Chapter 4
Impact of Climate Change on Coastal Agro-Ecosystems

Saon Banerjee, Suman Samanta, and Pramiti Kumar Chakraborti

Abstract Climate change is a major threat for ecosystems, food security, forests and other natural resources. Proper steps must be taken to reduce the vulnerability of the farming communities living in coastal areas, especially in the developing countries. This chapter reviews the impact of climate change on the coastal agro-ecosystem, and practices to improve sustainability. We found that 27 countries are the most vulnerable due to accelerated sea level rise. In some coastal areas, up to 40% biodiversity loss has already been observed. About 70% income is generated from crop cultivation and the rest is from fisheries and other animal husbandry activities. Hence, climate resilient agriculture can secure the rural livelihood. Adaptation measures may include agro-forestry practices, establishment of orchards, nutrient recycling, salinity management and rational use of water. Techniques of climate resilient agriculture vary with techniques available, needs of the farming community, resources and infrastructure.

Keywords Coastal ecosystem · Climate resilient agriculture · Climate change · Sea level rise · Cyclone

4.1 Introduction

Agriculture can be viewed as one form of ecological engineering for manipulation of populations, communities and ecosystem for human purposes. This concept considers the agricultural operations as ecosystem manipulation instead of only

S. Banerjee (✉)
AICRP on Agrometeorology, Directorate of Research, Bidhan Chandra KrishiViswavidyalaya, Kalyani, West Bengal, India

S. Samanta
Department of Environmental Studies, Visva-Bharati, Santiniketan, West Bengal, India

P. K. Chakraborti
AICRPAM-NICRA Project, Directorate of Research, Bidhan Chandra KrishiViswavidyalaya, Kalyani, West Bengal, India

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production process (Weiner 2003). A variety of agro-ecosystems exist side by side in a particular region, they are associated with different methods of farming, such as organic, integrated or conventional (Wezel et al. 2009). In present days, the different ecosystems are under threat mainly due to global warming and climate change. However, climate change and variability are not new. Many societies have coped with and adapted to climate variability and many other stressors during the past centuries (Mertz et al. 2009). Climate change is considered to be one of the major threats to sustainable development because of its effects on ecosystem, health, infrastructure, food security, forests, etc. (IPCC 2007). Global food security and imbalance in agro-ecosystems, threatened by climate change, are the most important challenges in the twenty-first century to supply sufficient food for the increasing global population (Magadza 2000; Lal 2005).

In recent years, more and more attention has been paid to the risks associated with climate change, which will increase uncertainty with respect to food production. The coastal ecosystems are more vulnerable to climate change (Dickson et al. 2007). Although some aquatic plants have their ability to adapt themselves in the diversified coastal environment due to climate change, the problems of soil salinity, sea level rise, etc., pose a threat to coastal agriculture (Cronk and Fennessy 2001). Moreover, the coastal zones of the world are mostly populated and any change would affect a considerable number of population. The effects of global warming would be first felt on these coastal zones. The rate of sea level rise increased from the nineteenth to twentieth century. The total twentieth century rise is estimated to be 0.17 m (Jena and Mishra 2011). Proper steps must be taken to reduce the vulnerability of farming community living in coastal areas, especially in the developing countries (Tompkins and Adger 2005). The present article intends to enumerate the application of climate resilient agriculture towards sustainability of coastal agro-ecosystem.

4.2 Coastal Agro-Ecosystems

The science of living organisms and their interaction with the natural environment is ecology. Ecology's root extends to the origins of humanity. Agricultural practices are too dates back to the time of civilization. So both agriculture and ecosystem are walking hand in hand and sometimes they become complementary to each other.

Ecology can be grouped according to the types of organisms or habitats being studied. Examples of habitats include marine and coastal ecosystems, rain-forests, deserts, etc. Coastal ecosystems may also be defined as a broad interaction between land and sea influencing each other in true sense. Coastal areas include marine and terrestrial ecosystems ranging from coastal lowlands to coral reefs with their unique characteristics and coastal ecology is the study of coastal ecosystems (Hoorweg and Muthiga 2009).

Coastal ecosystems are most productive but highly threatened ecosystems in the world. Coastal ecology includes both marine and terrestrial ecosystems. A large

