Migration · Salt tolerant · Soil salinity · Sundarban

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76.1 Introduction

Soil salinity has emerged as a problem that is not only reducing crop productivity (Singh and Singh 1995; Ali 2006; Sarwar and Khan 2007) but also putting far-reaching impacts on the livelihood options and strategies of farmers (Haider and Hossain 2013). This adversely influences people's living standards, socio-economic conditions as well as everyday life in the coastal areas (Haque and Saifuzzaman 2003; Tanwir et al. 2003; Miah et al. 2004; Rengasamy 2006; Srivastava et al. 2019). These adverse effects spread over 100 countries have been documented and thereby the importance for its mitigation, adaptation and coping strategies are gaining importance over the years. Due to the change of soil salinity, farm adjustments included the introduction of newer crop varieties, switching cropping sequences (Habiba and Shaw 2013) and saline-resistant seeds and new irrigation practices (Rabbani et al. 2013), excessive use of chemical fertilizers and more dependence on groundwater (Roy and Sharma 2015). In some cases, people changed their occupation as an alternative option (Khanom 2016) and also migrated from rural to urban areas (Dun 2012; Rabbani et al. 2013).

The entire area of Indian Sundarban faces the problem of salinity (Planning Commission 1981) and also there is a high degree of risk associated with agriculture as a result of high salinity levels (World Bank 2014). In Sundarban area agricultural land has been declining from 2149 km^2 in 2001 to 1700 km^2 in 2009 and simultaneously increasing the saline area from 39 km^2 in 2001 to 75 km^2 in 2009 (Hazra et al. 2010). Earlier this region was a major supplier of rice for the city of Kolkata but the yield has been consistently declining at present compared to the average yield in West Bengal where soil salinity has been considered as one of the major factors in this area (Mitra 1954). As a deltaic location people are exposed to natural hazards like cyclones, riverbank erosion and flood at different times. Despite these hazards, the majority of the people depend on their livelihood on agricultural practice. Changes in salinity of the soil due to inundation by saline seawater and overflow of the rivers during high tide are major problems. Under these circumstances, how do the people bring about changes in their traditional agricultural practice under the stress of soil salinity?

The is growing evidence about the adverse impact of salinity on the livelihood of the people and a few studies have been conducted in coastal Bangladesh and the Mekong delta. But there are no systematic studies on the impacts of salinity changes on livelihood, coping strategies of local people in the Indian Sundarban area. The present study attempts to understand the coping strategies adopted by the people in the context of changes in soil salinity in the Sundarban area of West Bengal.

76.2 Materials and Methods

76.2.1 Background of the Study Area

The study area comprises three villages namely Dakshin Garankati, Gopalganj and Kaikhali located in the Kultali block of South 24 Parganas district, West Bengal. The majority of people are traditionally engaged with agricultural activity in all three villages (Dakshin Garankati, Gopalganj and Kaikhali) in the Kultali block in South 24 Parganas district (Fig. 76.1). The most important source of income in all three villages is from the agriculture-related livelihood. Another important occupation of the people is fishing activity (CSSRI 2013). But in general, agriculture contributes low income (less than half of the total income) in Sundarban (CSSRI 2014); the average annual income of Sundarban is US$ 180 per capita (World Bank 2014). Here, paddy

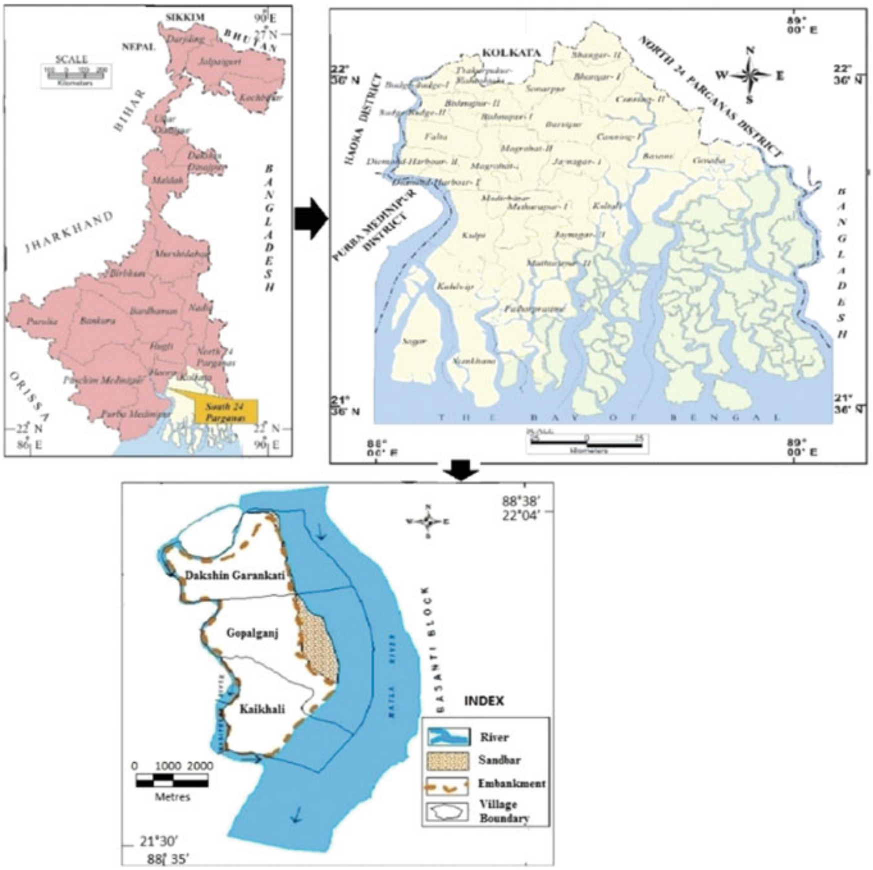

Fig. 76.1 Map showing study site locations

dominant cropping pattern is prevalent because of soil characteristics, flat topography, weather and climate, and availability of irrigation (CSSRI 2013). Paddy is usually grown during the kharif season as *aman* paddy which is specifically rain water-dependent and is cultivated in *ashar* (Mid-June to Mid-July)—*pous* (Mid-December to Mid-January) months and in rabi season, *boro* paddy is cultivated during *magh* (Mid-January to Mid-February)—*jaistha* (Mid-May to Mid June) months. Furthermore, any inundation of low land and medium highland and delay in the water retention affect the cultivation of *aman* paddy. During the rabi season, the farmers cultivate different vegetables i.e., chilli (*Capsicum frutescens*), bitter gourd *(Momordica charantia)*, tomato (*Solanum lycopersicum*), beet (*Beta vulgaris*), cabbage (*Brassica oleracea* var. *capitata*), cauliflower (*Brassica oleracea* var. *botrytis*) and brinjal (*Solanum melongena*). People utilize the rainy season for vegetable cultivation and grow some selected species i.e., Malabar spinach, locally known as *puishak (Basella alba),* ridge gourd *(Luffa),* bottle gourd (*Lagenaria siceraria*) during kharif season in their homesteads.

76.2.2 Sampling Methodology

This study was conducted from August to December in 2016 in three villages (Dakshin Garankati, Gopalganj and Kaikhali) of Kultali block in South 24 Parganas district. To obtain preliminary information on study sites, soil salinity, livelihood and cropping pattern, a pilot survey has been done in June 2016 and discussed the issues with local experienced farmers who are 40–60 years old. Additional information about soil salinity and cultivation were collected from ICAR-Central Soil Salinity Research Institute (CSSRI), Regional Research Station located at Canning and Ramkrishna Ashram Krishi Vigyan Kendra (KVK) at Nimpith in South 24 Parganas district.

A semi-structured questionnaire was prepared in English for household data collection pertaining to the soil salinity effect on livelihood and adaptive strategies in the study area. This questionnaire was administered among 15 farmers, 5 from each village. After pre-test, necessary correction, addition, alteration and rearrangements in the questionnaire were made. The questionnaire was then finalized for collecting data.

Households for survey were randomly selected. Only 5% of total populations in each study village were selected. Thus 80 samples out of 1606 households in Gopalganj, 60 samples out of 1219 households in Dakshin Garankati and 64 samples out of 1294 households in Kaikhali were selected (PCA 2011). For choosing the households in three villages, we collected the farm household list from the villagers and afterwards selection was done through lottery.

To obtain data of *pre-Aila* cyclone (before 2009) to *post-Aila* cyclone (after 2009) experience, a purposive random sampling procedure was used to select respondents above 30 years, who have been living and engaged in farming in the area before 2009 and after 2009. Interviews were conducted among the respondents at their homes.

Repeated visits were done to clarify data after analysis. All respondents for the household survey were men. As Indian women move to their husband's home after marriage, women in the study areas may not provide pre and post *Aila* cultivation data for that area. The respondents believed that soil salinity in their areas started in 2009. According to them, *Aila* (severe cyclone in 2009) was the major cause of soil salinity change where saline water intruded into agricultural land and there was a stagnation of saline water in the agricultural field for a long time. The year 2009 has been selected base year for comparison of the change in salinity. Since 2009 is a memorable year for responders, it was easier for them to recall the data. The soil salinity changes due to embankment breaching, upward capillary movement of saline ground water in rabi season and ingress of saline water from canals are also influential factors in the study area.

Discussions among the various sections of people who had knowledge about installation year of shallow tube well (STW) and submersible pump were undertaken due to lack of secondary data. Three Focus Group Discussions (FGDs) one in each village, were conducted among the females; each group consisted of 7 female participants who belonged to 22–38 years age group and understood experience of female labor participation in agriculture after change of soil salinity.

After completion of field survey, all the primary survey data were cleaned and edited and classified and then entered in MS excel sheet. The data were the analyzed using the software—Stata Release 13 after conversion from excel sheet.

76.3 Results and Discussion

76.3.1 Modifying Agricultural Practices

In order to mitigate the declining yield of rice, farmers showed a preference to increase fertilizer use and that was quite common in all three villages. It was observed that whereas before 2009, the average fertilizer used for *aman* rice was 37.72 kg ha^{-1} which has now increased to 93.46 kg ha^{-1} and from 188.37 to 389.92 kg ha^{-1} for *boro* rice, respectively (Fig. 76.2). The increase in fertilizer use was relatively higher for *aman* varieties compared to *boro* as the decline in yield for *aman* has been higher compared to *boro*. The farmers used (chemical) more fertilizers to compensate for the temporary loss of yield and to protect themselves against food insecurity. The situation, explained by Dilip Naskar (name changed) a farmer in Dakshin Garankati village:

> "*Before soil salinity increased I did not use chemical fertilizer in aman rice. But at present, if I do not use chemical fertilizer I will lose production.*"

The farmers have been switching to *boro* paddy cultivation when they noticed a sharp decline in yield of *aman* in the study area. At present 41% of respondents in Dakshin Garankati, 32% respondents in Gopalgang and 6.25% respondents in Kaikhali had shifted from single rice crop to double rice crop as the

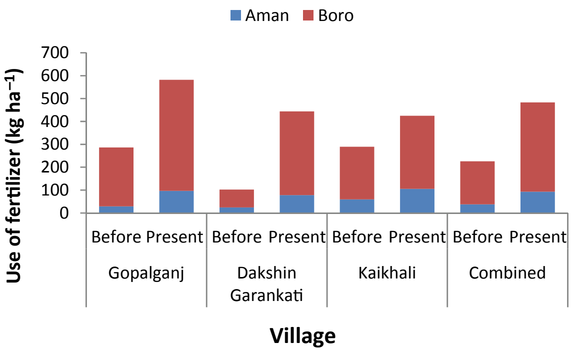

Fig. 76.2 Average use of chemical fertilizer at present (2015) and before 2009 in both *boro* (rabi) and *aman* (kharif) rice

single crop was un-remunerative due to an increase of soil salinity. In Goplaganj and Dakshin Garankati, fresh (non-saline) groundwater is available and small and marginal farmers invest in STWs with surface pumps for extraction of groundwater. There have some canals like *Dhora Bagdar Khal* from which water was used for irrigation in prior *Aila* but now water is saline in the dry season because the canal was inundated by saline water during *Aila*. Also, evaporation (which is high in dry season) removes water from the canal, but not the dissolved salt ions thereby increasing water salinity toward the later period of the dry season. Two to three years after the initial installation of STWs with surface pumps the farmers have switched over to submersible pumps as the surface pumps could not extract water from the STW due to the decline in the water table. The submersible pumps enabled easier extraction of groundwater when required and therefore there had been a steady decline in the number of STWs with surface pumps against the installation of submersible pump based tube wells after 2012 and now nobody is installing new STWs with surface pumps (Fig. 76.3) and the farmers have taken loan or support from their relatives for this technology upgrade. This not only generated additional costs but also resulted in larger volumes of groundwater use as extraction rates were quicker and more convenient. The increased demand for water has created a market and the submersible pump owners use the water to irrigate their fields as well as sell it to others for irrigating nearby fields. Those who are not able to install submersible pump base tube wells purchase the groundwater for irrigation paying Rs. 1500–2000 per bigha (one bigha = 1011.71 m^2) for one season.

In Kaikhali, the villagers are fully dependent on rainwater harvesting because groundwater is saline and no one has installed STW. The NGO, Ramakrishna Ashram KVK in Nimpith and ICAR-CSSRI, Regional Research Station, Canning Town have technically and financially supported rainwater harvesting under the ICAR-National Agricultural Innovation Project. The NGO followed two strategies for rainwater harvesting one is the excavation of new ponds in agricultural fields where the farm size is not less than two bighas as a criterion for excavation of new ponds and another is de-silting and renovation of existing and silted ponds. They have encouraged the villagers to dig ponds and trained them how to store and utilize the rainwater for agricultural production. Near about 129 new ponds are dug from 2013 to 2015 for

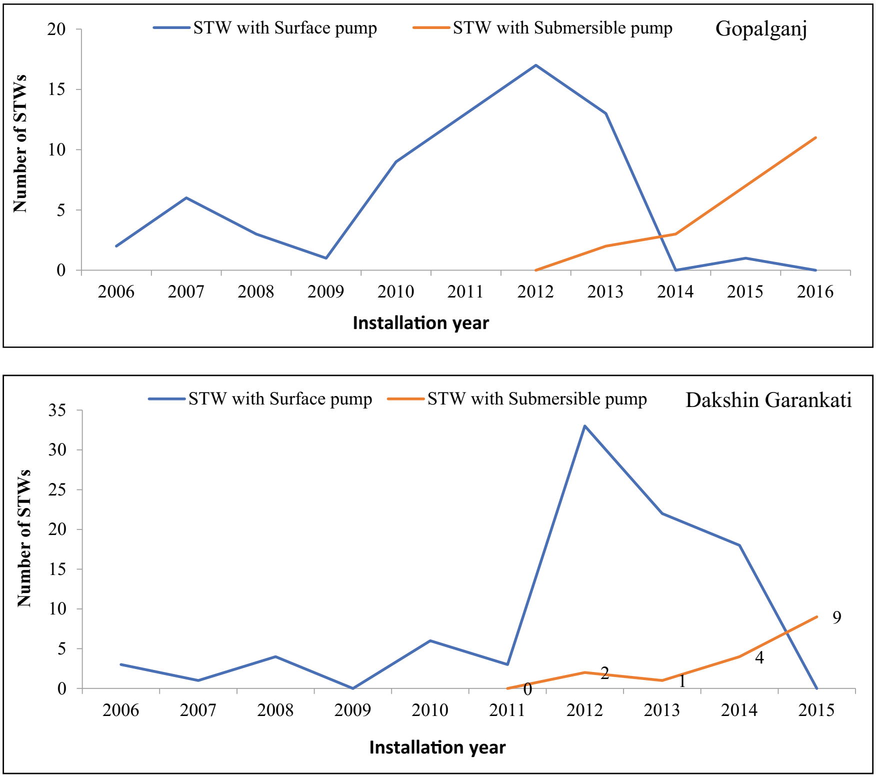

Fig. 76.3 Installation year of shallow tube well with surface pump and submersible pump in Gopalganj and Dakshin Garankati villages of Kultali block, South 24 Parganas district

rainwater harvesting in the village. This practice helps to sustain the cultivation in the village.

It was evident from our field survey that there has been a change in the cropping pattern as a consequence of the increase in soil salinity. The major part of the respondent in all study areas reported that they have discarded (85.94% in Kaikhali, 85% in Gopalganj and 81.67% in Dakshin Garankati) earlier crops such as khesari (Grass pea) and mung bean because they were no more feasible to cultivate under the conditions of high salinity (Fig. 76.4). These nutrient-rich pulse corps are not being cultivated as they are salt sensitive and are only cultivated to a limited extent in areas that have low soil salinity (Table 76.1). Since the farmers face the risk due to discarding of these crops which are cash crops, they have adopted newer crops and their varieties (73.44% in Kaikhali, 50% in Dakshin Garankati and 47.5% in Gopalganj) to minimize the risk. Most of them were cultivating chilli and bitter gourd in the high lands during the winter season. These salt-resistant cash crops increased their income as compared to earlier times.

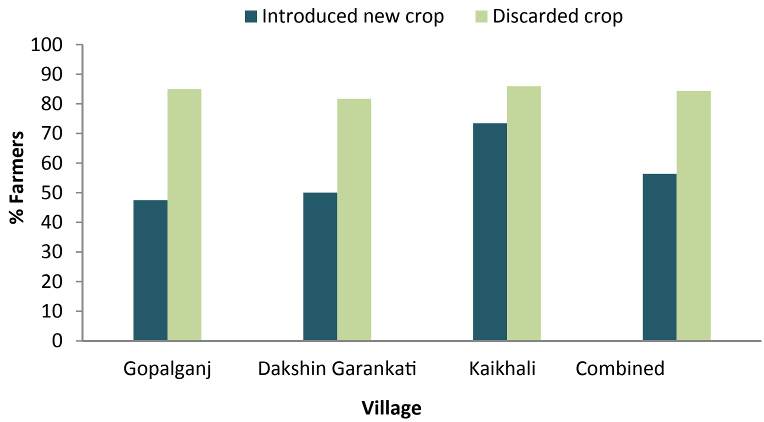

Fig. 76.4 Change in nature of cropping pattern in the study area

Table 76.1 Changes in vegetable cultivation in the study area

Name of the vegetables	Botanical name	Ideal pH	Gopalganj/Dakshin Garankati/Kaikhali	
			In 2015	Before 2009
Mung Bean	*Vigna radiata*	4.5	Not cultivated	Cultivated
Khesari	*Lathyrus sativus*	5.6–5.8	Not cultivated	Cultivated
Potato	*Solanum tuberosum*	5.0–6.0	Limited cultivation	Largely cultivated
Chilli	*Capsicum frutescens*	5–8.5	Largely cultivated	Less cultivated
Bitter gourd	*Momordica charantia*	5–8.5	Largely cultivated	Less cultivated

Land shaping is a significant adaptation strategy to arrest salinity buildup and crop diversification for secure livelihood in the study area. The primary survey indicated that in Kaikhali 78.12% of respondents have adopted land shaping followed by Dakshin Garankati (63.33%) and Gopalganj (46.25%) from traditional cultivation. Land shaping is a unique technology in which the configuration of the land is changed by using the dug-out soil to raise the height of a portion of the land locally known as *parh*. Paddy is cultivated within the lowland and vegetables like bitter gourd and chillis are grown on the raised land during kharif as well as rabi seasons. Due to higher elevation, the *parh* (high land) is free from water logging in kharif as well as there is less salinity build-up in the dry season. The farmers are more concentrated on this typical practice. It also calculated that 4.11 ha of rice land in Gopalganj ws converted to *parh* from 2009 to 2015, followed by Kaikhlai (3.35 ha) and Dakshin Garankati (1.51 ha) villages. *Parh* cultivation is a good substitute for the local people's survival in the changing salinity situation. As a result, traditional agricultural land has

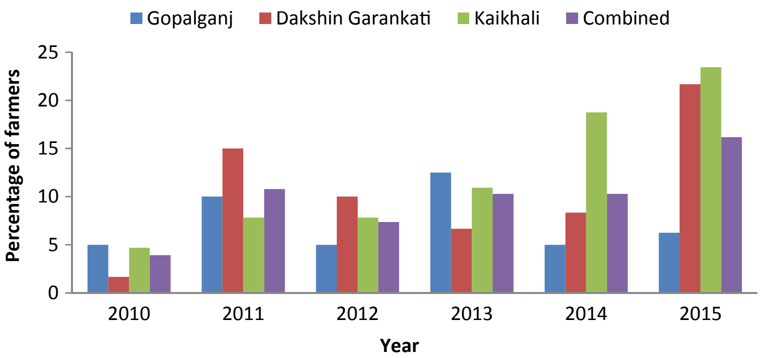

Fig. 76.5 Yearwise land shaping change from rice field to ‘parh’ cultivation in the study area

been affected drastically. The trend of traditional agriculture land converted to *parh* cultivation is presented in Fig. 76.5. In Gopalganj and Dakshin Garnkati, people learnt this strategy from their social network—kinship (blood relationship), who lived in other villages viz., Maipit, Gurguria and Gabtala village in Kultali Block. However, in Kaikhali, the farmers learnt the land shaping technique from NGO, Ramakrishna Ashram KVK in Nimpith and ICAR-CSSRI, RRS, Canning.

76.3.2 Cultivating Salt Tolerant Rice Varieties

Prior *Aila*, the respondents in the study areas cultivated a wide range of indigenous rice varieties in both kharif and rabi seasons, but these declined sharply due to salinity increase. In Gopalganj, indigenous rice varieties were no longer cultivated (Fig. 76.6) as most of them were not salt-tolerant, while the traditional varieties such as Dudheswar and Kalomota that have the ability to tolerate salinity and floods were intensively cultivated with low input cost than the modern ones. Some salt-tolerant varieties like Talmukur and Tangra are not cultivated due to non-availability of seed. However, this changing cultivation of rice varieties from non salt-tolerant to salt-tolerant ones are managed and there has been no external intervention in this regard. In Dakshin Garankati, the farmers had been cultivating 14 rice varieties prior *Aila,* but during the survey, the respondents informed that only 8 varieties are beign cultivated at present. The cultivation of a number of rice varieties in Dakshin Garankati dropped mostly because many of them were not salt-tolerant and farmers mostly grow Dudheswar and Kalomota (Fig. 76.7). In Gopalganj and Dakshin Garnkati, the farmers were continuously cultivating Pankaj variety though it is not a salt-tolerant rice variety but because of its taste. Kanakchur is another important indigenous rice variety and changes in soil salinity have affected the cultivation of this rice variety (Box 1).

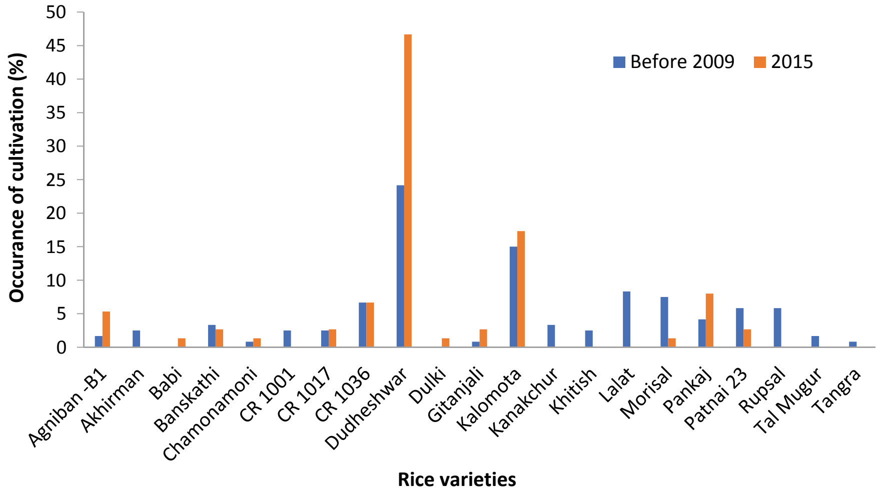

Fig. 76.6 Salinity effect on rice varieties cultivated during aman in Gopalganj

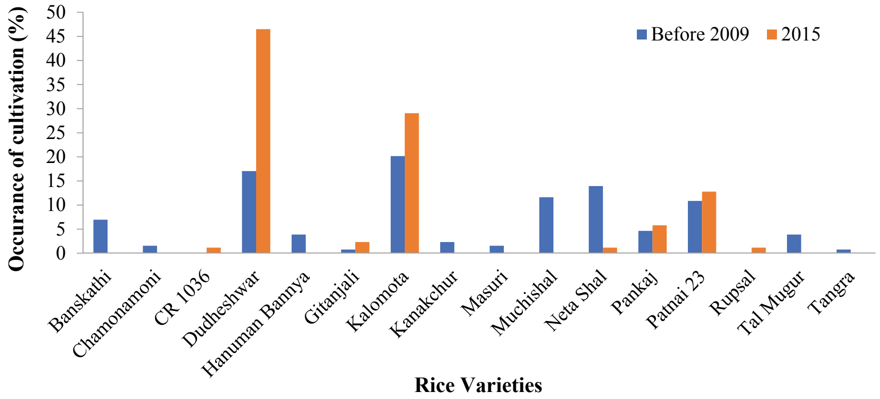

Fig. 76.7 Salinity effect on rice varieties cultivated during aman in Dakshin Garankati

In Kaikhali, indigenous rice varieties were no longer cultivated (Fig. 76.8) as most were not salt-tolerant, while the high yielding varieties such as the CR 1017, CR 1036 and CR 1009, developed by the ICAR-National Rice Research Institute (formerly Central Rice Research Institute), Cuttack were salt-tolerant and gave higher yield when intensively cultivated with chemical fertilizer and pesticides. The farmers had known these varieties from the NGO.

