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Preface

Global climate change is an existential threat. Climate models project increasing mean surface temperature both over land and ocean, increase in the frequency of extreme events, and imbalances and long-term changes in the complex climate system. Notwithstanding the proactive steps being taken to reduce greenhouse gas emission, Global Warming will persist for a longer period. Nevertheless, the climate-related risk is a function of the rate and magnitude of increase in surface air temperature, geographical setting, carbon-dependent economic development pathway, portfolio of mitigation and adaptation strategies, and vulnerability. The potential impacts of climate change are pervasive – it challenges our existence, growth and development and indeed the way of life. The existential environmental challenges and overshoot of planetary boundaries urged humanity to revisit the paradigms of sustainable development, self-discipline and sustainable consumption, Earth's life-support system, and carrying capacity. Incidentally, the turn of the last century witnessed the positive steps towards environment management, hunger and poverty reduction, and human health in the form of 'Millennium Development Goals', which was indeed a positive step in the right direction. Nevertheless, the need emerged for reformation and transformation in all spheres of human life. To achieve a sustainable and inclusive world with due recognition and respect to the planet, people, prosperity, peace and partnership, 'Sustainable Development Goals' were adopted by all the countries. The 17 global goals with 169 targets are comprehensive and provide a path (with milestones) to all nations to embark on a sustainable journey. It would be prudent to capitalise on the synergistic relationship between the goals. From this perspective, the book attempts to catalyse the thinking process about synergies and trade-offs between the sustainable development goals. The SDGs are interconnected goals and they largely address the challenges to sustainable development. Climate change is an important challenge to sustainable development and is reflected in SDG 13, which calls for urgent action to combat climate change and its impacts. The interconnections and the global reach of the SDGs can be gauged from the tangible connections between SDG 13 and other global goals like SDG 2 (food and nutrition security), SDG 3 (human well-being), SDG 5 (gender equality), SDG 6 (water security), SDG 7 (energy security), SDG 9 (resilient infrastructure), SDG 12 (sustainable consumption), SDG 14 (sustainable use of marine resources) and SDG 15 (sustainable management of forest, biodiversity, etc.). The book earnestly explores the synergies and trade-offs between climate change and other sustainable development goals. The book targets the scientists, researchers, academicians, graduates and doctoral students working in natural and biological sciences. It further quenches the needs of policymakers who endeavour to frame policies on climate change, food security, energy security, air pollution and human health. We are extremely honoured to receive chapters from leading scientists and professors with rich experience and expertise in the field of global climate change, sustainable agriculture, public policy, climate policy and biological diversity. The chapters focus on areas including but not limited to food and nutritional security, domestic water security and water productivity, climate-resilient sustainable food production system, smart mariculture technologies, the essentiality of adaptation options in the agriculture sector, energy policy, biodiversity, human health, and gender empowerment.

Our sincere gratitude goes to the contributors for their insights on global climate change and sustainable development. We sincerely thank Dr. Naren Aggarwal, Editorial Director, Springer; Ms. Aakanksha Tyagi, Associate Editor; Mr. Ashok Kumar; and Mr. Salmanul Faris Nedum Palli for their generous assistance, constant support and patience in finalising this book.

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Dr. Prasad has 12 years of teaching experience and has been awarded the Young Scientist Award and Prof. J.S. Datta Munshi Gold Medal by the International Society for Ecological Communications; FSAB fellowship by the Society for Applied Biotechnology; the American Cancer Society UICC International Fellowship for Beginning Investigators, USA; Outstanding Scientist Award in the field of microbiology by Venus International Foundation; and the BRICPL Science Investigator Award and Research Excellence Award. He is an editorial board member of *Frontiers in Microbiology*, *Frontiers in Nutrition*, *Archives of Phytopathology and Plant Protection*, *Phyton-International Journal of Experimental Botany*, *Academia Journal of Biotechnology*, and the *Journal of Renewable Materials*, and Series Editor of Nanotechnology in the Life Sciences, Springer Nature, USA. Previously, Dr. Prasad served as an Assistant Professor at Amity University, Uttar Pradesh, India; Visiting Assistant Professor, Whiting School of Engineering, Department of Mechanical Engineering, Johns Hopkins University, Baltimore, USA;, and Research Associate Professor in the School of Environmental Science and Engineering, Sun Yat-sen University, Guangzhou, China.

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1 Achieving Food and Nutrition Security and Climate Change: Clash of the Titans or Alignment of the Stars?

Chris Radcliffe and Jessica Singh

Abstract

In order to meet the demands of the world's growing population, food production needs to increase by almost 60%, yet this is in the face of increasing global malnutrition, land scarcity, extreme weather events and rainfall pattern shifts. Achieving the Sustainable Development Goal 2 (SDG 2) of 'zero hunger' requires a multifaceted approach which maximises synergism with climate change goals and minimises trade-offs. This approach requires transformative shifts in gender equality, education, research focus, technological development, market chains and agricultural practices. However, aspects of such transformative approaches can be in opposition to cultural beliefs, create household debt, increase labour requirements and place pressure on local resources. For enhanced SDG 2 and climate change outcomes, such trade-offs should be understood and minimised. Zero hunger is achieved by ensuring not just food security but also nutrition security for all people. Unfortunately, it is inevitable that some targets on achieving sustainable development goals, such as SDG 2 'zero hunger', may benefit some countries or regions yet will undermine the ability for others to reach climate change goals. This chapter explores the synergisms and trade-offs between climate change goals and achieving zero hunger through food and nutrition security. Indicators for SDG 2 will be used to highlight synergies and trade-offs with climate change goals. These examples demonstrate the need for policy design to be contextual, respond to regional needs and allow individuals

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and communities to understand, prepare for and adjust their agricultural and social systems to support the diversifying of household income. Whilst this chapter primarily explores synergies and trade-offs, some considerations are suggested for future policy development and decision-makers.

Keywords

Sustainable Development Goals · Climate change · Food security · Nutrition security · Climate-smart agriculture · Resilient agriculture · SDG 2

1.1 Introduction

Despite factors of population growth, urbanisation, land scarcity and land value, the world has witnessed a tripling of food crop production over the past 50 years, thwarting Malthusian theory.[1] The Green Revolution has been the core ingredient of this growth, providing an increase in global food supplies and lower food and feed costs (Venkatramanan et al. 2020a); in fact, estimates are that without the Green Revolution, world food prices would have been 35–65% higher (Evenson and Rosegrant 2003). Unfortunately, progress in food production has now slowed. Policy goals have been focused on economic and social development, resulting in agricultural development receiving little attention. In fact, the Agriculture Orientation Index for developing countries fell from 0.37 to 0.31 between 2001 and 2013 and aid to agriculture remains static at around 8% (down from 20% in the mid 1980's) (UNSD 2019). In order to meet the demands of the world's growing population, global food production needs to increase by almost 60% (Alexandratos and Bruinsma 2012), and despite the clear benefits of the Green Revolution, and there are many, the side effects (loss of biodiversity, pollution, erosion, etc.) are such that it is not likely that the practices of the Green Revolution are suited to sustainably reach production requirements.

Anthropogenic climate change impacts food and nutrition security both directly and indirectly. Climate change alters rainfall patterns and temperature and increases the number of extreme weather events and thus has direct biophysical effects on food and feed crop production. More indirectly, climate change impacts soil fertility, irrigation, economics and socio-politics. Shifts in food production have indirectly impacted agricultural markets which, in some cases, have led to an increase in food prices and, in the least developed countries, hunger and malnutrition. The fraction of the global population which will experience the direct and indirect impacts of climate change will rise with the level of warming. Generally, it is predicted that Asian monsoon rainfalls will increase while regions of North and South Africa become drier (Wheeler and Von Braun 2013). The Intergovernmental Panel on

[1] Thomas Robert Malthus theorized that population growth is exponential and food supply is linear; thus, if population was not controlled, then catastrophic events of starvation, war and disease would naturally maintain a 'sustainable' global population.

Climate Change (IPCC) Fifth Assessment Report (AR5) suggests increased water resources and high latitudes will interact with increased sediment, nutrient and pollutant loading and thus, there will be a reduction in raw water quality, whilst an increase in droughts in presently dry regions will see a reduction in groundwater resources (IPCC 2014). Projections for 2030–2049 suggest yield gains will increase by 10% for 10% of projections and around 10% of projections show yield losses of more than 25%; after 2050, the risk of more severe impacts will increase (IPCC 2014). Projections also show an increase in invasive agronomic weeds and pests, a decrease in growing seasons (due to higher frequency of frosts and extreme heat), increased mortality of livestock and a decrease in energy availability and access to food.

Agriculture is the primary mechanism for reducing poverty, improving food and nutrition security and stimulating the economy (Wheeler and von Braun 2013). Evidence from countries which have succeeded in increasing food and nutrition security shows that gross domestic product (GDP) growth originating from agriculture is twice as effective as non-agricultural GDP growth. However, global population increase, growth in wealth and consumption and competition for land, water and energy are developing a threefold challenge for the agriculture – match the rapidly changing food demand requirements from a more affluent population; achieve environmental and social sustainability; and target zero hunger among the world's poorest nations (Godfray et al. 2010).

The topic of food and nutrition security and climate change adaptation and mitigation and their relationship is a topic of complexities. It is outside the scope of this chapter to explore all relevant aspects. Thus, this chapter explores only some of the synergies and trade-offs between the SDG of food and nutrition security and climate change goals as a starting point.

1.2 Millennium Development Goals and the Founding of Sustainable Development Goal 2

In September 2000, United Nations member states adopted eight Millennium Development Goals (MDGs) constructed upon the commitment to *spare no effort to free our fellow men, women and children from the abject and dehumanising conditions of extreme poverty*. Whilst a range of factors need to be considered, between 2000 and 2015, extreme poverty halved as has the number of undernourished people; child mortality rates have decreased by more than half; and access to clean drinking water increased significantly. These improvements occurred mostly in the poorest of regions in the world, primarily due to an increase in income, economic growth and resource access. Whilst economic growth is imperative in reducing food insecurity, factors such as climate change, inequality and unequal food distribution also affect food and nutrition security. Despite the progress towards eradication of poverty, gaps still exist, and in fact, the Food and Agriculture Organization of the United Nations (FAO) highlights that the number of undernourished people in the world has been on the rise since 2014, reaching over 821 million in 2017 (FAO 2018). The

Table 1.1 Targets of Sustainable Development Goal 2

2.1 By 2030, end hunger and ensure access by all people, in particular the poor and people in vulnerable situations, including infants, to safe, nutritious and sufficient food all year round.
2.2 By 2030, end all forms of malnutrition, including achieving, by 2025, the internationally agreed targets on stunting and wasting in children below 5 years of age and address the nutritional needs of adolescent girls, pregnant and lactating women and older persons.
2.3 By 2030, double the agricultural productivity and incomes of small-scale food producers, in particular women, indigenous peoples, family farmers, pastoralists and fishers, including through secure and equal access to land, other productive resources and inputs, knowledge, financial services, markets and opportunities for value addition and non-farm employment.
2.4 By 2030, ensure sustainable food production systems and implement resilient agricultural practices that increase productivity and production, that help maintain ecosystems, that strengthen capacity for adaptation to climate change, extreme weather, drought, flooding and other disasters and that progressively improve land and soil quality.
2.5 By 2020, maintain the genetic diversity of seeds, cultivated plants and farmed and domesticated animals and their related wild species, including through soundly managed and diversified seed and plant banks at the national, regional and international levels, and promote access to and fair and equitable sharing of benefits arising from the utilisation of genetic resources and associated traditional knowledge, as internationally agreed.
2.A Increase investment, including through enhanced international cooperation, in rural infrastructure, agricultural research and extension services, technology development and plant and livestock gene banks in order to enhance agricultural productive capacity in developing countries and in particular least developed countries.
2.B Correct and prevent trade restrictions and distortions in world agricultural markets, including through the parallel elimination of all forms of agricultural export subsidies and all export measures with equivalent effect, in accordance with the mandate of the Doha development round.
2.C Adopt measures to ensure the proper functioning of food commodity markets and their derivatives and facilitate timely access to market information, including on food reserves, in order to help limit extreme food price volatility.