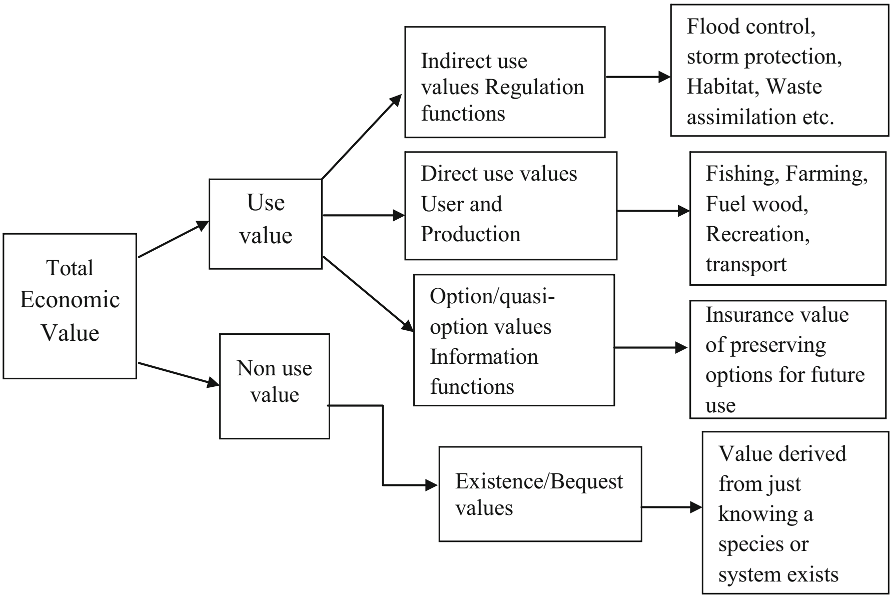

Fig. 4.1 Values of coastal ecosystems. (Adapted from Costanza et al. 1997)

range of functions and values are associated with coastal ecosystem (Fig. 4.1). Among them, regulation and supporting services such as shoreline stabilization, flood control, detoxification of polluted waters and waste disposal are indirect use value. The direct use values includes the utility which are derived directly from the use of many living and nonliving resources. The fishery sector is one of the major sources of income and livelihood for millions of people around the world. About 540 million or nearly 8% of the world's population are directly or indirectly involved with fishery production system (FAO 2010a, b).

Coastal ecosystems serve as breeding and nursery grounds for fish and other aquatic organisms as well as seasonal migration grounds for marine mammals and birds, and also includes plants such as mangroves, seaweed and sea grasses that require brackish to salty water to grow (Hoorweg and Muthiga 2009). World's coastal regions possess vast range environments which are shown in Table 4.1 (Burke et al. 2000). Mangroves and mudflat ecosystems play key roles for sheltering, feeding and spawning grounds for finfish and shellfish (Vidthayanon and Premcharoen 2002). One of the important sources of income for coastal communities in developing countries are the ornamental marine species like corals, invertebrates and fish having high economic value (Lem 2001).

Coastal ecosystems are frequently exposed to aberrant weather conditions and nowadays it becomes more vulnerable due to global warming. Since the 1950s, the quantity and magnitude of natural disasters increased significantly in the coastal

Table 4.1 Characteristics feature of the coastal environment

Zones	Features
Near shore terrestrial	Dunes, cliff, rocky and sandy shores; coastal xeromorphic habitats, urban, industrial and agricultural landscape
Intertidal	Estuaries, deltas, lagoons, mangrove forests, mud flats, salt marshes, salt pans, other coastal wet lands, ports and marinas, aqua cultural beds
Benthic	Kelp forest, sea grasses, coral reefs and soft bottom environment above the continental shelf, artificial reefs and structures
Pelagic	Open waters above continental shelf, freestanding fish farms e.g. plankton blooms, neustone zone, sea ice herring schools

Adapted from Burke et al. (2000)

areas, which may be due to climate change (Jena and Mishra 2011; Sovacool 2014). The increase in urbanization near the coast has serious environmental impacts. Worldwide, more than 600 million people are living in coastal zones which are less than 10 m in elevation; of which 360 million reside in urban areas (McGranahan et al. 2007). Let us take an example of India, a developing country, sharing more than 8000 Km long coastline with Arabian Sea, Bay of Bengal and Indian Ocean. More or less one third of the country's population lives in coastal zones with highly increasing population density. The major activities found along the Indian coastal zone are traditional activities like, fishing, tourism, agricultural activities, oil exploration, commercial and residential development. Fishing activities not only provides important source of food but also provides employment, income and foreign exchange for India (Senapati and Gupta 2014).

Within India we found mangrove ecosystem along the coastal areas of West Bengal which are distributed over North and South 24 Parganas, East Midnapur and southern parts of Howrah. The coastal region of West Bengal lies between $87^{0}25'$ E and 89^{0} E latitude and $21^{0}30'$ N and $23^{0}15'$ longitude, covering an large area along the Bay of Bengal coast. The major part of the coastal area in West Bengal falls within the boundary of the districts of South and North 24 Parganas. The coastal region of the districts of South and North 24 Parganas is popularly known as Sundarbans, due to the fact that the area is under mangrove forest dominated by the noble mangrove tree named Sundari *(Heritierafomes).* The forest has both regional and global importance for its diverse ecological resources (Islam 2003). In the said zone, main livelihood and major land use pattern in this coastal zone includes crop cultivation. Nearly 80–90% of the cultivated land is used for agricultural crop production. The next important land use is associated with fish cultivation in ponds and ditches. Almost 70% income is generated from crop cultivation and rest is from fisheries and other animal husbandry activities. Apart from rice, the other crops grown are chili, cucurbits, tomato, beet and bettlevine (Bandyopadhyay et al. 2003). A large number of natural vegetation is observed in Sunderban. In this zone salinity plays a key role in regulating the density of and diversity of phytoplankton (Raha et al. 2012).