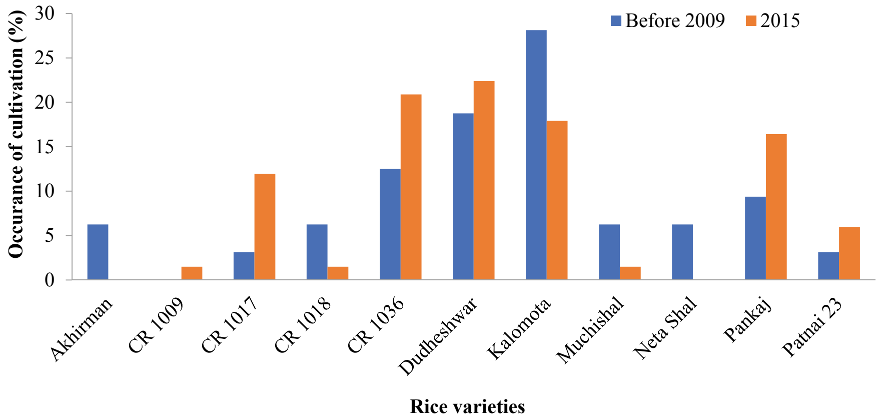

Fig. 76.8 Salinity effect on rice varieties cultivated during aman in Kaikhali

Box 1 Kanakchur Paddy: Case Study

Kanakchur is a variety of *Aman* paddy. As the gap between the nodes of paddy are higher, it is also referred as - '*chorii patla dhan*'. Puffed rice or *khoi* (retains the aroma)—'*footer dhan*' is prepared which is mainly used as an ingredient for making '*Joynagarer Moa*'. Joynagar sweet makers always use this particular variety. However due to an increase in soil salinity, production of this variety has declined. This variety is not a salt tolerant one. Earlier, average yield was 2184 kg ha^{-1} which has declined to 1344 kg ha^{-1}. Production cost has also increased substantially from Rs. 1500 to 4000 while the price at which it is sold has not increased simultaneously. Before 2009, 19 farmers cultivated *Kanakchur* in 54–57 bighas land, now only 2 farmers cultivate in about 8–10 bighas. These cultivators are shifting to cultivation of varieties such as *Dudheshwar* and *Patnai 23*. Now *khoi* making business is shrinking and so they have reduced the quantity of khoi produced from rice. A key informant told that "*Earlier, five bowls of khoi used to made from one bowl of paddy which now is getting two bowls. As well as khoi is shrinking again. Hence I reduced the paddy area from 7–9 bighas to 2 bighas.*"

There are also large numbers of steps of such transformation in *boro* cultivation as well in the study area. In Gopalganj, nearly 28% of the respondents cultivated Iri paddy followed by Joya (21.51%) and Lalat (12.65%), which has now been completed replaced by salt tolerating high yielding varieties (HYVs) such as Bidhan-1, Bidhan-2 and Lalminikit. Despite the same yield of both Bidhan-1 and Bidhan-2, farmers preferred to cultivate the Bidhan 2 variety due to its taste. Some are also cultivating Lalminikit for market price against high production cost; Rs. 900–1000 in Lalminikit against Rs. 800–850 in Bidhan-1 and Bidhan-2. It is quite common practice in the rest two villages. In Dakshin Garankati, earlier 12 rice varieties were cultivated which have now been reduced to only 5 varieties (Fig. 76.9). At present most of the farmers have been cultivating Lalminikit, Bidhan-1 and Bidhan-2 varieties. Incidentally, Bayer a multinational company has introduced a variety of paddy known as Male Female paddy, which has become popular in this village since 2014 (Box 2).

Box 2 Male Female Paddy: Case Study

The Bayer Company introduced the male female paddy in 2014, which was cultivated during the *boro* season. This paddy is locally known as *May moddyo* paddy. In this cultivation, the cultivators pool their cultivated land together, as 30–40 acres of cultivable plot is required. The company provided seed and initially gives Rs. 2000 for agricultural cost. Fifteen farmers cultivated in 6.07 ha in 2014, which increased to 48.56 ha by 55 farmers in 2015. In this cultivation there are two lines of male paddy and followed by eight lines of female paddy. These male female lines are oriented in the east west direction because during the month of *Chaittro* when the wind blows the pollens move in such a way that maximizes the pollination. Bayer paddy plants are taller so that it can easily shaken when the wind blows during *Chaitro*. The farmers usually shake the male paddy plant with the long sticks thrice daily for a week. During *Jaistho*, when paddy starts ripening, the farmers first cut the male paddy then after 34 days cut *female paddy* plants. Whereas *male paddy* only is used for consumption by the farmers, female paddy is taken by the company at a buy back price of Rs. 3700 per bag (One bag = 56 kg). During the field survey (2016) the yield of male female paddy was 1512 kg ha^{-1} for *female* and 1344 kg ha^{-1} for *male*. Although the yield of Bidhan-1, Bidhan-2 and Lalminikit on an average is 4872 kg ha^{-1}, these varieties fetch a relatively lower price in the market. The price of Bidhan-1 and Bidhan-2 is Rs. 800–850 and Lalminkit is Rs. 900–1000 per bag where as male female variety fetches Rs. 3700 per bag.

76.3.3 Strategies to Reclaim the Saline Land

The farmers apply different fertilizers to reclaim the land (Table 76.2). It is quite common practice in the three villages. Most of the farmers used phosphate (98.41% in Kaikhali, 96.67% in Dakshin Garankati and 88.75% in Gopalganj in respectively). Farmers also used lime 48.75% in Gopalganj 26.98% in Kaikhali and 25% in Gopalganj respectively. This practice is largely undertaken in the rabi season. During the primary survey, it was also observed that farmers are using more organic fertilizer at present due to soil salinity change.

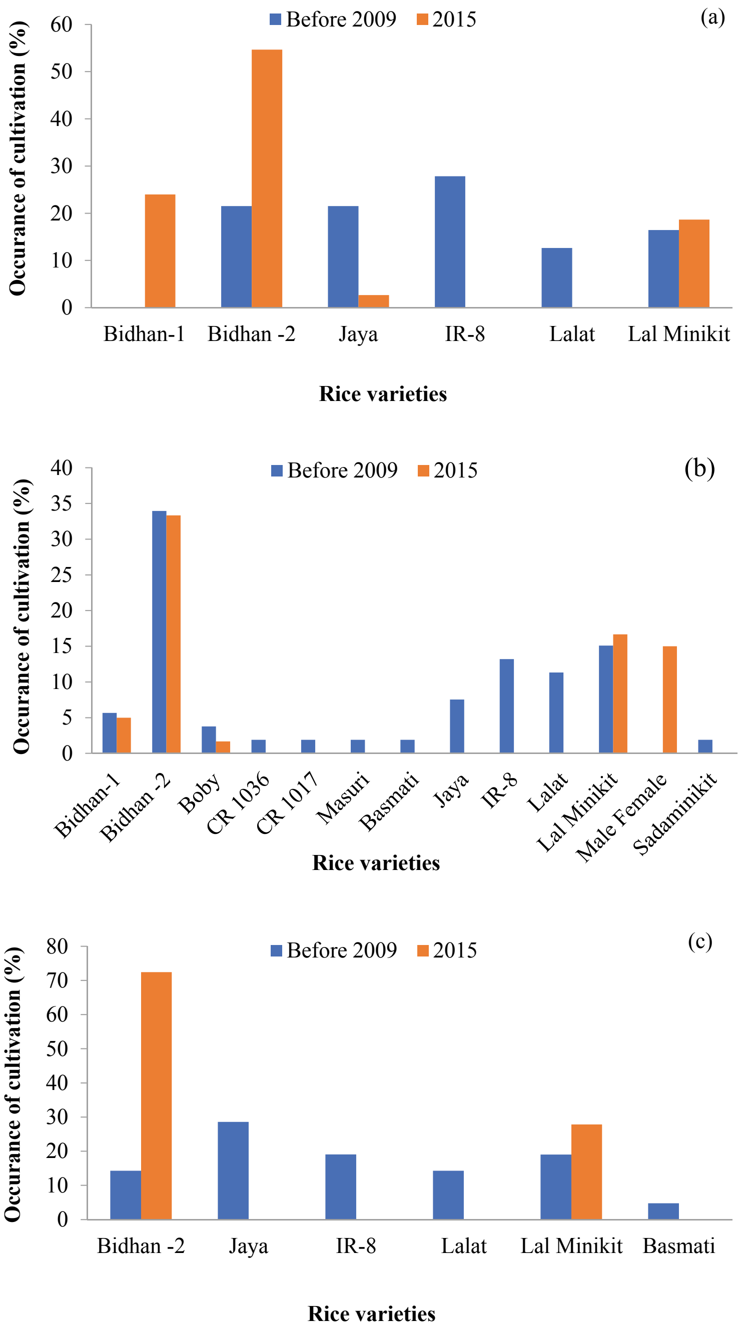

Fig. 76.9 Salinity effect on rice varieties cultivated during boro in **a** Gopalganj **b** Dakshin Garankati and **c** Kaikhali villages

Table 76.2 Uses of fertilizers in the study area

Fertilizer type		Gopalganj	Dakshin Garankati	Kaikhali	Combined
Chemical fertilizer	Phosphate	71(88.75)	58(96.67)	62(98.41)	191(93.63)
Non-chemical fertilizer	Lime	39(48.75)	15(25)	17(26.98)	71(34.08)
	Organic fertilizers	3(3.75)	–	15(23.43)	18(8.82)

Note Figures in parentheses denote percentage of respondents

Mulch is being used to cover the soil surface and check evaporation loss of soil moisture. It was observed during our field survey that application of mulch helps in reducing the soil temperature thereby minimizing evaporation, which in other words is also the main cause of the increase in soil salinity due to capillary action by which the saline groundwater moves upward to the surface leaving behind salts on evaporation. Mainly the rice stubbles which is available locally are applied to the soil surface as mulch and also the straw is used for surface cover. This practice is largely undertaken during the rabi season. The mulch is an important technique for preventing evaporation and reducing the concentration of salts at the surface of the soil (Peck 1978) where straw is an important material that protects against evaporation (Zhang 2014).

76.3.4 Switching to Alternative Livelihoods and Change in Labor Participation

The farmers whose income from agriculture has reduced substantially have changed their occupation profile (27.5% in Gopalganj, 15.56% in Kaikhali and 15% in Dakshin Garankati) to non-farm activities such as construction work, van puller, earthwork, catching crabs and fish. Prior to 2009, these farmers were full time engaged with agriculture, now they were only temporarily (3–4 months) engaged in those activities to secure their livelihood. It is not uncommon for such kind of occupation profile to change because most of the farmers have primary education (I to IV) without any technical skill as well as they are illiterate. Some of the people go to the river to catch fish as labour with other fishermen during the lean periods of agricultural activities.

The focused group discussions revealed that has been increasing female participation as labour in cultivation to minimize the cost where most of the people hire labour before salinity changes. Most of the participants told that they are mainly using family members as labour because production cost has increased while the yields are low after salinity change, as well as the wage of labour, has increased from Rs. 180–200 in 2008 to 300–350 in 2016 without food. Some of them told that there have been a ‘labour crisis’ during the rabi season because most of the men are migrating outside to find work in other sectors mainly non-farm activities as they are losing income from agriculture. Hence there is an increasing share of women in the agricultural workforce.

"Generally, we did domestic work in house, nobody goes to the field and I have seen people did hire during sowing and harvesting. But this scenario has changed after *Aila,* now people do not hire and are using family members due to loss of yield". (Participant in a focus group discussion, Dakshin Garankati village).

76.3.5 Migration as an Adaptive Strategy

Those people who were not coping with livelihood security challenges are forced to migrate for seeking jobs as an adaptation strategy. Two categories of migration were observed in this study: households that only had some members elsewhere and households where all members moved as a group, although it is little. The first category, marginal and small farmers, seasonally (summer season) migrated to Kolkata as well as North 24 Parganas and Purba Midnapore to work in informal sectors such as masons, labourer, etc. The second group of whole household migrants were among the most vulnerable, facing significant livelihood security challenges. Generally, poorer households with small plots of land or landless households moved to Kolkata with their whole family. Some neighbours look after their house without any maintenance cost. They could return home frequently during marriage and local festivals especially *Nil Koloni* and *Laal Koloni Mela* in January. FGDs conducted during our field survey, revealed that the young generation is more interested in alternative income sources e.g., rickshaw pulling, garments stitching, construction labour or shopkeeper instead of being a farmer in agriculture practice.

76.4 Conclusions

Changes in salinity level in soil not only reduce the agricultural potential but also cause an effect on the livelihood strategies of farmers. The increasing soil salinity impact on the quality and quantity of indigenous rice varieties have led to increased cultivation of salt-tolerant and HYV rice varieties. The most significant effect of the salinity level of the land is the changes in land shaping. Farmers have converted their agricultural fields to *parh* (raised land) to arrest salinity buildup and to cultivate cash crops to supplement reduced income from paddy cultivation as observed in this study. Farmers are using various devices (like STW and submersible pumps) to extract groundwater for *boro* rice cultivation on a large scale and thus there is overexploitation of groundwater in all study areas except the Kaikhali. Under these circumstances, people have migrated; salinity acting as a push factor, to surrounding districts and are switching to non-farming activities to secure their livelihood. The younger generation are also not interested in farming activities.

References

Ali AMS (2006) Rice to shrimp: land use/land cover changes and soil degradation in Southwestern Bangladesh. Land Use Policy 23(4):421–435

CSSRI (2013) Land shaping—a unique technology for improving the productivity of coastal land. Technical bulletin: CSSRI/Canning Town/Bulletin/2013/02. ICAR-central soil salinity research institute, Regional Research Station, Canning Town, West Bengal, India

CSSRI (2014). NAIP sub-project, Strategies for sustainable management of degraded coastal land and water for enhancing livelihood security of farming communities, component 3, GEF funded, ICAR-central soil salinity research institute, regional research station, Canning Town

Dun O (2012) Agricultural change, increasing salinisation and migration in the Mekong Delta: insights for potential future climate change impacts. In: L. Elliott (eds) Climate change, migration and human security in Southeast Asia, S. Rajaratnam School of International Studies, Nanyang Technological University, Singapore

Habiba U, Shaw R (2013) Enhancing farmers resilience to cope with climate induced drought in Northwestern Bangladesh. J Disaster Res 8(1):203–204

Haider MZ, Hossain MZ (2013) Impact of salinity on livelihood strategies of farmers. Soil Sci Plant Nutr 13(2):417–431

Haque MZ, Saifuzzaman M (2003) Social and environmental effects of shrimp cultivation in Bangladesh: notes on study methods. In: Rahman M (ed) Globalization, environmental crisis and social change in Bangladesh. Disaster Research Institute, University of Manitoba, Canada, pp 280–298

Hazra S, Samanta K, Mukhopadhyay A et al (2010) Temporal change detection (2001–2008), study of Sundarban, final report, school of oceanographic studies. Jadavpur University, Kolkata, West Bengal, India

Khanom T (2016) Effect of salinity on food security in the context of interior coast of Bangladesh. Ocean Coast Manage 130:205–212

Miah MY, Mannan MA, Quddus KG et al (2004) Salinity on cultivable land and its effects on crops. Pak J Biol Sci 7(8):1322–1326

Mitra A (1954) District handbook 24-Parganas. West Bengal Government Press, Alipore, Kolkata, West Bengal

PCA (2011) Census of India, Government of India

Peck AJ (1978) Note on the role of a shallow aquifer in dry land salinity. Aust J Soil Res 16:237–240

Planning Commission (1981) Report on development of coastal areas affected areas, planning commission. Govt. of India, New Delhi, India

Rabbani G, Rahman A, Mainuddin K (2013) Salinity-induced loss and damage to farming households in coastal Bangladesh. Int J Glob Warm 5(4):400–415

Rengasamy P (2006) World salinization with emphasis on Australia. J Exp Bot 57:1017–1023

Roy AK, Sharma S (2015) Perceptions and adaptations of the coastal community to the challenges of climate change: a case of Jamnagar city region, Gujarat. India. Environ Urban Asia 6(1):71–91

Sarwar GM, Khan MH (2007) Sea level rise: a threat to the coast of Bangladesh. Int Asian Forum 38:375–397

Singh J, Singh JP (1995) Land degradation and economic stability. Ecol Econ 15(1):77–86

Srivastava P, Wu QS, Giri B (2019) Salinity: an overview. In: Giri B, Varma A (eds) Microorganisms in saline environments: strategies and functions. Springer, pp 3–18

Tanwir F, Saboor A, Newaz N (2003) Soil salinity and the livelihood strategies of small farmers: a case study in Faisalabad District, Punjab, Pakistan. Int J Agric Biol 5(4):440–441

Word Bank (2014) Building resilience for sustainable development of the Sundarbans: through estuary management, poverty reduction, and biodiversity conservation, strategy Report No. 88061-IN, South Asia Region, sustainable development Department, environment & water resources management unit, The World Bank, Washington DC, USA

Zhang J (2014) Environment & water resources management unit coastal saline soil rehabilitation and utilization based on forestry approaches in China. Springer, London

Chapter 77
Mechanization of Small Farms to Reduce Drudgery of Women Workers

C. R. Mehta

Abstract Mechanizing small and non-contiguous groups of small farms is against 'economies of scale' for individual ownership of farm machinery. With no possibility of increase in net cultivated area and diminishing farm labour availability, intensive agriculture with higher input use efficiency is essential for the growth of Indian agriculture. The increased participation of women's workforce in agriculture demand more emphasis on development of gender-friendly tools, equipment and workplaces. Women workers need to be empowered through demonstrations and trainings on proper and safe operation of modern farm tools and machinery. Presently, the farm machineries in India are being used primarily for production of food crops. Mechanization level of Indian agriculture has increased considerably and reached 45%. Large number of manual, animal-drawn, self-propelled, power-tiller and tractor-operated equipment and machinery have been developed and are commercially available for different farm operations in major crops. The widely fragmented and scattered land holdings in many parts of the country as in coastal ecosystems need to be consolidated to reap the benefits of agricultural mechanization. There is a need to innovate custom service or a rental model by institutionalization for high-cost farm machinery to reduce the cost of operation on small farms.

Keywords Drudgery of workers · Farm mechanization · Small farms · Women workers

77.1 Introduction

India is an agrarian country where about 60% of the population is dependent on agriculture. Indian agriculture employs about 45% of the total workforce and contributes to only 17% of the gross domestic product (GDP) of our country which makes farming in India less remunerative. India has a cultivated area of about 140 million ha fragmented in 138 million farm holdings. The average farm size in India is small (1.08 ha)

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and small and marginal land holdings (less than 2.0 ha) account for more than 86% of land holdings. The yearly food grain production in India is about 296 million tonnes (2019–20). Traditional agriculture used mainly human and animal power sources. However, nowadays, due to modernization, mechanical and electrical power sources are being used extensively for various farm operations. Human power, apart from being a source of power for manually operated farm equipment and hand tools, is also used extensively for operating self-propelled and power-operated agricultural machines.

As per 2011 census of India, the share of agricultural workers to total workers has reduced from 58% in 2001 to 55% (i.e. 263 million) in 2011 (Anonymous 2013). Of these, the women workforce is 97 million which amounts to about 37% of the total agricultural workers in the country. It is estimated that by 2020, the share of agricultural workers will go down to about 41% (i.e. 230 million) and of these 45% will be women workers. The labour availability in agriculture is expected to go down to 26% of total workforce by 2050. Women participate in different production and post-production agricultural operations including storage, packaging, transport and marketing. Besides household management, most of the work related to management of cattle/other farm animals is done by women. To have higher productivity per unit land per year, reduce cost of cultivation and reduce drudgery, more and more machines will be used on farms for various operations.

There are about 150 million agricultural machines operated either by tractors, power-tillers, electric motors, diesel engines, animals or by human workforce. Of these, about 6.5 million are tractors, 0.5 million power tillers, 17 million electric motors/pump sets, and 9 million diesel engines/pump sets. The numbers of agricultural hand tools in use are about 500 million. At present, majority of the agricultural workers in our country are used as a source of muscular power. However, it is a known fact that human beings are not best suited as a source of muscle power, but, suited as controller of machines. They have a vast potential and capacity for information processing and taking actions on that basis. Therefore, it is always better to use human workforce as controller of machines as far as possible.

Modernization of agriculture is taking place at a faster pace. However, jobs attended by women, more or less, remained the same. Though, considerable work has been done to develop agriculture with major emphasis on technical and economic achievement, very little attention has been given to gender issues. Women have different technological needs than men due to their different ergonomical characteristics, level of education, experiences, skills, etc. Therefore, many of the technologies developed are not suitable for women users. In future, for most of the farm activities, there will be machines available which may be self-propelled, power-operated or engine-operated manually guided. It is estimated that as of today, in case of male workers about 30% work as controller of machines and 70% as source of power. In case of women workers, the corresponding figures are 5 and 95%. Therefore, the status and strategies for small farm mechanization in India are discussed in the paper to reduce drudgery of women workers.

77.2 Farm Mechanization in India

Farm mechanization has the potential to meet contemporary challenges and to increase productivity in a sustainable way. Fragmentation of agriculture land due to increase in family sizes has led to sharp increase in land holdings of less than one hectare. The sale of high-cost machinery like combine, laser-guided land leveller and rice transplanter are growing fast for operation in custom hiring mode, since the demand is more. The market for threshers (multi-crop and paddy), rotavator, planters and zero-till drill in India is highly unorganized and is dominated by a large number of small and medium scale enterprises (SMEs) located majorly in the states of Punjab, Haryana, Uttar Pradesh, Madhya Pradesh, Gujarat, Maharashtra, Tamil Nadu and Andhra Pradesh (Mehta et al. 2014). The brief details of farm implements and machinery developed in the country for different farm operations are as follows.

77.2.1 Tillage and Seedbed Preparation Equipment

The seedbed preparation/tillage operation for cultivation of different food-grains and horticulture crops is more or less mechanized and equipment for different power sources are available. Improved implements operated by animals, power tillers and tractors for primary and secondary tillage viz., mould board plough, rotavator, puddler, disc harrow-cum-puddler, power harrow, tine cultivator, duck foot cultivator, peg tooth harrow, patela harrow, spring tine harrow, multi-purpose tool frame, ridgers, furrowers, bed formers, levellers, etc. are commonly used and commercially manufactured. Tractor, power tiller and engine operated post hole diggers are also commercially available. Power tillers with rotary tiller are useful for preparation of basins around orchard trees for manuring and fertilizer application and need to be demonstrated and adopted. An animal-drawn patela harrow is a secondary tillage equipment for clod crushing, stubble or trash collection, levelling and smoothening of land surface before seeding (Fig. 77.1). It is available in working width of 1.5 and 2.0 m. The frame carries a bar to which curved and pointed hooks are attached. The effective field capacity of the equipment is 0.3 ha h^{-1} and labour requirement is 3–4 man-h ha^{-1}.

77.2.2 Sowing and Planting Equipment

Mechanically metered seed drills and seed-cum-fertilizer-drills operated by manual, animal, power tiller and tractor have been developed and are being manufactured suiting to specific crops and regions for sowing/planting of wheat, rice, coarse cereals, pulses, oilseeds and maize crops. Tractor-mounted pneumatic precision planters and

Fig. 77.1 Animal drawn patela harrow

no-till drills, multi-crop planters using inclined plate metering mechanism, strip till drill and sugarcane planters are some of the significant designs.

Power tiller operated 3-row inclined plate planter has been designed and developed for sowing maize, soybean and pea crops in terraces and valley lands of hilly region (Fig. 77.2). The row-to-row spacing of the planter is adjustable (130–280 mm) by sliding the furrow openers on tool bar. Different crops can be sown by changing seed plates and by changing the transmission ratio. The effective field capacity of equipment is 0.12 ha h^{-1} in hilly region.

For paddy transplanting, manual and self-propelled walking and riding type rice transplanters are now commercially available (Fig. 77.3). Presently, many companies in India are importing rice transplanters from China and Korea and marketing them.

The vegetable crops are sown both by seeding and transplanting. Direct seeding of vegetable crops is mostly done manually except for crops like pea, okra, beans, etc. having medium or large size seeds which can be easily sown with the help of seed drill or planters. For direct sowing of small-seeded vegetable crops having very low seed

Fig. 77.2 Power tiller operated inclined plate planter

Fig. 77.3 Self-propelled rice transplanter

rates like onion, carrot, etc., mechanical/pneumatic planting systems are being developed and adopted. A six-row tractor-operated small seed planter for sowing small seeds (onion) at 150 mm row spacing and adjustable plant-to-plant spacing was developed at PAU, Ludhiana. Transplanting of seedlings of vegetable crops is carried out manually. Tractor-operated two-row semi-automatic vegetable transplanters suitable for bare root seedlings have been developed at CIAE, Bhopal and PAU, Ludhiana. Tractor-operated vegetable transplanters for cup-type seedlings developed at TNAU, Coimbatore and IIHR, Bangalore are under limited commercialization and need further popularization.

Potato planters both semi-automatic and automatic types have been developed and are commercially available and gaining popularity especially in Uttar Pradesh and Punjab states. The manual, animal and tractor-operated garlic planters have been developed at PAU, Ludhiana and MPUAT, Udaipur. The tractor mounted turmeric rhizome ridger planter having effective field capacity of 0.15 ha h^{-1} has been developed at TNAU, Coimbatore.

Tractor operated semi-automatic sugarcane planter and sugarcane sett cutter-cum-planter are commercially available. A paired row planting ridger has also been developed which makes two furrows at close row to row spacing of 300 mm and third furrow at 1500 mm spacing. It helps in saving the cane crop from lodging and an inter-crop can also be grown successfully.

77.2.3 Weeding, Hoeing and Interculture Equipment

For weeding and interculture operations, a variety of manual hand tools, bullock drawn and power operated equipment have been developed and are commercially available. The developed equipment included manual wheel type weeders, animal-drawn tined and sweep type weeders and self-propelled tined and rotary weeders and tractor operated rotary weeders.

Fig. 77.4 Cono weeder

The cono weeder is used to remove weeds between rows of paddy crop (Fig. 77.4). The weeder consists of two rotors, float, frame and handle. The rotors are mounted in tandem with opposite orientation and create a back and forth movement in the top 30 mm of soil. The push–pull operation of cono weeder in between rows makes weeding effective. It costs Rs 1900/- and field capacity is 0.18 ha day^{-1}.

A tractor-drawn three-in-one implement has been developed to reduce cost of cultivation of sugarcane crops. It helps in interculture operation to control weeds, applies fertilizer along the root zone for more efficient fertilizer use and does earthing up of the crop to save it from lodging in grown-up plant and ratoon crop.

77.2.4 Plant Protection Equipment

Different types of manual, animal, small engine, power tiller and tractor operated dusters and sprayers have been developed and are commercially available. The tractor-operated high clearance, long swath sprayer for cotton and sugarcane crops and self-propelled high clearance sprayer and air carrier sprayer for tall crops have been developed. Tractor mounted boom sprayer is suitable for uniform and effective spray over crops (Fig. 77.5). It consists of a tank made of fibre glass or plastic, pump assembly, suction pipe with strainer, pressure gauges, pressure regulators, air chamber, delivery pipe and spray boom fitted with nozzles. It uses high pressure and high discharge pump as the number of nozzles may be up to 20 depending upon the crop and size of the sprayer.

Low volume and ultra low volume (ULV) sprayers and CDA crop sprayers which require comparatively smaller quantity of water are also in use. However, their adoption level is still low. The spraying in cotton, rice, sugarcane, fruits and vegetables, oilseeds and pulses crops has become popular in India.

Fig. 77.5 Tractor mounted boom sprayer

77.2.5 Harvesting Equipment

Harvesting tools are needed to cut crops above ground level, to dig out those growing in the soil and to gather them. The main harvesting equipment includes improved designs of sickles for cereal crops, scythes for sugarcane and other hard-stemmed crops, and self-propelled (Fig. 77.6), power tiller and tractor mounted vertical conveyor reapers and reaper binders. The self-propelled and tractor on top combine harvesters for different crops are largely owned by custom hiring contractors. Straw combines have been developed to facilitate straw retrieval after combining.

For groundnut, potato and root crops, which have to be lifted and separated from the soil, digging prongs or blades serve the purpose; and for gathering these crops many kinds of tines or rakes are used. For harvesting of root crop like potato, good design of harvesting and windrowing equipment are available.

Fig. 77.6 Self-propelled vertical conveyor reaper

Tractor-operated harvesters for groundnut and potato are also available commercially. Harvesters/diggers need to be adopted for harvesting onion, carrot, rhizomes (ginger, turmeric, etc.) and other crops.

Most of the horticultural fruit and plantation crops are harvested by manual picking all over the country. Manual tools/aids for harvesting fruit and plantation crops have been developed and need to be adopted. Power/hydraulically operated elevated platforms are being tested for harvesting fruits from tall trees. A self-propelled (8.2 kW petrol engine) multi-purpose hydraulic system has been developed at CIAE, Bhopal for harvesting, pruning and spraying of fruit crops like mango, sapota and citrus.