Source: United Nations Webpage: https://www.un.org/sustainabledevelopment/hunger/

increase has occurred as result of conflict, climate change, sociopolitical shifts and population growth.

Succeeding the Millennium Development Goals is the establishment of a further 17 universal and interlinked goals, falling under the banner of the Sustainable Development Goals (SDGs). Of the seventeen goals established, goal number 2, *End hunger, achieve food security and improved nutrition and promote sustainable agriculture*, is essential in the success of many of the targets and indicators for the remaining 16 goals. This chapter reviews SDG 2 and explores its connection with climate change reduction policies and targets as outlined in SDG 13, *Take urgent action to combat climate change and its impacts*. This chapter highlights that whilst the United Nations Framework Convention on Climate Change, SDG13 and SDG 2 are synergistic, there are significant trade-offs. Targets for achieving SDG 2 have been clearly defined by the United Nations and are given in Table 1.1.

In terms of its transformational challenge in developed countries, an assessment of SDGs by the stakeholder (an international organisation working to advance sustainable development) ranks SDG 2 low, at 2.1 out of 8, compared to combating climate change SDG 13 which ranked highest (Osborn et al. 2015). Whilst each of the SDGs has challenges, combating climate change and its impacts will be the most challenging for developed countries, and policies which promote a business as usual culture will not enable the necessary changes. Rather, it is necessary for transformational change to the fundamental values and visions of nations, both developing and developed, to be more in alignment with climate change goals. If such transformational change is achieved, then developed countries can significantly reduce global resource pressure and enhance food and nutrition security in some of the most vulnerable developing countries.

Thus, the success of SDG 2 will be more likely achieved when integrated with climate change mitigation and adaptation responses; however, this is a highly complex integration with inevitable trade-offs, despite some synergies. It is therefore vital to examine the key targets and indicators of SDG 2 in compliment, or contrast, to climate change goals. The main themes of SDG 2 are outlined below based on information provided in the UN SDGs. These themes include end hunger and to achieve food and nutrition security. To further frame these two themes, the following section also explores the shift in global nutrition.

1.2.1 End Hunger

Hunger is probably the most obvious manifestation of poverty and, as long as poverty exists, hunger will continue to impact millions of people. The concept of hunger ranges from short-term physical discomfort through to life-threatening starvation due to lack of food. There is no simple resolution to hunger as it is intrinsically linked to the availability of natural resources, technologies, economic and social policy, vulnerability, extreme environmental events and conflict. Whilst levels of hunger have declined significantly since 2000 (von Grebner et al. 2016), conflict and famine are the two forces which are the most difficult to address. Despite this, calamitous famines (where more than one million people die), which plagued so many nations up until the mid-twentieth century, have all but vanished.

Despite these improvements, monitoring UN agencies offer some sobering assessments regarding the world's capacity to meet SDG 2, as outlined in the Global Hunger Index (2018 para. 3):

- *We are still far from a world without malnutrition. The joint estimates... cover indicators of stunting, wasting, severe wasting and overweight among children under 5, and reveal insufficient progress to reach the World Health Assembly targets set for 2025 and the Sustainable Development Goals set for 2030;*
- *The ambition of a world without hunger and malnutrition by 2030 will be challenging - achieving it will require renewed efforts through new ways of working... Achieving zero hunger and ending undernutrition could be out of reach for many countries affected by conflict;*
- *Accelerated progress will be needed in more than a quarter of all countries to achieve SDG targets in child survival.*

The achievement of SDG 2 may be further derailed by the growing threat of climate change if the synergies and trade-offs between food and nutrition security and climate change reduction are not clearly assessed.

1.2.2 Achieve Food and Nutrition Security

Challenges to food and nutrition security are broad and varied and will differ across the various contexts. However, the majority of food systems will be exposed to a growing population, a shift in demographics (particularly a growth of those considered middle income), changes in diet, and hence demand, and a decrease in the availability of natural resources.

It has been estimated that climate change will put a further 1.7 billion people at risk of undernourishment by 2050 if adaptation strategies are not embraced at a global scale (Dawson et al. 2016). It is predicted that by 2050, in the absence of agricultural innovation, global production of wheat, maize and soybean will decrease up to 40, 50 and 50%, respectively, leading to 50% of populations in South America, Africa, Australia and central Asia at risk of undernourishment (Dawson et al. 2016). Whilst wheat production in the United States increases by 24%, a population growth of 40% exceeds the production growth. Production growth in countries such as India and China will result in a decrease in undernourishment.

The UK Chief Scientific advisor, Prof. John Beddington (2009), in his 'perfect storm' speech described the intrinsic link between rapid population growth, climate change, land availability, the rapidly growing demand for energy and water and food security, predicting the world will need to produce 50% more food and energy and 30% more clean water all whilst mitigating and adapting to climate change. Food production is indeed important to food security; however, framing food production in such a way fails to address the complexities of food security and ignores nutrition security.

As agreed at the World Summit in 1996, food security exists when all people, at all times, have physical, social and economic access to sufficient, safe and nutritious food to meet their dietary needs and food preferences for an active and healthy life (FAO 1996). This chapter refers to the four cornerstones of food security – availability, access, utilisation and stability (Venkatramanan and Shah 2020). The nutritional perspective is an intrinsic part of food security (Venkatramanan and Shah 2019).

Food security is a highly complex system which relies on the functioning of these four pillars. Food and nutrition is secure when the available food meets nutritional requirements, is accessible without placing oneself at risk of physical or emotional harm, can be prepared in a hygienic manner and the source of food is not exposed to sudden shocks (such as an economic or climate crisis) or cyclical events. When considering these requirements, it is easy to see why food security affects over 820 million people. With the global population set to grow to an estimated 9.7 billion by 2050 and 11.2 billion by 2100 (United Nations n.d.), it is likely that food insecurity will become a reality for an increasing proportion of the world's population. The biggest margin of population growth will be seen in Africa, and with one in four people in Africa already undernourished, the population growth parallel with climate change will likely result in extensive food and nutrition insecurity if climate adaptations are not adopted or are unsuccessful.

1.3 Achieving Zero Hunger: Climate Change Trade-offs and Synergies

The targets of SDG 2, as outlined prior in Table 1.1, are accompanied with indicators designed to action food and nutrition security goals for a healthy population whilst protecting the planet from degradation, so as to ensure ongoing global prosperity. The targets and indicators are neither a blueprint nor an enforceable mandate; rather, they are a roadmap for global action, requiring each nation to take ownership and report accurately.

This section of the chapter explores the 8 targets and 14 indicators associated with SDG 2, highlighting synergies and trade-offs between SDG 2 and climate change goals. Throughout this section, policy suggestions are also made.

1.3.1 Sustainable Development Goal 2, Target 1: Access to Nutritious and Sufficient Food

To achieve food and nutrition security, target 1 of SDG 2 is to, by 2030, end hunger and ensure access, by all people, in particular the poor and people in vulnerable situations, including infants, to safe, nutritious and sufficient food all year round. In order to measure progress of this particular SDG target, two indicators have been established, which are as follows:

1. Prevalence of undernourishment
2. Prevalence of moderate or severe food insecurity in the population, based on the Food Insecurity Experience Scale (FIES)

1.3.1.1 Reducing the Prevalence of Undernourishment: Trade-offs and Synergies with Climate Change Goals

Currently, undernourishment is considered by the WHO as the biggest threat to the world's health (WHO n.d.). Furthermore, whilst nourishment is key to good health and energy, it is also a driver in productivity. Workers who have optimal nourishment are likely to be more productive and have less time off (Popkin 1978), an example of this is the positive relationship between haemoglobin levels and number of hours worked, with lower haemoglobin levels also being associated with more days of work missed in a study on rubber plantation workers conducted in the Philippines. Also reported was the cost-effectiveness of iron supplementation on productivity (Basta et al. 1979).

Additionally, the importance of nourishment in women of childbearing age can provide a lifelong impact on the next generation, in turn affecting chronic disease development, such as obesity, cardiovascular disease (CVD) and diabetes, associated with the metabolic syndrome (Bruce and Cagampang 2011). These conditions have a large impact on the economy through healthcare costs to the government, also a negative impact on productivity, through an increased number of sick leaves taken over the span of life. In a changing climate, further compromises to human nourishment are likely as resources, such as availability of nutritious and fresh foods, are strained.

Achieving food security will require an increase in food production whilst maintaining or decreasing farming costs, creating a ‘breeder’s dilemma’. In response, researchers have tended to focus plant breeding on high-yielding, easy-processing and pest- and disease-resistant varieties, which may have resulted in the global consumption of foods which are associated with health problems such as obesity, cardiovascular disease and diabetes (Morris and Sands 2006). Creating foods, particularly staple foods, which are more nutritious may require selecting cultivars which are lower yielding, more difficult/costly to process and more sensitive to pests and diseases (Morris and Sands 2006). In response to this issue, research considers biofortification as one approach to improve nutritional quality of food crops by increasing the density of vitamins and minerals and hence, can improve human nutrition. In Rwanda, iron-depleted women showed increased haemoglobin after 18 weeks of consuming biofortified beans (Haas et al. 2017); in Uganda. biofortified sweet potato improved vitamin A intakes of children (Hotz et al. 2012); and children in Zambia showed increased body stores of vitamin A after 3 months of consuming biofortified maize (Gannon et al. 2014). Whilst biofortified food crops are being consumed in many counties, research has found that consumption and acceptability are influenced greatly by sensory and cultural attributes (Hummel et al. 2018). Indigenous communities in particular, have complex cultural laws around specific foods and whilst replacing a cultural crop such as taro with biofortified taro may improve community nutrition, if it is not accepted culturally then the trade-offs may have more dire impact on people’s lives than the nutrient deficiency itself. However, biofortification has significant potential to enhance production of food crops without compromising nutrition security, allowing for selection of more climate-smart farming practices. In this context, climate change goals and SDG 2 are synergistic; however, achieving nourishment via food security will possibly impact climate change negatively through increased production requirements, and hence, strategies such as biofortification may allow food security to be achieved without compromising nutrition security in the process and allow for selection of more climate change-friendly farming.