4.3 Climate Change Impact on Coastal Ecology

With increasing rate of greenhouse gases in atmosphere due to urbanization and industrialization, climate change has emerged as the most prominent environmental issue. Most of the third world countries, mainly developing countries, are facing the devastating consequences of climate change. The main problems arises due to climate change are rising temperature, melting glaciers which in turn rises the sea level leading to inundation of coastal areas (IPCC 2007). Precipitation pattern also changes along with the increasing tendency of high intensity rainfall for short time leading to increased risk of either devastating floods or recurrent droughts. Expansion of pest attack due to unnatural weather condition may harm the biodiversity along with many public health related issues. Thus it is obvious that different ecosystems are going to be disturbed due to imbalance in their systems. People living in different ecosystems across the world have been recognized as being predominantly risk prone to the impacts of climate change (Pittock 2005). It is also true that ecosystems are under severe threat from poor and unsustainable resource management along with the impact of climate change (Sokona and Denton 2001).

Generally climate change negatively affects natural ecosystems leading to biodiversity loss which may be up to 40% before the end of the century in some areas. The Climate Change Vulnerability Index measures the current vulnerability condition of different countries to extreme climate-related events and how well it is prepared to combat the impacts of climate change. A report based on the study on 160 countries revealed that many countries mainly Africa, south and south-east Asia are at ‘extreme risk’ from the impacts of climate change (Maplecroft 2010). Poor nations with few natural resources, limited infrastructure and most importantly large scale population are the main victims of climate change. Thus African and south Asian countries like Somalia, Haiti, Afghanistan, Pakistan, Philippines, India and Indonesia are topping the list. In India, coastal areas and Indo-Gangetic plains are declared as the most vulnerable zones for extreme weather events.

Among all ecosystems, coastal ecosystem is the most productive but highly threatened ecosystems in the world. The ecosystem derived from marine habitats is greatly affected by human activities and large numbers of population pressure in the coastal areas (MEA 2005; McGranahan et al. 2007). Economic opportunities like highly fertile low lying delta areas with good transport facilities and easy access to sea food are the main reason for high population density near the coastal areas (Darwin and Tol 2001). Coastal ecosystems are very rich in species diversity (flora and fauna) like mangrove forests, coral reefs, sea fish and aquaculture, etc. Coastal areas have a relatively higher Gross Domestic Product share compared to other inland regions due to their productive nature (Dasgupta et al. 2007). During recent years the physical, biological and biogeochemical characteristics of the oceans and coasts are changing due to pollution and climate change impact which modify the ecological structure and functions.

Reviewing a large numbers of literatures and articles it can be stated that the two main concerning impacts of climate change for coastal ecosystem are:

(i) Sea level rise and
(ii) Extreme weather events such as cyclones, storms, heavy rainfall, etc.

4.4 Impact of Sea Level Rise on Coastal Ecosystem

The rise in sea level has a negative impact on the biophysical and socio economic characteristics of coastal ecosystem. According to a report, most of the destructive consequences of climate change are evolving around water-resource (Stern 2006). It is expected that sea levels may rise approximately 50 cm by the year 2100 compared to 1990 levels. The most alarming news according to them is 'some island nations like the Seychelles and Maldives are expected to be submerged into the sea within the next century if the present rate of sea level rises continue'. Approximately 1.28% of the total population live in developing countries will be affected if the sea level rises 1 m in height (Dasgupta et al. 2007). A study was conducted to estimate the potential impacts of sea level rise for different countries (developed, and developing) considering a 1–5 m rise in sea levels (TERI 1996). Few other researchers also tried to find out the impact of SLR at regional level (Nicholls and Mimura 1998; Darwin and Tol 2001; Dasgupta et al. 2007). Another study was conducted to estimate the climate change impact for 84 developing countries situated in the coastal region by grouping them into five world regions, namely, Latin America and the Caribbean countries; Middle East and North Africa; Sub-Saharan Africa; East Asia and South Asia (Dasgupta et al. 2007). Based on six indicators (land, population, GDP, urban extent, agricultural extent and wetlands), the researchers identified the most affected regions due to sea level rise are East Asia and South East Asia. If we consider the scenario of south Asian countries, researchers reported that sea level has risen at a rate of 2.5 mm per year along the Indian coastline since 1950s. India has also been identified in the top 27 most vulnerable countries list which are mostly affected by the impacts of climate change related accelerated sea level rise (UNEP 1989).

Report of IPCC claimed that through the twentieth century, global sea level rise contributed to increase in coastal inundation, erosion and ecosystem losses, but with considerable local and regional variations (IPCC 2007). Researchers across the world predicted that changes in water temperature, precipitation and oceanographic variables like, wind velocity, wave action and sea level rise can bring significant ecological and biological changes to coastal ecosystems. Loss of property and life due to increasing flood risk along with loss of habitats, infrastructure damage, loss of tourism, recreation and transportation functions and most importantly degradation of soil and water quality affecting agriculture and aquaculture, are the main issues on climate change (Nicholls and Lowe 2004). Coral reefs have significant importance in the livelihood of coastal people because these reefs are acting as a food source to marine fishes as well as it attracts the tourists too. Degradation of coastal ecosystems will definitely destroy those coral reefs which have a direct socioeconomic impact on the societies dependent on the coastal ecosystems for goods and services.