77.2.6 Threshing Equipment

Hand held maize shellers (Fig. 77.7) and groundnut and castor decorticators (Fig. 77.8) are the main manually operated threshing tools/equipment. Manual groundnut decorticators, groundnut strippers and axial flow groundnut threshers have been developed for threshing and shelling of groundnut. Power-operated threshers have been developed for rice, wheat, soybean, sunflower, groundnut and maize crops. In addition, power and tractor operated crop-specific and high capacity multi-crop threshers such as semi-axial flow multi-crop thresher, PAU axial flow sunflower thresher and sunflower seed sheller employing different mechanisms for threshing and cleaning were also developed. The farmers use them on individual ownership or

Fig. 77.7 Maize sheller

Fig. 77.8 Groundnut decorticator

on custom hiring basis. These threshers are preferred for threshing oilseeds, soybean, peas, pigeon pea and sunflower crops.

77.3 Women Workers and Farm Mechanization

With higher participation of female workforce and changing scenario of farm technologies' demand, more emphasis is being given on development of gender-friendly tools, equipment as well as work places. Women have different ergonomical characteristics and therefore, it is necessary to give due considerations to their capabilities and limitations while designing various machines suitable to them. ICAR-Central Institute of Agricultural Engineering (CIAE), Bhopal, ICAR-Central Institute for Women in Agriculture (CIWA), Bhubaneswar, Centres of AICRP on Ergonomics and Safety in Agriculture (ESA) and AICRP on Home Science and State Agricultural Universities (SAUs) carried out ergonomical evaluation of hand tools/equipment developed by various research organizations in the country and found some of those suitable for women workers. It is important to ensure greater access for farm women to various inputs (including farm tools and equipment) needed by them to carry out their work more efficiently and with minimal drudgery. The assured supply of improved tools and equipment to farm women needs to be ensured as per their requirement at village level (Mehta et al. 2018).

Technology development should invariably follow up by awareness creation, commercialization and infrastructure support for transfer of technologies to the end users in the most effective way. Also, skill upgradation of women workers is necessary to enable them to operate the farm equipment and machinery. It only requires infrastructure and facilities for training them at places which are within their reach.

77.4 Strategies for Small Farm Mechanization

The policies for agricultural mechanization in India must be tailored to local needs and should include cooperation and partnership schemes between public–private sectors. The broad strategies to mechanize Indian agriculture are as follows (Mehta 2020):

- **Selective**: it enables farmers to adjust and adopt suitable technologies for their farm, based on local/regional conditions and needs.
- **Inclusive**: it provides benefits to farm holdings of different types and sizes and the overall rural community.
- **Integrated:** A broader, integrated approach is needed which foresees public–private partnership. It requires an active participation and support of farmers, key agri-business stakeholders such as tractor and farm machinery manufacturers and financial institutions.

The key strategies for mechanization of small land holders are as follows.

- Design the tools/equipment keeping in view the anthropometric data of user population.
- Organize demonstrations and trainings for rural women/farmers at local level for safe and proper operation of farm equipment and machinery.
- Promote agro-processing at community level to locally add more value to farm outputs.
- Encourage the establishment of farm machinery banks that enable joint purchases and ownership structures.
- Promote custom hiring or contractual services for certain field operations (e.g. land preparation, seeding, fertilizing, harvesting and threshing) for the benefit of small holders' farmers.
- Strengthen rural or agricultural credit mechanisms to provide the finance to farmers to buy the much-needed inputs and equipment.
- Adequate supporting infrastructure for farm machinery repair and maintenance services, parts supply, fuel and lubricants in rural areas.

77.5 Conclusions

The widely fragmented and scattered land holdings in many parts of the country as in coastal eco-systems need to be consolidated to reap the benefits of agricultural mechanization. There is a need to innovate custom service or a rental model by institutionalization for high-cost farm machinery such as combine harvester, paddy transplanter, laser-guided land leveller, rotavator, threshers (multi-crop and paddy), etc. to reduce the cost of operation on small farms and can be adopted by private players or state or central organizations in major production hubs.

Precision agriculture using GIS/GPS techniques for region-specific crop planning, controlled precision application of inputs (seeds, fertilizers, chemicals, water, etc.), conservation agriculture for carbon sequestration, multi-functional farm equipment to conserve energy and to reduce the turnaround time, farm machinery management, application of drones in agriculture, application of sensors, micro-processor and computer in agriculture are some of the areas that need more attention in India for sustainable agriculture. In future, agriculture is expected to be dominated by precision and cloud data and supported by advanced infrastructures like smart small tractors, unmanned aerial vehicles and wireless technology. There is a need to simplify these technologies to rudimentary levels and made them cost-efficient for maximum acceptance.

References

Anonymous (2013) Census of India. Office of Registrar General and Census Commissioner. Govt of India, New Delhi

Mehta CR (2020) Small farm mechanization—status and prospects in Afro-Asian countries. Afr Asian J Rural Dev 53(1):7–26

Mehta CR, Chandel NS, Senthilkumar T (2014) Status, challenges and strategies for farm mechanization in India. AMA Agric Mech Asia Afr Lat Am 45(4):43–50

Mehta CR, Gite LP, Khadatkar A (2018) Women empowerment through agricultural mechanization in India. Curr Sci 114(9):1934–1940

Chapter 78
Development and Performance Evaluation of Finger Millet (*Eleusine coracana*) Cleaning System

R. V. Powar, V. V. Aware, A. A. Deogirikar, and S. B. Patil

Abstract Traditionally, the finger millet (*Eleusine coracana*) cleaning (FMC) operation is performed manually. This process is labour-intensive, drudgery prone, time-consuming, and skilful. Therefore, to overcome these problems, a finger millet cleaning system (FMCS) was developed. The developed FMCS is a part of finger millet thresher-cum-pearler (FMTCP). The throughput capacity of FMTCP is 36 kg h^{-1}. The performance of the cleaning system is depending on its operational parameters, viz., sieve slope (S_S), stroke length (S_L), and frequency of stroke (F_S). The study aims to optimize the operational parameters of the cleaning system to achieve maximum cleaning efficiency (C_E) and minimum spilled grain (S_G). The analysis was carried out using the response surface method (RSM) along with the 'User Defined Design' statistical tool. The optimum operational parameters of the cleaning system were found as S_L of 20 mm, F_S of 400 strokes min^{-1}, and S_S of 3.5° that predicts maximum C_E of 96.53% and S_G of 1.26%. In the end, the performance of the cleaning system was validated by setting optimum conditions. This results, the maximum C_E of 97.5% along with 1.3% S_G. The validated performance evaluation of the cleaning system was better than the predicted. The designed cleaning system overcomes the problems associated with FMCS. As per standard prescribed by BIS ($C_E \geq 96\%$ and $S_G \leq 1.5\%$), the developed cleaning system is accepted for FMTCP.

Keywords Finger millet · Threshing · Pearling · Cleaning · UDD · RSM

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78.1 Introduction

Finger millet is the second-largest cereal crop after paddy taken in the Konkan region of Maharashtra, India (Powar et al. 2019a). The red colour (high iron content) and well-drain soil is favourable for finger millet cultivation. In Maharashtra state, it is taken in both season kharif and *rabi*. Finger millet is identified by local names such as *Ragi* and *Nachni* (Pradhan et al. 2010). This is having higher nutritional and medicinal values as compared with other cereal crops (Sail 2018). Also, this is the source of calcium, iron, amino acid, and sulphur (Powar et al. 2018a).

The finger millet cleaning includes the removal of husk, crop waste, and other impurities (stone, soil). Traditionally, FMC is carried with two methods, i.e., hand pounding method and blow the impurities with drag of natural wind. The fine dust of finger millet husk is hazardous for the human being. The solon nose, cough, and fever are caused due to respiration of dust. Powar et al. (2019a) evaluated the performance of manual threshing, pearling, and cleaning of finger millet. They reported that the two time cleaning operations were needed to obtain the clean grains. The capacity of threshing, pearling, cleaning after threshing, and cleaning after pearling were found to be 24.3, 11.6, 11.23, and 9.1 kg h^{-1}, respectively. The energy required to process (threshing, pearling, and cleaning) one tonne of finger millet grains with manually was 675 MJ. The cleaning operation accounts for 57% of the overall energy usage. Therefore, manual cleaning of finger millet is energy and labour-intensive. A limited number of attempts had been done on development of cleaning system. Verma et al. (2014) developed a finger millet pearler without cleaning system. Parman and and Verma (2015) developed and tested a pedal-operated finger millet thresher. They used the aspirated blower and sieve walker mechanism for development of the cleaning system. They found the maximum cleaning efficiency of 69%. Chandrakanthappa et al. (2001) evaluated the performance of finger millet thresher. They reported the maximum cleaning efficiency of 70%. None of the above threshers meets the acceptable level of C_E (>96%) as standard prescribed by BIS. To overcome the above issues, the research work was undertaken to design and develop a finger millet cleaning system (FMCS).

78.2 Material and Methods

The following subsections address the construction of a finger millet thresher-cum-pearler (FMTCP), as well as the cleaning system and performance assessment of the developed cleaning system.

78.2.1 Finger Millet Thresher-Cum-Pearler

The FMTCP (Fig. 78.1) has a capacity of 36 kg h^{-1}. The threshing and pearling drums were operated by a two-horsepower single-phase electric motor. A threshing cylinder, concave, threshing sieve, and outer casing make the threshing drum. The threshing drum had a diameter of 200 mm and a length of 300 mm, respectively. A 2 mm threshing sieve was installed at the bottom of the drum. The presence of a threshing sieve within the drum enhances the repeated impact and residence time of finger millet panicles (Powar et al. 2020). It is selected based on the average diameter of finger millet grains (Powar et al. 2019c). The optimum operating conditions of the threshing drum, i.e. feed rate, concave clearance, and drum speed were found as 36 kg h^{-1}, 5 mm, and 7.11 m s^{-1}, respectively, with 99% threshing efficiency, 86% pearling efficiency, and 0.1% grain damage (Powar et al. 2019a). The pearling drum was created to match the threshing drum's capacity. The pearling cylinder, concave, pearling sieve, and outer casing are all part of it. The pearling cylinder had a diameter of 200 mm and a length of 180 mm, respectively. The optimum pearling drum operating conditions, namely drum speed, concave clearance, and pearling sieve size, were 7.25 m s^{-1}, 3 mm, and 2 mm, with % pearling efficiency and % grain damage, respectively (Powar et al. 2019a, b, c). The constructional details of the threshing drum and pearling drum were described in detail in the cited article (Powar et al. 2019a, b).

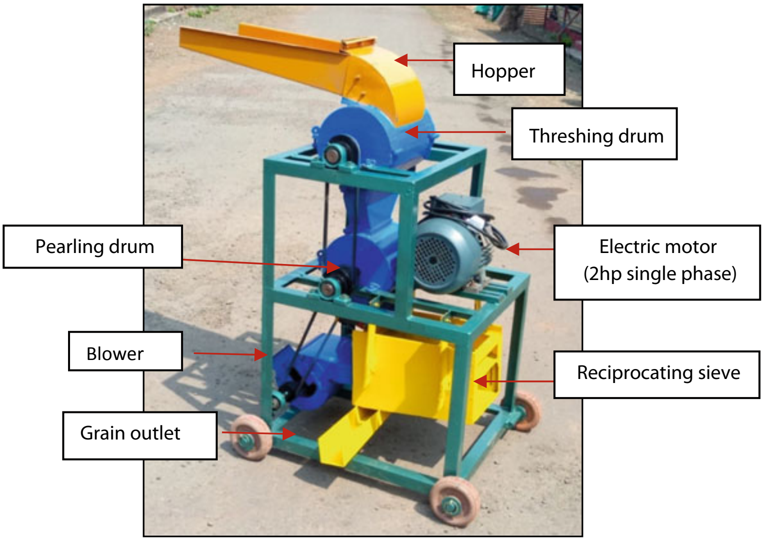


Fig. 78.1 Finger millet thresher-cum-pearler

78.2.2 Development of Cleaning System

The cleaning device was designed to handle 36 kg h^{-1} of input raw material (grain + bhusa (bran)). The finger millet panicles were fed into the hopper after being dried (M.C 12% db.) and then passed to the threshing drum for separation of the finger millet grains from the panicles. The threshed grains were then sent to the pearling drum in the same way. It removes the finger millet grains' upper seed coat.

The cleaning system consists of sieve walker and blower. The sieve walker was developed to remove the straw from mixture of grain and *bhusa*. It was consisted of sieve and sieve shaker unit. The shape and size of sieve were selected based on the maximum diameter and sphericity of finger millet kernel. The maximum diameter and sphericity of finger millet kernel were 1.80 mm and 0.94, respectively, at 15% (db) moisture content. Therefore, a sieve size with 2 mm diameter holes was selected. Devnani and Ojha (2016) recommended that the sieve slope angle for cereal crop was in the range 2–3.5°. Therefore, the sieve slope was considered as 3.5°. The width and length of sieve were determined based on the quantity of material to be handled by the sieve. The sieving unit was made of a rectangular sieve of 250 mm × 375 mm dimension with 2 mm sieve size. The sieve was placed on M.S angle frame with 3.5° horizontal slope. The eccentric unit consisted of rotating hub and reciprocating fork. The rotating hub consisted of circular M.S. plate with 40 mm diameter and 10 mm thickness. It was welded at centre on one side of the shaft having diameter 15 mm. To study effect of S_L on C_E, three different holes offset from the centre with radius 10, 20, and 30 mm were drilled on the plate. The fork made of M.S. flat plate of 15 mm width and 5 mm thickness having bearing at one side. The fork received circular motion from the plate and converted it into reciprocating motion. The blower was used to blow the fine *bhusa* falling from the sieve walker. It was consisted of impeller and outer casing. The width of blower casing was taken equal to width of sieve, i.e. 250 mm. The width of blower outlet was taken as 60 mm. The impeller was made up of four blades each of size 180 × 60 mm. All the four blades were mounted on periphery of a hub of 30 mm diameter at 90° apart. The casing of the blower was made of 16 gauge M.S sheet. The diameter of casing was 200 mm with 60 mm × 250 mm outlet opening.

78.2.3 Experiment Design

In user-defined design (UDD), the analysis was carried out using RSM with the feting second-order polynomial equation. The optimization and analysis were carried out using the 'Design Expert 10' software. User-defined function based on the construction of a balanced complete block design. In this design, the user has an opportunity to select levels of the variable according to the author's plan. This design suitable for 1–10 factors. Table 78.1 shows the experimental levels to conduct the performance of the cleaning system. Table 78.2a represents the performance evaluation of

Table 78.1 Experimental levels to conduct cleaning unit study

Sr. no	Factor	Level 1	Level 2	Level 3
1	Sieve slope (S_S), degree	2	3.5	5
2	Stroke length (S_L), mm	10	20	30
3	Frequency of stroke (F_S), strokes min^{-1}	300	400	500
Nomenclature				
b_0	Constant	n_c	Number of central experiments	
b_i	Linear regression coefficient	x_1	Coded value of SL	
b_{ii}	Quadratic regression coefficient	x_2	Coded value of FS	
b_{ij}	Interaction regression coefficient	x_3	Coded value of SS	
UDD	User defined design	x_i	coded value of the *i*th variable	
F_{loc}	*F*-value for lack of fit	Y_{ai}	Experimental value of the *i*th response	
K	Number of independent variables considered for optimization	Y_{ci}	Calculated value of the *i*th response	
N	Total number of experiments	y_{av}	Average of actual values of responses	

the cleaning system. Three independent variables, viz., drum speed, concave clearance, and pearling sieve size were taken to obtain maximum cleaning efficiency and minimum spilled grains. Non-linear second-order regression Eqs. (78.1) and (78.2) was developed to optimize the cleaning efficiency and spilled grains for the response as functions of the coded value of the independent parameters of the cleaning system (Savic et al. 2015).

$$\text{CE} = b_0 + \sum_{i=0}^{3} b_i x_i + \sum_{i=1}^{3} b_{\text{ii}} \text{x}_{\text{ii}}^2 + \sum_{\text{i}=1}^{2} \sum_{\text{j}=\text{i}+1}^{3} b_{\text{ij}}\, x_i x_j \tag{78.1}$$

$$\text{SG} = b_0 + \sum_{i=0}^{3} b_i x_i + \sum_{i=1}^{3} b_{\text{ii}} x_{\text{ii}}^2 + \sum_{\text{i}=1}^{2} \sum_{\text{j}=\text{i}+1}^{3} b_{\text{ij}}\, x_i x_j \tag{78.2}$$

The *F*-value for lack of fit was used to assess the goodness of fit of the existing non-linear equations (Flof).

$$F_{\text{lof}} = \frac{\sum_{i=1}^{N} (Y_{\text{ai}} - Y_{\text{ci}})^2 - \sum_{i=1}^{n_c} (Y_{\text{ai}} - Y_{\text{av}})^2}{N - \text{no. of coefficients in regression equation} - N_c + 1} \tag{78.3}$$

Table 78.2 Performance evaluation of cleaning system

Run	S_S, degree	S_L, mm	F_S, strokes min^{-1}	C_E, %	S_G, %
1	2	10	300	90	2.5
2	2	10	400	93	2
3	2	10	500	89	3
4	2	20	300	92	1.4
5	2	20	400	94	1.2
6	2	20	500	91	1.9
7	2	30	300	89	3.5
8	2	30	400	92	3
9	2	30	500	87.5	4.5
10	3.5	10	300	93	3
11	3.5	10	400	95.4	2.5
12	3.5	10	500	92	4
13	3.5	20	300	94	1.5
14	3.5	20	400	96.5	1.2
15	3.5	20	500	93	2
16	3.5	30	300	92	4
17	3.5	30	400	94	3.7
18	3.5	30	500	91.5	6
19	5	10	300	93.8	3.8
20	5	10	400	96	3
21	5	10	500	93	5.3
22	5	20	300	95	2.4
23	5	20	400	97	1.8
24	5	20	500	94	2.9
25	5	30	300	93	4.8
26	5	30	400	95	3.6
27	5	30	500	92	7

The values of errors and correlation coefficients were used to compare the experimental and expected response values. The root mean square error (RMSE), mean absolute error (MAE), cross-validated correlation coefficient (q^2), and correlation coefficient were used to validate the model (r^2). The MAE is a measure for calculating how close expected values are to actual values. The respective values reflected the absolute error's average value. Equations (78.4), (78.5), (78.6), and (78.7), respectively, yielded the values MSE, MAE, and q^2. The respective values represented an average value of the absolute error. The values MSE, MAE, and q^2 were found by Eqs. (78.4), (78.5), (78.6) and (78.7), respectively (Powar et al. 2019a, b).

$$\mathrm{RMSE} = \sqrt{\frac{\sum\left(y_i^p - y_i^m\right)^2}{N}} \tag{78.4}$$

$$\mathrm{MSE} = \frac{\sum\left(y_i^p - y_i^m\right)^2}{N} \tag{78.5}$$

$$\mathrm{MAE} = \frac{\left|\left(y_i^p - y_i^m\right)^2\right|}{N} \tag{78.6}$$

$$q^2 = 1 - \frac{\sum_{i=1}^{n}\left(y_i^p - y_i^m\right)^2}{\sum\left(y_i^m - y_i^{-m}\right)^2} \tag{78.7}$$

A total of 81 experiments were performed, with the three independent variables being taken at three different stages.

78.3 Results and Discussion

This section covers the detailed discussion on optimization of operational parameters of cleaning system and the effect of operational parameters on the performance of the cleaning system.

78.3.1 Optimizing Operational Parameters of Cleaning System

The performance evaluation of the cleaning system was carried out as per the statistical experiment given in Table 78.2 Same table also represents the response of the cleaning system in terms of C_E and S_G.

The software generated optimum conditions within the given 'range' were difficult to maintain. Therefore, it was targeted to near the value of optimum setting (range), which is possible to maintain in the cleaning system. It can be observed from Table 78.3 that the change in a goal from 'range' to 'target' (values close to optimum setting) did not show any major effect on the performance of the system in terms of C_E and S_G. Therefore, a S_S of 3.5°, S_L of 20 mm and F_S of 400 strokes min^{-1} were selected as optimum values for further analysis. Table 78.3 shows the graphical optimization of the operational parameters of the cleaning system and software setting with its stated performance. The optimum operating conditions for the parameters, viz., S_S, S_L, and F_S were found as 400 strokes min^{-1}, 20 mm, and 3.5°, respectively. The performance of cleaning system was validated by setting optimum conditions of operational parameters. The C_E was found to be 97.5% against predicted 96.53%

Table 78.3 Numerical and graphical optimization of cleaning system variables

Sr. No	Parameters	Criteria			Optimum value				
		Goal	Limits		S_S, Deg.	S_L, mm	F_S, strokes min^{-1}	C_E, %	S_G, %
			Min.	Max.					
Numerical optimization									
1	S_S, %	Range	2	5	3.5	18.31	382	96.53	1.25
	S_L, mm	Range	300	500					
	F_S, strokes min^{-1}	Range	10	30					
	C_E, %	Max.	87.5	97					
	S_G, %	Min.	1.2	7					
2	S_S, %	Target	2	5	3.5	20	400	96.27	1.26
	S_L, mm	Target	300	500					
	F_S, strokes min^{-1}	Target	10	30					
	C_E, %	Max.	87.5	97					
	S_G, %	Min.	1.2	7					
Graphical optimization									
Sr. No	Parameters	Criteria		Optimum value					
		Min.	Max.	S_S, Deg.	S_L, Mm	F_S, strokes min^{-1}	C_E, %	S_G, %	
1	S_S, %	2	5	3.5	20	400	96.27	1	
	S_L, mm	300	500						
	F_S, strokes min^{-1}	10	30						
	C_E, %	87.5	97						
	S_G, %	1.2	7						

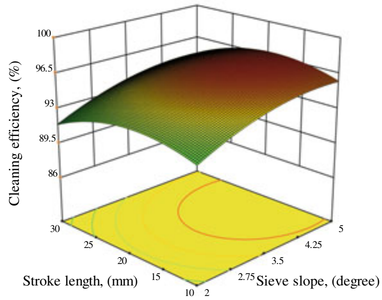
and S_G was 1.3% against predicted 1.26%. Devnani and Ojha (2016) recommended that the S_S, S_L, and F_S for cereal crops were range in between 2 and 3.5°, 20–40 mm, and 300–400 strokes min^{-1}.

78.3.2 *Effect of Operational Parameters on the Performance of the Cleaning System*

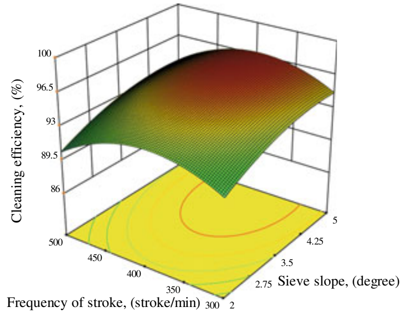
To study the effect of operational parameters on the C_E (Fig. 78.2a, b, and c) and S_G (Fig. 78.2d, e and f) were studied by preparing 3D graph. The detail discussion is given in the following subsection.

78.3.2.1 Cleaning Efficiency

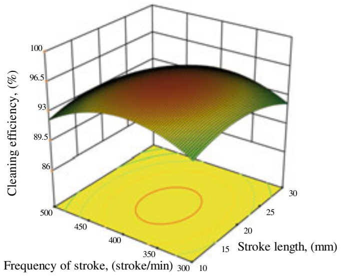
It was observed that the C_E increased with an increase in S_S (Fig. 78.2a). Similarly, it was increased with an increase in S_L up to 20 mm; thereafter, it decreased. The maximum C_E of 96.95% was observed at 20 mm S_L and 5° S_S. It was observed in



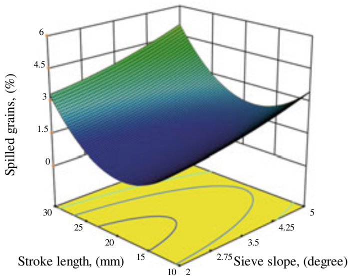
(a) Effect of stroke length and sieve slope on the cleaning efficiency



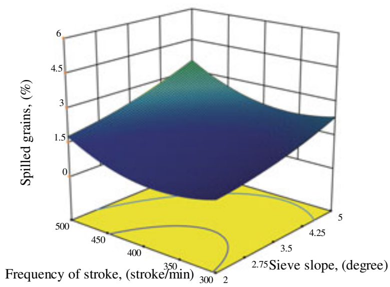
(b) Effect of frequency of stoke and sieve slope on the cleaning efficiency



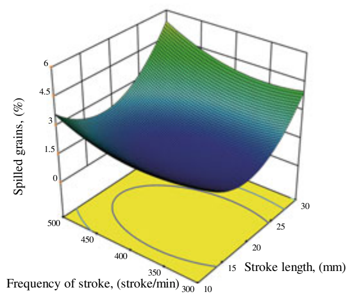
(c) Effect of frequency of stroke and stroke length on the cleaning efficiency



(d) Effect of stroke length and sieve slope on the spilled grain



(e) Effect of frequency of stroke and sieve slope on the spilled grain



(f) Effect of frequency of stroke and stroke length on the spilled grain

Fig. 78.2 The combined effect of operational parameters on cleaning efficiency and spilled grain

Fig. 78.2b that the C_E increased with an increase in the F_S up to 400 strokes min^{-1}; thereafter, it decreased. It was also increased with an increase in S_S. The maximum C_E of 96.92% was observed at 400 strokes min^{-1} and 5° S_S. Figure 78.2c indicated that the C_E increased with an increase in the F_S and S_L from 300 to 400 strokes min^{-1} and 10–20 mm, respectively; thereafter, it decreased from 400 to 500 strokes min^{-1} and 20 to 30 mm S_L. The maximum C_E (96.31%) was observed at 20 mm S_L and 400 strokes min^{-1} F_S.

To study the effect of S_S, S_L, and F_S on C_E, the ANOVA was prepared and presented in Table 78.4. It can be seen from the ANOVA Table 78.4 that the higher value of F (36.58) suggesting that the quadratic model can be successfully used to fit experimental data ($p < 0.0001$). The linear term of the model, i.e., S_S ($p < 0.0001$), S_L (0.0036), and F_S (0.0043) and quadratic term of the model, i.e., S_S ($p < 0.0010$), S_L ($p < 0.0001$), and F_S ($p < 0.0001$) has significant effect on the C_E at 1% level of significance. The interaction terms of the model have no significant effect on the C_E even at 10% level of significance.