1.3.1.2 Applying the Food Insecurity Experience Scale: Synergies and Trade-offs with Climate Change Goals

As described earlier, accessing food is a key element to food and nutrition security. Individual access to food can be constrained by a broad range of social and economic factors, and understanding individual access has traditionally been difficult to measure. In response to this challenge, the FAO established the Food Insecurity Experience Scale (FIES) in 2014. The Food Insecurity Experience Scale is a statistical scale which consists of eight questions regarding individual and household access to food (FAO 2019a). The FIES is described by the FAO as *the tool with the greatest potential for becoming a global standard capable of providing comparable information on food insecurity experience .... to track progress on reducing food insecurity and hunger* (Ballard et al. 2013 p 10).

The questions of the FIES create a synergism with climate change goals in several ways:

1. Information resulting from the FIES is relevant and accessible to broad audiences from government officials making policy decisions to climate researchers and climate advocates.
2. When aligning the information from the FIES with climate data, there is potential for a deeper understanding of the individual consequences resulting from climate change, as the questions themselves, when connected with regional climate data, may provide decision-makers with a clearer perspective of the geographical relationship between climate adaptation practices and the increase or decrease in food security.
3. The FIES data, as collected through the Gallup World Poll, has established a sound set of baseline data from which the impacts of regional climate policy have on food security can be reported. For example, food access impacts of a particular climate policy, in a region where FIES data identifies a high proportion of individuals that have poor access, can be monitored through follow-up FIES surveys. If in the follow-up survey individuals respond that food access has improved, then the climate policy has had a positive impact on food access.
   The trade-off of the FIES is that it does not measure prevalence of malnutrition, nutrient deficiencies or obesity and as such will fail in delivering essential data on food insecurity and health outcomes.

Considerations for Achieving Target 1

Adaptation and mitigation of climate change will have a positive impact on achieving SDG 2 target 1. Biotech advancement, for example, biofortification, and collection of data using the FIES will be key in achieving target 1 of providing safe, nutritious and sufficient food without compromising the achievement of climate change goals; however, cultural acceptability and limitations of data captured by the FIES may impede success.

1.3.2 Sustainable Development Goal 2, Target 2: End All Forms of Malnutrition

Target 2 aims to, by 2030, end all forms of malnutrition, including achieving, by 2025, the internationally agreed targets on stunting and wasting in children below

5 years of age, and address the nutritional needs of adolescent girls, pregnant and lactating women and older persons.

In order to measure progress of this particular SDG target, two indicators have been established. They are:

1. Prevalence of stunting (height for age < -2 standard deviation from the median of the World Health Organization (WHO) Child Growth Standards) among children below 5 years of age.
2. Prevalence of malnutrition (weight for height $> +2$ or < -2 standard deviation from the median of the WHO Child Growth Standards) among children below 5 years of age, by type (wasting and overweight).

1.3.2.1 Decreasing the Prevalence of Stunting in Children Below 5: Trade-offs and/or Synergies with Climate Change Goals

Stunting figures continue to remain high in children below 5 years, particularly in developing countries; however, the coexistence of stunting and wasting or stunting and overweight creates a spectrum of problems. Recent statistics report that 15.95 million children are suffering from wasting and stunting, and 8.23 million children are affected by stunting and overweight (WHO 2018). Despite higher rates of child mortality associated with stunting and wasting, there remain two sides to the problem of stunting in children below 5, and hence achieving targets associated with stunting requires more than simply an increase in energy intake. Rather, the main driver for reducing the prevalence of stunting is through achieving food and nutrition security.

A report on the progress of countries in meeting targets for nutrition goals set for 2025 showed that out of 194 countries assessed, 24 are on track for achieving stunting targets, 37 for wasting and 18 for stunting and wasting targets. This leaves many countries yet to make substantial progress within a short timeframe. In order to achieve targets, substantial and impactful action needs to take place (WHO 2018).

Furthermore, stunting rates are not simply overcome by providing food and nutrition security to children, but also women of childbearing age, as stunting often begins through maternal malnutrition. Hence, food and nutrition security for all lies at the heart of achieving stunting targets in children, providing a focus for addressing malnutrition targets in women of childbearing ages and children below 5.

Whilst working towards a low climate change environment appears to reduce stunting rates in itself, based on global-level modelling predictions, the main focus for reducing the prevalence of stunting in children below 5 years should not just be on increased food production but on the relationship between farmers income and food price (Lloyd et al. 2018).

1.3.2.2 Reducing Global Malnutrition: Trade-offs and Synergies with Climate Change Goals

Malnutrition captures both under- and overnutrition, resulting in underweight or overweight and obesity. Both forms of malnutrition have negative impacts on health outcomes, quality of life, productivity and hence economic burden. Whilst developed countries show trends of higher prevalence of obesity in relation to malnutrition, low- and middle-income countries (LMICs) are experiencing the double burden of malnutrition, with continuing high prevalence of underweight, yet with a rise in rates of overweight and obesity.

Whilst some countries are making progress regarding reducing rates of stunting and are on track to meet targets, none of the 194 countries assessed for meeting targets on adult obesity are projected to achieve this target by 2025 (WHO 2018), suggesting malnutrition in the form of overnutrition requires more drastic policy changes for any chance of success in achieving malnutrition targets. Promotion of reducing overconsumption would have positive effects on these rates and similarly on climate change. In order to improve the projected outcomes for obesity targets, policy needs to readdress the research on prevention and reversal of obesity.

Climate change also has an impact on the nutrition content of food, with studies reporting a substantial effect on zinc, iron and protein content of wheat, rice, field peas and soybeans due to raised CO_2 levels predicted by 2050 (Myers et al. 2014).

Achieving climate change goals will therefore be synergistic with improving nutrient availability and thus reducing risk of undernutrition. Also, reducing overconsumption will work to reduce rates of overnutrition and have a positive impact on climate change.

Considerations for Achieving Target 2

Whilst climate change goals are in alignment with aiding the achievement of the targets for ending all forms of malnutrition including preventing impacts on vitamin and mineral content of foods due to increased CO_2 levels and focusing on sustainable consumption to reduce prevalence of overnutrition, farmers' income and food price are factors which should also be considered in working towards reducing stunting when it comes to climate change policies.

1.3.3 Sustainable Development Goal 2, Target 3: Double Agricultural Productivity

The third target for food and nutrition security is to, by 2030, double the agricultural productivity and incomes of small-scale food producers, in particular women, indigenous peoples, family farmers, pastoralists and fishers, including through secure and equal access to land, other productive resources and inputs, knowledge, financial services, markets and opportunities for value addition and non-farm employment.

In order to measure progress of this particular SDG target, two indicators have been established; they are as follows:

1. Volume of production per labour unit, by classes of farming/pastoral/forestry enterprise size
2. Average income of small-scale food producers, by sex and indigenous status

1.3.3.1 Volume of Production: Trade-offs and Synergies with Climate Change Goals

Agriculture contributes to around one-third of total greenhouse gas (GHG) emissions (Yadav et al. 2015), with the resultant temperature changes, rainfall and CO_2 levels negatively affecting agricultural production (Venkatramanan and Shah 2019; Venkatramanan et al. 2020a). Thus, the challenge for scientists, farmers and decision-makers is to increase agricultural production to achieve global food and nutrition security whilst meeting climate change goals (Venkatramanan et al. 2020b). This section of the chapter explores land access, indigenous knowledge, gender and off-farm income as drivers for improved food and nutrition security along with their trade-offs and synergies with climate change goals.

Every year, 12 million hectares of productive land become unusable due to desertification, which is equivalent to a lost opportunity of producing 20 million tonnes of grain (United Nations Convention to Combat Desertification 2019). In fact, experts predict that nearly 33% of the world's arable land has been lost in the past 40 years from erosion and/or pollution (Grantham Centre for Sustainable Futures 2015). Such a rapid decline in available arable land is placing pressure on nations and investors to secure their future food and nutrition requirements, which at times is outside the boundaries of their nation. Achieving SDG 2 will require secure and equal access to land and productive resources. Current constraints to secure and equitable land access include, land grabbing, a decrease in arable land and conflict.

Land grabbing refers to international investors leasing or buying agricultural land, for example, in Africa, Asia and South America, for food and fuel production. Some investors do this to secure food and feed for their own country, whilst others are capitalising on what is seen as a promising financial return. Some proponents of this type of investment argue that land grabbing supports economic growth, food production and conservation; for example, investments in the Caribbean, South America and Central America have contributed to the largest global annual increase in tree plantations, used for internal production as well as exportation, making major contributions to the economic growth of these regions. Proponents also highlight investments made in land conservation, such as Douglas Tomkins, founder of the North Face apparel company who purchased over 880,000 ha of land in South America, allocating much of this to conservation whilst using the remaining as models of sustainable agriculture. Critics of land grabbing argue that the practice marginalises the vulnerable (smallholder farmers and indigenous people), displacing them from the land and resources essential to their survival.

Whilst investment in land can contribute to climate change goals through conservation and carbon-offset programmes, recognition of the rights of the owners of the land it is should be a priority. Policies, which take a rights-based approach to land leasing and investment, will more likely achieve economic growth, whilst simultaneously improving sustainable agriculture, conservation and land security and equity for smallholder farmers and indigenous peoples.

Equal and secure access to land is certainly hampered by land grabbing, but it is also under pressure from population growth, urban spread, allocation for natural conservation, poor farming techniques and climate change. Although climate models suggest that global arable land may increase in high latitude regions such as Russia, China and the Unites States, due to an increase in temperature and humidity, arable land in tropical regions will be lost (Zhang and Cai 2011). People in those regions where arable land decreases will be seeking new land. Traditionally, new agricultural land has come at the expense of native forests (Gibbs et al. 2010), which has placed pressure on global diversity and natural resources. However, new agricultural technologies may minimise the impact of agricultural production in native forests, allowing the two to coexist. Yet, the trade-offs between biodiversity and food production are prevalent and debate is divided, leaving policymakers to question whether policy should create a separation between agricultural land and land for nature (land sparing) or should policy encourage the coexistence of the two (land sharing).

Land sharing offers a number of benefits, including increased access to arable land for agriculture, high levels of natural biodiversity (which may improve yields) and protection of natural resources rather than destruction of natural resources for new agricultural land. The potential trade-offs from land sharing include the potential for increased pest numbers, loss of native species and environmental degradation from poor agricultural practices.

Land sparing clearly distinguishes land for agriculture and land for nature. Maintaining or increasing land for nature is essential in achieving the climate change goals of regulating ecosystems, protecting biodiversity and sequestration of carbon. Successful land sparing policy needs to be multi-pronged. Land sparing policy should prioritise sustainable intensification of agriculture and a reduction of food waste and restrict low-yield crops. Achieving these three priorities would allow agricultural land to provide multiple environmental services in addition to food production. If land sparing policy fails to increase available arable land, then it achieves nothing but to ‘lock out’ access by those people who rely on those natural habitats for their economic development, not to mention their very survival, missing an opportunity for global food and nutrition security for many people.