4.5 Extreme Weather Events and Their Impact

The coastal communities over the world are witnessing many extreme weather events like cyclone, storm, tornedo, etc., specially from beginning of twenty-first century and scientists are expecting a lot more to come. Reports claimed that nearly 120 million people across the globe are exposed to tropical cyclones annually, which killed 2,50,000 people from 1980 to 2000. Scientists predicted a 15% increase in the intensity of tropical cyclones which would significantly enhance the vulnerability of population living along the shoreline of India (Aggarwal and Lal 2008). Cyclonic storms affect the coast more adversely as it is associated with high tides along with heavy rainfall which is sufficient to destroy coastal habitats in few hours. For example, severe cyclonic storm ‘Aila’ formed at Bay of Bengal and hit the coast of West Bengal, India and the coasts of Bangladesh on 25th May, 2009 (Table 4.2). The cyclone hit the coast with 6.5 m high tidal surges and affected 11 coastal districts of India and Bangladesh. This surge of water damaged and washed away over 1743 km of embankments and forced many people to leave their villages. The actual calamities started after the cyclone when daily high tides, and particularly during periods of full moon, inundated the coastal area due to absence of embankments. These tidal waves cause intrusion of huge amount of saline water into the agricultural land and stays there for a long time. As a result, salinity of the soil increased highly which severely affected the agricultural production. Fresh water resources like ponds, wells are also contaminated with the saline water which caused severe drinking water scarcity in the area. Aila has altered the livelihood of the peoples by severely hampering the economy of this region for few years.

Table 4.2 Damage caused by the cyclone ‘Aila’

Damages caused by the Aila	
Number of villages affected:	4249
Size of affected population:	25,62,442
Number of people missing:	8000
Number of deaths:	Official-70; Unofficial-300
Length of embankment breached:	400 km
Number of cattle lost:	2,12,8512,12,851
Total area of agricultural land affected:	1,25,872 ha
Estimated financial loss in agriculture:	Rs. 337 crore
Number of houses fully damaged:	1,94,390
Number of houses partially damaged:	1,94,701
Total loss:	Rs. 1495.63 crore

Adapted from Rudra (2010)

4.6 Impact of Climate Change on Agriculture

Climate is one of the most important factors for agricultural productivity. At a global scale, scientists offer different views at the impact of climate change on agriculture as they thought that there might be no significant losses on its production with changing climate (IPCC 2007; Mendelsohn 2008). They explained this point by the logic that production losses in drier African regions will be compensated by increased production in high latitude regions where global warming will raise temperatures and extend planting seasons by reducing the risk of frost (Hassan 2010). The overall impact of climate change on agriculture is given in Table 4.3. Though we are very much concerned about the impact of climate change on agriculture but it is also true that this sector itself contributes to global warming through carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) gas emissions. At a global scale, approximately 20% of the annual increase in greenhouse gas emissions was contributed by agricultural system (IPCC 2007).

Many researchers studied the impact of global warming on crop growth and production (Kurukulasuriya and Rosenthal 2003; Easterling et al. 2007; Lobell and Gourdji 2012). Most of the authors opined that the crop and livestock productivity may decline because of rising temperatures and drought-related stress, especially in

Table 4.3 Impact of climate change on agriculture

Climatic element	Expected changes by 2050's	Confidence in prediction	Effects on agriculture
CO_2	Increase from 360 ppm to 450–600 ppm (2005 levels now at 379 ppm)	Very high	Good for crops: increased photosynthesis; reduced water use
Sea level rise	Rise by 10–15 cm increased in south and offset in north by natural subsistence/rebound	Very high	Loss of land, coastal erosion, flooding, salinisation of groundwater
Temperature	Rise by 1–2 °C. Winters warming more than summers. Increased frequency of heat waves	High	Faster, shorter, earlier growing seasons, range moving north and to higher altitudes, heat stress risk, increased evapotranspiration
Precipitation	Seasonal changes by ±10%	Low	Impacts on drought risk' soil workability, water logging irrigation supply, transpiration
Storminess	Increased wind speeds, especially in north. More intense rainfall events.	Very low	Lodging, soil erosion, reduced infiltration of rainfall
Variability	Increases across most climatic variables. Predictions uncertain	Very low	Changing risk of damaging events (heat waves, frost, droughts floods) which effect crops and timing of farm operations

Adapted from Mahato (2014)

the tropical regions. Studies revealed that a 2.5–4.9 °C temperature rises in India may reduce the rice yields by 32–40% and wheat yields by 41–52% which will cause GDP to fall by 1.8–3.4% (GoI 2011; Guiteras 2007). Many authors predicted that depending on crop variety its productivity may also increase reasonably with the increment in mean ambient air temperature of up to 1–3 °C. Though this scenario can only be experienced at mid to high latitude regions. Same experiment at lower latitude regions produced negative result. Moderate increase in temperature will reduce crop yields as crops become intolerant of high temperatures. The intrusion of sea-water in the fertile land due to cyclone or water surge, the fertility of the soil can be destroyed (Figs. 4.2 and 4.3). For example, due to Aila, the production of rice reduced to 3000 Kg per ha compared to the 6000 Kg per ha in the coastal zone of West Bengal (Debnath 2013). Historical studies claimed that, at global level, a significant climate-associated yield reductions of 40 million tons per year was experienced from 1981 to 2002 for maize, wheat and other major crops (Lobell et al. 2011). Projecting the agricultural production under various climate scenarios of 2055, some scientists expected a 10% reduction in maize production for Africa and Latin America which may result a loss of US$2 billion per year (Jones and Thornton 2003).