At lower levels of the S_S (2°), S_L (10 mm), and F_S (300 mm), the minimum C_E was observed. It happened due to the cleaning system did not meet the capacity of the feed rate. Therefore, it increased the residence time of grain-straw on the sieve. It gave maximum opportunity to heavyweight straw fallout from the sieve. Those heavyweight straws were not possible to separate pneumatically using a blower because the straw had higher terminal velocity compared to grain. Vice versa, it was

Table 78.4 ANOVA for study effect of sieve slope, stroke length, and frequency of stroke on cleaning efficiency and spilled grain

Source of variation	Degree of freedom	Sum of squares		F value	
		C_E	S_G	C_E	S_G
Model	9	130.98	50.99	36.58	20.96
S_S	1	46.61	11.26	117.16*	41.66*
S_L	1	4.52	8.02	11.35*	29.67*
F_S	1	4.30	5.23	10.81*	19.34*
$S_S \times S_L$	1	0.020	0.12	0.050	0.46
$S_S \times F_S$	1	0.041	0.40	0.10	1.49
$S_L \times F_S$	1	0.003333	0.40	0.008379	1.49
${S_S}^2$	1	6.33	0.39	15.91*	1.43
${S_L}^2$	1	15.03	23.79	37.78*	88.04*
${F_S}^2$	1	39.69	3.51	99.76*	12.98*
Lack of fit	5	4.76	4.59	0.15	0.11
Residual	17	6.76	2.97	17	17
Pure error	1	2.00	1.62	1	1
Cor total	26	137.75	55.58	26	26

* Significant at 1% level, ** significant at 5% level
ns non-significant

observed for higher S_S, S_L, and F_S. As S_L and F_S were higher than the optimum levels; C_E was decreased. Because at higher levels of the setting, the excessive acceleration in the system was produced. Due to this, the heavyweight straw is passed from the sieve, which is not possible to separate pneumatically, resulting in decreased C_E. On increasing the sieve slope, the C_E was increased. But after the optimum level of S_S, it was not possible to increase the C_E further. As higher S_S was responsible for maximum S_G percentage and was not compensated with higher C_E.

The polynomial regression Eq. 78.8 of C_E based on the input parameters, viz., S_S, S_L and F_S with R^2 0.95 is given below.

$$\begin{aligned} C_E &= 96.27 + 1.63\mathrm{SS} - 0.52 S_L - 0.49 F_S + 0.043\mathrm{SS} \times S_L \\ &\quad + 0.058 S_S \times F_S - 0.017 S_L \times F_S - 1.03 S_S^2 - 1.57\mathrm{S_L} - 2.61 F_S^2 \end{aligned} \tag{78.8}$$

78.3.2.2 Spilled Grain

The overflow of the grains was observed from the cleaning sieve due to the improper setting of the cleaning unit. To find out the major reason behind it, a study was carried out with its independent parameters, viz., S_S, S_L, and F_S. It can be observed from Fig. 78.2a that the S_G was increased with an increase in S_S and decreased as S_L increased from 10 to 20 mm; thereafter, it increased from 20 to 30 mm S_L. The maximum S_G of 4.9% was observed at 5° S_S and 30 mm $\mathrm{S_L}$ and minimum S_G of 0.69% was observed at 2° S_S and 20 mm S_L. Figure 78.2b indicated that the S_G was increased with increasing S_S and decreased up to 400 strokes min^{-1}; thereafter, it increased. The maximum S_G of 3.23% was observed at 5° S_S and 500 strokes min^{-1}. Also, minimum S_G of 0.71% was observed at 2° S_S and 400 strokes min^{-1}. Similarly, Fig. 78.2c revealed that the increasing F_S increased the S_G and decreases as S_L increased from 10 to 20 mm, and thereafter, it increased again as S_L increased from 20 to 30 mm. The highest S_G of 4.92% was observed at 30 mm S_L and 500 strokes min^{-1}, and lowest S_G of 1.32% was observed at 20 mm and 300 strokes min^{-1}.

At lower levels of the S_S (2°), S_L (10 mm), and F_S (300 strokes min^{-1}), the cleaning unit did not meet the capacity. Hence, at this setting of the cleaning unit, the heap of grain and straw was formed on the cleaning sieve, resulting in the grains and straw over flowed from the sieve. At higher levels of parameters, viz., S_S (5°), S_L (30 mm), and F_S (500 strokes min^{-1}), the excessive acceleration in the cleaning system was seen, resulting in the grains being thrown out from the sieve. Hence, maximum $\mathrm{S_G}$ was observed at respective levels. Also '*Nachni*' word itself indicated that dancing in nature. Hence, at higher acceleration, the finger millet grains start dancing, resulting in it bouncing out from the cleaning sieve.

Table 78.4 shows the ANOVA for study the effect of S_S, S_L, and F_S on S_G. The high value of F (20.96) implies that the quadratic model can be successfully used to fit experimental data ($p < 0.0001$). The linear terms, i.e., S_S, S_L, the F_S and quadratic terms of S_L and F_S have a significant effect on the S_G at a 1% level of significance. The remaining all terms of interaction and $S_S$at quadratic have no significant effect even at a 10% level of significance.

The polynomial regression Eq. 78.9 of S_G in percentage based on the input parameters, viz., S_S, S_L, and F_S with R^2 0.91 is given below.

$$S_G = 1.27 + 0.80S_S - 0.69S_L - 0.54F_S + 0.11\mathrm{SS} \times S_L + 0.18S_S \times F_S - 0.18S_L \times F_S - 0.25S_S^2 - 1.97S_L^2 - 0.77F_S^2 \quad (78.9)$$

78.4 Conclusions

The cleaning system was developed for FMTCP with a processing capacity of 36 kg h^{-1}. The operational parameters, viz., sieve slope, (2–5°), stroke length (10–30 mm), and frequency of stroke (300–500 strokes min^{-1}) play a dominant role in the development of FMCS. The optimization process was carried to determine the optimum operating parameters of the FMCS. This is accomplished by the response surface method with a user-defined design. A total of 81 experiments were set to obtain the maximum cleaning efficiency and minimum spilt grains. The optimum operational parameters were found to be 3.5° sieve slope, 20 mm stroke length, and 400 strokes min^{-1} frequency of stroke. The performance of the FMCS was validated by setting optimum operating conditions in the cleaning system. The cleaning efficiency was found to be 97.5% against predicted 96.53% and spilt grain of 1.3% against predicted 1.26%. As per the standard prescribed by BIS ($C_E \geq 96\%$ and $S_G \leq 1.5\%$), the designed cleaning system is accepted for FMTCP.

References

Chandrakanthappa K, Batagurki SB, Kumar C (2001) Evaluation of different threshing methods for primary processing of finger millet. Mysore J Agric Sci 35(2):128–132

Devnani RS and Ojha TP (2016) Theory and applications of crop threshing technologies. Indian Council of Agricultural Research, New Delhi, India, pp 25–38

Parmanand, Verma A (2015) Development and testing of pedal operated thresher for finger millet. Int J Agric Sci Res 5(3): 299–308. https://doi.org/10.15740/HAS/IJAE/8.2/175-180

Powar RV, Aware VV, Shahare PU et al (2018a) Moisture dependent physical properties of finger millet grain and kernel (*Eleusine coracana L.*) Gaertn). J Indian Soc Coastal Agric Res 36(1):48–56

Powar RV, Shahare PU, Aware VV et al (2018b) Energy audit of paddy cultivation practices in Konkan region of Maharashtra. Int J Agric Eng 2(10):1–9. https://doi.org/10.15740/HAS/IJAE/10.2/647-654

Powar RV, Aware VV, Shahare PU (2019a) Optimizing operational parameters of finger millet threshing drum using RSM. J Food Sci Technol 56(7):3481–3491. https://doi.org/10.1007/s13197-019-03836-0

Powar RV, Aware VV, Shahare PU (2019b) Modeling and optimization of finger millet pearling process by using RSM. J Food Sci Technol 56(7):3272–3281. https://doi.org/10.1007/s13197-019-03792-9

Powar RV (2019c) Design and development of finger millet thresher-cum-pearler. Unpublished Ph.D thesis, Dr. BSKKV Dapoli, pp 98–103

Powar RV, Aware VV, Patil SB, Shahare PU (2019c) Development and evaluation of finger millet thresher-cum- pearler. J Biosyst Eng 44(4):194–206. https://doi.org/10.1007/s42853-019-00029-7

Powar RV, Aware VV, Patil SB et al (2020) Finger millet threshing and pearling technologies in India: a comprehensive review. J Biosyst Eng 45(2):71–84. https://doi.org/10.1007/s42853-020-00046-x

Sail SK (2018) Development and evaluation of ragi thresher-cum-pearler operated by bullock power in rotary mode. Unpublished M. Tech thesis. Orissa University of Agricultural and Technology Bhubaneswar, pp 66–109

Savic IM, Nikolic VD, Savic-Gajic IM et al (2015) Optimization of technological procedure for amygdalin isolation from plum seeds (*Pruni domesticae semen*). Frontiers Plant Sci 6:76

Verma SS, Singh A, Shahi NC (2014) Response surface methodology for selection of machine parameters for enhancing pearling efficiency of finger millet dehuller-cum-pearler. Int J Sci Res 3(10):1469–1472

Correction to: Mapping of Aquaculture Potential Zones Using Geospatial Multi-Criteria Method for Sustainable Aquaculture Development-Thiruvallur District

R. Nishan Raja, P. Nila Rekha, Soumyabrata Sarkar, Albin Sunny, V. Chandrasekar, and C. P. Balasubramanian

Correction to: Chapter 36 in: T. D. Lama et al. (eds.), *Transforming Coastal Zone for Sustainable Food and Income Security*, https://doi.org/10.1007/978-3-030-95618-9_36

The original version of the book was inadvertently published with an incorrect Table header in the chapter (Mapping of Aquaculture Potential Zones Using Geospatial Multi-Criteria Method for Sustainable Aquaculture Development-Thiruvallur District). Table header of Table 36.2 has been corrected.

The chapter and book have been updated with the changes.

The updated original version of this chapter can be found at https://doi.org/10.1007/978-3-030-95618-9_36

T. D. Lama et al. (eds.), *Transforming Coastal Zone for Sustainable Food and Income Security*, https://doi.org/10.1007/978-3-030-95618-9_79

List of Presentations

ISCA Webinar—International Symposium on Coastal Agriculture: Transforming Coastal Zone for Sustainable Food and Income Security

March 16–19, 2021

Day 1: March 16, 2021

3rd Dr. J. S. P. Yadav Memorial Lecture

S. No.	Name	Affiliation	Title
1	Dr. A. K. Singh	Former VC, Rajmata Vijayaraje Scindia Krishi Vishwa Vidyalaya, Gwalior, India, and Former DDG (NRM), ICAR, New Delhi, India	Impact of climate change on coastal and island ecosystems
	Chairman: Dr. S. B. Kadrekar, Former Vice Chancellor, Dr. B. S. Konkam Krishi Vidyapeeth, Dapoli, Maharashtra, India **Co-Chairman**: Dr. A. K. Bandyopadhyay, Former Director, ICAR-Central Island Agricultural Research Institute, Port Blair, A & N Islands, India		

Plenum Lectures

S. No.	Name	Affiliation	Title
Day 1: March 16, 2021			
1	Professor Timothy John Flowers	School of Life Sciences, University of Sussex, Brighton, United Kingdom	How can eHALOPH, a database of salt-tolerant plants; help your research?

(continued)

T. D. Lama et al. (eds.), *Transforming Coastal Zone for Sustainable Food and Income Security*, https://doi.org/10.1007/978-3-030-95618-9

(continued)

S. No.	Name	Affiliation	Title
	Chairman: Dr. Arun Lahiri Majumdar, INSA Senior Scientist, Bose Institute, Kolkata, India		
2	Dr. Michael Phillips	Director, Aquaculture & Fishery Sciences, World Fish Center, Malaysia	The future of fish Agri-food systems
	Chairman: Dr. M. Vijay Gupta, Former Assistant Director General, International Relations and Partnerships, World Fish Center, Malaysia		
Day 2: March 17, 2021			
3	Dr. M. Vijay Gupta	Former Assistant Director General, International Relations and Partnerships, World Fish Center, Malaysia	Improving food and income security of coastal communities through fisheries and aquaculture management
	Chairman: Dr. J. K. Jena, Deputy Director General (Fisheries Science), Indian Council of Agricultural Research, New Delhi, India		
4	Dr. Abdelbagi M. Ismail	Principal Scientist and IRRI Representative, Nairobi, Kenya, Africa	Agricultural systems transformation for food and income security in coastal zones
	Chairman: Dr. R. K. Singh, Head of Crop Diversification and Genetics Section, ICBA, Dubai		
5	Professor Rattan Lal	Director, Carbon Management and Sequestration Center, Ohio State University, Columbus, Ohio, USA	Impact of soil carbon dynamics on the environment and management of improved soil health in the coastal ecosystems
	Chairman: Prof. Biswapati Mandal, Bidhan Chandra Krishi Viswavidyalaya, Mohanpur, West Bengal, India		
Day 3: March 18, 2021			
6	Dr. N.H. Ravindranath	Professor (Retd.), Centre for Sustainable Technologies, Indian Institute of Science, Bangalore, India	Natural ecosystems, biodiversity and climate change
	Chairman: Dr. T. Ravishankar, President, Centre for Nature and Culture, Kakinada, Andhra Pradesh, India		
7	Dr. Anupma Sharma	Scientist-F, Groundwater Hydrology Division, National Institute of Hydrology, Roorkee, India	Water management strategies to mitigate saltwater intrusion with special reference to coastal Saurashtra
	Chairman: Dr. Mohammed Mainuddin, Principal Research Scientist, CSIRO Land and Water, Canberra, Australia		

(continued)

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S. No.	Name	Affiliation	Title
8	Professor T. G. Sitharam	Director, Indian Institute of Technology, Guwahati, Assam, India	Water resource potential & uses along the coastal zone: Role of coastal reservoirs
	Chairman: Dr. N. K. Tyagi, Former Member, ASRB, New Delhi and Former Director, ICAR-Central Soil Salinity Research Institute, Karnal, Haryana, India		
9	Dr. M. M. Qader Mirza	Adjunct Professor, Department of Physical and Environmental Sciences, University of Toronto, Scarborough, Toronto, Ontario, Canada	Coastal agriculture under future climate change: Can developing countries adapt?
	Chairman: Balakrishnan Nair T. M., Group Director & Scientist-G, National Centre for Ocean Information Services (INCOIS) Hyderabad, Telangana, India		
Day 4: March 19, 2021			
10	Dr. Sanjay K. Srivastava	Chief of Disaster Risk Reduction at UN Economic and Social Commission for Asia and Pacific, Bangkok, Thailand	Building the coastal resilience in Asia and the Pacific: Opportunities and challenges
	Chairman: Dr. D. R. Pattanaik, Scientist F & Head, Numerical Weather Prediction Division, Indian Meteorological Department, New Delhi, India		
11	Dr. Pramod Kumar Joshi	Former Director, South Asia, IFPRI, New Delhi, India	Coastal ecosystems—explore value chains, processing and exports for poverty alleviation
	Chairman: Dr. Gyanendra Mani, Chief General Manager, National Bank for Agric. and Rural Development, Uttarakhand, India		

Technical Sessions

Theme I: Systems approach for coastal zone development: agriculture, horticulture & plantation crops and their tolerance to biotic & abiotic stresses

Session I: Agricultural crop improvement including biotechnological approaches, genetic resource management, abiotic stress tolerance

Invited Lectures & Oral Presentations—Day 1: March 16, 2021

Chairman: Dr. P. K. Das, Former Head, Department of Genetics & Plant Breeding, BCKV, West Bengal, India

Co-Chairman: Dr. Arun Lahiri Majumdar, INSA Senior Scientist, Bose Institute, Kolkata, India

Dr. R. K. Singh, Head of Crop Diversification and Genetics Section, International Centre for Biosaline Agriculture, Dubai

S. No.	Name	Affiliation	Title
1	Prof. Prasanta K. Subudhi	School of Plant, Environmental, and Soil Sciences, Louisiana State University Agricultural Center, Baton Rouge, LA, USA	Challenges and opportunities in designing salt tolerant rice
2	Dr. E. Septiningsih	Associate Professor, Texas A&M University, Texas, USA	Anaerobic germination tolerance in rice: the underlying genetics and breeding efforts
3	Prof. Zeba I. Seraj	Director, Centre for Bioinformatics Learning Advancement and Systematics Learning (CBLAST), University of Dhaka, Dhaka, Bangladesh	Wild halophytic rice, *P. coarctata* as a resource for rice cultivation in saline soil
4	Prof. Michael J. Thomson	HM Beachell Rice Chair, Department of Soil and Crop Sciences, Texas A&M University Texas A&M AgriLife Research, USA	Biotechnological approaches to develop salt-tolerant rice for the coastal regions
5	Prof. Glenn B. Gregario	Director of Southeast Asian Regional Center For Graduate Study and Research in Agriculture (SEARCA), Laguna, Philippines	Worries of salinity intrusion in the Mekong river delta, Vietnam: what innovative solutions can we offer through breeding for salt tolerant rice?
6	Dr. Tapan Kumar Mondal	Principal Scientist (Plant Biotechnology), ICAR-National Institute for Plant Biotechnology (Formerly ICAR-NRCPB), IARI, New Delhi, India	Dhani (*Oryza coarctata*): A wild relative of rice is a potential source of coastal salinity tolerance genes suitable for rice breeding
7	Dr. Gayatri Venkataraman	Principal Scientist, Biotechnology Programme Area, M. S. Swaminathan Research Foundation, Chennai, India	Sodium transporter HKT1;5 function the halophytic wild rice *Oryza coarctata*
8	Dr. Manoj Majee	Scientist V, National Institute of Plant Genome Research (NIPGR), Aruna Asaf Ali Marg New Delhi	Protein l-isoaspartyl methyltransferase (PIMT): A key enzyme for plant survival under abiotic stress

(continued)

(continued)

S. No.	Name	Affiliation	Title
9	Dr. Viswanathan Chinnusamy	Principal Scientist, Nanaji Deshmukh Plant Phenomics Centre, Div. of Plant Physiology, Indian Agricultural Research Institute, New Delhi, India	Genetic engineering and genome editing for abiotic stress tolerance of rice
10	Dr. V. Dhanushkodi	Krishi Vigyan Kendra, Sirugamani, Tiruchirappalli, Tamil Nadu, India	Evaluation different salt tolerant paddy varieties in sodic soil and farmers preference for adoption in Tiruchirappalli district in Tamil Nadu
11	Dr. K. K. Manohara	Crop Sciences Section, ICAR-Central Coastal Agricultural Research Institute, Ella, Old Goa, Goa, India	Response of landraces and wild relatives of rice from Goa and Karnataka coast for induced salt stress at the seedling stage
12	Dr. Shridevi A. Jakkeral	Zonal Agricultural and Horticultural Research Station, Brahmavar, Udupi Dist. Karnataka, India	Submergence tolerant red rice variety Sahyadri Panchamukhi for low land situation of coastal Karnataka
13	Mr. Nitish Ranjan Prakash	ICAR-Central Soil Salinity Research Institute, Regional Research Station, Canning Town, South 24 Parganas, West Bengal, India	Evaluation of rice genotypes for tolerance to seedling stage salinity under hydroponics
14	Dr. S. V. Sawardekar	Plant Biotechnology Centre, College of Agriculture, Dr. Balasaheb Sawant Konkan Krishi Vidyapeeth, Dapoli, Maharashtra, India	DNA Barcoding of rice (*Oryza sativa* L.) varieties developed by Dr. Balasaheb Sawant Konkan Krishi Vidyapeeth, Dapoli
15	Dr. Veena Vighneswaran	Rice Research Station, Kerala Agricultural University, Vyttila, Kerala, India	SSR marker analysis for the identification of the elite rice variety Lavanya with its parent VTL-3 and DNA fingerprinting

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S. No.	Name	Affiliation	Title
16	Dr. R. T. Maruthi	ICAR-Central Research Institute for Jute and Allied Fibres, Barrackpore, West Bengal, India	A GIS-based diversity assessment of Indian sunnhemp (*Crotalaria juncea* L.) accessions for enhanced biomass and fibre yield

Poster Presentations—Day 2: March 17, 2021
Chairman: Dr. K. Das, Principal Scientist, ICAR-National Bureau of Soil Survey & Land Use Planning, Kolkata Centre, Salt Lake, Kolkata, West Bengal, India
Co-Chairman: Dr. Sanjoy Saha, Principal Scientist, ICAR-National Rice Research Institute, Cuttack, Odisha, India

S. No.	Name	Affiliation	Title
17	Dr. Deepa John	Rice Research Station, Kerala Agricultural University Vyttila, Kerala, India	Agro-morphological, yield and grain quality analysis of Sub1 introgressed lines of Jyothi
18	Miss K. V. Arya	Rice Research Station, Kerala Agricultural University, Vyttila, Kochi, Kerala, India	Field evaluation of agro-morphological characters in Sub1 introgressed BC_3 lines developed through MABB
19	Miss L. J. Kappen	College of Horticulture, Kerala Agricultural University, Thrissur, Kerala, India	Chemical priming for improving salinity tolerance in rice
20	Mr. Angshuman Mohapatra	ICAR- Central Institute of Freshwater Aquaculture, Bhubaneswar, Odisha, India	Effect of potassium and coastal saline water on yield, nutrient accumulation and uptake by rice
21	Dr. Subhojit Datta	ICAR- Central Research Institute for Jute and Allied Fibres Barrackpore, West Bengal, India	Genomic and transcriptomic approaches to accelerate salinity stress tolerance in jute (*Corchorus spp.*)
22	Dr. Bidisha Mondal	The Neotia University, Jhinger Pole Sarisha, West Bengal, India	Development of Ionome (Salt-Omic) for the varietal improvement and food security of coastal population of India
23	Dr. Surendra Kumar Meena	ICAR-IIPR, Regional Centre CAZRI, Bikaner, Rajasthan, India	Genotypic variability in physiological traits of blackgram under salinity stress
24	Dr. J. K. Meena	ICAR-Central Research Institute for Jute and Allied Fibres, Barrackpore, West Bengal, India	Screening of segregating mapping population of Tossa jute (*Corchorus olitorius*) for stem rot resistance
25	Dr. T. J. Bedse	Regional Agricultural Research Station, Karjat, Raigad, Maharashtra, India	Rice grain quality characteristics of improved varieties of Karjat centre under B.S.K.V.V. Dapoli University

Theme I: Systems approach for coastal zone development: agriculture, horticulture & plantation crops and their tolerance to biotic & abiotic stresses

Session II: Agricultural crop management and cropping system intensification

Invited Lectures & Oral Presentations—Day 2: March 17, 2021.

Chairman: Prof. Richard Bell, Murdoch University, Perth, Western Australia.

Co-Chairman: Dr. D. K. Sharma, Former Director, ICAR-Central Soil Salinity Research Institute, Karnal, India.

S. No.	Name	Affiliation	Title
1	Dr. M. Mainuddin	Principal Research Scientist, CSIRO, Canberra, Australia	Cropping intensification in the salt affected coastal zones of the Ganges delta
2	Dr. Jatish C. Biswas	Chief Scientific Officer & Head (Rtd), Soil Science Division, Bangladesh Rice Research Institute, Bangladesh	Coastal agricultural development in Bangladesh: soil fertility and land productivity
3	Prof. Richard Bell	Murdoch University, Perth, Western Australia	The benefits and risks of early sowing of rabi season crops in the coastal zone of the Ganges delta
4	Dr. D. K. Sharma	Former Director, ICAR-Central Soil Salinity Research Institute, Karnal, India & Former Emeritus Scientist, ICAR	Farming system intensification for the coastal ecosystems
5	Dr. Gouranga Kar	Director, ICAR-Central Research Institute for Jute & Allied Fibres, Barrackpore, 24 Parganas (N), West Bengal, India	Cropping system characterization of coastal seasonal waterlogged areas using geo-spatial technology
6	Mr. Bidhan Chandro Sarker	Agrotechnology Discipline, Khulna University, Khulna, Bangladesh	Optimization of nitrogen rate for wheat grown under zero tillage in coastal saline soils
7	Mrs. C. Krithika	Pandit Jawaharlal Nehru College of Agriculture and Research Institute, Karaikal, Puducherry, India	Exploring nutrient prescription techniques for sustaining rice productivity in coastal ecosystem
8	Dr. R. Mohan	PJN College of Agriculture and Research Institute, Karaikal, Puducherry, India	Evaluation of *Zymo Grainrich* on the growth, physiology and yield of rice
9	Dr. Tushar Narayan Thorat	Dr. Balasaheb Sawant Konkan Krishi Vidyapeeth, Dapoli, Maharashtra, India	Effect of planting time, levels and time of nitrogen application on growth and yield of sweet potato (*Ipomea batatas* L.)