In addition to land grabbing, land sharing and land sparing are the issues of conflict over land resources. Land conflict has historically been a significant factor in secure and equitable land access. Conflict may arise from multiple factors including political tensions or tribal uprisings. There are suggestions that climate change is also resulting in conflict, although this is still an area of conjecture; for example, research into land conflict in Mali found little evidence that climate change factors of water scarcity and environmental change were drivers of land conflict (Benjaminsen et al. 2012). Rather, conflict was a result of agricultural encroachment on livestock corridors, reducing the mobility of herders and animals caused by policy which promotes farming projects. Also attributed to the conflict was a political vacuum which allowed opportunistic claims of land and resource ownership and a lack of faith in government institutions in resolving land ownership issues. Whilst Benjaminsen’s research found no evidence that climate change was a factor in the Mali conflict, local and regional tensions and the potential for conflict in least developed countries are more likely if food and nutrition security is not achieved.

1.3.3.2 Increased Average Income of Small-Scale Food Producers, by Sex and Indigenous Status: Synergies and Trade-offs with Climate Change Goals

Climate change will impact agricultural productivity and on-farm income of both large-scale and small-scale farmers. Whilst large-scale farmers often quickly adopt climate-smart technology, smallholder farmers are also more resilient to climate change than they appear. For many thousands of years, smallholder farmers have developed methods to maintain food and nutrition security during natural disasters, for example, storing breadfruit and yams in the soil to improve their shelf life, applying natural pest management techniques, planning for natural disasters (Radcliffe et al. 2018) and preparing and cooking native plants (Hart 2007). In fact, it is estimated that half of all smallholder farmers apply resource-conserving agriculture (Toledo and Barrera-Bassols 2008). Indigenous knowledge represents an important contribution to food and nutrition security of smallholder farmers and its potential in sustainable agriculture is well published; however, trade-offs from the use of indigenous knowledge need consideration, particularly the issue of intellectual property and misrepresentation.

Unlike multinational organisations that have clear legal intellectual property rights processes, indigenous knowledge has often been obtained by Western researchers without recognition or payment. Although treaties now outline the importance of recognition of indigenous knowledge, they are often ineffective and open the way for creative policy alternatives (Norchi 2000). Some academics are advocating for indigenous knowledge to become a tradable commodity, similar to knowledge commodities of multinational corporations; however, this may result in indigenous knowledge being sold to the highest bidder. This would limit access to indigenous knowledge by many sustainable development projects, resulting in projects which cannot adopt the most effective practices without paying royalties and thus, potentially reducing food and nutrition security and climate change goals, despite the opportunity to increase income in these farmers.

Western society has long misrepresented indigenous knowledge through commercial copies of art and textiles for the tourism industry, adaptions of indigenous music/songs and the mimicry of cultural beliefs (Flor 2013). Whilst there has been some excellent participatory research, science has an unfortunate history of placing little value on the environmental knowledge of indigenous people, which often results in agricultural projects which only include aspects of indigenous knowledge that mirror science and allow for manipulation. Indigenous knowledge has significant value and may greatly contribute to improving food and nutrition security and climate change goals.

Women are integral in achieving both, SDG 2 and climate change goals, yet often, and particularly in developing countries, women have a lack of entitlements, endowments and are more reliant on natural resources. Hence, women are often more exposed to climate change than men. The Food and Agriculture Organization estimates that if women had the same access to agricultural resources as men, yields could increase by 30% and the number of undernourished people could decrease by up to 17% (FAO 2011). With 50% of the agricultural workforce being women, the role women play in food and nutrition security cannot be understated (FAO 2018; Venkatramanan and Shah 2020). Cultural, traditional and social limitations in many countries limit women's access to resources such as land, credit and training and thus constrain women's contribution to food production. Since 2011, nutrition education has been conducted in the Gaza strip as part of the World Food Programme (WFP). Thousands of women, men and children have participated, learning about food-related topics such as a healthy diet on a small budget, food preparation, hygiene, pregnancy nutrition and breast feeding. Outcomes of this project are yet to be reported; however, based on past monitoring in Palestine, maternal education and supplementation have been shown to improve feeding patterns and growth outcomes in children (Tulchinsky et al. 1994). Gender plays a role in nutrition security, with know-how for women in sourcing nutritious food and preparing food in healthy ways, particularly in times of financial difficulty. For men, knowing the value of nutrition and health may increase money allocated to meals, when budgets are determined by men, which in turn may increase productivity and health outcomes of often the main income provider of the family. This highlights a vital link between gender and nutrition security and food security. However, careful consideration is needed when promoting more women in agriculture; whilst it can positively impact child dietary intake and morbidity, there may be unintended negative impacts such as child welfare where women become unavailable for childcare due to their responsibilities in food production (Berti et al. 2004).

For improved food production, the Food and Agriculture Organization (FAO) recommend that policy should aim to:

- Provide equal rights for resources

  In response, the FAO has developed a set of gender-sensitive indicators regarding access to water for agriculture called the 'UN World Water Assessment Programme'. The FAO's Gender and Land Rights Database provides an analysis of national policies which support gender-equitable land rights.
- Tailor agricultural extension to meet the needs of women

  In response, the UN has launched an online portal for empowering women titled 'knowledge gateway for economic empowerment'.
- Introduce technologies which free up women's time for income-producing activities
- Improve nutritional status of women and children
- Promote women's organisations

Women also play a pivotal role in improving household income through off-farm work. Although agriculture employs 22% of the global workforce and contributes to 40% of GDP in Africa and 28% in Asia (Yadav et al. 2015), models predict a significant decrease in production in many of these regions, and therefore, off-farm income will be an essential element in maintaining household food and nutrition security. When off-farm income increases total household income, families have better access to food, and therefore, food and nutrition security is improved. Research in Nigeria found that off-farm income, such as handicrafts, food processing and agricultural trade, improves calorie and micronutrient supply and improves child nutritional status (Babatunde and Qaim 2010). However, off-farm income can create negative impacts when it competes with on-farm work and in such circumstances, families find a reduction of household food availability (Babatunde and Qaim 2010).

Off-farm income is synergistic with climate change goals when it encourages solutions to agricultural issues. For example, off-farm income from crafts which increase household income mean that families do not solely rely on agriculture for income, and therefore, farmers may seek to plant a more diverse range of crops, thereby improving biodiversity. This may also be through innovative design and sale of tools or techniques for improved sustainable agricultural practices.

Considerations for Achieving Target 3

Agriculture contributes to around one-third of global greenhouse emissions, further exacerbating climate-induced food and nutrition insecurity. It is within this context that agricultural production needs to increase by 60%. Achieving global agricultural system which emits minimal greenhouse gas whilst producing enough food to feed the world is a significant challenge. Achieving target 3 can be synergistic with climate change goals in that it may encourage climate-smart technology, sustainable agriculture through land sharing, gender equality, improved household income, increased land for conservation and enhanced biodiversity. However, inadequate policy may result in significant trade-offs such as increased pest numbers, loss of native species, environmental degradation, potential child welfare issues, land lock-out and a loss of indigenous knowledge.

1.3.4 Sustainable Development Goal 2, Target 4: Sustainable Food Production

The fourth target for food and nutrition security is to, by 2030, ensure sustainable food production systems and implement resilient agricultural practices that increase productivity and production; help maintain ecosystems; strengthen capacity for adaptation to climate change, extreme weather, drought, flooding and other disasters; and that progressively improve land and soil quality.

In order to measure progress of this particular SDG target, a key indicator was established. It is as follows:

1. Proportion of agricultural area under productive and sustainable agriculture

1.3.4.1 Increasing the Proportion of Agricultural Area Under Productive and Sustainable Agriculture: Synergies and Trade-offs with Climate Change Goals

Industrial agriculture is input-intensive and reliant on high-level application of pesticides, herbicides and inorganic fertilisers, seasonal tillage, monoculture cultivation and extensive irrigation (Woodhouse 2010), which all are reliant on fossil fuels for production (Lin et al. 2011). The heavy use of fossil fuels results in agriculture being responsible for about one-fifth of global greenhouse gas emissions (FAO 2018).

Whilst industrial agriculture has been key to the rapid increase in food production, there have been social and environmental consequences. Industrial agriculture is reliant on chemicals and machinery as a substitute for traditional human energy, resulting in a decline of people working on farms. Capital costs have increased rapidly and health issues resulting from exposure to chemicals have risen (Clunies-Ross and Hildyard 2013). Although pests have always challenged farmers, declining soil fertility, water availability and the standardisation of industrial agriculture magnifies these problems resulting in a further increase of inorganic inputs, creating a treadmill of short-term fixes (Weis 2010).

The ineffectiveness of modern industrial agriculture for food and nutrition security is further evidenced by the fact that we produce food for 12 billion people, when there are only 7 billion people living, resulting in over 800 million suffering from malnutrition and 1.7 billion suffering from obesity (Petrini and Lionette 2007). Viewed separately, the adverse effects of industrial agriculture may be considered simply as side effects of an otherwise successful system; however, in viewing the whole picture, it is clear that current industrial agriculture practices are destructive, socially unjust and unsustainable.

International bodies pose two paths to food security: sustainable agriculture and industrial agriculture. Whatever path chosen, it is clear that the planet will transit to sustainability; the question is whether this will be an orderly transition or whether it will be dictated by the planet's physical limits and environmental damage (UNESCO 1991). Planning for an orderly transition will require a participatory and ground-up approach, clear policies which consider both climate change and food and nutrition security, climate-smart technology and improved agricultural extension in both developed and developing countries. For any hope of creating a more sustainable relationship between humans and the earth, there is a need to radically restructure agriculture, that is, to convert unsustainable food productions into more sustainable ones (Gliessman and Rosemeyer 2009).

There is no shortage of ideas, theories and case studies on sustainable agriculture. Some proponents argue that sustainable agriculture can be achieved by studying traditional farming knowledge (Altieri 2004), some argue that sustainable agriculture will come from investment into technology (Tilman et al. 2011), whilst others argue that sustainable agriculture requires shifts in political governance (Kemp and Martens 2007). For the purpose of this chapter, sustainable agriculture is defined as a system for change which:

> 'maintains the natural resources needed, preserves communities and social and cultural systems that allow for the appropriate distribution of food, and provides the possibility of decent livelihoods in rural areas'. (The International Commission on the Future of Food and Agriculture 2006 p 15)

What is clear from this definition is that sustainable agriculture requires a multi-pronged approach that will include indigenous farming knowledge, technology and the support of national and international governing policies. Policies designed to transition agricultural practices from current intensive industrial practices to sustainable ones will differ from nation to nation and region to region; there is no one-size-fits-all blueprint for sustainable agriculture. There are, however, synergies and trade-offs with climate change goals, which a policy should consider. Synergies associated with productive and sustainable agriculture and climate change goals may include the following:

- More diverse crops grown that can improve household nutrition and soil fertility
- Less inorganic inputs, therefore less emissions in the production and transport, better water quality, etc.
- Promotion of agroforestry increases biodiversity.
- Soil management reduces erosion (reducing CO_2 release), promotes soil biota and therefore ensures long-term soil availability.
- Sustainable agriculture promotes soil moisture retention, a core element in adaptation to climate change.
- Sustainable agriculture incorporates cover crops for fallow, which can result in additional feed for livestock.