Fig. 4.2 Sea water intrusion in the coastal region of West Bengal, India

Fig. 4.3 Visible impact of sea-water intrusion

4.7 Impact of Climate Change on Fisheries and Aquaculture

High tides during cyclonic storm or sea level rise not only contaminate the fresh water resources but also destroy the fresh water fish population through salinisation, coastal erosion and wetland flooding. Some freshwater fish species can't survive on saline water and may become extinct along the coastlines. Degradation of coral reefs due to the increasing oceanic temperature, coastal fish population has also declined considerably. Increase in oceanic temperature and destruction of coral reefs along the coasts of many Asian cities reduced the fish population near the coast and hampered the fishery sector severely. Many researchers found that marine fisheries are affected by the direct and indirect impacts of climate change (Allison et al. 2005; Vivekanandan 2006; Allison et al. 2009; Badjeck et al. 2010; Sumaila et al. 2011). Although it is also true that many non-climatic factors are also associated with this declination in fish catch. But there is no doubt that climate change will add to the problems in fishery sector that is already visualized in the coastal regions.

In a nutshell, the ecological impacts of climate change on fishery include:

(a) Change species distribution i.e. fish migration, increased variability of catches, changes in seasonality of production i.e. decrease in fishing season.
(b) Damage to infrastructure, damage to fishing gears, increased danger at sea and problem in navigation routes.
(c) Socio-economic impact, migration, rehabilitation, increase in fuel costs, reduced health due to diseases.

4.8 Climate Resilient Agriculture

It is the integral part of sustaining agriculture in the era of climate change involving proper management of resources used for agricultural operations. It aims at increase of farm production and productivity and to minimize the adverse effect of climate change. The natural resource management, soil health improvement, crop production enhancement and livestock management are the major components of any climate resilient agriculture system. Climate resilient agriculture offers both mitigation and adaptation measures to climate changes (FAO 2010a, b; Matthews et al. 2013). The adaptation measures vary a lot depending upon the region, agroclimatic situation and socioeconomic status of the farming community. They may be switching over to agro-forestry practices, establishment of orchards, nutrient recycling and use and rational use of water towards greater water productivity (Pretty et al. 2006). Diversification of crops in promotion of mixed farming and agroforestry will also help the farmer to fight weather extremes, disease epidemics and crop failures and sustain the farmers' livelihood support (Davis et al. 2012; Lin 2011).

One of the more talked about issues in climate change is carbon sequestration and orchards and agro-forestry shall pave the way for more carbon assimilation and delay the pace of climate change (Blanco-Canqui and Lal 2004). This is because diversity of ecological attributes arising from a large number of species also provides easier access to limited resources and may also reduce instability in the ecosystem processes through asynchronous responses of the different species to environmental fluctuations. As water is becoming scarce over time there will be a decline in rice areas and rice ecosystems are to be gradually shifted to others. At the same time promotion of fodder and animal husbandry along with poultry will indicate a better balance of sustainability in agriculture and welcome the way for greater organic interventions and internal resources in input use pattern (Ortmann and Machethe 2003; Zheng et al. 2014). This in conjunction with mixed farming becomes important very much because in the light of greater use of farm supported energetic in crop production and cutting down of fossil fuel use in manufacture of inputs (Figs. 4.4 and 4.5).

Domestic waste water if at all used to support and get a harvest out of a homestead garden can contribute to the awareness of the value of water and its rational use. The models of agriculture supported by mixed cropping and animal husbandry is not only climate friendly but also it creates man-days and takes care of farm employment

Fig. 4.4 Intensified farming through utilization of banks of pond for vegetable cultivation

Fig. 4.5 Vegetable cultivation in the bunds of rice field

which also contributes to sustainability in a greater way (Magdoff 2007). Conservation tillage will be an important strategy to combat the climate change also. It not only means less fossil fuel spent on the mechanical operations on part of the farmer or enterprise, it also means less compaction of the farm lands due to lessened burden of traffic. Further opening the entire land by cultivators more carbon from below the surface gets oxidised and escapes in the atmosphere. Less compaction also results in more biological tillage by worms and less disturbed micro-flora and drives the system towards sustainability. Organic residue of rice is normally burned in many areas which promotes carbon emissions. Organic residues of the crop when incorporated it helps to attain the soil quality and water balance improvements that are needed to realise the benefits which offer resilience to climate change.

Different types of livelihood assets (physical, financial, social, human and natural capital) form the basis for households' choices of livelihood strategies, including agricultural practices, which in turn influence their food security status and level of well-being. We find empirical evidence that land (natural capital) and household asset and ownership (physical capital) are positively linked to household food security levels. Relevant information available, their integration, capacity building allows further receptivity and makes education (human capital) is closely associated with adaptation by the vulnerable households. The results also show that households that diversify what they choose to produce, as well as to sell, are pursuing key livelihood strategies that make them more food secure, and more able to take up new agricultural practices to deal with changing circumstances.