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S. No.	Name	Affiliation	Title
10	Dr. Sitangshu Sarkar	ICAR-Central Research Institute for Jute and Allied Fibres, Barrackpore, West Bengal, India	Upgraded mechanical weeder and novel herbicide for efficient jute weed management in southern Bengal condition
11	Dr. B. S. Satapathy	ICAR-National Rice Research Institute, Cuttack, Odisha, India	Intensification of rice (*Oryza sativa* L.) based cropping system for enhancing land productivity and profitability under coastal region
12	Dr. M. Maniruzzaman	Bangladesh Rice Research Institute, Gazipur, Bangladesh	Influence of rainfall variability and waterlogging on coastal cropping intensity in Bangladesh
13	Dr. S. B. Bhagat	Chief Agronomist, Regional Agriculture Research Station, Karjat, Dist-Raigad, Maharashtra, India	effect of organic, inorganic and integrated nutrient management practices and various cropping systems on yield, economics and soil fertility in North Konkan coastal zone of Maharashtra

Poster Presentations—Day 2: March 17, 2021
Chairman: Dr. K. Das, Principal Scientist, ICAR-National Bureau of Soil Survey & Land Use Planning, Kolkata Centre, Salt Lake, Kolkata, West Bengal, India
Co-Chairman: Dr. Sanjoy Saha, Principal Scientist, ICAR-National Rice Research Institute, Cuttack, Odisha, India

Sl. No.	Name	Affiliation	Title
14	Miss Afrin Jahan Mila	Land Management Group, Agriculture Discipline, College of Science, Health, Engineering and Education, Murdoch University, Perth, Western Australia	Supplemental use of non-saline irrigation with saline irrigation during the dry season can triple sunflower fresh water productivity in the Ganges delta
15	Mr. Amit Dagdu Yadav	Department of Soil Science and Agril. Chemistry, College of Agriculture, Dapoli, Maharashtra, India	Effect of boron and zinc application on yield of cowpea (*Vigna unguiculata* L.) and soil properties in Alfisol of Konkan
16	Dr. A. S. Dalvi	Regional Agricultural Research Station, Karjat, Raigad, Maharashtra, India	Development of technology for enhancing the productivity and Profitability of organic kharif rice and rabi chickpea cropping system in Konkan coastal region of Maharashtra
17	Mr. Bidhan Chandro Sarker	Agrotechnology Discipline, Khulna University, Khulna, Bangladesh	Timing of nitrogen application influence the seed yield of sunflower grown in the coastal soils of southwestern Bangladesh

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S. No.	Name	Affiliation	Title
18	Dr. Deepak Kashinath Borse	Khar Land Research Station, Dr. B. S. K. K. V. Panvel, Raigad, Maharashtra, India	Effect of different methods of land configuration on yields and nutrients uptake by wheat (*Triticum aestivum* L.) under partially reclaimed coastal salt affected soil of South Gujarat
19	Dr. Manoj R. Wahane	Department of Soil Science and Agricultural Chemistry, College of Agriculture, Dr. B. S. Konkan Krishi Vidyapeeth, Dapoli, Maharashtra, India	Effect of phosphorus and biofertilizers on growth, yield and quality of groundnut (*Arachis hypogaea* L.) in coastal region of Maharashtra
20	Dr. Emily Alias	College of Agriculture, Kerala Agricultural University, Vellanikkara, Kerala, India	Management of plant Na/K ratio for yield enhancement in coastal saline *Pokkali* rice of Kerala
21	Miss Sonali Patel	Department of Soil Science and Agricultural Chemistry, Siksha "O" Anusandhan Deemed to be University, Bhubaneswar, Odisha, India	Interactive effects of salinity and potassium on maize
22	Dr. S. B. Dodake	Department of Soil Science and Agriculture Chemistry, College of Agriculture, Dr. B. S. K. K. V. Dapoli Ratnagiri, Maharashtra, India	Effect of saline irrigation water on growth and yield of leafy vegetables under coastal saline soils of north Konkan region
23	Dr. Priya Lal Chandra Paul	Irrigation and Water Management Division, Bangladesh Rice Research Institute, Gazipur, Bangladesh	Impact of different tillage systems on the dynamics of soil water and salinity in the cultivation of maize in a salt-affected clayey soil of the Ganges delta
24	Dr. Subarna Kundu	Bangladesh Agricultural Research Institute, Gazipur, Bangladesh	Optimum sowing date and variety for zero tillage potato production in the post-rice season in the salinity-affected coastal Ganges Delta
25	Dr. Tuli Sen	Department of Geography and E.M., Vidyasagar University, Midnapore, West Bengal, India	Coastal agricultural land use: Emerging challenges on south-east coast at Sagar Island
26	Dr. V. Mini	Onattukara Regional Agricultural Research Station, Kerala Agricultural University, Kayamkulam, Kerala, India	Customized nutrient management strategies for acid saline soils (Orumundakan tract) of Kerala

Theme I: Systems approach for coastal zone development: agriculture, horticulture & plantation crops and their tolerance to biotic & abiotic stresses

Session III: Horticulture & plantation crops and grassland ecosystems: crop improvement including biotechnological approaches and their management

Invited Lectures & Oral Presentations—Day 2: March 17, 2021 and Day 3: March 18, 2021

Chairman: Dr. G. V. Thomas, Former Director, ICAR-Central Plantation Crops Research Institute, Kasargod, Kerala, India

Co-Chairman: Dr. P. Hazra, Dean, Post Graduate Studies, Faculty of Horticulture, Bidhan Chandra Krishi Viswavidyalaya, Mohanpur, West Bengal, India

Dr. P. Murugesan, Principal Scientist, ICAR-Central Tuber Crops Research Institute, Thiruvananthapuram, Kerala, India

S. No.	Name	Affiliation	Title
1	Dr. George V. Thomas	Former Director, ICAR-CPCRI, Kasargod, Kerala, India	Unravelling the potential of below-ground and above-ground biodiversity for resilience in soil health management of plantation crops in coastal agro-ecosystem
2	Prof. Pranab Hazra	Dean, Post Graduate Studies, Department of Vegetable Science, Faculty of Horticulture, BCKV, Mohanpur, West Bengal, India	Biodiversity of vegetables: sustainable food and nutritional security in coastal areas
3	Dr. V. Arunachalam	Principal Scientist (Horticulture) ICAR-Central Coastal Agricultural Research Institute, Goa, India	Advances in the banana production technologies for the coastal ecosystems
4	Dr. P. Murugesan	Principal Scientist (Horticulture), ICAR-Central Tuber Crops Research Institute, Thiruvananthapuram, Kerala, India	Planting material in oil palm: progress from seed to clone
Day 3: March 18, 2021			
5	Dr. M. Sangeetha	Krishi Vigyan Kendra, Tamil Nadu Agricultural University, Dharmapuri, Tamil Nadu, India	Performance of tomato (*Solanum lycopersicum* L.) under saline soil condition

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S. No.	Name	Affiliation	Title
6	Dr. Aparna Veluru	ICAR-Central plantation Crops Research Institute, Kasaragod, Kerala, India	Performance of rose cultivars (*Rosa* × *hybrida* L.) for their growth and flowering under coconut plantation in coastal humid climate of India
7	Dr. P. Subramanian	ICAR-Central Plantation Crop Research Institute, Kasaragod, Kerala, India	Feasibility studies of growing sapota as intercrop in coconut garden under coastal sandy soil of west coast region

Poster Presentations—Day 2: March 17, 2021
Chairman: Dr. K. Das, Principal Scientist, ICAR-National Bureau of Soil Survey & Land Use Planning, Kolkata Centre, Salt Lake, Kolkata, West Bengal, India
Co-Chairman: Dr. Sanjoy Saha, Principal Scientist, ICAR-National Rice Research Institute, Cuttack, Odisha, India

Sl. No.	Name	Affiliation	Title
8	Dr. Nitin Khobragade	Department of Soil Science and Agril. Chemistry, College of Agriculture, Dr. B.S. Konkan Krishi Vidyapeeth, Dapoli, Maharashtra, India	Effect of graded levels of nitrogen on yield of turmeric, soil properties and nutrient status under *Acacia mangium* based agroforestry system in lateritic soils of Konkan
9	Miss R. Ara	Upazilla Agriculture Officer, Department of Agricultural Extension, People's Republic of Bangladesh	Potentials of Teen (*Ficus carica*) as a fruit crop in coastal Bangladesh
10	Mrs. Z. Sultana	Khulna University, Khulna, Bangladesh	Effect of Salinity on Seed Germination of Cashew Nut (*Anacardium occidentale* L.)
11	Dr. Sagar Kailas Ghumare	College of Horticulture, Dr. B.S. Konkan Krishi Vidyapeeth, Dapoli, Maharashtra, India	Effect of potting media on survival and growth of cashew grafts (*Anacardium occidentale* L.) Cv. Vengurla-4
12	Dr. Raviraja Shetty G	Agricultural & Horticultural Research Station, University of Agricultural & Horticultural Sciences Ullal, Mangalore, Karnataka, India	Phytodiversity and approaches to preserve medicinal plants of high value

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S. No.	Name	Affiliation	Title
13	Dr. Raviraja Shetty G	Agricultural & Horticultural Research Station, University of Agricultural & Horticultural Sciences Ullal, Mangalore, Karnataka, India	Success of cuttings as propagation material in *Embelia ribes* Burm.f.—An endangered medicinal plant
14	Mr. Sandesh H J	Department of Horticulture, ZAHRS, Brahmvara, UAHS, Shivamogga India	Performance of single node cutting on propagation of pepper (*Piper nigrum*) treated with different concentration of IBA
15	Dr. Sagar Subhash More	Department of Soil Science and Agricultural Chemistry, Dr. B. S. Konkan Krishi Vidyapeeth, Dapoli, Maharsahtra, India	Impact of different sources of silica with varying levels through soil and foliar application on yield and quality of Alphonso mango in soils of *Konkan* Region
16	Dr. Kanthswamy Veerabahu	Professor (Horticulture), Pandit Jawaharlal Nehru College of Agriculture and Research Institute, Karaikal, Puducherry, India	Studies on organic farming in coriander [*Coriandrum sativum* (L.)] - radish [*Raphanus sativus* (L.)] cropping sequence in coastal region of Karaikal
17	Dr. T. R. Ranganath	Agricultural and Horticultural Research Station, Ullal, Mangaluru-575020, Karnataka, India	Exploring the growth and yield performance of intercrops in cashew orchard under coastal zone of Karnataka

Theme I: Systems approach for coastal zone development: agriculture, horticulture & plantation crops and their tolerance to biotic & abiotic stresses

Session IV: Plant protection measures: use of nanotechnology and integrated practices including natural therapies

Invited Lectures & Oral Presentations—Day 1: March 16, 2021

Chairman: Dr. C. A. Jayaprakash, Principal Scientist & Head, Crop Protection, ICAR-Central Tuber Crops Research Institute, Thiruvananthapuram, Kerala, India

Co-Chairman: Dr. J. C. Tarafdar, Former Principal Scientist, ICAR-Central Arid Zone Research Institute, Jodhpur, Rajasthan, India

S. No.	Name	Affiliation	Title
1	Prof. Abraham Verghese	Former Director ICAR-NBAII, Bengaluru, Former Head, Division of Entomology and Nematology, ICAR-IIHR	Managing major insect pests of mango in southern coastal belts
2	Dr. J. C. Tarafdar	Former Principal Scientist, ICAR-Central Arid Zone Research Institute, Jodhpur, Rajasthan, India	Nanofertilizer and nanobioformulations: Blessings for global farming
3	Dr. Rafiq Islam	Program Director, College of Food, Agriculture & Environmental Sciences, Ohio State University, Ohio, USA	Nano-fertilization and chemical inducing to improve crop growth in coastal areas
4	Mr. R. T. P. Pandian	ICAR-Central Plantation Crops Research Institute, Regional Station, Vittal, Karnataka, India	Identification of an effective isolate of *Trichoderma harzianum* ACT1 for the management of basal stem rot disease in arecanut

Poster Presentations—Day 2: March 17, 2021
Chairman: Dr. K. Das, Principal Scientist, ICAR-National Bureau of Soil Survey & Land Use Planning, Kolkata Centre, Salt Lake, Kolkata, West Bengal, India
Co-Chairman: Dr. Sanjoy Saha, Principal Scientist, ICAR-National Rice Research Institute, Cuttack, Odisha, India

Sl. No.	Name	Affiliation	Title
5	Mr. T. R. Ranganath	Agricultural and Horticultural Research Station, Ullal, Mangaluru, Karnataka, India	Efficacy of fungicides against cashew dieback incited by tea mosquito bug in coastal Karnataka
6	Miss Seema Naik	Department of Plant Pathology, ZAHRS, Brahmavara, UAHS, Shivamogga	Management of wilt of Udupi Mallige in Coastal Karnataka

Theme II: Technological developments in fisheries, livestock and poultry management, water pollution trends, and ecological security for coral reefs, farming system modules

Session I: Fresh and brackish water aquaculture: technological innovations and emerging options including fish health and water management

Invited Lectures & Oral Presentations—Day 1: March 16, 2021 and Day 2: March 17, 2021

Chairman: Dr. K. K. Vijayan, Director, ICAR- Central Institute of Brackishwater Aquaculture, Chennai, Tamil Nadu. India

Co-Chairman: Dr. T. K. Ghoshal, Principal Scientist, Kakdwip Research Centre, ICAR-Central Institute of Brackishwater Aquaculture, Kakdwip, West Bengal, India

Dr. J. K. Sundaray, Principal Scientist & Head, Fish Genetics & Biotechnology Division, ICAR-Central Institute of Freshwater Aquaculture, Bhubaneswar, Odisha, India

Dr. A. K. Sahoo, Senior Scientist, ICAR-Central Inland Fisheries Research Institute, Barrackpore, West Bengal, India

S. No.	Name	Affiliation	Title
1	Dr. J. K. Jena	DDG (Fisheries Science), ICAR, New Delhi, India	New paradigms in freshwater aquaculture in coastal ecosystems in India: Happiness and hope
2	Dr. Baban Ingole	Visiting Scientist, ESSO-National Centre for Polar & Ocean Research, Headland Sada, Vasco-Da-Gama, Goa, India	Changing land-use patterns for enhancing fish production through coastal aquaculture
3	Dr. K. K.Vijayan	Director, ICAR - Central Institute of Brackishwater Aquaculture, Chennai, Tamil Nadu. India	Brackishwater aquaculture as the economic engine of Indian blue revolution
4	Dr. Sharad Kr. Jain	Former Director, National Institute of Hydrology, Roorkee Visiting Professor, Civil Engg. Dept. Indian Institute of Technology Roorkee, India	River basin approach for sustainable water and fisheries management
5	Dr. Piotr Parasiewicz	Assoc. Professor & Head, River Fisheries Department, S. Sakowicz Inland Fisheries Institute, Olszytn, Poland	Defining environmental flows for India with help of mesoHABSIM model
6	Dr. G.H. Pailan	Principal Scientist & Officer-In-Charge, ICAR-Central Institute of Fisheries Education, Kolkata Centre, WB, India	Feed & feeding strategies in freshwater aquaculture
7	Dr. Debasis De	Principal Scientist & Officer-In-Charge, Kakdwip Research Centre, ICAR-Central Institute of Brackishwater Aquaculture, Kakdwip, West Bengal, India	Brackishwater aquaculture: Opportunities and challenges for meeting livelihood demand in Indian Sundarbans

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S. No.	Name	Affiliation	Title
8	Dr. Nila Rekha	Principal Scientist, ICAR-Central Institute of Brackishwater Aquaculture, Chennai, India	Water management in brackishwater aquaculture in coastal ecosystem
9	Dr. Subhendu Adhikari	Principal Scientist and Scientist-In-Charge, Regional Research Centre, ICAR-Central Institute of Freshwater Aquaculture, Rahara, Kolkata, India	Wastewater management through aquaculture practices
10	Dr. P. E. Shingare	Senior Scientific Officer & Head, Marine Biological Research Station, Ratnagiri, Maharashtra, India	Constraints of shrimp farming in Maharashtra and its measures
11	Dr. Md Aklakur	RRTC, Motipur Ganna Kendra Muzaffarpur campus, Bihar, India	3P3C a novel model of mix farming in aquaculture
12	Miss Sujata Mohapatra	College of Basic Science and Humanities, Odisha University of Agriculture and Technology, Bhubaneswar	Changes in the hepatosomatic index (HSI) and liver histology of *Anabas testudineus* on exposure to two agrochemicals
13	Dr. G. Biswas	Kakdwip Research Centre of ICAR-Central Institute of Brackishwater Aquaculture, Kakdwip, West Bengal, India	An innovative nursery rearing method of brackishwater catfish, *Mystus gulio* at varied densities in simplified floc system
14	Dr. Prem Kumar	Kakdwip Research Centre of ICAR-Central Institute of Brackishwater Aquaculture, Kakdwip, West Bengal, India	Estradiol dependent stimulation of brain dopaminergic systems in the female gold spot mullet, *Liza parsia*
15	Dr. Rashmi Ranjan Das	ICAR-Central Institute of Brackishwater Aquaculture, Chennai, Tamil Nadu, India	Growth potential and immunity of the Indian White shrimp, *Penaeus indicus* (H. Milne-Edwards, 1837), cultured in grow-out ponds at varying densities and salinities in diverse geographical locations of India

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S. No.	Name	Affiliation	Title
16	Dr. Sanjoy Das	Kakdwip Research Centre of ICAR-Central Institute of Brackishwater Aquaculture, Kakdwip, West Bengal, India	Beneficial effects of guava leaf extract for its potential use in aquaculture
Day 2: March 17, 2021			
17	Dr. Vidya Rajendran	ICAR-Central Institute of Brackishwater Aquaculture, Chennai, Tamil Nadu, India	Microbial composition in larval development of herbivorous brackishwater fish, *Chanos chanos* (Milk fish)
18	Dr. V. R. Sadawarte	Marine Biological Research Station, Dr. B. S. Konkan Krishi Vidyapeeth Zadgaon, Ratnagiri, Maharashtra, India	Grow out cage culture trial of mangrove red snapper (*Lutjanus argentimaculatus*) in brackishwater ponds

Poster Presentations—Day 2: March 17, 2021
Chairman: Dr. T. K. Ghoshal, Principal Scientist, Kakdwip Research Centre, ICAR-Central Institute of Brackishwater Aquaculture, Kakdwip, West Bengal, India
Co-Chairman: Dr. G. Biswas, Senior Scientist, Kakdwip Research Centre of ICAR-Central Institute of Brackishwater Aquaculture, Kakdwip, West Bengal, India

Sl. No.	Name	Affiliation	Title
19	Mr. Md. Moazzem Hossain	Laboratory of Fish Ecophysiology, Department of Fisheries Management, Bangladesh Agricultural University, Mymensingh, Bangladesh	Suitable fish species combination in polyculture using *Hygroryza aristata* Asian water grass as feed in the coastal wetlands of Bangladesh
20	Mr. Nishan Raja	ICAR-Central Institute of Brackishwater Aquaculture, Chennai, Tamil Nadu, India	Mapping of aquaculture potential zones using geospatial multi criteria method for sustainable aquaculture development-Thiruvallur district
21	Dr. Sujata Sahoo	ICAR-Central Institute of Fisheries Education, Kolkata Centre, Kolkata, West Bengal, India	Water spinach leaf meal as an alternate feed ingredient for rohu

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S. No.	Name	Affiliation	Title
22	Miss Pragyan Paramita Swain	ICAR-Central Institute of Freshwater Aquaculture, Bhubaneswar-751002, India	The presence of aquatic macrophyte and soil bottom in concrete tanks positively stimulates gonadosomatic index and reproductive hormones in *Channa striata*

Poster Presentations—Day 3: March 18, 2021
Chairman: Dr. T. K. Ghoshal, Principal Scientist, Kakdwip Research Centre, ICAR-Central Institute of Brackishwater Aquaculture, Kakdwip, West Bengal, India
Co-Chairman: Dr. G. Biswas, Senior Scientist, Kakdwip Research Centre of ICAR-Central Institute of Brackishwater Aquaculture, Kakdwip, West Bengal, India

S. No.	Name	Affiliation	Title
23	Dr. Dilip Kumar Singh	ICAR-Central Institute of Fisheries Education, Kolkata Centre, Kolkata, West Bengal, India	Utilization of berseem (*Trifolium alexandrinum*) leaf meal as deoiled rice bran replacer in the diet of *Labeo rohita* (Hamilton, 1822) fingerlings: Effect on growth performance and physio-immunological responses
24	Mr. Smit Lende	Postgraduate Institute of Fisheries Education & Research, Kamdhenu University Rajpur (Nava) Himmatnagar, Gujarat, India	The effects of partial replacement of fish meal with roasted guar korma meal on growth, feed utilization and survival of Tilapia (*Oreochromis niloticus*) advance fry
25	Dr. Shyamala Shingare	Department of Chemical Engineering, Bharati Vidyapeeth College of Engineering, Navi Mumbai, Maharashtra, India	Treatment of wastewater from fish pond using rotating biological contactor
26	Miss SanchitaNaskar	Kakdwip Research Centre of ICAR-Central Institute of Brackishwater Aquaculture, Kakdwip, West Bengal, India	Optimization of biomass density of estuarine oyster, *Crassostrea cuttackensis* in integrated multi-trophic aquaculture (IMTA) system for better water quality and production performance
27	Mr. Rajesh J. Vasava	Postgraduate Institute of Fisheries Education & Research, Kamdhenu University, Rajpur (Nava), Himmatnagar, Gujarat, India	Comparative study of survival and growth performance of *Penaeus vannamei* (Boone, 1931) with probiotic supplementation at higher salinities

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S. No.	Name	Affiliation	Title
28	Dr. B. V. Naik	College of Fisheries, Dr. Balasaheb Sawant Konkan Krishi Vidyapeeth, Ratnagiri, Maharashtra. India	Better management practices and their adoption in shrimp farming: A case from South Konkan Region, Maharashtra
29	Mr. Albin Sunny	ICAR - Central Institute of Brackishwater Aquaculture, Chennai, Tamil Nadu, India	Dietary supplementation of crustacean shell waste derivatives on the growth performance and survival of *Penaeus monodon* (Fabricius, 1798)
30	Dr. Shashikant Jaychand Meshram	College of Fisheries, Dr. Balasaheb Sawant Konkan Krishi Vidyapeeth, Ratnagiri, Maharashtra. India	Biofloc system: A new approach for fish seed rearing
31	Dr. Rehana Raj	ICAR-Central Institute of Fisheries Technology, Cochin, India	An attempt to characterize seaweed-based biochar in application of its quenching ability on pesticide compounds for its incorporation in water purification system
32	Miss Aathira S	Kerala University of Fisheries & Ocean Studies, Fisheries Station Campus, Kochi, Kerala, India	Assessment of intertidal mangrove zones along the banks of northern Cochin estuary
33	Dr. K. M. Sandhya	ICAR - Central Institute of Fisheries Technology, Kochi, Kerala, India	Fishing methods and species composition of landings in Meenkara reservoir, Kerala, India

Theme II: Technological developments in fisheries, livestock and poultry management, water pollution trends, and ecological security for coral reefs, farming system modules

Session II: Estuarine and marine fisheries: resource management & technological innovations, fish processing technologies

Invited Lectures & Oral Presentations—Day 2: March 17, 2021.

Chairman: Dr. J. K. Jena, Deputy Director General (Fisheries Science), Indian Council of Agricultural Research, New Delhi, India

Co-Chairman: Dr. Srinivasa Gopal, Former Director, ICAR-Central Institute of Fisheries Technology, Kochi, Kerala, India

Dr. T. V. Sathianandan, Principal Scientist & Head, Fishery Resources Assessment Division, ICAR-Central Marine Fisheries Research Institute, Kochi, Kerala, India

S. No.	Name	Affiliation	Title
1	Dr. C. N. Ravishankar/Dr. George Ninan	Director, ICAR-Central Institute of Fisheries Technology, Kochi, Kerala, India	Value addition and options for entrepreneurship development in the fisheries post harvest sector
2	Dr. T. V. Sathianandan	Principal Scientist & Head, Fishery Resources Assessment Division, ICAR-Central Marine Fisheries Research Institute, Kochi, Kerala, India	Diversity in fished taxa along the Indian coast
3	Dr. K. S. Mohamed	Former Head, Molluscan Fisheries Division, ICAR-Central Marine Fisheries Research Institute, Kochi Kerala, India	Moving India's marine fisheries towards sustainability
4	Dr. J. K. Sundaray	Head, Division of Fish Genetics & Biotechnology, ICAR-Central Institute of Freshwater Aquaculture, Bhubaneswar, India	Application of genetics and "omics" technology towards sustainable aquaculture production
5	Dr. C. O. Mohan	Fish Processing Division, ICAR- Central Institute of Fisheries Technology, Kochi, Kerala	Packaging of fish & fishery products
6	Dr. Santosh Metar	Marine Biological Research Station, Dr. B. S. Konkan Krishi Vidyapeeth Zadgaon, Ratnagiri, Maharashtra, India	Occurrence of marine ornamental fishes in trawl net operated along Ratnagiri coast and a novel approach to transport them to the market for fishermen
7	Dr. Dibakar Bhakta	ICAR-Central Inland Fisheries Research Institute, Barrackpore, West Bengal, India	Food and feeding habits of *Otolithoides pama* (Hamilton, 1822) from Hooghly-Matlah estuary of east coast of India
8	Dr. Monalisha Devi Sukham	Mumbai Research Centre of ICAR - Central Institute of Fisheries Technology, Navi Mumbai, Maharashtra, India	Fishery resources of *Pristipomoides filamentosus* (Valenciennes, 1830) and *Pristipomoides multidens* (Day, 1871) from Andaman Water
9	Dr. L. Sahoo	Fish Genetics and Biotechnology Division, ICAR-CIFA, Bhubaneswar-Odisha, India	Genome wide characterization and analysis of simple sequence repeats in *Cultrinae* species

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S. No.	Name	Affiliation	Title
10	Dr. G. B. Sreekanth	ICAR-Central Coastal Agricultural Research Institute, Old Goa, Goa, India	Estuarine fisheries and Covid-19 pandemic: Lesson learnt from small-scale estuarine fisheries
11	Dr. Debabrata Das	ICAR-Central Inland Fisheries Research Institute, Barrackpore, West Bengal, India	Natural growth-medium in promoting or inhibiting cell-growths with the principle of biotechnology
12	Dr. L. N. Murthy	Mumbai Research Centre of ICAR - Central Institute of Fisheries Technology, Navi Mumbai, Maharashtra, India	Effect of zinc oxide - carboxy methyl cellulose - sodium packaging film on the quality and shelf life of refrigerated stored fish cutlets
13	Dr. Jayappa Koli	Professor, Fish Processing Technology & Microbiology College of Fisheries Shirgaon, Ratnagiri Maharashtra India	Development of soup powder from hooded oyster *Saccostrea cucullata*

Poster Presentations—Day 3: March 18, 2021
Chairman: Dr. T. K. Ghoshal, Principal Scientist, Kakdwip Research Centre, ICAR-Central Institute of Brackishwater Aquaculture, Kakdwip, West Bengal, India
Co-Chairman: Dr. G. Biswas, Senior Scientist, Kakdwip Research Centre of ICAR-Central Institute of Brackishwater Aquaculture, Kakdwip, West Bengal, India

S. No.	Name	Affiliation	Title
14	Mr. Vikas Pathak	ICAR-Central Institute of Fisheries Education, Mumbai, Maharashtra, India	Quantification of otolith characteristics of fishes inhabiting Dharamtar estuary, Arabian Sea
15	Dr. Dibakar Bhakta	ICAR-CIFRI, Barrackpore, Kolkata, West Bengal, India	The relationships between fish and otolith sizes of Pama croaker, *Otolithoides pama* (Hamilton, 1822) from Narmada estuary, India
16	Dr. Narendra Chogale	Marine Biological Research Station, Dr. B. S. Konkan Krishi Vidyapeeth Zadgaon, Ratnagiri, Maharashtra, India	Traditional knowledge on cast net design and selectivity along the coastal area of Sindhudurg, Maharashtra, India
17	Dr. Vivek H. Nirmale	College of Fisheries, Dr. Balasaheb Sawant Konkan Krishi Vidyapeeth, Shirgaon, Ratnagiri, Maharashtra, India	Studies on growth and mortality of spineless cuttlefish, *Sepiella inermis* from Ratnagiri (Arabian Sea; Northwest Coast of India)

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S. No.	Name	Affiliation	Title
18	Dr. Monalisha Devi Sukham	Mumbai Research Center of ICAR - Central Institute of Fisheries Technology, Navi Mumbai, Maharashtra, India	Length–weight relationship, Gonadosomatic Index and fecundity of *Pristipomoides filamentosus* (Valenciennes, 1830) from Andaman Sea
19	Mr. Sachin Satam	College of Fisheries, Dr. Balasaheb Sawant Konkan Krishi Vidyapeeth, Shirgaon, Ratnagiri, Maharashtra, India	Antibacterial activity of two seaweeds from Ratnagiri coast
20	Dr. P. T. Rajan	Andaman and Nicobar Regional Center, Zoological Survey of India, Port Blair, Andaman and Nicobar Islands, India	Diversity, distribution and conservation of commercially important Groupers (Epinehelinidae), Snappers (Lutjanidae) and Emperors (Lethrinidae) of Andaman and Nicobar Islands with two new records
21	Dr. Shesdev Patro	Department of Marine Sciences, Berhampur University, Bhanjabihar, Odisha, India	Is the sea off Odisha, north-western Bay of Bengal a favourable feeding ground of Bryde's whale [*Balaenoptera edeni* Anderson, 1878]?
22	Dr. K. R. Sreelakshmi	ICAR-Central Institute of Fisheries Technology, Kochi, Kerala, India	Chitosan - gold nanocomposites as smart indicator for frozen storage temperature history
23	Dr. Debabrata Das	ICAR-Central Inland Fisheries Research Institute, Barrackpore, West Bengal, India	May the few rules in digital-fisheries viz. growth & fecundity are negatively correlated with "TDS" and "CEC" and approximated linear models
24	Dr. Debabrata Das	ICAR-Central Inland Fisheries Research Institute, Barrackpore, West Bengal, India	Fecundity of any fish may environmentally controlled, and values are negatively correlated both with the "TDS" AND "CEC"
25	Dr. A Pagarkar	Marine Biological Research Station, Dr. B. S. Konkan Krishi Vidyapeeth, Zadgaon, Ratnagiri, Maharashtra, India	Novel product: Ready-to-eat fish spread and its quality assessment
26	Dr. P. K. Binsi	ICAR-Central Institute of Fisheries Technology, Cochin, Kerala, India	Photo-protective effect of cuttlefish ink melanin on human hair