Trade-offs from sustainable agriculture regarding climate change goals may include the following:

- Shifting/adapting from conventional agriculture can have costs, for example, more efficient machinery purchase costs (which can create household debt and increase the need for cash crops), loss of cash crops, higher manual labour requirements.
- Mulching may require the use of resources which were traditionally used for feeding livestock or thatching etc., lowering the quality of livestock herds. If mulching is a source of firewood, there may be an increase of pressure on local trees, shrubs and forests.
- Soil management techniques such as direct sowing (particularly mechanised) will create efficiencies but will also reduce the local employment, impacting on those who are landless.
- Placing land in fallow can result in decreased income and household food security during the fallow period, which may result in farmers opening up new land to agriculture.

Creating a more sustainable, resilient and smart agricultural system will come from agricultural transformation (Venkatramanan et al. 2020b) and shifts in farming practices, both internal and external. Internal factors include farmers reducing tillage, developing diverse agroecosystems and being more conscious of chemical use and the associated impacts on the local environment. External factors may include increasing energy costs, thereby lowering profit margins of conventional practices, and, creating new and stronger markets for organic product (Gliessman and Rosemeyer 2009). Sustainable agriculture is the primary driver in achieving SDG

2 and whilst policy should understand the trade-offs, further application of sustainable agricultural practices should be of high priority.

Considerations for Achieving Target 4
Industrial agriculture is input-intensive and reliant on non-renewable resources. Following a path to sustainable agriculture can provide food and nutrition security, offer mechanisms for mitigation and adaptations to climate change and maintain natural resources. A multi-pronged approach is required to achieve sustainable agriculture including improved training, innovation of climate-smart technologies and shifts in national policy.

1.3.5 Sustainable Development Goal 2, Target 5: Genetic Diversity

The fifth target for food and nutrition security is to, by 2020, maintain the genetic diversity of seeds, cultivated plants and farmed and domesticated animals and their related wild species, including through soundly managed and diversified seed and plant banks at the national, regional and international levels, and promote access to and fair and equitable sharing of benefits arising from the utilisation of genetic resources and associated traditional knowledge, as internationally agreed.

In order to measure progress of this particular SDG target, two indicators have been established. They are as follows:

1. Number of plant and animal genetic resources for food and agriculture secured in either medium or long-term conservation facilities
2. Proportion of local breeds classified as being at risk, not-at-risk or at unknown level of risk of extinction

1.3.5.1 Securing Plant and Animal Genetic Resources: Synergies and Trade-offs with Climate Change Goals

Food and nutrition security is reliant on both quantity and quality of food, and achievement of one should not be at the expense of the other. Quantity is achieved through increased global food production, whereas quality is achieved through the provision of food crop diversity. Diverse food crop varieties, both farmed and wild, are vital to integrating new traits and new variants, and their continued existence and use is essential. However, global diversity is being threatened; in fact, a recent report into the state of the world's biodiversity for food and agriculture (FAO 2019b p 113) found that:

- Many components of food and agriculture at genetic, species and ecosystem levels are in decline.
- The proportion of animal breeds at risk of extinction is increasing; in some regions, crop diversity in farmers' fields is decreasing; and nearly a third of fish stocks are overfished.

- Species vital to agroecosystems are in decline, including pollinators, natural enemies of pests, soil organisms and wild food species.
- Ecosystems which deliver essential services to agriculture (forests, mangroves, rangelands, coral reefs and wetlands) are rapidly declining.

The narrowing of diversity in both production systems and food supplies is a threat not only to global food and nutrition security (Khoury et al. 2014) but equally to climate change goals; for example, crop wild relatives (the ancestors that provide genes for plant breeding) are beneficial sources of diversity for enhanced plant adaptation to water stress or extreme temperatures. Acting to conserve genetic diversity is no longer an option but a fundamental priority for all nations, and a part of this priority is the ongoing development of gene banks. Gene banks are the world's gene pool repository for landraces and wild crop types. The FAO estimates that there are over 1750 gene banks around the world, of which 130 hold more than 10,000 accessions each (FAO 2010), such as the Svalbard Global Seed Vault located 1300 km north of the Arctic circle (https://www.seedvault.no/).

1.3.5.2 Increasing or Maintaining the Proportion of Local Breeds Being Extinct: Trade-offs and Synergies with Climate Change Goals

Gene banks should not be relied on as the only approach to maintaining genetic diversity. A review of climate change adaptation plans across United States, Canada, England, Mexico and South America found four broad approaches to maintaining genetic diversity: land and water protection, direct species management, monitoring and planning and law and policy (Mawdsley et al. 2009). Maintaining and improving genetic diversity is essential for food and nutrition security and climate change goals; however, policy must be designed to best exploit genetic diversity in a way that benefits all people equally.

Ongoing concerns regarding the sovereignty of plant genetic resources has placed a spotlight over the rights of farmers and the equal access for all nations. Trade-offs resulting from the efforts to maintain plant genetic material include, in some cases, corporate appropriation of genetic material, intellectual property rights over plant genetic material, a growing monopoly by multinational corporations over the seed market and the imposition of seed certification for transgenic crops (Kloppenburg 2014). Efforts continue to be made to minimising such trade-offs, such as the International Treaty on Plant Genetic Resources for Food and Agriculture (ITPGFA), which facilitates access to 64 crops (which together account for 80% of the plant-based food) for all ratifying nations. All nations who access genetic material through this multilateral system have agreed to pool, manage and share any benefits from the use of plant genetic resources. Equal access to plant genetic resources by farmers will be further improved through the recent approval by the United Nations Declaration on the Rights of Peasants and Other People Working in Rural Areas. An example of where this declaration may improve access is Article 17 of the Declaration, which describes the right to equitable sharing of the benefits and to protection of knowledge relevant to plant genetic material. However, the declaration does not provide a legal basis for remuneration for genetic material –

instead, it promotes existing human rights and relevant jurisdiction requirements – neither does the Declaration state who is entitled to intellectual property rights of genetic resources, rather it points to existing agreements under the current ITPGFA treaty.

Considerations for Achieving Target 5

Maintaining genetic diversity is an essential element in 'future proofing' food and nutrition security, but only to those who have equitable access to the genetic resources. Treaties may need to be reviewed and amended so as to provide equal access to all components of genetic diversity and restrict the commodification of genetic resources. Improved diversity and number of plant and animal genetic resources being conserved synergistically respond to climate change goals by improving global adaptive capacity and climate resilience (such as climate resilient crops). Trade-offs may include corporate appropriation of genetic material, intellectual property rights over plant genetic material, a monopolisation by multinational corporations over the seed market and the imposition of seed certification for transgenic crops; however, such trade-offs will vary regionally.

1.3.6 Sustainable Development Goal 2, Target 6: Increase Investment

The sixth target for food and nutrition security is to increase investment, including through enhanced international cooperation in rural infrastructure, agricultural research and extension services, technology development and plant and livestock gene banks in order to enhance agricultural productive capacity in developing countries, in particular least developed countries.

In order to measure progress of this particular SDG target, two indicators have been established. They are as follows:

1. The agriculture orientation index for government expenditures
2. Total official flows (official development assistance plus other official flows) to the agriculture sector

1.3.6.1 Agriculture Orientation Index: Synergies and Trade-offs with Climate Change Goals

To achieve food and nutrition security, increased investment from both private and government investors is required, particularly, in the areas of infrastructure, technology, research and extension. Government investment into the agricultural sector is essential in creating an environment of confidence for other investors. Currently, this is not the case; in fact, the Agriculture Orientation Index (AOI), which is calculated as a ratio by dividing the agriculture share of government expenditure by the agriculture share of GDP, has declined from 0.42 in 2001 to 0.26 in 2017 (FAO 2009). The long-term decline of the AOI suggests that government investment into other sectors has taken precedence over the SDG 2. Alongside a decline in worldwide AOI, international aid to agriculture remains static at around 8% (down from 20% in the mid-1980s) (UNSD 2019). Encouraging investment into the agricultural sector requires a multi-pronged approach, including through public pressure of socially responsible investment, research subsidies, increased government investment, increased international aid and improved investment policy.

Investment policy trade-offs should be carefully considered though. Investors often act as a ‘herd’, buying and selling significant quantities at the same time, and this has, in the past, led to increased food price volatility. In addition, whilst increased investment in rural infrastructure has enabled many rural households to connect to electricity, which has assisted in food storage and food preparation; however, the increased used in electricity results in increased emission from power stations as well as redirecting government money into the ongoing maintenance of the infrastructure.

1.3.6.2 Total Official Flows: Synergies and Trade-offs with Climate Change Goals

In some cases, a complete overhaul of international aid programmes is required. As an example, the Least Developed Countries Fund (LDCF) funded 51 adaptation projects, totalling US$934 million. Of these funds, 28% was used for SDG 2. The funds mandate was to fully fund projects; however, insufficient and uncertain funding left host nations having to cosponsor or find other institutions to match contributions, which resulted in developing countries redirecting funds from other projects into projects which should have been fully funded. The funding attached to the LDCF was also clearly insufficient to meet climate project needs, which require US$10–100 billion annually to prepare developing countries for climate change. It was also noted that administrative structure was convoluted, and the complexity of adaptation challenged many user nations and reduced project outcomes, which highlights that there is no one-size-fits-all approach. An inability to eliminate risk has limited the success of LDCF; for example, Bangladesh developed salt-tolerant rice varieties, but the concentration of salinity is rising above the tolerance levels of the rice variety.

Priority investment should be to shift food production systems from managing climate risk to food production systems which adapt to climate change. Agricultural extension is crucial in supporting on-farm transformation, yet funding to extension services has declined, and improved policy is needed to rebuild these services (Hannah et al. 2017). Agricultural extension directly influences Sustainable Development Goals of zero hunger, quality education, gender equality and climate action (United Nations 2015). Whilst investment into agricultural extension can offer synergies such as higher yielding crops, improved soil management, maintaining or increasing biodiversity, carbon sequestration, trade-offs need to be understood. Evidence shows low levels of technology uptake of smallholder farmers (Shiferaw et al. 2009; Meijer et al. 2015), and therefore, climate change adaptation such as drought- or flood-resistant transgenic crops may have limited impact on agricultural systems in many of the developing regions, resulting in exposure to food and nutrition insecurity. A key factor of low uptake of technology by farmers is that government-funded agricultural extension continues to be a policy-directed top-down approach, that is, the regarded superiority of scientific theory and technology over all other knowledge (Greer Consulting 2008; Thapa 2010; Sitapai 2012; Rasheed 2012; Curtis 2013; Abdullah et al. 2014; Buyinza et al. 2015; Mossie and Meseret 2015; Ragasa and Niu 2017). This approach fails to recognise the context and discounts local and indigenous knowledge. It has been found that technology uptake can be improved if farmers are provided an opportunity to use their knowledge to adapt and apply the technology to their context (Meijer et al. 2015). A higher uptake of technology by smallholder farmers will result in improved climate change adaptation and increased food production. International investment into agricultural extension is, generally speaking, more participatory and often more synergistic; however, inconsistent policy results in a range of philosophical and methodological foundations. A common theme of participatory approaches is the notion of 'allowing' participants to negotiate and determine the outcomes (Bruges and Smith 2007). Participatory approaches are also often incorporated into research in order for researchers to access funding, as funding often stipulates direct engagement and benefit for farmers (Bruges and Smith 2007) and researchers often take the results, and associated intellectual property rights, to the country which provided the researcher with their funding. Such influences create what Leeuwis (2013) refers to as the participation paradox, where people are capable and knowledgeable, but participatory projects assume people cannot achieve the outcomes themselves.