To bridge the gap between science and field application, there is a need for 'translators' of climate information to assist communities and planners to understand the implications of results for their immediate planning decisions. Enhanced communication between producers and users of climate science is clearly a requirement. New climatological information that is too coarse in resolution for application to crop decision-making must be downscaled for use at the field decision-making level. Developing tools and documents for mainstreaming climate information to agricultural decision making, with the building of a large-scale system of support for the operational use of seasonal climate information for the countries are needed. It will be important to devise best practices for integrating local knowledge with scientific knowledge in the formulation of adaptation strategies. While local knowledge has much to offer in terms of informing adaptation strategies, combining the two has proven challenging to date. Participatory mechanisms for bringing farmers together to disseminate expert knowledge and weather information are necessary. Active collaboration between climate forecasters, agrometeorologists, agricultural research and extension agencies in developing appropriate products for farming communities is essential.

In India, considering the importance of climate resilient agriculture, National Initiative on Climate Resilient Agriculture (NICRA) was launched in the year 2011 by Indian Council of Agricultural Research (ICAR) with the funding from Ministry of Agriculture, Government of India. The mega project has three major objectives of strategic research, technology demonstrations and capacity building (ICAR 2016). Under strategic research, assessment of the impact of climate change simultaneous with formulation of adaptive strategies is the main approach. The climate resilient agricultural technologies aim at increasing farm production and productivity and managing natural resource in a better way. The objectives of NICRA are to enhance the resilience of Indian agriculture covering crops, livestock and fisheries to climatic variability and climate change through development and application of improved production and risk management technologies; to demonstrate site specific technology packages on farmers' fields for adapting to current climate risks and to enhance the capacity of scientists and other stakeholders in climate resilient agricultural research and its application. Presently the technology demonstration component is going on in 100 vulnerable villages through Krishi Vigyan Kendra i.e., Farmers' Scientific Centre (Figs. 4.6 and 4.7).

Under NICRA, the village level interventions towards climate resilient agriculture are as follows:

(a) Maintaining soil health: Resilience of crop production under changing climate is mainly dependent on soil health. A number of interventions are made to build soil carbon, control soil loss due to erosion and enhance water holding capacity of soils, all of which build resilience in soil. Improved methods of fertilizer application should be practiced matching with crop requirement to reduce nitrous oxide emission.
(b) Adapted cultivars and cropping systems: Improved, early duration drought, heat and flood tolerant varieties should be adopted as per climatic situation of a village. Crops and varieties should be chosen in such a way that optimum yields can be achieved despite climatic stresses.
(c) Agromet Advisory service system: Village level weather based agro advisories and contingency crop planning should be prepared on regular basis.
(d) Rainwater harvesting and recycling rainwater: Rainwater harvesting and recycling through farm ponds, restoration of old ponds in dryland/rainfed areas, percolation ponds for recharging of open wells, bore wells and injection wells for recharging ground water are taken up for enhancing farm level water storage.
(e) Water saving technologies: Deficit irrigation, water saving technologies like direct seeded rice, zero tillage and other resource conservation practices should be introduced at drought prone villages.
(f) Livestock and fishery interventions: Use of community lands for fodder production during droughts/floods, improved fodder/feed storage methods, feed supplements, micronutrient use to enhance adaptation to heat stress, vaccination, improved shelters for reducing heat/cold stress in livestock, management of fish ponds/tanks during water scarcity and excess water are some key interventions in livestock/fishery sector.
(g) Formation of cooperative and Institutional interventions: Seed bank, fodder bank, commodity groups, custom hiring centre, collective marketing, introduction of weather index based insurance and climate literacy through a village level weather station should be introduced to ensure effective adaptation of all other interventions.

Fig. 4.6 Farmers' Awareness Program for technology demonstration

Fig. 4.7 Farmers-scientists interaction program in one vulnerable village

4.9 Conclusion

The coastal zone is the most vulnerable region due to climate change. The climate resilient agriculture operation must be implemented for the sustainable development of agricultural system in the coastal area. In the early phase, the major focus should be on assessing vulnerabilities and identifying adaptation options for coastal ecosystems. Designing optimum adaptation strategies are extremely difficult due to its multidisciplinary nature and multi-sector, multi-stakeholder interests. Successful implementation of farm level climate resilient agriculture depends on how different stakeholders play their roles. There are many stakeholders at various levels like national, regional and international organizations, dealing with various elements of climate change adaptation. Additionally, various NGOs operating at regional levels should be involved in community-based interventions to improve the livelihoods of farmers, water and food security. In the coastal zone of developing countries, major emphasis should be given on poverty reduction and disaster mitigation.

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References

Aggarwal D, Lal M (2008) Vulnerability of the Indian coastline to sea level rise, SURVAS (Flood Hazard Research Centre). http://www.survas.mdx.ac.uk/pdfs/3dikshas.pdf

Allison EH, Adger WN, Badjeck MC, Brown K, Conway D, Dulvy NK, Halls Perry A, Reynolds JD (2005) Effects of climate change on the sustainability of capture and enhancement fishery important to the poor: analysis of the vulnerability and adaptability of fisherfolk living in poverty, Project No. R4778J, Fishery management science programme, Department for International Development (DFID). http://r4d.dfid.gov.uk/Output/122513/

Allison E, Allison LP, Badjeck M, Adger WN, Brown K, Conway D, Ashley SH, Pillin GM, Reynolds JD, Andrew NL, Dulvy NK (2009) Vulnerability of national economies to the impacts of climate change on fishery. Fish Fish 10:1–24. https://doi.org/10.1111/j.1467-2979.2008.00310.x