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S. No.	Name	Affiliation	Title
27	Dr. Jesmi Debbarma	ICAR-Central Institute of Fisheries Technology, Visakhapatnam Research Centre, Visakhapatnam, Andhra Pradesh, India	Enzyme assisted peeling of white leg shrimp (*Litopenaeus vannamei*) for efficient pre-processing
28	Dr. A. Jeyakumari	Mumbai Research Centre of ICAR-Central Institute of Fisheries Technology, Navi Mumbai, Maharashtra, India	Quality characteristics fish oil microencapsulates incorporated restructured fish product
29	Dr. A. Jeyakumari	Mumbai Research Centre of ICAR-Central Institute of Fisheries Technology, Navi Mumbai, Maharashtra, India	Effect of spice extract on the quality of dried Bombay duck
30	Dr. U. Parvathy	ICAR-Central Institute of Fisheries Technology, Kochi, Kerala, India	Peptides from anchovy head waste for its application as foliar spray
31	Mrs. S. J. Laly	Mumbai Research Centre of ICAR-Central Institute of Fisheries Technology, Navi Mumbai, Maharashtra, India	Effect of electron beam irradiation in combination with thermal and non thermal treatments on shrimp allergen, tropomyosin
32	Mrs. S. J. Laly	Mumbai Research Centre of ICAR-Central Institute of Fisheries Technology, Navi Mumbai, Maharashtra, India	Biochemical quality, microbial safety and heavy metal content in dry fish samples available in local markets of Navi Mumbai
33	Dr. P. Viji	ICAR-Central Institute of Fisheries Technology, Visakhapatnam Research Centre, Visakhapatnam, Andhra Pradesh, India	Protein powder from *Squilla sp.* - Improved utilization of an unconventional coastal resource to meet the nutritional security
34	Mr. Sachin Satam	College of Fisheries, B. S. Konkan Krishi Vidyapeeth, Shirgaon, Ratnagiri Maharashtra, India	Effect of different drying methods on quality of squid rings
35	Dr. J. Jayalakshmi	ICAR-Central Institute of Fisheries Technology, Willigdon island, Cochin, Kerala, India	Development of ready-to-eat crispy from fish scales
36	Dr. K. M. Shinde	Marine Biological Research Station, Dr. B. S. Konkan Krishi Vidyapeeth, Zadgaon, Ratnagiri, Maharashtra, India	Design, development and performance evaluation of fish de-scaler cum knife

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S. No.	Name	Affiliation	Title
37	Dr. Jayappa Koli	Professor, Fish Processing Technology & Microbiology, College of Fisheries Shirgaon, Ratnagiri, Maharashtra, India	Extraction of chitin, chitosan and preparation of meal from mantis shrimp (*Squilla*) and study their functional properties and shelf life
38	Dr. R. D. Palve	College of Fisheries, Dr. B.S. Konkan Krishi Vidyapeeth, Ratnagiri, Maharashtra, India	Beneficial effects of spices in seafood preservation**:** A review
39	Dr. Ajay S. Desai	College of Fisheries, Dr. B.S. Konkan Krishi Vidyapeeth, Ratnagiri, Maharashtra, India	Effect of different drying methods on biochemical characteristics of sole fish, *Cynoglossus macrostomus* (Norman, 1928)

Theme II: Technological developments in fisheries, livestock and poultry management, water pollution trends, and ecological security for coral reefs, farming system modules

Session III: Water pollution: sedimentation, eutrophication & formation of dead-end zones—threat to fisheries, corals & coral reefs

Invited Lectures & Oral Presentations—Day 3: March 18, 2021

Chairman: Dr. B. K. Das, Director, ICAR-Central Inland Fisheries Research Institute, Barrackpore, West Bengal, India

Co-Chairman: Dr. S. Dam Roy, Principal Scientist & Officer-in-Charge, ICAR-Central Inland Fisheries Research Institute, Kolkata Centre, Kolkata, West Bengal, India

S. No.	Name	Affiliation	Title
1	Dr. B. K. Das	ICAR-Central Inland Fisheries Research Institute, Barrackpore, West Bengal, India	Aquatic pollution vis-a-vis fish health
2	Prof. Vipul Bansal	Director, Sir. Ian Potter BioSensing Facility, School of Science, RMIT University, Melbourne, Australia	Biosensors for water pollution monitoring using enzyme-mimic nano systems

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S. No.	Name	Affiliation	Title
3	Dr. Srikanta Samanta	Principal Scientist & Head (Acting), Riverine and Estuarine Fisheries Division, ICAR-Central Inland Fisheries Research Institute, Barrackpore, West Bengal, India	Arsenic contaminations in the aquatic ecosystems and its associated impacts
4	Prof. J. G. Ray	School of Biosciences. Mahatma Gandhi University, Kottayam, Kerala, India	Eutrophication as an opportunity for the utilization of algal resources in rural development
5	Dr. S. Dam Roy	Principal Scientist & Officer-in-Charge, ICAR-Central Inland Fisheries Research Institute, Kolkata Centre, Salt Lake, Kolkata, West Bengal, India	Coral growth and sustenance under water pollution and global warming
6	Prof. Biju Kumar	Head, Department of Aquatic Biology and Fisheries, University of Kerala, Thiruvananthapuram, Kerala, India	Climate change, coral reefs and fisheries sustainability: emerging paradigms
7	Dr. Subir Kumar Nag	ICAR-Central Inland Fisheries Research Institute, Barrackpore, West Bengal, India	Accumulation of heavy metals in some aquatic vegetation and crustaceans at lower part of river Hooghly

Poster Presentations—Day 3: March 18, 2021
Chairman: Dr. T. K. Ghoshal, Principal Scientist, Kakdwip Research Centre, ICAR-Central Institute of Brackishwater Aquaculture, Kakdwip, West Bengal, India
Co-Chairman: Dr. G. Biswas, Senior Scientist, Kakdwip Research Centre of ICAR-Central Institute of Brackishwater Aquaculture, Kakdwip, West Bengal, India

S. No.	Name	Affiliation	Title
8	Dr. S. M. Wasave	College of Fisheries, Dr. B. S. Konkan Krishi Vidyapeeth, Ratnagiri, Maharashtra, India	Consequences of pollution on fishes and marine ecosystem
9	Dr. P. Krishnan	ICAR-National Academy of Agricultural Research Management, Hyderabad, Telangana, India	Impact of commercial cultivation of *Kappaphycus alvarezii* on coral reefs of Palk Bay and Gulf of Mannar, South India
10	Miss Sayeri Paul	Jadavpur University, Kolkata, West Bengal, India	Feedback loop between Parrot fish and coral reef

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S. No.	Name	Affiliation	Title
11	Mr. Raviraj Dave	Center for Applied Geomatics, CRDF, CEPT University, Ahmedabad, Gujarat, India	Change detection of water-inundated areas of Pirotan reef, India using object based image analysis

Theme II: Technological developments in fisheries, livestock and poultry management, water pollution trends, and ecological security for coral reefs, farming system modules

Session IV: Livestock & poultry: technological innovations & options for management and production developments

Invited Lectures & Oral Presentations—Day 2: March 17, 2021.

Chairman: Dr. A. Kundu, Project Director (RGM) and Controlling Officer (APRI), Dr. Rajendra Prasad Central Agricultural University, Pusa, Bihar, India

Co-Chairman: Dr. Ajoy Mandal, Principal Scientist, ICAR-National Dairy Research Institute, Eastern Regional Station, Kalyani, Nadia, West Bengal, India

S. No.	Name	Affiliation	Title
1	Dr. A. Kundu	Project Director (RGM) and Controlling Officer (APRI), Dr. Rajendra Prasad Central Agricultural University, Pusa, Bihar, India	Strategies for development of livestock sector in Indian island regions
2	Dr. Ajoy Mandal	Principal Scientist (Animal Genetics & Breeding), ICAR-National Dairy Research Institute, Eastern Regional Station, Kalyani, Nadia, West Bengal, India	Genetic resources of livestock & poultry in coastal ecosystems of India
3	Dr. M. R. Reddy	Principal Scientist, Avian Health Section ICAR-Directorate of Poultry Research Hyderabad, Telengana, India	Respiratory disease complex in poultry: diagnosis and control strategies

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S. No.	Name	Affiliation	Title
4	Dr. Parimal Roy	Professor, Centre for Animal Health Studies, Tamil Nadu Veterinary and Animal Sciences University, Chennai, Tamil Nadu, India	Livestock disease management in coastal areas of India

Poster Presentations—Day 3: March 18, 2021
Chairman: Dr. T. K. Ghoshal, Principal Scientist, Kakdwip Research Centre, ICAR-Central Institute of Brackishwater Aquaculture, Kakdwip, West Bengal, India
Co-Chairman: Dr. G. Biswas, Senior Scientist, Kakdwip Research Centre of ICAR-Central Institute of Brackishwater Aquaculture, Kakdwip, West Bengal, India

S. No.	Name	Affiliation	Title
5	Dr. Writdhama Prasad	ICAR-National Dairy Research Institute, Karnal, Haryana, India	Iron binding ability of exopolysaccharides producing lactic acid bacteria in whey, a dairy by-product
6	Mr. Arghyadeep Das	ICAR-National Dairy Research Institute, Karnal, Haryana, India	Livestock-based farming systems in saline areas of West Bengal
7	Dr. P. Perumal	ICAR-Central Island Agricultural Research Institute, Port Blair, Andaman & Nicobar Islands, India	Basic blood indices, serum biochemical profiles, antioxidant and oxidative stress profiles of Andaman local buffaloes at different stages of reproduction
8	Mr. K. Muniswamy	ICAR-Central Island Agricultural Research Institute, Port Blair, Andaman & Nicobar Islands, India	Exploring the population diversity and ancestry of Nicobari fowl using complete D-loop sequences of mitochondrial DNA
9	Dr. P. Perumal	ICAR-Central Island Agricultural Research Institute, Port Blair, Andaman & Nicobar Islands, India	Flaxseed oil on endocrinological profiles and scrotal biometric attributes in indigenous bucks of Andaman and Nicobar Islands
10	Dr. P. Perumal	ICAR-Central Island Agricultural Research Institute, Port Blair, Andaman & Nicobar Islands, India	Exogenous melatonin effect on endocrinological and biochemical profiles in post partum anestrus Andaman local buffaloes in humid tropical island ecosystem
11	Miss Ishani Roy	ICAR-National Dairy Research Institute, Eastern Regional Station, Kalyani, West Bengal, India	Garole—a promising sheep breed in coastal West Bengal

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S. No.	Name	Affiliation	Title
12	Dr. S. Nayakvadi	ICAR-Central Coastal Agricultural Research Institute, Old Goa, Goa, India	Evaluation of β-*casein* (CSN2) for detection of A1 and A2 genetic variants in *Shweta Kapila* cattle of Goa by allele-specific PCR (AS-PCR) and sequencing
13	Dr. T. Sujatha	ICAR-Central Island Agricultural Research Institute, Port Blair, Andaman & Nicobar Islands, India	Study on locally available herbal vaccine boosters against Newcastle disease vaccine in rural poultry in A&N Islands
14	Dr. Susitha Rajkumar	ICAR-Central Coastal Agricultural Research Institute, Old Goa, Goa, India	Antibiotic resistance characteristics of the prevalent coagulase negative *Staphylo cocci* species isolates from bovine subclinical mastitis
15	Dr. S. Nayakvadi	ICAR-Central Coastal Agricultural Research Institute, Old Goa, Goa, India	Studies on clinico-pathological and molecular diagnosis of Lumpy skin disease (LSD) in dairy cattle in west coastal India

Theme II: Technological developments in fisheries, livestock and poultry management, water pollution trends, and ecological security for coral reefs, farming system modules

Session V: Farming system approach: rice-cum-fish culture & homestead production system including social-forestry

Invited Lectures & Oral Presentations—Day 1: March 16, 2021

Chairman: Dr. C. Jayanthi, Former Director, Directorate of Crop Management, Tamil Nadu Agricultural University, Coimbatore, Tamil Nadu, India

Co-Chairman: Dr. D. P. Sinhababu, Former Principal Scientist, ICAR-National Rice Research Institute, Cuttack, Odisha, India

S. No.	Name	Affiliation	Title
1	Dr. D. P. Sinhababu	Former Principal Scientist, ICAR-National Rice Research Institute, Cuttack, Odisha, India	Development in rice-fish-livestock farming for higher production and income in coastal areas

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S. No.	Name	Affiliation	Title
2	Dr. S. K. Sarangi	Principal Scientist, ICAR-CSSRI, RRS, Canning Town, West Bengal, India	Coastal homestead farming systems for enhancing income and nutritional security of small-holder farmers
3	Dr. Annie Poonam	ICAR- National Rice Research Institute, Cuttack, Odisha, India	Rice-fish-duck: Effect of co-culture system on rice cultivation under coastal lowlands
4	Dr. S. K. Rautaray	ICAR-Indian Institute of Water Management, Bhubaneswar, Odisha, India	Water budgeting and enhancing water productivity in lowland rice-fish farming system

Poster Presentations—Day 3: March 18, 2021

Chairman: Dr. T. K. Ghoshal, Principal Scientist, Kakdwip Research Centre, ICAR-Central Institute of Brackishwater Aquaculture, Kakdwip, West Bengal, India

Co-Chairman: Dr. G. Biswas, Senior Scientist, Kakdwip Research Centre of ICAR-Central Institute of Brackishwater Aquaculture, Kakdwip, West Bengal, India

S. No.	Name	Affiliation	Title
5	Dr. Sreelatha A.K	Rice Research Station, Kerala Agricultural University, Vyttila, Kochi Kerala, India	Multilevel integrated farming model in Pokkali lands of Kerala
6	Dr. Deepa Thomas	Aromatic and Medicinal Plants Research Station, Kerala Agricultural University, Odakkali, Kerala, India	Sustainable nutritional and income security through integrated farming in coastal saline Pokkali ecosystem of Kerala
7	Mr. Amol Vinayakrao Dahipahle	Dr Balasaheb Sawant Konkan Krishi Vidyapeeth, Dapoli, Maharashtra, India	On farm diversification of existing farming systems under marginal household conditions in south Konkan coastal zone of Maharashtra
8	Dr. C. K. Thankamani	ICAR-Indian Institute of Spices Research, Kozhikode, Kerala, India	Integrated organic farming system involving turmeric for livelihood security
9	Dr. Namdev V. Mhaskar	AICRP on IFS, Regional Agricultural Research Station, Dr. B. S. Konkan Krishi Vidyapeet, Karjat, Raigad, Maharashtra, India	Integrated farming system model for sustainable production, livelihood security, income and employment generation to farmers under north Konkan Coastal Zone of Maharashtra

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S. No.	Name	Affiliation	Title
10	Mr. Soumyabrata Sarkar	ICAR-Central Institute of Brackishwater Aquaculture, Chennai, Tamil Nadu, India	Integrated multi-trophic aquaculture (IMTA): A potential farming system to enhance production of the red seaweed *Gracilaria tenuistipitata* (Chang and Xia) in brackishwater
11	Dr. V. G. Yewale	College of Fisheries, Dr. B. S. Konkan Krishi Vidyapeeth, Ratnagiri, Maharashtra, India	Exploring possibilities of income generation through fish culture in polythene lined farm ponds in Ratnagiri District, Maharashtra
12	Dr. Dhanushkodi Vellaiyan	ICAR-Krishi Vigyan Kendra, Sirugamani, Tiruchirappalli, Tamil Nadu, India	Fish farming: A promising source for income and employment generation under sodic soil
13	Dr. P. P Shameena Beegum	ICAR-Central Plantation Crops Research Institute, Kasaragod, Kerala, India	Coconut farming in Lakshadweep islands: Strategies for enhancing sustainability

Theme III: Natural resources and carbon flow dynamics vis-à-vis soil quality, water use trends, and integrated water management including ground water and farm machinery developments

Session I: Natural resources: assessment and degradation, management

Invited Lectures & Oral Presentations—Day 2: March 17, 2021

Chairman: Dr. Mohammed Mainuddin, Principal Research Scientist, CSIRO Land and Water, Canberra, Australia

Co-Chairman: Dr. Ed Barrett Lennard, Professorial Fellow, Murdoch University, Perth, Western Australia, Australia

S. No.	Name	Affiliation	Title
1	Professor Leigh Sullivan	Deputy Vice-Chancellor, Research and Innovation, University of Canberra, Canberra, Australia	Assessment and management of monosulfidic black ooze accumulations in coastal waterways and wetlands

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S. No.	Name	Affiliation	Title
2	Dr. Jorge Luis Peña Arancibia	Senior Research Scientist, CSIRO Land and Water, Canberra, Australia	Cutting-edge remote sensing to underpin water resources assessments
3	Dr. Ed Barrett Lennard	Professorial Fellow, Murdoch University, Perth, Western Australia, Australia	Crop growth in saline soils is not (mostly) affected by the ECe
4	Dr. Anil Chinchmalatpure	Head, ICAR- Central Soil Salinity Research Institute, RRS, Bharuch, Gujarat, India	Saline soils of coastal ecosystem: Spatial and temporal variation of soil properties, classification, fertility status and management for sustained production
5	Dr. Uttam Kumar Mandal	Principal Scientist, ICAR-Central Soil Salinity Research Institute, Regional Research Station, Canning Town, West Bengal	A remote sensing assessment of spatio-temporal dynamics of coastal ecosystem: Evidence from Indian Sundarbans
6	Dr. T. D. Lama	Principal Scientist, ICAR-Central Soil Salinity Research Institute, Regional Research Station, Canning Town, West Bengal	Coastal saline soils of West Bengal and their management for augmenting productivity
7	Dr. D. G. Jondhale	Jr. Soil Scientist, Regional Agril. Research Station, Dr. B. S. Konkan Krishi Vidyapeeth, Karjat, Maharashtra, India	Soil fertility and productivity of rice-groundnut cropping system in north Konkan coastal zone as influenced by organic nutrient management

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S. No.	Name	Affiliation	Title
8	Dr. Uma Bagavathi Ammal	Dept. of Soil Science and Agricultural Chemistry, Pandit Jawaharlal Nehru College of Agriculture and Research Institute, Karaikal, Puducherry, India	STCR—A tool for fertilizer recommendation for rice (ADT 43) in UT of Puducherry
9	Dr. Vijay Gopal Salvi	Department of Soil Science and Agricultural Chemistry, Dr. B. S. Konkan Krishi Vidyapeeth, Dapoli, Maharsahtra, India	Effect of inorganic and organic manure on biological properties of soil and yield of yam bean (*Pachyrrhizus erosus* L.) in lateritic soil of Konkan
10	Dr. K. K. Mahanta	Principal Scientist, ICAR-Central Soil Salinity Research Institute, Regional Research Station, Canning Town, West Bengal	Effect of saline water irrigation through drip system on okra in salt affected soils of West Bengal

Poster Presentations—Day 2: March 17, 2021
Chairman: Dr. B. Saha, Principal Scientist, ICAR-National Institute of Natural Fibre Engineering and Technology, Kolkata, West Bengal, India
Co-Chairman: Dr. S. K. Jena, Principal Scientist, ICAR-Indian Institute of Water Management, Bhubaneshwar, Odisha, India

Sl. No.	Name	Affiliation	Title
11	Miss Neha Unni	College of Agriculture, Kerala Agricultural University, Thrissur, Kerala, India	Assessment of soil nutrient index in the post flood scenario in Pokkali soils
12	Dr. Ranu Rani Sethi	ICAR-Indian Institute of Water Management, Bhubaneswar, Odisha, India	Time series analysis of climate variables for Baitarini river basin of Odisha

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S. No.	Name	Affiliation	Title
13	Mr. Bhavishya	ICAR-Central Plantation Crops Research Institute, Regional Station, Vittal, Karnataka, India	Nano-potassium intercalated composted coir pith: a slow releasing fertilizer for laterite soils of humid tropics of India
14	Dr. L. Aruna	PJN College of Agriculture and Research Institute, Karaikal, Puducherry, India	Soil quality and productivity assessment for bridging the yield gap in farmers' fields of coastal Cauvery deltaic region of Karaikal
15	Miss K Jamuna Rani	PJN College of Agriculture and Research Institute, Karaikal, Puducherry, India	Phosphorus fixation and release studies in major rice growing soil series at coastal deltaic region of Karaikal
16	Dr. Uma Bagavathi Ammal	PJN College of Agriculture and Research Institute, Karaikal, Puducherry, India	Validation of soil test crop response based integrated plant nutrition system (STCR-IPNS) recommendations for hybrid bhendi in U.T. of Puducherry
17	Dr. Vijay Gopal Salvi	Department of Soil Science and Agricultural Chemistry, Dr. B. S. Konkan Krishi Vidyapeeth, Dapoli, Maharsahtra, India	Effect of inorganic and organic manure on yield and quality parameters of yam bean (*Pachyrrhizus erosus* L.) in lateritic soil of Konkan

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S. No.	Name	Affiliation	Title
18	Dr. Susmit Saha	College of Agriculture, Bidhan Chandra Krishi Viswavidyalaya, Bardhaman, Purba Bardhaman, West Bengal, India	Zinc enrichment in cereals with proper scheduling of Zn application protocol and cultivar choice

Theme III: Natural resources and carbon flow dynamics vis-à-vis soil quality, water use trends, and integrated water management including ground water and farm machinery developments

Session II: River flow dynamics, bank erosion, surface & underground water flow modelling vis-à-vis climate change

Invited Lectures & Oral Presentations—Day 3: March 18, 2021

Chairman: Dr. Robyn Johnston, Research Program Manager for Water and Climate, Australian Centre for International Agricultural Research, Bruce, ACT, Australia

Co-Chairman: Prof. L. Elango, Head, Dept. of Geology, Anna University, Chennai, Tamil Nadu, India

S. No.	Name	Affiliation	Title
1	Prof. Ashis Kumar Paul	Professor and Former Head, Department of Geography, Vidyasagar University, Midnapore, West Bengal, India	Dynamic behaviours of the estuaries in response to the phenomenon of global warming in the coastal ecosystems of West Bengal and Odisha, India
2	Dr. Y. R. Satyaji Rao	Scientist G and Head, deltaic regional centre, National Institute of Hydrology, Kakinada, Andhra Pradesh	Potential of river bank filtration (RBF) for safe water supplies from saline coastal aquifers
3	Prof. L. Elango	Head, Dept. of Geology, Anna University, Chennai, Tamil Nadu, India	Groundwater modelling for sustainable management of coastal aquifers of irrigated regions under climate change

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S. No.	Name	Affiliation	Title
4	Dr. Ranvir Singh	Farmed Landscapes Research Centre, School of Agriculture and Environment, Massey University, New Zealand	Water sensitive agriculture - the use of innovative models to help increase land and water productivity and water quality protection in coastal ecosystems

Poster Presentations—Day 2: March 17, 2021

Chairman: Dr. B. Saha, Principal Scientist, ICAR-National Institute of Natural Fibre Engineering and Technology, Kolkata, West Bengal, India

Co-Chairman: Dr. S. K. Jena, Principal Scientist, ICAR-Indian Institute of Water Management, Bhubaneshwar, Odisha, India

S. No.	Name	Affiliation	Title
5	Dr. Sujeet Desai	ICAR-Central Coastal Agricultural Research Institute, Old Goa, Goa, India	Assessment of long term trends in stream flow of river basins flowing in the west coast of India
6	Dr. S. Roy	Dept. of Soil Water and Cons. Eng., College of Agril. Eng. and Tech., Orissa University of Agriculture and Technology, Bhubaneswar, Odisha, India	Design of a sand based storm-water filtration unit for groundwater recharge

Theme III: Natural resources and carbon flow dynamics vis-à-vis soil quality, water use trends, and integrated water management including ground water and farm machinery developments

Session III: Jute geo-textiles and its applications in coastal ecosystems

Invited Lectures & Oral Presentations—Day 2: March 17, 2021

Chairman: Mr. Moloy Chakraborty, Jute Commissioner & Secretary, National Jute Board, Ministry of Textiles, Govt. of India, Kolkata, West Bengal, India

S. No	Name	Affiliation	Title
1	Dr. Tapobrata Sanyal	Former Chief Hydraulic Engineer, Kolkata Port Trust, Kolkata, West Bengal, India	Application of synthetic geotextiles for protection against coastal erosion
2	Dr. Pradip Choudhury	Principal Technologist, National Jute Board, Ministry of Textiles, Govt. of India, Kolkata, West Bengal, India	Efficacy of jute geotextiles in mitigating soil related problems along with a few case studies

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S. No	Name	Affiliation	Title
3	Dr. Gautam Bose	Ex-Principal Scientist & Head, Mechanical Processing Division, ICAR-National Institute of Natural Fibre Engineering and Technology, Kolkata, India	Protection of soil erosion of earth embankment using natural fibre-based composite-structured geotextiles

Theme III: Natural resources and carbon flow dynamics vis-à-vis soil quality, water use trends, and integrated water management including ground water and farm machinery developments

Session IV: Carbon dynamics and C sequestration in coastal ecosystems vis-à-vis soil quality

Invited Lectures & Oral Presentations—Day 1: March 16, 2021

Chairman: Dr. R. K. Gupta, Former Group Leader, Conservation Agriculture Programme, CIMMYT and Borlaug Institute for South Asia, NASC Complex, Pusa, New Delhi, India

Co-Chairman: Dr. H. Pathak, Director, ICAR-National Institute of Abiotic Stress Management, Baramati, Maharashtra, India

S. No.	Name	Affiliation	Title
1	Dr. Himanshu Pathak	Director, ICAR-National Institute of Abiotic Stress Management, Baramati, Maharashtra, India	Carbon sequestration and quality of coastal soils
2	Prof. Biswapati Mandal	Department of Agricultural Chemistry & Soil Science, Bidhan Chandra Krishi Viswavidyalaya, Mohanpur, West Bengal, India	Soil quality assessment for coastal agro-ecosystem - Problems and perspectives
3	Dr. P. Bhattacharya	ICAR-National Fellow & Principal Scientist, National Rice Research Institute, Cuttack, Odisha, India	Carbon dynamics and greenhouse gases emissions in coastal agriculture: mangrove-rice ecology in Sundarban, India
4	Dr. U. K. Priya	ICAR-Central plantation crops Research Institute, Regional Station, Vittal, Karnataka, India	Carbon dynamics in plantation crops under different cropping systems in Ultisols of coastal belt of Karnataka

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S. No.	Name	Affiliation	Title
5	Dr. Shishir Raut	ICAR-Central Soil Salinity Research Institute, Regional Research Station, Canning Town, West Bengal	Influence of ameliorants on soil physico-chemical parameters and salinity studied in a coastal soil of West Bengal, India
6	Dr. B. P. Mallik	ICAR-National Rice Research Institute, Cuttack, Odisha, India	Soil quality assessment of Integrated rice-based farming system in Bramhagiri block of Puri District

Poster Presentations—Day 2: March 17, 2021

Chairman: Dr. B. Saha, Principal Scientist, ICAR-National Institute of Natural Fibre Engineering and Technology, Kolkata, West Bengal, India

Co-Chairman: Dr. S. K. Jena, Principal Scientist, ICAR-Indian Institute of Water Management, Bhubaneshwar, Odisha, India

Sl. No.	Name	Affiliation	Title
7	Dr. I. E. John	Agricultural Officer, Chekkiad Krishi Bhavan, Kozhikode, Kerala, India	Carbon:nitrogen ratio based nitrogen prescription in acid sulphate rice soils of Kerala
8	Mr. R. Rajakumar	Pandit Jawaharlal Nehru College of Agriculture and Research Institute, Karaikal, Puducherry, India	Carbon dynamics as influenced by biochar application in Ultisols (Typic Plinthustults) of Kerala

Theme III: Natural resources and carbon flow dynamics vis-à-vis soil quality, water use trends, and integrated water management including ground water and farm machinery developments

Session V: Coastal water use trends—sources and availabilities, integrated strategies for irrigation & drainage, and other location-specific irrigation practices including poor quality water use

Invited Lectures & Oral Presentations—Day 1: March 16, 2021

Chairman: Dr. N. K. Tyagi, Former Member, ASRB, New Delhi and Former Director, ICAR-Central Soil Salinity Research Institute, Karnal, Haryana, India

Co-Chairman: Prof. Yella Reddy, Dean, Faculty of Agril. Eng. & Tech., Acharya NG Ranga Agricultural University, Guntur, Andhra Pradesh, India

S. No	Name	Affiliation	Title
1	Prof. K. Yella Reddy	Dean, Faculty of Agricultural Engineering & Technology, ANGRAU, Guntur, Andhra Pradesh, India	Adaptive measures in water management for higher water productivity and increased efficiency
2	Dr. Marco Arcieri	Secretary General, Comitato Nazionale Italiano ICID (ITAL-ICID), Rome, Italy	Water resources and irrigation management in Southern Italy coastal ecosystems: The Basilicata region
3	Dr. S. K. Jena	Principal Scientist, ICAR-Indian Institute of Water Management, Bhubaneshwar, Odisha, India	Use of geoinformatics for drainage planning of eastern coast
4	Dr. Rajesh Tulshiram Thokal	Chief Scientist, AICRP on Irrigation Water Management, Central Experiment Station, Dr. B. S. Konkan Krishi Vidyapeeth, Wakawali, Maharashtra, India	Management of problem soils, rainwater harvesting and judicious water utilization for agriculture in coastal ecosystem
5	Dr. D. S. Bundela	Principal Scientist & Head, Division of Irrigation and Drainage Engineering, ICAR-Central Soil Salinity Research Institute, Karnal, Haryana, India	Methods of drainage and irrigation for enhancing productivity in coastal ecosystems
6	Dr. Gopal Krishan	Scientist-C, Groundwater hydrology Division, National Institute of Hydrology, Roorkee, Uttarakhand, India	Groundwater salinity-impacts and possible remedial measures and management solutions
7	Dr. Anwar Zahid	Director, Ground Water Hydrology, Bangladesh Water Development Board, Dhaka, Bangladesh	Groundwater salinity distribution in the coastal aquifers of the Bengal delta and suitability assessment for irrigation use

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S. No	Name	Affiliation	Title
8	Mr. Deb Kumar Nath	Bangladesh Agricultural University, Mymensingh, Bangladesh	Water governance in coastal polder ecosystems of Bangladesh: Are the water management organizations positioned to accept the responsibility?