Considerations for Achieving Target 6

To achieve target 6, further investment in rural infrastructure, government and non-government aid and research and extension will be necessary. Whilst target 6 is synergistic with climate change goals, particularly regarding climate-smart technologies, gene technologies, sustainable agriculture and carbon sequestration, achieving target 6 may also result in trade-offs. Specifically, trade-offs include increased emissions from new infrastructure and increased costs to farmers from the intellectual property rights of private research firms.

1.3.7 Sustainable Development Goal 2, Target 7: Correct and Prevent Trade Restrictions

The seventh target for food and nutrition security is to correct and prevent trade restrictions and distortions in world agricultural markets, including through the parallel elimination of all forms of agricultural export subsidies and all export measures with equivalent effect, in accordance with the mandate of the Doha Development Round.

In order to measure progress of this particular SDG target, two indicators have been established. They are as follows:

1. Producer support estimate
2. Agricultural export subsidies

1.3.7.1 Correction and Prevention of Trade Restrictions and Distortions: Synergies and Trade-offs with Climate Change Goals

Global agricultural trade has grown threefold in the past decade, and projections are that this trend will continue to grow (FAO 2015). Global agricultural trade is essential to achieving SDG 2, as trade can not only increase food, but if all countries were open to international trade and investment, there would be an improved resource efficiency, an increase in household income and reduced fluctuations of international food prices and quantities (Anderson 2015). Whilst an increase in global trade does have a direct impact on increased carbon emissions through increased transportation, the environmental and social consequences are considered smaller than the gains (Costinot et al. 2016).

Whilst trade can increase the availability of food, it can also leave countries reliant on international markets and with this brings exposure to market shocks which often result in high consumer prices and supply shortages. Hence, it is important that agricultural trade policies work for improved food and nutrition security and not against it. History has demonstrated that policy for improved food and nutrition security is challenging; in fact, the United Nations considers both reduced regulation of agricultural production and trade and removal of agricultural tariffs as key structural factors behind the 2008 food price crisis (Mittal 2009).

Agricultural subsidies are financial payments designed to offset agricultural costs or raise or lower agricultural prices in pursuit of the public interest (Dorward and Morrison 2015). Agricultural trade subsidies often target a select few monoculture crops, which are selected due to their economic efficiency and the potential to produce large amounts of standardised commodities. The result of targeting a select few monoculture crops, or quantity over quality, can result in a lack of diversity, which can affect people's dietary choice and may reduce the likelihood of people having access to nutritional foods. Monoculture crops reduce local ecological diversity and negatively impact soil fertility.

In December 2015, members of the World Trade Organization's (WTO) 10th Ministerial Conference agreed to abolish agricultural export subsidies and immediately eliminate their remaining scheduled export subsidy entitlements and not provide export credit, export guarantees or insurance programmes (WTO 2015). However, during the following Ministerial Conference in Buenos Aires, members were unable to reach an agreement regarding affirmation of the importance of the WTO to the global trade nor its role in providing development support to least developed countries, and therefore, no collective agreement was made regarding agricultural market access (Hannah et al. 2018). Rather than gaining ground toward the abolishment of agricultural export subsidies, there has been a gradual distancing from the multilateral binding deals that were the intention of the Doha rounds, to simple statements of intent by many of the members. This has left pathways open for particular members to move outside the intransigence, which has blocked the negotiating function of the WTO (Hannah et al. 2018).

As highlighted earlier in this chapter, climate change has differential impacts on agricultural production. Just as higher latitude countries are predicted to see increased production levels of particular food crops, and many equatorial countries will see a decrease in production of particular food crops, so too will climate change impact levels of biodiversity. A core element of many climate change goals is to maintain or increase biodiversity. One method for preventing biodiversity loss would be to increase trade between countries which have low agricultural production but high levels of biodiversity, with countries of high agricultural production and low biodiversity. By facilitating an increase in trade between such countries, those countries who have a high level of biodiversity would not need to clear as much land for agricultural production, thus maintaining the global biodiversity levels whilst sustaining supply (Oki and Kanae 2006).

Export trade subsidies have the potential to create market distortions, lead to overuse of non-renewable resources and decrease food and nutrition security. Improving food and nutrition security whilst responding to climate change is, in most cases, mutually supportive, but this will require agricultural trade to be open, fair and predictable. Responding to the Doha round, decision-makers may implement policy which eliminates agricultural export subsidies so as to minimise trade-offs and maximise synergies; however, such policies require monitoring.

Monitoring and evaluating agricultural policies can be achieved through the Producer Support Estimate (PSE). The PSE indicator is the annual value from consumers and taxpayers to agricultural producers, which stems from policy measures (OECD 2016). The concept behind the PSE is to establish a common base for international policy dialogue as well as to assess the effectiveness of agricultural policy (OECD 2016). The level of policy support made by governments is captured by the PSE, improving the transparency of agricultural support. The trade-off of the PSE is that it does not capture changing nature of policy regimes and their effects on trade nor does the PSE measure market price support against undistorted world market prices (Tangermann 2005), both of which may impede assessment of policy intended to respond to climate change goals.

Consideration for Achieving Target 7

Elimination of agricultural export subsidies offers a way forward in achieving food and nutrition security by preventing trade distortions and fluctuations, improving resource efficiency and household income. Elimination of agricultural export subsidies is synergistic to climate change goals in that they address issues of biodiversity, improve global water conservation and promote climate-smart agriculture. However, elimination of agricultural export subsidies will likely increase transportation emissions which contribute to overall carbon emissions from the agricultural industry.

Improving food and nutrition security whilst responding to climate change is, in most cases, mutually supportive, but this will require agricultural trade to be open, fair and predictable.

1.3.8 Sustainable Development Goal 2, Target 8: Ensure the Proper Functioning of Commodity Markets

The eighth target for food and nutrition security is to adopt measures to ensure the proper functioning of food commodity markets and their derivatives and facilitate timely access to market information, including on food reserves, in order to help limit extreme food price volatility.

In order to measure progress of this particular SDG target, a key indicator has been established, which is as follows:

1. Indicator of food price anomalies

1.3.8.1 Reducing Food Price Anomalies: Synergies and Trade-offs with Climate Change Goals

Mechanisms for ensuring food availability and consistent pricing vary from nation to nation. Gilbert (2011) describes three general scenarios of food balance: 1) Nations who are exporters of grain are generally food secure; however, importation price variability, from global to local, often requires governments to shield consumers from import price variability. 2) Nations who are importers of grain are less food-secure as they not only face the same import price variability but are also significantly exposed to food shortage when market distortions reduce availability. 3) Most nations fall between these two scenarios in that they are generally food self-sufficient but rely on food importation after extreme weather events. Nations of this third scenario can also find themselves transitioning to the second scenario when population growth and the impacts of climate change reduce self-sufficiency.

Earlier in this chapter, we suggested that food access and availability are key elements of food and nutrition security, but they are also key elements of food price. Currently, access and availability, at a national level, is not a serious problem in the major developed market economies, in fact, no developed economy had trouble in providing access and availability of food to its citizens during the 2007–2008 or 2010–2011 food price crisis (Gilbert 2011). However, rainfall changes and increased extreme weather events resulting from climate change will disrupt an already sensitive agricultural commodity market, requiring all nations to establish policies which ensure the proper functioning of commodity markets so as to maintain or improve access and availability of food and promote self-sufficiency. Policy recommendations for improved food access and availability through agricultural commodity markets, as suggested by Lewis et al. (2014), may include:

1. Diversification of import commodities
   (a) Synergy—this will not only even out distribution of the negative and positive impacts of climate change but will also minimise food price variability.
   (b) Trade-off – diversification may result in increased transportation emissions as commodities may be sought from further afield.
2. Strengthening trading relations with Russia and Canada

   (a) Synergies – projections show that Russia and Canada will likely receive increased production as a result of climate change, and therefore, strengthened trading relationships with these, and other nations whose agricultural sectors are positively affected, will reduce the export burden of nations likely to see negative impacts from climate change.
   (b) Trade-off – export pressure may result in rapid increases in agricultural production, which fail to align with the philosophies of sustainable agricultural systems and practices, resulting in further land degradation.
3. Increased production for export
   (a) Synergies – extreme weather events or conflict may reduce regional exports, impacting global commodity prices. Thus, increasing agricultural commodity exports will improve the stability of commodity prices.
   (b) Trade-offs – increased agricultural exports may end up being tied to export subsidies, leading to monoculture cropping, increased levels of inorganic inputs and increased land use for agriculture.
4. Establishing a surplus
   (a) Synergy – during periods of high production and low prices, establishing a surplus of agricultural commodities may reduce vulnerability to extreme events.
   (b) Trade-off – a food surplus can result in food loss when food storage infrastructure is inefficient or ineffective. A surplus may also contribute to the already enormous amount of food waste (current estimates are that one-third of all food is wasted). Agricultural commodity policies should aim to meet food needs rather than exceeding them.

In addition to policies which improve food access and availability, there is the need for policies which create more efficient market chains. In developing countries, it is expected that 60% of the population will live in urban centres (Hawkes and Ruel 2006), and effective market chains will be essential to ensure food and nutrition security to the urban population. Market chain policies should include infrastructure development as poor road/sea access to markets often exacerbates production losses from extreme events such as drought, fire, flood and cyclones. Another essential element for policy design is to enable regional and global market chains to work in collaboration with health sectors as a way to shift the focus from production, to a system which enables available and affordable fruit and vegetables to the urban populations, whilst supporting smallholder access to markets.

Considerations for Achieving Target 8

Finding a market system that balances agricultural production with sustainable access to nutritional food is becoming a challenge more and more nations are required to consider. As with all targets of SDG 2, there is no one-size-fits-all solution. Methods of food production, infrastructure, geography and trade relationships are only some of the factors which require consideration. Policy should be designed to minimise trade-offs with climate change goals, such as, limiting emissions and unsustainable agricultural practices, and reducing food waste, whilst maximising synergies, such as improved economic stability, increased stability of food prices and enhanced climate-smart infrastructure.

1.4 Monitoring and Minimising Trade-offs

Failure to achieve Sustainable Development Goal 2 will affect the current and future populations to food and nutrition insecurity. It is inevitable that some nations will make decisions which benefit them yet undermine the food and nutrition security of others; therefore, global transparency of policies related to SDG 2 and climate change goals should be agreed to by all nations. Making balanced, yet transformative shifts, requires trade-offs to be clearly communicated, ensuring that corrections can be made when outcomes are being compromised. Trade-off analysis is an emerging field of study and offers explicit measurement of trade-off outcomes. Trade-off analysis was first developed on a cost benefit analysis model and applied in the Green Revolution to examine economic margins. The parameters of trade-off analysis have since broadened to include social and environmental outcomes.