Badjeck MC, Allison EH, Halls AS, Dulvy NK (2010) Impacts of climate variability and change on fishery-based livelihoods. Mar Policy 34:375–383. https://doi.org/10.1016/j.marpol.2009.08.007

Bandyopadhyay BK, Maji B, Sen HS, Tyagi NK (2003) Coastal soils of West Bengal – their nature, distribution and characteristics, Bulletin No. 1/2003. Canning Town, West Bengal, India: Central Soil Salinity Research Institute, Regional Research Station, p 62

Blanco-Canqui H, Lal R (2004) Mechanisms of carbon sequestration in soil aggregates. Crit Rev Plant Sci 23:481–504. https://doi.org/10.1080/07352680490886842

Burke LA, Kura Y, Kaseem K, Ravenga C, Spalding M, McAllister D (2000) Pilot analysis of global ecosystems: coastal ecosystems. World Resource Institute, Washington, DC

Costanza R, Arge R, Groot R, Farber S, Grasso M, Hannon B, Limburg K, Naeem S, O'Neill RV, Paruelo J, Raskin RG, Sutton P, Belt M (1997) The value of the world's ecosystem services and natural capital. Nature 387:253–260

Cronk JK, Fennessy MS (2001) Wetland plants: biology and ecology. Lewis Publishers, Washington, DC

Darwin RF, Tol RSJ (2001) Estimates of the economic cost of sea level rise. Environ Resour Econ 19(2):113–129. https://doi.org/10.1023/A:1011136417375

Dasgupta S, Laplante B, Meisner C, Wheeler D, Yan J (2007) The impact of sea level rise on developing countries: a comparative analysis. World Bank policy research working paper 4136

Davis AS, Hill JD, Chase CA, Johanns AM, Liebman M (2012) Increasing cropping system diversity balances productivity, profitability and environmental health. PLoS One 7(10): e47149. https://doi.org/10.1371/journal.pone.0047149

Debnath A (2013) Condition of agricultural productivity of Gosaba C.D. Block, South24 Parganas, West Bengal, India after severe cyclone Aila. Int J Sci Res Publ 3(7):1–4

Dickson ME, Walkden MJ, Hall JW (2007) Systemic impacts of climate change on an eroding coastal region over the twenty-first century. Clim Chang 84(2):141–166. https://doi.org/10.1007/s10584-006-9200-9

Easterling WE, Aggarwal PK, Batima P, Brander KM, Erda L, Howden SM, Kirilenko A, Morton J, Soussana JF, Schmidhuber J, Tubiello JN (2007) Food, fiber and forest products. In: Parry ML (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, pp 273–313

FAO (2010a) Climate-smart agriculture policies, practices and financing for food security. Adaptation and mitigation. http://www.fao.org/docrep/013/i1881e/i1881e00.pdf

FAO (2010b) The state of world fishery and aquaculture. The United Nations/Food and Agriculture Organization, Rome

GOI (2011) Census of India 2011, Government of India (GOI), New Delhi

Guiteras R (2007) The impact of climate change on Indian agriculture. Working paper, Department of Economics, MIT

Hassan RM (2010) Implications of climate change for agricultural sector performance in Africa: policy challenges and research agenda (dagger). J Afr Econ 19(Supplement 2):77–105. https://doi.org/10.1093/jae/ejp026

Hoorweg J, Muthiga N (2009) Advances in coastal ecology people, processes and ecosystems in Kenya. African studies collection (20). African Studies Centre, Leiden

ICAR (2016) Climate resilient agriculture-NICRA. Accessed through www.nicra-icar.in

IPCC (2007) 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

Islam S (2003) Sustainable eco-tourism as a practical site management policy. AH Development Publishing House, Dhaka

Jena KC, Mishra MR (2011) Effect of global warming and climate change on coastal zones and sea level. Orissa Rev 10(8):82–94

Jones PG, Thornton PK (2003) The potential impacts of climate change on maize production in Africa and Latin America in 2055. Glob Environ Chang 13:51–59. https://doi.org/10.1016/S0959-3780(02)00090-0

Kurukulasuriya P, Rosenthal S (2003) Climate change and agriculture a review of impacts and adaptations. Climate change series paper, (91). World Bank, Washington

Lal R (2005) Climate change, soil carbon dynamics, and global food security. In: Lal R, Stewart B, Uphoff N (eds) Climate change and global food security. CRC Press, Boca Raton, pp 113–143

Lem A (2001) International trade in ornamental fish. In: Proceedings of 2nd international conference on marine ornamentals: collection, culture and conservation. Florida, USA. November 26 – December 01, 2001

Lin BB (2011) Resilience in agriculture through crop diversification: adaptive management for environmental change. BioScience 61:183–193. https://doi.org/10.1525/bio.2011.61.3.4

Lobell DB, Gourdji SM (2012) The influence of climate change on global crop productivity. Plant Physiol 160:1686–1697. https://doi.org/10.1104/pp.112.208298

Lobell DB, Schlenker W, Costa-Roberts J (2011) Climate trends and global crop production since 1980. Science 333:616–620. https://doi.org/10.1126/science.1204531

Magadza CHD (2000) Climate change impacts and human settlements in Africa: prospects for adaptation. Environ Monit Assess 61(1):193–205. https://doi.org/10.1023/A:1006355210516