Poster Presentations—Day 2: March 17, 2021
Chairman: Dr. B. Saha, Principal Scientist, ICAR-National Institute of Natural Fibre Engineering and Technology, Kolkata, West Bengal, India
Co-Chairman: Dr. S. K. Jena, Principal Scientist, ICAR-Indian Institute of Water Management, Bhubaneshwar, Odisha, India

S. No.	Name	Affiliation	Title
9	Mr. Mohammad Nazrul Islam	Senior Scientific Officer, Soil Science Division, Bangladesh Rice Research Institute, Gazipur, Bangladesh	The combination of shallow surface and subsurface drains alleviates waterlogging and salinity in a clay-textured soil and improves sunflower (*Helianthus annuus* L.) yield in the Ganges delta

Theme III: Natural resources and carbon flow dynamics vis-à-vis soil quality, water use trends, and integrated water management including ground water and farm machinery developments

Session VI: Farm machinery development compatible with small land holdings and for women-friendly use

Invited Lectures & Oral Presentations—Day 2: March 17, 2021

Chairman: Dr. V. K. Tewari, Director, Indian Institute of Technology, Kharagpur, West Bengal, India

S. No.	Name	Affiliation	Title
1	Dr. C. R. Mehta	Director, ICAR-Central Institute of Agricultural Engineering, Bhopal, Madhya Pradesh, India	Mechanization of small farms to reduce drudgery of women workers
2	Dr. R. V. Powar	Dr. D. Y. Patil College of Agricultural Engineering and Technology, Talsande, Kolhapur, Maharashtra, India	Development and performance evaluation of finger millet cleaning system

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S. No.	Name	Affiliation	Title
3	Dr. Ranjan Kumar Naik	ICAR-Central Research Institute for Jute & Allied Fibres, Barrackpore, West Bengal, India	Machinery development for improved sowing and weeding for small and marginal farmers

Theme IV: Forestry & biodiversity and spatio-temporal changes, integrated forest management policy for ecological sustenance and eco-tourism for livelihood

Session I: Coastal forestry: mangrove dynamics and temporal changes, biodiversity including algal species

Invited Lectures & Oral Presentations—Day 1: March 16, 2021

Chairman: Dr. T. Ravishankar, President, Centre for Nature and Culture, Kakinada, Andhra Pradesh, India

Co-Chairman: Dr. A. G. Pandurangan, Former Director, Jawaharlal Nehru Tropical Botanic Garden & Research Institute, Thiruvananthapuram, Kerala, India

S. No.	Name	Affiliation	Title
1	Dr. K. S. Murali	Executive Director, M.S. Swaminathan Research Foundation, Chennai, Tamil Nadu, India	Spatial and temporal dynamics of the mangroves of Indian coast
2	Dr. Rathindra Nath Mandal	Principal Scientist, Regional Research Centre, ICAR-CIFA, Rahara, Kolkata, India	Mangroves vegetative dynamics vis-à-vis mangroves diversity in the ecological perspective
3	Dr. R. Ramasubramanian	Mangrove Biologist, M.S. Swaminathan Research Foundation, Chennai, Tamil Nadu, India	Participatory mangrove conservation and management in Andhra Pradesh, India
4	Dr. Ravishankar Thupalli	Risk Evaluation & Management Specialist, FAO & President, Centre for Nature and Culture, Kakinada, Andhra Pradesh, India	Policy for integrated management for ecological sustenance of coastal and mangrove ecosystems in India
5	Dr. Ajanta Dey	Joint Secretary & Programme Director, Nature Environment & Wild Life Society, Kolkata, West Bengal, India	Community governance in forest management is key to ensure long term protection of forest ecosystems

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S. No.	Name	Affiliation	Title
6	Dr. A.G. Pandurangan	Advisor, Centre for Science & Social Action & Former Director, Jawaharlal Nehru Tropical Botanic Garden & Research Institute, Thiruvananthapuram, Kerala, India	Phytogeographic, evolutionary and economic importance of costal endemic plants of Kerala
7	Dr. Dipanjan Das Majumdar	Department of Geography, Netaji Satabarshiki Mahavidyalaya, Ashoknagar, West Bengal, India	Application of modified forest canopy density model to identify mangrove forest dynamics during pre and post Aila cyclone
8	Dr. Swagata Bera	Department of Geography, Dum Dum Motijheel College, Kolkata-West Bengal, India	Assessment of land use/land cover change and vegetation health condition for the implementation of integrated management policy in South Andaman Island, India
9	Dr. Saravanan Raju	Mandapam Regional Centre of ICAR-CMFRI, Mandapam Camp, Tamil Nadu, India	Studies on the diversity in Muthupettai lagoon ecosystem
10	Dr. Saravanan Raju	Mandapam Regional Centre of ICAR-CMFRI, Mandapam Camp, Tamil Nadu, India	Beach-cast seagrass wrack diversity along coastal Ramanathapuram district and its management

Theme IV: Forestry & biodiversity and spatio-temporal changes, integrated forest management policy for ecological sustenance and eco-tourism for livelihood

Session II: Eco-tourism for livelihood security

Invited Lectures & Oral Presentations—Day 1: March 16, 2021

Chairman: Dr. N. Anil Kumar, Senior Director, M.S. Swaminathan Research Foundation, Community Agrodiversity Centre, Kerala, India

Co-Chairman: Dr. E. B. Chakurkar, Director (A), ICAR-Central Coastal Agricultural Research Institute, Old Goa, Goa, India

S. No	Name	Affiliation	Title
1	Dr. N. Anil Kumar	Senior Director, M.S. Swaminathan Research Foundation, Community Agrodiversity Centre Kerala, India	Community based tourism around coastal agricultural heritage sites of India: a need for promoting improved livelihood of the coastal inhabitants
2	Dr. E. B. Chakurkar	Director (A), ICAR-Central Coastal Agricultural Research Institute, Old Goa, Goa, India	Agro-tourism as an innovative integrated farming system model for sustainable agriculture in the coastal ecosystems
3	Dr. Maneesha S. R	ICAR-Central Coastal Agricultural Research Institute, Old Goa, Goa, India	Dhanvantari Vatika – A model herbal garden for an agro eco-tourism unit

Theme V: Climate change and disaster occurrence, its impact, IT & remote sensing for rapid dissemination and early warning protocols, mainstreaming climate change policies for regional integration

Session I: Climate change trends a dynamic phenomenon and its impact on agriculture, fisheries, forestry & animal husbandry

Invited Lectures & Oral Presentations—Day 1: March 16, 2021

Chairman: Dr. M. M. Qader Mirza, Adjunct Professor, Department of Physical and Environmental Sciences, University of Toronto, Scarborough, Canada

Co-Chairman: Dr. Dibyendu Dutta, General Manager, Regional Remote Sensing Centre-East, NRSC, ISRO, New Town, Kolkata West Bengal, India

S. No.	Name	Affiliation	Title
1	Dr. Ch. Srinivasa Rao	Director, ICAR-National Academy of Agricultural Research Management, Hyderabad, Telangana, India	Impacts of climate change and weather forecasting on agriculture and food systems in coastal ecosystems of India
2	Dr. M. Prabhakar	PI-NICRA, ICAR-Central Research Institute for Dryland Agriculture, Hyderabad, Telangana, India	Impact of climate change on coastal agricultural ecosystems - Adaptation interventions from NICRA
3	Dr. Sugata Hazra	School of Oceanographic Studies Jadavpur University, Kolkata, West Bengal, India	Climate change and marine fisheries of Andaman Islands, India

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S. No.	Name	Affiliation	Title
4	Dr Mannava V. K. Sivakumar	Former Director, Climate Prediction & Adaptation Branch, WMO, Geneva, Switzerland	Management of climate change and natural disaster impacts in agriculture
5	Dr. Ajaya Dixit	Former Executive Director, Institute for Social and Environmental Transition (ISET - Nepal), Lalitpur, Nepal	Water challenges need holistic approach and conversations
6	Prof. Rex Victor O. Cruz	Director, Forestry Programme, College of Forestry and Natural Resources, University of Philippines, Laguna, Philippines	Adaptation and disaster risk reduction in the coastal municipalities of Manila bay
7	Dr. Md. Golam Rabbani	Head, Climate Bridge Fund Secretariat, BRAC Centre, Dhaka, Bangladesh	Adaptation technologies/practices to the adverse effects of climate change in the agriculture sectors of coastal region of Bangladesh
8	Dr. Namdev V. Mhaskar	AICRP on IFS, Regional Agricultural Research Station, Dr. B.S. Konkan Krishi Vidyapeeth Karjat, Maharashtra, India	Tuber crops in Konkan: An alternative crops for climate smart, sustainable, economical viable and nutritionally rich
9	Dr. D. Barman	ICAR Central Research Institute for Jute and Allied Fibres, Barrackpore, West Bengal, India	Trend analysis of rainfall and temperature of coastal districts of West Bengal for computing irrigation water requirement of jute crop using CROPWAT model
10	Dr. M. L. Roy	ICAR Central Research Institute for Jute and Allied Fibres, Barrackpore, West Bengal, India	Effect of climate variability on jute-based cropping system as perceived by the agricultural scientists
11	Miss Lal Muansangi	ICAR- National Dairy Research Institute, Eastern Regional Station Kalyani, West Bengal, India	Climate resilience livestock production in coastal ecosystem of India
12	Dr. Bappa Das	ICAR-Central Coastal Agricultural Research Institute, Old Goa, Goa, India	Assessment of climate change vulnerability in coastal districts of India

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S. No.	Name	Affiliation	Title
13	Miss Zahra Noorisameleh	University of Toronto, Scarborough, Toronto, Ontario, Canada	The challenge of climate change in agriculture management in the Persian Gulf-Oman Sea coasts in Iran

Poster Presentations—Day 2: March 17, 2021
Chairman: Dr. B. Saha, Principal Scientist, ICAR-National Institute of Natural Fibre Engineering and Technology, Kolkata, West Bengal, India
Co-Chairman: Dr. S. K. Jena, Principal Scientist, ICAR-Indian Institute of Water Management, Bhubaneshwar, Odisha, India

S. No.	Name	Affiliation	Title
14	Miss Sangeeta Kujur	Department of Agronomy, College of Agriculture, Indira Gandhi Krishi Vishwavidyalaya, Raipur, Chhattisgarh, India	Planting date and nutrient management: adaptation strategies for rice production in coastal areas under present climate change
15	Dr. Dimpal Sanghvi	M. G. Science Institute, Navarangpura, Ahmedabad, Gujarat, India	Microhabitat preferences of Rhodophyta on shore platform of Dwarka, Gujarat, India
16	Dr. N. M. Alam	ICAR Central Research Institute for Jute and Allied Fibres, Barrackpore, West Bengal, India	Probability analysis of weekly rainfall for jute crop planning in North 24 Parganas, West Bengal

Theme V: Climate change and disaster occurrence, its impact, IT & remote sensing for rapid dissemination and early warning protocols, mainstreaming climate change policies for regional integration

Session II: Meteorological, hydrological & geological disasters: characteristics and likely impact on population dynamics

Invited Lectures & Oral Presentations—Day 1: March 16, 2021

Chairman: Dr. M. V. K. Sivakumar, Former Director, Climate Prediction & Adaptation Branch, World Meteorological Organization, Geneva, Switzerland

Sl No.	Name	Affiliation	Title
1	Dr. D. R. Pattanaik	Scientist F & Head, Numerical Weather Prediction Division, Indian Meteorological Department, New Delhi, India	Climate change and extreme weather events
2	Dr. Pushpanjali	ICAR-Central Research Institute for Dryland Agriculture, Hyderabad, Telangana, India	Soil management interventions in cyclone affected coastal areas

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Sl No.	Name	Affiliation	Title
3	Dr. A. Gopala Krishna Reddy	ICAR-Central Research Institute for Dryland Agriculture, Hyderabad, Telangana, India	Impacts of cyclones on perennial horticulture crops and sustainable management strategies for livelihood security

Theme V: Climate change and disaster occurrence, its impact, IT & remote sensing for rapid dissemination and early warning protocols, mainstreaming climate change policies for regional integration

Session III: Disaster management: IT and remote sensing—scope for preparedness, early warning models to combat adverse impact, researchers' code as per UN guidelines

Invited Lectures & Oral Presentations—Day 1: March 16, 2021

Chairman: Dr. Balakrishnan Nair T. M., Group Director & Scientist-G, National Centre for Ocean Information Services (INCOIS) Hyderabad, Telangana, India

S. No.	Name	Affiliation	Title
1	Dr. T. M. Balakrishnan Nair	Group Director & Scientist-G, National Centre for Ocean Information Services (INCOIS) Hyderabad, Telangana, India	Advances in early warning systems for oceanogenic hazards in Indian Ocean region
2	Dr. Dibyendu Dutta	General Manager, Regional Remote Sensing Centre-East, National Remote Sensing Centre (ISRO), New Town, Kolkata West Bengal, India	Evolution and morphodynamics of Bhasan char island using multi-temporal satellite remote sensing data and cyclone vulnerability
3	Dr. K. H. V. Durga Rao	Head, Disaster Management Support Group, Remote Sensing Applications National Remote Sensing Centre (NRSC), ISRO, Hyderabad, India	Flood monitoring, mapping and modelling using space data
4	Dr. Dilip Kumar Mandal	ICAR- National Dairy Research Institute, Eastern Regional Station Kalyani, West Bengal, India	Animal shelter designs and construction in tropical cyclone prone coastal areas as disaster management strategies for livestock

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S. No.	Name	Affiliation	Title
5	Dr. Shalini Saxena	Mahalanobis National Crop Forecast Centre, Pusa Campus, New Delhi, India	Satellite based assessment of agricultural drought in coastal states of India: Comparison of 2018 with 2020

Theme VI: Technology impact on the socio-economic, gender issues, ICT application to assess and monitor, strengthening market linkage and business models on post-harvest and value chain for livelihood security and employment generation

Session I: Technology impact on socio-economy: food & income security and market linkages

Invited Lectures & Oral Presentations—Day 2: March 17, 2021

Chairman: Dr. Barun Deb Pal, Project Manager - South Asia, International Food Policy Research Institute, New Delhi, India

Co-Chairman: Dr. Souvik Ghosh, Professor, Palli Siksha Bhavana (Institute of Agriculture), Visva-Bharati University, Sriniketan, West Bengal, India

Dr. Subhasis Mandal, Principal Scientist, Division of Social Science Research, ICAR-Central Soil Salinity Research Institute, Karnal, Haryana, India

S. No.	Name	Affiliation	Title
1	Dr. Nidhi Nagabhatla	Adjunct Professor, McMaster University, Canada and Fellow at The United Nations University Institute on Comparative Regional Integration Studies (UNU-CRIS), Belgium	Sustainable development and coastal ecosystems: agenda for change, innovations and impact investment
2	Dr. Suresh Pal	Director, ICAR-National Institute of Agricultural Economics and Policy Research, New Delhi, India	Development of coastal agro-ecosystems: Role of technology and policy
3	Dr. Anjani Kumar	Senior Research Fellow, International Food Policy Research Institute, Pusa, New Delhi, India	Understanding the diffusion and impact of agricultural technologies in India

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S. No.	Name	Affiliation	Title
4	Dr. Shamna. A	ICAR Central Research Institute for Jute and Allied Fibres, Barrackpore, West Bengal, India	Impact of jute production technological interventions on farm women empowerment
5	Dr Gobinda Ch. Acharya	Central Horticultural Experiment Station ICAR-IIHR, Bhubaneswar, Odisha, India	Neglected edible leafy vegetables-road to nutritional security
6	Dr. S. K. Jha	Principal Scientist, ICAR Central Research Institute for Jute and Allied Fibres, Barrackpore, West Bengal, India	Impact of improved jute cultivation practices in jute farmers' economy
7	Dr. Subhasis Mandal	Principal Scientist, Division of Social Science Research, ICAR-Central Soil Salinity Research Institute, Karnal, Haryana, India	Food security contribution of coastal agriculture in India – Status and policy perspectives

Poster Presentations—Day 2: March 17, 2021
Chairman: Dr. S. K. Jha, Principal Scientist, ICAR Central Research Institute for Jute and Allied Fibres, Barrackpore, West Bengal, India
Co-Chairman: Dr. Subhasis Mandal, Principal Scientist, Division of Social Science Research, ICAR-Central Soil Salinity Research Institute, Karnal, Haryana, India

S. No.	Name	Affiliation	Title
8	Mr. Ganesh Das	Department of Agricultural Extension, Palli Siksha Bhavana, Visva-Bharati, Sriniketan, Birbhum, West Bengal, India	Identifying the factors influencing farm women's information network output
9	Dr. S. V. Patil	College of Fisheries, Dr. B.S. Konkan Krishi Vidyapeeth, Ratnagiri, Maharashtra, India	Has brackishwater shrimp farming development been gender neutral: A case of Maharashtra?
10	Dr. Manohara K. K.	ICAR Central Coastal Agricultural Research Institute, Ella, Old Goa, Goa India	Popularizing drought-tolerant rice variety Sahbhagi Dhan in upland areas of Goa state through Front Line demonstrations - An impact assessment

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S. No.	Name	Affiliation	Title
11	Dr. Riya Sarkar	Faculty Centre for Integrated Rural Development and Management, Ramakrishna Mission Vivekananda Educational and Research Institute, Narendrapur, Kolkata, West Bengal, India	Contribution of women in agriculture - Insights from coastal West Bengal
12	Dr. P. Anithakumari	ICAR Central Plantation Crops Research Institute, Regional Station, Kayamkulam, Kerala, India	Impact of technology integration among women farmers of coastal district, Alappuzha, Kerala
13	Mr. Aminul Haque Mistry	Assistant Professor, Department of Geography, Sagar Mahavidyalaya, South 24 Parganas, West Bengal, India	Soil salinity effects on traditional agricultural practice in three costal, rural villages of Indian Sundarban, West Bengal

Theme VI: Technology impact on the socio-economic, gender issues, ICT application to assess and monitor, strengthening market linkage and business models on post-harvest and value chain for livelihood security and employment generation

Session II: Innovative ICT applications and effectiveness of on-going government schemes and their contributions

Invited Lectures & Oral Presentations—Day 2: March 17, 2021

Chairman: Dr. Saravanan Raj, Director (Agricultural Extension), National Institute of Agricultural Extension Management (MANAGE), Hyderabad, Telangana, India

Co-Chairman: Dr. Sankar Acharya, Former Director, Dept. of Extension Education, Bidhan Chandra Krishi Viswavidyalaya, Mohanpur, West Bengal, India

S. No.	Name	Affiliation	Title
1	Prof. Sankar Acharya	Former Director, Dept. of Extension Education, Bidhan Chandra Krishi Viswavidyalaya, Mohanpur, West Bengal, India	Decision support system (DSS) for monitoring coastal agro-ecosystem: concept, scope, and application

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S. No.	Name	Affiliation	Title
2	Dr. Sarvanan Raj	Director (Agricultural Extension), National Institute of Agricultural Extension Management (MANAGE), Hyderabad, Telangana, India	ICTs based fisheries value chain extension by startups and aquapreneurs

Theme VI: Technology impact on the socio-economic, gender issues, ICT application to assess and monitor, strengthening market linkage and business models on post-harvest and value chain for livelihood security and employment generation

Session III: Business models on value chain and post-harvest use: FPOs, Impact on income & livelihood security, employment opportunities in rural sectors

Invited Lectures & Oral Presentations—Day 3: March 18, 2021

Chairman: Dr. P. S. Birthal, National Professor, ICAR-National Institute of Agricultural Economics and Policy Research, New Delhi, India

Co-Chairman: Dr. M. Ismail Hossain, Professor, Department of Agribusiness and Marketing, Bangladesh Agricultural University, Mymensingh, Bangladesh

S. No.	Name	Affiliation	Title
1	Prof. Mohammad Ismail Hossain	Department of Agribusiness and Marketing, Bangladesh Agricultural University, Mymensingh, Bangladesh	Analysis of seaweed value chain to improve coastal livelihood and blue economy of Bangladesh
2	Dr. Parappurathu Shinoj	Senior Scientist, ICAR-Central Marine Fisheries Research Institute, Kochi, Kerala, India	Strengthening agricultural & allied produce value chains for income and livelihood security in coastal ecosystems
3	Dr. M. S. V. H. Priyashadi	Department of Fisheries and Aquaculture, Faculty of Fisheries and Marine Sciences & Technology, University of Ruhuna, Matara, Sri Lanka	Value chain of the marine ornamental reef fish trade in Trincomalee, eastern Sri Lanka

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S. No.	Name	Affiliation	Title
4	Dr. P. P. Shameena Beegum	ICAR-Central Plantation Crops Research Institute, Kasaragod, Kerala, India	Bean to bite chocolate: a model value chain for cocoa growers
Poster Presentations—Day 2: March 17, 2021 **Chairman**: Dr. S. K. Jha, Principal Scientist, ICAR Central Research Institute for Jute and Allied Fibres, Barrackpore, West Bengal, India **Co-Chairman**: Dr. Subhasis Mandal, Principal Scientist, Division of Social Science Research, ICAR-Central Soil Salinity Research Institute, Karnal, Haryana, India			
S. No.	Name	Affiliation	Title
5	Mr. Amitava Panja	ICAR-National Dairy Research Institute, Karnal, Haryana, India	Entrepreneurial behaviour of agricultural input dealers in West Bengal
6	Dr. Namdev V. Mhaskar	AICRP on IFS, Regional Agricultural Research Station, Dr. B.S. Konkan Krishi Vidyapeeth, Karjat, Maharashtra, India	Creation of employment opportunity through organizing training programmes on traditional and diversified value added products of tuber crops
7	Mr. S. K Gorai	ICAR-Indian Agricultural Research Institute, New Delhi, India	Group dynamics effectiveness among the members of farmer producer organizations in West Bengal
8	Dr. P. E. Jeyya Jeyanthi	Extension, Information and Statistics Division, ICAR-Central Institute of Fisheries Technology, Kochi, Kerala, India	Labour productivity in trawl fishing of Kerala, India

Dr. J.S.P. Yadav Best Paper Award Presentation

Day 3: March 18, 2021 Time: 14:30–15:42 IST (Webinar Room—I)

Chairman: Dr. N. K. Tyagi, Former Member, ASRB, New Delhi and Former Director, ICAR-Central Soil Salinity Research Institute, Karnal, Haryana, India

S. No.	Name	Affiliation	Title of the paper	Time
1	Md. Tarikul Islam	Institute of Water Modelling, Mohakhali DOHS, Dhaka, Bangladesh	Groundwater salinity modelling in the South West Region of Bangladesh considering climate change by Md. Tarikul Islam, Bushra Monowar Duti, Md. Rezaul Hasan, Md. Atiqur Rahman and S. M. Sahabuddin published in 2020 in Volume 38 No. 2 at pages 76 to 84 of the Journal of the Indian Society of Coastal Agricultural Research	17:00–17:30 IST

ISCAR Best Paper Presentation Award for Early Career Researcher

Best Paper Award Presentation—Day 3: March 18, 2021

Chairman: Dr. S. K. Sanyal, Former Vice Chancellor, Bidhan Chandra Krishi Viswavidyalaya, Mohanpur, West Bengal, India

Co-Chairman: Dr. J. K. Sundaray, Principal Scientist & Head, Fish Genetics & Biotechnology Division, ICAR-Central Institute of Freshwater Aquaculture, Bhubaneswar, Odisha, India

Dr. J. C. Tarafdar, Former Principal Scientist, ICAR-Central Arid Zone Research Institute, Jodhpur, Rajasthan, India

S. No.	Name	Affiliation	Title
1	Amrutha S. Ajayan	Department of Soil Science and Agricultural Chemistry, College of Agriculture, University of Agricultural Sciences, Dharwad, Karnataka, India	Green synthesized zinc oxide nanoparticles as nutrient source for maize (*Zea mays* L.) grown on calcareous Vertisol

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S. No.	Name	Affiliation	Title
2	Gopal Ramdas Mahajan	ICAR-Central Coastal Agricultural Research Institute, Old Goa, Goa, India	Hyperspectral remote sensing-based prediction of the soil pH and salinity in the soil to water suspension and saturation paste extract of salt-affected soils of the west coast region
3	Peter T. Birteeb	ICAR-Indian Agricultural Statistics Research Institute, Pusa, New Delhi, India & University for Development Studies, Nyankpala Campus, Tamale, Ghana, Africa	Development of selection index for agroforestry systems
4	S. Remya	ICAR-Central Institute of Fisheries Technology, Kochi, Kerala, India	Development of chitosan based novel antioxidant film for fish packaging application
5	S. Mullick	University of Calcutta, Kolkata, West Bengal, India	Spatio-temporal change in salinity dynamics in different land-use systems of climatically vulnerable Indian Sundarbans
6	Sathiyabama N	Pandit Jawaharlal Nehru College of Agriculture & Research Institute, Karaikal, Puducherry, India	Nitrogen dynamics in organically cultivated paddy soils of coastal Cauvery deltaic region

Proceedings of the ISCA Webinar

ISCAR

Summary of Proceedings of the ISCA Webinar—International Symposium on Coastal Agriculture: Transforming Coastal Zone for Sustainable Food and Income Security

March 16–19, 2021

The International Symposium on Coastal Agriculture (ISCA Webinar): Transforming Coastal Zone for Sustainable Food and Income Security was organized by Indian Society of Coastal Agricultural Research (ISCAR) in collaboration with ICAR-Central Soil Salinity Research Institute, Karnal, India, during March 16–19, 2021, in virtual mode.