Trade-off analysis is reliant on key indicators; thus, the selection of indicators needs to be driven by the desirable outcomes which are determined by multiple stakeholders and consider the local context. Whilst indicators should convey reliable data, they can include broad parameters such as soil moisture retention, food nutrient levels or gender equity. Kanter et al. (2018), describe three key criteria in selecting trade-off analysis indicators as follows: (1) unambiguous, well understood and sensitive, (2) reliable and accurate and (3) easy and cost-effective to monitor.

Trade-off analysis can provide clear and reliable information relevant to policies designed to achieve food and nutrition security and climate change goals. However, uptake of trade-off analysis results by decision-makers is often limited due to lack of contextualisation (Kanter et al. 2018). As an example, rice yields in some regions in China will correlate positively with temperature, whilst yields in other regions will correlate negatively (Zhang et al. 2008). In this situation, a trade-off analysis with yield as an indicator would produce inaccurate and unreliable information unless indicators were relevant to the context. Trade-off analysis information needs to 'speak' to the end user, be it farmers, NGOs or decision-makers (Kanter et al. 2018). Further research and development of trade-off analysis may be necessary before all nations accept its applicability as a transparent global measurement.

1.5 Suggested Policy Amendments

Policy, both vertical and horizontal,[2] required for the exploitation of synergies and the minimisation of trade-offs needs to be a coherent integration of climate change adaptation and mitigation measurements and food and nutrition security (Di Gregorio et al. 2017). Social, environmental and economic variances require policy to be adaptable to regional requirements rather than an all-encompassing national policy approach. Development policy outcomes are improved when climate change reduction policies generate benefits to food and nutrition security and vice versa.

Regions which require transformational change need adaptation policy which is incremental and allows for farmers to understand, prepare for and adjust their farming systems and supports them in diversifying their household income (particularly when transformational change results in their land being unsuited to cash cropping.

In an analysis of sustainable adaptation, Eriksen et al. (2011) identified four principles in ensuring appropriate adaptation responses. They are as follows:

1. Recognising that different contexts have varying vulnerability and understand the multiple stressors
2. Understanding the values and interests which affect adaptation outcomes
3. Valuing and integrating local knowledge into adaptation responses
4. Considering the interconnectedness between local adaptations and global implications

The relationship between SDG 2 and climate change goals is complex and requires researchers, decision-makers and investors to take a holistic view of food and nutrition security and climate change adaptation and mitigation measurements, so as to make every effort to understand the synergies and trade-offs involved in implementing interventions to address both goals.

1.6 Further Considerations: Transitions in Global Nutrition and Links with Climate Change

Nutrition transition refers to the change in diets seen across nations, particularly post economic growth and in response to changes to demographics (particularly, decreased fertility and mortality rates) and epidemiology shifts (from high risk of infectious diseases towards more chronic and degenerative diseases) (Popkin 1993). This field of study was first referred to as 'nutrition transition' by nutrition epidemiologist Barry Popkin. Popkin refers to five transition patterns: 1) collecting food, 2) famine, 3) receding famine, 4) degenerative diseases and 5) behavioural change,

[2]Vertical refers to the mandate of one ministerial authority, e.g. climate change, whereas horizontal refers to the cross-sectoral policies

with most developed countries sitting between the last two patterns and low-medium income countries (LMICs) mostly situated across patterns 2–4. Generally, changes to the diet after socio-economic development include changes to the macronutrient and micronutrient profile with an increase in refined carbohydrates, added sweeteners, edible oils and animal source foods and a decrease in legumes, vegetables and fruit (Popkin 2015). These dietary changes not only have negative impacts on health but can also have negative impacts on climate change; for example, intake of animal source foods has an impact on greenhouse gas emissions. Global health modelling predictions have shown that a more plant-based diet, designed around standard dietary guidelines, is estimated to decrease both global mortality and food-related greenhouse gas emissions by 6–10% and 29–70%, respectively, by 2050 (Springmann et al. 2016).

Governments have begun to grapple with the complexities of continuing to support the growth and economic development of a country in parallel with off-setting rising rates of non-communicable diseases (NCDs), such as obesity, diabetes and cardiovascular disease (CVD), through efforts such as education, marketing, labelling regulations and, sometimes, taxes, and now must consider these in the context of climate change. As urban sprawl increases and globalisation leads to more rural communities having access to major fast food chains and ultra-processed foods, dietary shifts are occurring globally. Fresh foods on shelves are being replaced with long-life processed food items and sugar sweetened beverages; this displacement of healthier and more traditional food options, together with targeted marketing, food labelling and the cost of food, is changing the diets of many LMICs. However, despite likely projections of the effects of the nutrition transition on large populations of LMICs and the impact of this on future rates of NCDs, a study of successful behavioural changes can help to transition these countries whilst minimising the economic and quality-of-life burden subsequent to a rapid increase in NCDs (Popkin 2006) and consider the co-benefits of dietary changes on health and climate change (Springmann et al. 2016).

Whilst ‘nutrition transition’ is a global occurrence, nations that are currently or yet to substantially transition socioeconomically provide a place for policies to offset the negative consequential health effects on populations through education, marketing, food taxes, food labelling and some governance of supply and choice. Few examples of successful nutrition transition have been set, including the positive impact of relative pricing of selected foods and improvements in NCD rates in Norway (Milio 1990); also, community-level strategies to reduce total and saturated fat consumption are having positive impacts on population blood cholesterol and blood pressure in South Korea (Puska et al. 2002). Also, intervention in dietary changes during these times of transition in LMICs may impact the climate through, for example, minimising increased animal-based foods, and thus greenhouse gas emissions in these countries. Nutrition transition, taken in this context, ties together an understanding of food and nutrition security in light of sustainability.

As the transition occurs, a focus on the sustainability of dietary adaptations, particularly regarding the effect on health outcomes in ageing populations, in alignment with climate change goals will require nutrition transition knowledge to be considered in government policies and to help achieve food and nutrition security.

1.7 Conclusion

Achieving Sustainable Development Goal (SDG) 2 requires a transformational shift in both developed and developing countries. We are fast reaching the point (if not already past) where policies can no longer continue to promote business as usual. Transformational change is necessary across all facets which influence the world's ability to end hunger, achieve food security and improve nutrition and sustainable agriculture. The current estimate of 871 million undernourished people may double by 2050 if global transformational change is not realised.

Policies and practices designed to achieve SDG 2 will inevitably result in synergies and trade-offs with climate change goals. Understanding these trade-offs and synergies will allow synergies to be maximised; for example, achieving SDG 2 may promote land for conservation, sustainable agriculture, climate-smart technologies, carbon sequestration programmes, maintenance of genetic biodiversity, agricultural trade which takes advantage of climate shifts, application of indigenous knowledge, improved gender equality, decreased application of inorganic fertiliser and pesticides and reduction of greenhouse gas emissions.

In contrast, poor policy designed to achieve SDG 2 may minimise synergies and increase trade-offs such as rapid growth of unsustainable industrial agriculture, increased greenhouse gas emissions, devalue indigenous people and their knowledge and culture, create inefficient and ineffective agricultural trade agreements and decrease genetic biodiversity.

Achieving SDG 2 is a complex and multifaceted process. Decisions which nations make will inevitably have wider, and often global, social, environmental and economic implications. Achieving the SDG 2 is not a win-win paradigm. Climate trade-offs are the rule rather than the exception; therefore, decisions, policies and agreements should be made with a clear understanding of the trade-offs, and mechanisms should be designed to minimise these trade-offs whilst simultaneously maximising synergies.

The purpose of this chapter was to explore synergisms and trade-offs between SDG 2 and climate change goals. Investigation of the indicators derived from SDG 2 highlight that whilst some general principles can be applied, global diversity should make us cautious in establishing policies which are universally relevant. Policies will need to be tailored to suit not only each nation but also the contrasting regions within each nation. Policies will also need to be developed from the ground up, taking advantage of the knowledge base of those who face the daily challenges of hunger and food and nutrition insecurity.

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2 Climate Change, Hunger and Food Security in Asia with Special Reference to Sri Lanka: Can the Sustainable Development Goals Be Achieved by 2030?

Gamini Herath and Wai Ching Poon

Abstract

"The United Nations Rio+20 summit in 2012 committed governments to create a set of Sustainable Development Goals (SDGs) as a follow-up to the Millennium Development Goals (MDGs) after their 2015 deadline". "The Sustainable Development Goals (SDGs) are a universal call to action to end poverty, protect the planet and ensure that all people enjoy peace and prosperity". Climate change has emerged as an important challenge to achieve sustainable development. Climate change can exacerbate hunger, poverty and food insecurity in Asian developing countries through its negative impacts on food production. This chapter explores these interlinks and the synergies and trade-offs among the Sustainable Development Goals (SDGs) from the perspective of Sri Lanka. Achieving the SDGs for Sri Lanka will be a great challenge. Nevertheless, the state-society synergy is a very useful tool to encourage a bottom-up process. Civil society, the private sector, academia and the professionals can play a pre-eminent role in the implementation of the SDGs. Institutions and actors must focus on their capacity to achieve progress on key nationally identified SDGs. Sri Lanka must develop cross-cutting coordination mechanisms to allocate resources, share data and information, facilitate research and innovation, and build capacity to respond to climate change.

Keywords

Sustainable Development Goals · Climate change · Food security · Nutrition security · Sri Lanka

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2.1 Introduction

The sustainable development (SD) paradigm emerged due to serious degradation and overexploitation of natural resources in various countries. SD focuses on future generations (WCED 1987) and the interconnections between environmental, social and economic dimensions. In 2016, the UN ratified 17 Sustainable Development Goals (SDGs) and 169 targets supported by 193 countries. The SDGs include poverty alleviation, elimination of hunger and malnutrition, sustainable consumption, health and sanitation and climate change. *Human activities are estimated to have caused approximately 1.0°C of global warming above pre-industrial levels.... Global warming is likely to reach 1.5°C between 2030 and 2052 if it continues to increase at the current rate* (IPCC 2018). It is estimated that the global greenhouse gas (GHG) emissions in 2030 will be 52–58 $GtCO_2eq$ per year. Increasing population and associated developments are responsible for increasing greenhouse gas concentration in the atmosphere. GHG emissions differ with countries, economic development, fossil fuels use and land use changes. For instance, forest clearing is a major activity in Southeast Asian (SEA) countries which contain a significant forest cover in the world (de Jong et al. 2017). Logging and expansion of oil palm caused severe deforestation between 1985 and 2002, which is estimated to be around 56% (Nicholas et al. 2010). Intensive logging for crops like oil palm in Indonesia and Malaysia can significantly increase GHG emissions (Herath and Leeves 2015). "Climate change impacts and responses are closely linked to sustainable development which balances social well-being, economic prosperity and environmental protection" (IPCC 2018).

Climate change can exacerbate hunger, poverty and food insecurity in Asian developing countries through its negative impacts on food production (Venkatramanan et al. 2020a, b). This chapter explores these interlinks and the synergies and trade-offs among the SDGs. The chapter explores major linkages of natural resources and food security which feature prominently in most SDGs and summarizes the main policy leverages to achieve sustainable and secure food systems in Asia with special reference to Sri Lanka.