Magdoff F (2007) Ecological agriculture: principles, practices, and constraints. Renewable Agric Food Syst 22(2):109–117. https://doi.org/10.1017/S1742170507001846

Mahato A (2014) Climate change and its impact on agriculture. Int J Sci Res Publ 4(4):1-–11

Maplecroft (2010) Climate change risk atlas 2010. https://maplecroft.com/about/news/climate_change_risk_list_highlights_vulnerable_nations_and_safe_havens_05.html

Matthews RB, Rivington M, Muhammed S, Newton AC, Hallet PD (2013) Adapting crops and cropping systems to future climates to ensure food security: the role of crop modelling. Glob Food Sec 2:24–28. https://doi.org/10.1016/j.gfs.2012.11.009

McGranahan G, Balk D, Anderson B (2007) The rising tide: assessing the risks of climate change and human settlements in low-elevation coastal zones. Environ Urban 19(1):17–37. https://doi.org/10.1177/0956247807076960

MEA (2005) Ecosystems and human well-being: current state and trends. In: Hassan R, Scholes R, Ash N (eds) Findings of the condition and trends working group millennium ecosystem assessment. Island Press, Washington, DC. http://www.maweb.org/en/Condition.aspx

Mendelsohn R (2008) The impact of climate change on agriculture in developing countries. J Nat Resour Policy Res 1(1):5–19. https://doi.org/10.1080/19390450802495882

Mertz O, Halsnæs K, Olesen JE, Rasmussen K (2009) Adaptation to climate change in developing countries. Environ Manag 43:743–752. https://doi.org/10.1007/s00267-008-9259-3

Nicholls RJ, Lowe JA (2004) Benefits of mitigation of climate change for coastal areas. Glob Environ Chang 14:229–244. https://doi.org/10.1016/j.gloenvcha.2004.04.005

Nicholls RJ, Mimura N (1998) Regional issues raised by sea level rise and their policy implications. Clim Res 11:5–18

Ortmann G, Machethe C (2003) Problems and opportunities in south African agriculture. In: Nieuwoudt L, Groenewald J (eds) The challenge of change: agriculture, land and the South African economy. University Natal Press, Pietermaritzburg, pp 47–62

Pittock B (2005) Climate change – turning up the heat. Earthscan/CSIRO Publishing, Melbourne

Pretty J, Noble AD, Bossio D, Dixon J, Hine RE, Penning de Vries FW, Morison JI (2006) Resource- conserving agriculture increases yields in developing countries. Environ Sci Technol 40:1114–1119. https://doi.org/10.1021/es051670d

Raha A, Das S, Banerjee K, Mitra A (2012) Climate change impacts on Indian Sunderbans: a time series analysis (1924–2008). Biodivers Conserv 21:1289–1307. https://doi.org/10.1007/s10531-012-0260-z

Rudra K (2010) Aila: unpublished records of the Government of West Bengal. A South Asian journal on forced mitigation. MCRG, Kolkata, pp 86–93

Senapati S, Gupta V (2014) Climate change and coastal ecosystem in India: issues in perspectives. Int J Environ Sci 5(3):530–543. https://doi.org/10.6088/ijes.2014050100047

Sokona Y, Denton F (2001) Climate change impacts: can Africa cope with the challenges? Clim Pol 1(1):117–123. https://doi.org/10.1016/S1469-3062(00)00009-7

Sovacool BK (2014) Environmental issues, climate changes, and energy security in developing Asia. ADB economics working paper series, No. 399. Asian Development Bank, Philippines

Stern N (2006) What is the economics of climate change? World Econ 7:1–10. https://doi.org/10.1257/aer.98.2.1

Sumaila UR, Cheung WWL, Lam VWY, Pauly D, Herrick S (2011) Climate change impacts on the biophysics and economics of world fishery. Nat Clim Chang 1301:1–8. https://doi.org/10.1038/NCLIMATE1301

TERI (1996) The economic impact of a one metre sea level rise on the Indian coastline: method and case studies, report submitted to the ford foundation. Tata Energy Research Institute, New Delhi

Tompkins EL, Adger WN (2005) Defining a response capacity for climate change. Environ Sci Policy 8:562–571. https://doi.org/10.1016/j.envsci.2005.06.012

UNEP (1989) Criteria for assessing vulnerability to sea level rise: a global inventory to high risk area (Delft: Delft Hydraulics), 51, United Nations environment Programme (UNEP)

Vidthayanon C, Premcharoen S (2002) The status of estuarine fish diversity in Thailand. Mar Freshw Res 53:471–478

Vivekanandan E (2006) Impact of climate change on marine fishery, Central Marine Fishery Research Institute, CMFRI Newsletter, No 112

Weiner J (2003) Ecology – the science of agriculture in the 21st century. J Agric Sci 141:371–377. https://doi.org/10.1017/S0021859603003605

Wezel A, Bellon S, Dore T, Francis C, Vallod D, David C (2009) Agroecology as a science, a movement or a practice. A review. Agron Sustain Dev 29(4):503–515

Zheng C, Jiang Y, Chen C, Sun Y, Feng J, Deng A, Song Z et al (2014) The impacts of conservation agriculture on crop yield in China depend on specific practices, crops and cropping regions. Crop J 2:289–296. https://doi.org/10.1016/j.cj.2014.06.006