T. D. Lama et al. (eds.), *Transforming Coastal Zone for Sustainable Food and Income Security*, https://doi.org/10.1007/978-3-030-95618-9

Inauguration, Themes and Sessions

The symposium was inaugurated by Dr. Trilochan Mohapatra, Secretary DARE & DG, ICAR, New Delhi, India, as Chief Guest in the presence of Dr. Luke York, Counsellor (Agriculture) Australian High Commission, New Delhi, India, as Guest of Honour. Dr. Shaikh Mohammad Bokhtair, Executive Chairman, Bangladesh Agricultural Research Council (BARC), Dhaka, Bangladesh, Dr. S.K. Chaudhari, DDG (NRM), ICAR, New Delhi, India, and Dr. A.R. Khan, Chief General Manager, NABARD, Kolkata, West Bengal, India, were the Special Guests. The welcome address was delivered by Dr. P. C. Sharma, Director, ICAR-CSSRI, Karnal, Haryana, India, and the opening remarks by Dr. H.S. Sen, President, ISCAR, Canning Town, West Bengal, India.

The symposium was held across 4 days with different sessions under each theme that dealt with various aspects of coastal agriculture as follows:

Theme I: *Systems approach for coastal zone development: agriculture, horticulture & plantation crops and their tolerance to biotic & abiotic stresses*

- Session I: Agricultural crop improvement including biotechnological approaches, genetic resource management, abiotic stress tolerance
- Session II: Agricultural crop management and cropping system intensification
- Session III: Horticulture & plantation crops and grassland ecosystems: crop improvement including biotechnological approaches and their management
- Session IV: Plant protection measures: use of nanotechnology and integrated practices including natural therapies

Theme II: *Technological developments in fisheries, livestock and poultry management, water pollution trends, and ecological security for coral reefs, farming system modules*

- Session I: Fresh and brackish water aquaculture: technological innovations and emerging options including fish health and water management
- Session II: Estuarine and marine fisheries: resource management & technological innovations, fish processing technologies
- Session III: Water pollution: sedimentation, eutrophication & formation of dead-end zones—threat to fisheries, corals & coral reefs
- Session IV: Livestock& poultry: technological innovations & options for management and production developments
- Session V: Farming system approach: rice-cum-fish culture & homestead production system including social-forestry

Theme III: *Natural resources and carbon flow dynamics vis-à-vis soil quality, water use trends, and integrated water management including ground water and farm machinery developments*

- Session I: Natural resources: assessment and degradation, management

- Session II: River flow dynamics, bank erosion, surface & underground water flow modelling vis-à-vis climate change
- Session III: Jute geo-textiles and its applications in coastal ecosystems
- Session IV: Carbon dynamics and C sequestration in coastal ecosystems vis-à-vis soil quality
- Session V: Coastal water use trends—sources and availabilities, integrated strategies for irrigation & drainage, and other location-specific irrigation practices including poor quality water use
- Session VI: Farm machinery development compatible with small land holdings and for women-friendly use

Theme IV: *Forestry & biodiversity and spatio-temporal changes, integrated forest management policy for ecological sustenance and eco-tourism for livelihood*

- Session I: Coastal forestry: mangrove dynamics and temporal changes, and biodiversity including algal species
- Session II: Eco-tourism for livelihood security

Theme V: *Climate change and disaster occurrence, its impact, IT & remote sensing for rapid dissemination and early warning protocols, mainstreaming climate change policies for regional integration*

- Session I: Climate change trends a dynamic phenomenon and its impact on agriculture, fisheries, forestry & animal husbandry
- Session II: Meteorological, hydrological & geological disasters: characteristics and likely impact on population dynamics
- Session III: Disaster management: IT and remote sensing—scope for preparedness, early warning models to combat adverse impact, researchers' code as per UN guidelines

Theme VI: *Technology impact on the socio-economic, gender issues, ICT application to assess and monitor, strengthening market linkage and business models on post-harvest and value chain for livelihood security and employment generation*

- Session I: Technology impact on socio-economy: food & income security and market linkages
- Session II: Innovative ICT applications and effectiveness of on-going government schemes and their contributions
- Session III: Business models on value chain and post-harvest use: FPOs, Impact on income & livelihood security, employment opportunities in rural sectors

ISCAR has been organizing a lecture in memory of Padma Shri Late Dr. J. S. P. Yadav, the founder President of the society, a doyen in soil science research & management and recognized in the soil science fraternity eminent soil scientist, since the last two symposiums. During this symposium on March 16, 2021, the 3rd Dr. J. S. P. Yadav Memorial lecture was delivered by Dr. A. K. Singh, Former VC, Rajmata Vijayaraje Scindia Krishi Vishwa Vidyalaya, Gwalior, India, and Former

DDG (NRM), ICAR, New Delhi, India on "Impact of Climate Change on Coastal and Island Ecosystems".

During the International Symposium, eleven plenum lectures were delivered by eminent researchers as follows.

Speakers	*Topic*
Professor Timothy John Flowers, School of Life Sciences, University of Sussex, Brighton, United Kingdom	How can eHALOPH, a database of salt-tolerant plants; help your research?
Dr. Michael Phillips, Director, Aquaculture & Fishery Sciences, WorldFish Center, Malaysia	The future of fish agri-food systems
Dr. M. Vijay Gupta, Former Assistant Director General, International Relations and Partnerships, WorldFish, Malaysia	Improving food and income security of coastal communities through fisheries and aquaculture management
Dr. Abdelbagi M. Ismail, Principal Scientist and IRRI Representative, Nairobi, Kenya, Africa	Agricultural systems transformation for food and income security in coastal zones
Professor Rattan Lal, Laureate World Food Prize 2020 and Director, Carbon Management and Sequestration Center, Ohio State University, Columbus,Ohio, USA	Impact of soil carbon dynamics on the environment and management of improved soil health in the coastal ecosystems
Dr. N. H. Ravindranath, Professor (Retd.), Centre for Sustainable Technologies, Indian Institute of Science, Bangalore, India	Natural ecosystems, biodiversity and climate change
Dr. Anupma Sharma, Scientist-F, Groundwater Hydrology Division, National Institute of Hydrology, Roorkee, India	Water management strategies to mitigate saltwater intrusion with special reference to coastal Saurashtra
Professor T. G. Sitharam, Director, Indian Institute of Technology, Guwahati, Assam, India	Water resource potential & uses along the coastal zone: Role of coastal reservoirs
Dr. M. M. Qader Mirza, Adjunct Professor, Department of Physical and Environmental Sciences, University of Toronto, Scarborough, Toronto, Ontario, Canada	Coastal agriculture under future climate change: Can developing countries adapt?
Dr. Sanjay K Srivastava, Chief of Disaster Risk Reduction at UN Economic and Social Commission for Asia and Pacific, Bangkok, Thailand	Building the coastal resilience in Asia and the Pacific: Opportunities and challenges
Dr. Pramod Kumar Joshi, Former Director, South Asia, IFPRI, New Delhi, India	Coastal ecosystems – explore value chains, processing and exports for poverty alleviation

A panel discussion on "Addressing coastal problems for improving economy and livelihood security" was also held for coming out with an action plan to address the technology and socio-economic, policy and institutional issues for removing the bottlenecks for improving the economy and livelihoods of the farmers in the coastal regions. The session was chaired by Dr. S. K. Chaudhari, DDG (NRM), ICAR, and there were 26 intervention areas addressed by eminent scientists specializing in different key areas identified. The recommendations of the discussion have been included in this proceedings under the relevant themes.

Awards in Different Sections

During the symposium, various honours and awards were also conferred by the society to outstanding researchers working in the field of coastal agriculture. The ISCAR fellow award was conferred to Dr. Gouranga Kar, Director, ICAR-Central Research Institute for Jute and Allied Fibres, Barrackpore, West Bengal, Dr. Sukanta Kumar Sarangi, Principal Scientist, ICAR-Central Soil Salinity Research Institute, RRS, Canning Town, West Bengal, and Dr. S.V. Sawardekar, Associate Professor, College of Agriculture, Dr. B. S. Konkan Krishi Vidyapeeth, Dapoli, Maharashtra. The Dr. J. S. P. Yadav Best Paper Award for the years 2018–2020 was conferred to Md. Tarikul Islam, Bushra Monowar Duti, Md. Rezaul Hasan, Md. Atiqur Rahman and S. M. Sahabuddin for their research paper entitled “Groundwater Salinity Modelling in the South West Region of Bangladesh Considering Climate Change” published in 2020 in the Journal of the Indian Society of Coastal Agricultural Research, Volume 38 No.2, page 76 to 84.

The Dr. H. S. Sen Best Poster Presentation Award was awarded to M. N. Islam, R. W. Bell, E. G. Barrett-Lennard and M. Maniruzzaman for their paper entitled “The Combination of Shallow Surface and Subsurface Drains Alleviates Waterlogging and Salinity in a Clay-Textured Soil and Improves Sunflower (*Helianthus annuus* L.) yield in the Ganges Delta” adjudged as the Best Poster Presented during the Symposium. Besides four other best poster presentation awards were also given to the participants (“Genomic and Transcriptomic Approaches to Accelerate Salinity Stress Tolerance in Jute (*Corchorus spp.*)” by Subhojit Datta, D. Saha, P. Satya, A. Anil Kumar, J. Mitraand G. Kar; “Photo-Protective Effect of Cuttlefish Ink Melanin on Human Hair” by P. K. Binsi, P. Muhamed Ashraf, U. Parvathy and A. A. Zynudheen; “Assessment of Long Term Trends in Stream Flow of River Basins Flowing in the West Coast of India by Sujeet Desai, Bappa Das, G. B. Sreekanth and Gopal Mahajan;“Popularizing Drought-Tolerant Rice Variety Sahbhagi Dhan in Upland Areas of Goa State through Front Line Demonstrations - An Impact Assessment” by K. K. Manohara, N. P. Mandal and N. P. Singh).

The Society also confers best paper presentation award to early career researchers (below 40 years). During the International Symposium on Coastal Agriculture (ISCA Webinar - 2021), the ISCAR Best Paper Presentation Award for Early Career Researcher Award was conferred jointly to Ms. S. Remya, ICAR-Central Institute of Fisheries Technology, Cochin, Kerala for the paper entitled “Development of Chitosan Based Novel Antioxidant Film for Fish Packaging Application" co-authored with C.O. Mohan, J. Bindu & C.N. Ravishankar and to Ms. Amrutha S.

Ajayan, Department of Soil Science and Agricultural Chemistry, College of Agriculture, University of Agricultural Sciences, Dharwad for the paper entitled “Green Synthesized Zinc Oxide Nanoparticles as Nutrient Source for Maize (*Zea mays* L.) Grown on Calcareous Vertisol” co-authored with N.S. Hebsur.

At the end, during the plenary session, the summary of the deliberations and recommendations were presented by the rapporteurs for the different sessions.

The symposium was attended by more than 300 delegates comprising researchers, academicians and students from Australia, UK, USA, Bangladesh, Canada, Kenya, Ghana, Thailand, Malaysia, Poland, Italy, Philippines, New Zealand and various parts of the coastal states of India. The Symposium was supported by the Indian Council of Agricultural Research, Australian Centre for International Agricultural Research (ACIAR), National Jute Board and NABARD.

The recommendations that emerged out of the deliberations during the symposium are given below.

Recommendations Theme-Wise

Theme I: ***Systems approach for coastal zone development: agriculture, horticulture & plantation crops and their tolerance to biotic & abiotic stress***

- eHALOPH, database of salt-tolerant halophytes can be used for screening of different salinity tolerance plant types and plant breeding.
- Salinity tolerance (CR405, BR47, BINA Dhan 8), submergence tolerance (Swarna-sub1, CR1009-sub1, BR11-sub1, Gosaba 5, Gosaba 6, etc.), and drought tolerance (Sahbhagi Dhan) rice variety has been developed for coastal South Asian region. Emphasis to be given multiple stress-tolerant rice varieties that fits with the best management practices.
- Modern breeding tools to be employed to develop the sustainable resilient cropping system for aggravated climatic scenarios to ensure regular income to the farmers.
- A complete profile of salt-tolerant mechanism at different stages of rice such as seed germination, seedling and at flowering (reproductive) to be developed at molecular, cellular and morphological level with the application of modern bio technologies.
- Emphasis to be given to the reproductive stage as it translates into yield through ascertaining mechanisms, developing exclusive molecular markers and to apply them in practical breeding.
- The mining of elite genes is needed from gene pools of different sources to facilitate gene pyramiding to confer resistance to salt tolerance.
- The DNA barcoding with efficient molecular markers to be extended to establish the claim right against bio piracy.
- Molecular assisted breeding, QTL mapping, etc., to be explored to develop precision breeding.

- To cope with the situations of rainfall variability, waterlogging, freshwater scarcity in coastal areas, location-specific land use, on-farm water harvesting, improved drainage, alternative water use (such as brackish water), multiple use of water, crop diversification, multiple crop cultivation besides developing tolerant crop varieties under different scenario is essential.
- The avenues to enhance vegetable production using floating gardens and embankment farming to be promoted.
- Large number of horticulture crops including fruits, vegetables, roots and tuber crops, plantation crops, medicinal and aromatic crops, spices and flower crops are grown commercially in the coastal ecosystem. Technological interventions to be carried out to address the challenges faced by the crops and to achieve sustainable productivity in the coastal ecosystem.
- In mango variety Alphonso, concentrated in Konkan Region of Maharashtra and having unique export quality, rootstock breeding work is to be explored with the wild species of *Mangifera* available in Western Ghats.
- In cyclone prone areas, establishment of coconut-based agroforestry system in coastal lines could be effective in protecting the vulnerable coastal ecosystem and to reduce the damage on crops and property.
- In cashew, mass production of quality planting material of early bearing dwarfing genotype through soft wood planting technique and high density planting to enhance cashew production for meeting the growing domestic demand as well as to meet the requirement of the industry.
- While embark on import of advanced new varieties/clonal seeds from abroad, performance of such varieties under local conditions may be evaluated, and package of good practices may also be disseminated for adoption to capture genetic potentials.

Theme II: ***Technological developments in fisheries, livestock and poultry management, water pollution trends, and ecological security for coral reefs, farming system modules***

- The rich species diversity of Indian waters (more than 1100 taxa) is a common feature keeping Indian situation at better position with regard to the marine fishery resources. The increasing demand for fish for consumption keeps the challenges towards maintaining the sustainability in resource, production, supply and utilization.
- Species and farming system diversification in aquaculture is the need of the hour to meet up the increasing demand of fish with the accelerating population, on a sustainable mode.
- Promotion of the native shrimp species such as Indian white shrimp, *Penaeus indicus* as a complimentary species to *P. vannamei* through stock improvement by selective breeding and large-scale seed production is required for the growth trajectory of Indian shrimp farming sector.
- Low input-based technologies should be popularized among resource-poor small and marginal coastal shell fish and finfish farmers.

- Development and popularization of location-specific farming models with locally available fish species, using cost-effective indigenous formulated feeds for improvement of livelihood of coastal farmers.
- The Eco-labelling and certification of marketed fish and fishery products to flag and extend the sustainability concept towards the consumers.
- Emphasis to be given in innovations in fish processing and value addition sectors like micro-encapsulated sardine oil, seaweed enriched products, nutritional mix from fish scale collagen peptide, encapsulated fish calcium, chitosan-based hydro-alcoholic sanitizer, ready to serve fish products, fish curry in retort pouches, instant fish gravy powder, fish soup powder, extruded fish products, cured, smoked and dried products, fish pickle, canned fish products, fish by-products, battered and breaded products, etc.
- Advocate developing cost-effective newer and modern packaging methods like modified atmospheric packaging (MAP), SMART packaging, active packaging (AP), sensor-based film packaging to detect the spoilage and to improve shelf life of fishes.
- To overcome risks emanating out of disasters including pandemics like COVID-19, there is a need for policy support the fishers through immediate relief schemes, online fish marketing channels, special cash package for fishermen families, moratorium for credit payments, inclusion of fishing and allied activities under MGNREGS, priority-based support for traditional fishers, fisherwomen, mechanized fishers and processors.
- Biosensors for water pollution monitoring using enzyme-mimic nano systems for continuous monitoring of different ecologically and economically important aquatic ecosystems for emerging toxic pollutants and micro-plastics on real-time basis.
- Climate change *vis-a-vis* global warming, sea level rise, extreme events like tsunami, cyclone and sea-surges and anthropogenic activities leading to coastal erosion and consequent sedimentation has got an indelible impact on coral growth and sustenance which ultimately causes the destruction coral reef ecosystem. Thus, a comprehensive policy and planning is needed to protect this important natural resource.
- The rice-fish-horticulture-livestock-based integrated farming technologies/models and similar models on rice- fish/duck farming need to be popularized in the suitable coastal areas in the country. Similarly, various homestead farming system models being practiced in Kerala and West Bengal in India need dissemination in other coastal areas.
- The institutional support in terms of fund, quality inputs, capacity building and proper marketing is vital to boost large-scale adoption of this farming system.
- Region-specific livestock breeding to be encouraged to improve animal activity in island ecosystem.
- Region-specific fodder cultivation to be encouraged to enhance feed security.
- Sero monitoring and surveillance are to be strengthened keeping in view to endemic and emerging diseases of livestock and poultry.

- Inclusion of alternate poultry species like Japanese Quails, ducks, turkey and guinea fowl in coastal region.

Theme III: ***Natural resources and carbon flow dynamics vis-à-vis soil quality, water use trends and integrated water management including ground water and farm machinery developments***

- The interaction of climate change and intensifying land use in the coastal zone is driving rapid change in coastal rivers, estuaries and the benefit they provide in the ecosystem services. Careful monitoring is essential to understand long-term trends as the basis for current management and future planning of coastal water resources.
- Attention to be given to decline in groundwater quality due to sea-level rise as well as saline water intrusion. More focus is needed on research, monitoring and management of coastal salinity and seawater intrusion.
- Conjunctive use of surface and groundwater resources, techniques such as managed aquifer recharge and riverbank filtration in mitigating salinity and maintaining groundwater quality for human use.
- Integrated modelling of surface—groundwater interactions is required for planning and design of management interventions and to understand long-term trends due to changing climate and water use.
- Land use planning for agriculture in the coastal zone must take account of both field and landscape scale impacts and profitability. Land suitability assessments across scales are needed to increase productivity within environmental limits.
- Concepts of crop water profitability and nutritional water productivity, as well as economic profitability, will help in assessing the real benefits and costs of different land uses.
- The mechanism of long-term soil organic matter stabilization in coastal region is thought to be through physical protection by micro-aggregate, chemical protection by binding with oxyhydrates and to molecular recalcitrance of hydrophobic particulate organic matter contributing to C sequestration in paddy soils.
- To reduce transport of sediments, plant nutrients and other pollutants, rehabilitation of upper riverine through introduction of agroforestry, conservation agriculture, regenerative agriculture, etc., is needed.
- Coastal natural vegetation (mangrove, marsh and seagrass) captures and holds a significant amount of global carbon, known as blue carbon. Continuous human intervention (like conversion to croplands, pollution, oil-spill and erosion) has degraded these ecologies a lot in last few decades. Proper conservation measures are required for their preservation.
- Conversion of natural vegetation to cultivation always results in soil more of a source of carbon than sink.
- The components of tree and shrubs in farming system and perennialization of coastal agriculture are essential to make the coastal ecosystem more resilient.
- Agriculture subsidies to shift towards support for more ecological production systems that enhance soil C, water quality, animal welfare and biodiversity protection.

- There is a need of women-friendly improved farm implements for enhancing work efficiency and reduction in drudgery of farm women engaged in different agricultural operations starting from sowing to harvesting and post-harvest operations in coastal region.
- The fibre crop, jute, is being pushed to the marginal low-productive lands in order to make more room for food crops; the highly versatile and environmental-friendly natural fibre has a great scope to adopt in coastal saline region.
- A feasible strategy for realizing the potential of degraded coastal land appears to be intensification through integrated farming of agri-aquaculture systems by harvesting a portion of the huge available surplus run-off by land shaping and using it for supplemental irrigation at the critical crop growth stages.

Theme IV: ***Forestry & biodiversity and spatio- temporal changes, integrated forest management policy for ecological sustenance and eco-tourism for livelihood***

- Using remote sensing in estimating mangroves is essential which makes easier to convince policy makers for Government institutions contributions in conservation and sustainable management of mangroves.
- Emphasis to be given on mangrove dynamics vis-a-vis sediment supply in relation to continental drift and sea level rise using palynological data of mangrove species, namely *Nypa, Rhizophora, Avicennia*, etc.
- Community engagement for mangrove restoration and conservation based on case studies from Andhra Pradesh carried out by MSSRF in collaboration with Andhra Forest Department.
- Promote agro eco-tourism by developing "Bio Villages" in coastal areas to conserve local biodiversity, tradition and culture and to help in livelihood sustainability by integrating agriculture and allied activities with tourism.
- The need for publishing in local language for effective awareness generation tool is essential.
- Nature base solution with biosheilds with local communities be the nature's own solutions to natural hazards—help to protect people from the danger of floods, storms, and sea level rise, build resilience, also increase biodiversity, food, and provide other livelihood resources.

Theme V: ***Climate change and disaster occurrence, its impact, IT & remote sensing for rapid dissemination and early warning protocols, mainstreaming climate change policies for regional integration***

- Integrated assessments of climatic change in coastal areas are crucial to support the management policy development in order to achieve sustainability in coastal agriculture under climate change.
- Comprehensive agrometeorological adaptation policy guidelines, focusing on preparedness and adaptation measures to support sustainable agricultural development are needed to cope with the impacts of climate change.
- Upscaling of the proven resilient technologies to enable farmers to reduce the yield losses and enhance their adaptive capacity against climatic variability in coastal regions.

- To cope up the natural calamities, several climate change adaptation measures at different time scales need to be evolved along with mitigation strategies including flood tolerant varieties, real-time agroadvisories, preparedness, rehabilitation, sub-surface drainage, etc.
- The impact of change in sea surface temperature and coral bleaching need to be studied in details along the coastal zones which has direct relevance with the fish catch.
- Tuber crops to be promoted to the poor people as an alternative crop in Konkan, the coastal belt of Maharashtra, India as climate smart, sustainable, economically viable and nutritionally rich food crop.
- Adopting several strategies like use of locally adapted breeds/varieties, improved housing and diet, better herd and grassland management, genetic improvement for heat tolerance in animals, smart villages with shelters for man and animals during climatic havocs in combating with the changing climate.
- Potential impacts of climate change on the corals, mangroves and associated marine fisheries of Islands ecosystems need to be studied for improving the fishery strategies ensuring sustainable fishing practices as well as preserving pristine environmental condition of this unique eco-region.

Theme VI: ***Technology impact on the socio-economics, gender issues, ICT applications to assess and monitor, strengthening market linkage and business models on post-harvest and value chain for livelihood security and employment generation***

- Seaweed cultivation is emerging as a sustainable livelihood opportunity for the farmers living in coastal areas.
- Investment on creating awareness among the households living in coastal areas, start-up grant to set up seaweed value chain are essential for scaling up seaweed business across the coastal region.
- Introduce disaster insurance to reduce the risk of investing in marine aquaculture industry.
- Coastal eco-tourism has potential to provide sustainable livelihood opportunity for the people living in coastal areas, and this requires effective policy and institutional arrangements.
- Farm women mobilization through self-help groups and linking them to value chain would help to increase the income from agriculture and to empower them.
- Identify and restore the cultivation of indigenous plant species to ensure nutrition security and social and cultural value of the tribal people living in coastal areas.
- Investment to strengthen coastal value chain can ensure higher return from the produce, enhance land productivity and quality of the produce and thereby ensure food and livelihood security of the households inhabited in coastal areas.
- Imparting of knowledge and skill on technologies to farmers and farm women regarding the cropping system along with capacity building on value addition and value chain management for the farmers is the need of the hour.
- An operational work plan involving scientists, computer analyst, service providers and panchayati functionaries for short as well as long-term planning in unison.

- Emphasized on holding aqua clinics/agri-clinics and entrepreneurship development programmes for creating employment for graduates.
- Fisheries and Aquaculture R&D stakeholders should adopt "Value Chain Extension Approach in Fisheries/ Aquaculture.
- ICT-based Smart Aquaculture models, aquapreneurs and fisheries start-ups need to be supported by the partnership, networking and policy support.
- Farmers groups, FPOs/Co-operatives/SHGs in Fisheries/Aquaculture needs to be mobilized and handholding support need to be enhanced.

The symposium ended with thanks to all participants including Chairman, Co-chairman, speakers, both invited and voluntary categories, for each session. The plenum and plenary session lectures deserved high appreciation. The Society also expresses its extreme gratitude to Dr. M. S. Swaminathan, Chairman, Advisory Committee, Dr. Trilochan Mohapatra, Chief Patron, Dr. S. B. Kadrekar, Patron and Dr. A. K. Bandyopadhyay, Patron and members of the International and National Advisory Boards for their guidance and support for successful organization of the International Symposium. The contribution of all members of the organizing committee in organization of the event was highly appreciated.

Dr. H. S. Sen, President of ISCAR, offered thanks to all his colleagues, partners and stakeholders for all their painstaking & highly disciplined support to make the symposium a good success hoping the recommendations and research highlights drawn will suggest new horizons in coastal research and management worldwide. It was strongly envisaged that ISCAR would thus establish its role as a leading partner in the area.

[The summary was circulated amongst the members and participants by Dr. Uttam Kumar Mandal, Hony. Secretary, ISCAR on August 5, 2021].