2.2 Sustainable Development Goals

"The United Nations Rio+20 summit in 2012 committed governments to create a set of Sustainable Development Goals (SDGs) that would be integrated into the follow-up to the Millennium Development Goals (MDGs) after their 2015 deadline" (Griggs et al. 2013; Shah and Ramanan 2018). "There are indeed 17 SDG's comprising 69 targets and this global development agenda spans from 2015–2030" (Lu et al. 2015). "The Sustainable Development Goals (SDGs).... are a universal call to action to end poverty, protect the planet and ensure that all people enjoy peace and prosperity. The goals are interconnected – often the key to success on one will involve tackling issues more commonly associated with another" (Shah and Ramanan 2018). The SDGs provide a normative framework to ensure a fair,

Table 2.1 The Sustainable Development Goals

Goal no.	Goal
1.	Elimination of poverty
2.	Improve food security, hunger and nutrition
3.	Ensure improved health and well-being of the population
4.	Ensure high-quality education and promote lifelong learning
5.	Achieve gender equality and empower all women and girls
6.	Sustainable management of water and sanitation for all
7.	Create reliable, modern energy sources for the population
8.	Promote economic growth and productive employment for all
9.	Provide infrastructure and sustainable industrialization and innovation
10.	Reduce inequality within and among countries
11.	Develop safe and resilient cities
12.	Ensure sustainable consumption and production
13.	Ensure quick response to climate change
14.	Conserve oceans, seas and marine resources
15.	Protect terrestrial ecosystems and forests, combat desertification and halt biodiversity loss
16.	Promote peaceful and inclusive societies with access to justice for all
17.	Support global partnership for sustainable development

Source: United Nations (2016)

equitable balance across the economic, social and environmental dimensions of sustainability. Table 2.1 lists the 17 SDGs representing an inclusive approach to alleviate poverty (SDG 1), enhance income equality (SDG 5), mitigate climate change (SDG13) and create gender equity (SDG 5) (Sachs et al. 2016). The SDGs tackle root causes of poverty, climate change, good governance, racial equality, peace building, disaster risk and economic inequality. "SDGs are well connected as evidenced in the connection of SDG 2 with SDG 13 (climate security), SDG 6 (water security), SDG 15 (soil security), SDG 7 (energy security), and SDG 5 (gender equality)" (Venkatramanan and Shah 2019). United Nations Development Programme (UNDP) provides support to governments to integrate the SDGs into their national development plans and policies (Shah and Ramanan 2018).

2.3 Intersection Between Climate Change, Agriculture and Food Security in Asia

"Food security exists when all people, at all times, have physical, social and economic access to sufficient, safe and nutritious food to meet their dietary needs and food preferences for an active and healthy life" (FAO 1996, 2009; Barrett 2010). The path to achieve food security is challenged by a multitude of factors, namely climate change, declining soil fertility and gender inequality (Venkatramanan and Shah 2020) (Fig. 2.1). The four cornerstones of food security are availability, access,

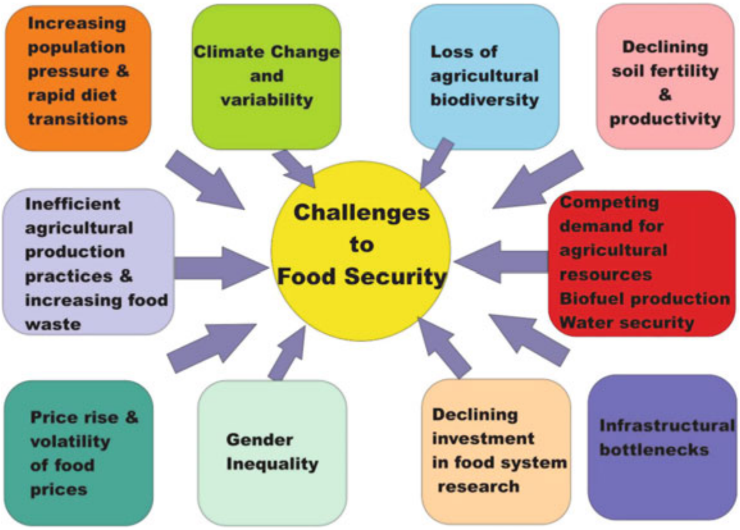

Fig. 2.1 Challenges to food security. (Source: Venkatramanan and Shah 2020)

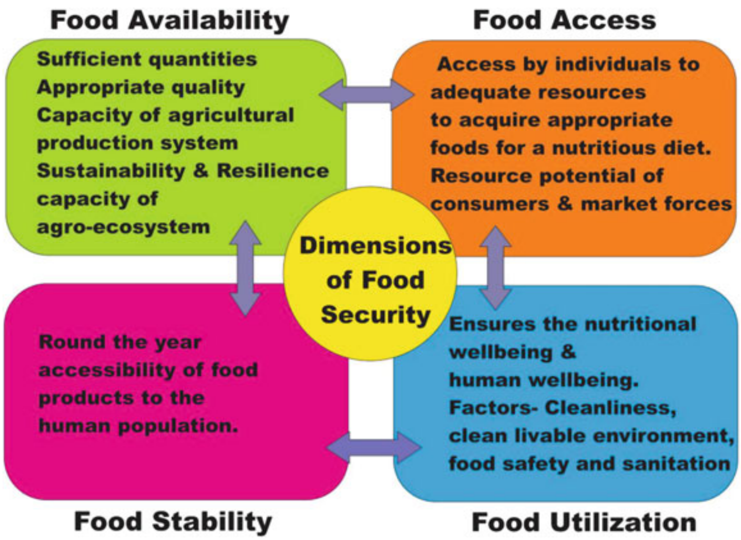

Fig. 2.2 Dimensions of food security. (Source: Venkatramanan and Shah 2020)

utilization and stability (Fig. 2.2) (Venkatramanan and Shah 2019). Table 2.2 shows the food security index for some selected countries. The food security status of few Asian countries is grim. Myanmar, Laos and Cambodia have very low ranking in terms of security. Climate change will be a major factor influencing food security in the future. Climate change impacts vary with the region, geographical setting, socio-

Table 2.2 Food Security Index

Global rank	Country	Overall score	Affordability	Quality and safety
1	Singapore	85.9	94.3	78.1
28	Malaysia	73.8	81.7	70.6
52	Thailand	65.1	77.1	52.6
54	Vietnam	64.6	75.1	51.7
62	Indonesia	62.6	70.4	47.1
64	Philippines	61.05	68.9	50.3
77	Myanmar	57.0	59.1	51.3
90	Cambodia	49.4	56.7	34.6
92	Laos	49.1	55.5	37.4
66	Sri Lanka	60.8	65.0	52.4
72	India	58.9	64.2	47.0
83	Bangladesh	53.2	60.4	30.6

Source: Global Food Security Index, Rankings and Trends 2019

economic status of the countries, vulnerability of the countries and economic and ecological bottlenecks of the countries; for instance, the temperature in Malaysia will rise by 1.5 °C due to climate change and will seriously affect agricultural production and food security (Lewis 2009). Warming in Malaysia since the 1970s has been three times as rapid as the preceding 100 years (Raman 2009). While about 9% of the land in Malaysia is flood-prone (Al-Amin et al. 2011), India will be facing a multitude of effects that include floods, droughts, heat waves, and food, feed and water crises. Further, in the Trans-Gangetic plains of India, which are known for their agricultural wealth, due to heavy groundwater extraction, water table has gone down by more than 900 m.

"Climate-related risks to health, livelihoods, food security, water supply, human security, and economic growth are projected to increase as the global average surface temperature rise to 1.5°C" (IPCC 2018). The global food system is a complex system as its sustainability is driven by its innate potential, biophysical environment and socio-economic conditions (Venkatramanan and Shah 2019). It is reported that "the global food chain is under constant pressure from pest and disease outbreaks, life cycle GHG emissions. . . . demand and supply side constraints" (Venkatramanan and Shah 2019). Climate change can affect the livelihoods of millions of poor farmers, their access to food purchasing power, nutritional knowledge and health. Studies (Veghifi et al. 2011; Auffhammer et al. 2011) have categorically reported the vulnerability of agriculture to climate change. Rice is the staple food crop in Asia, which uses nearly 40% of the freshwater resources in Asia. The Asian Development Bank (2009) estimated that the Philippines, Indonesia, Vietnam and Thailand will experience a fall of rice yield by about 50% by 2100 compared to rice yields in 1990. It could lead to food price rise of between 3% and 84% by 2050. Food security would be a major issue in feeding around 9.8 billion people by 2050, mostly concentrated in India, Indonesia, Bangladesh and Pakistan. Nearly 19 countries are facing severe food shortages due to climate change (Veghifi et al. 2011).

The SDGs are complex and interdependent objectives with intense synergies between targets and goals. As stated earlier, there are 169 targets overall for the

17 SDGs. An empirical evaluation showed that 238 target-level interactions between SDG 2, SDG 3, SDG 7 and SDG 14 are positive. Another 66 were with 12 neutral interactions; for instance, poverty alleviation (SDG 1) depends on agricultural productivity and food security. Completion of secondary school by girls (SDG 3) may promote the use of renewable energy (SDG 7), lessening their dependence on firewood in rural areas. Study of these interactions is very important to implement the SDGs effectively; for example, SDG 1 and SDG 2 are closely interrelated. SDG 2 can affect health (SDG 3). Water security (SDG 6) can affect food production and health. Elimination of hunger (SDG 2) can support health (SDG 4) by reducing maternal mortality and deaths of children below 5 years of age. Such a myriad of positive interactions among the goals is of significance for the implementation of the SDGs (ICFS 2017; Tennakoon 2019).

These SDGs must operate within an integrated framework that puts the individual, human rights and social justice at the centre. The challenge is how to achieve the interconnected SDGs in a highly complex political economy and weak policy and institutional environment of developing countries of Asia. Since all SDGs are interconnected, the synergies must be maximized by appropriate policies that could mutually support each other to realize the co-benefits. The complexity of the SDGs and the lack of robust and easily useable tools for evaluation of the SD further complicates these issues (Juncurt 2016).

There can be negative interactions among the goal targets which need to be minimized. New agricultural technology such as the “Green Revolution” can increase food production but may lead to declining water quality, poor soils, poor land quality and water scarcity, affecting agricultural productivity and food security (Venkatramanan et al. 2020a). Health among the farmer community deteriorated due to excess use of fertilizers and pesticides. In Sri Lanka, many farmers suffered from the chronic kidney disease (CKD)/chronic kidney disease of unknown aetiology (CKDu) due to water pollution. From January 2010 to December 2015, there were 29,662 patients diagnosed with CKD/CKD and in 2016; another 3820 cases had been registered in Sri Lanka, related to the use of pesticides (SDG 3) (Herath 2017). These negative interactions or trade-offs can reduce the progress made in one area at the expense of progress in others.

SDG 2 can improve learning, attendance and enrolment in primary schools and quality of education for all (SDG 4). Improving food security can reduce inequality (SDG10), and access to safe and nutritious food will ensure healthy lives and promote well-being for all (SDG 3). Tackling obesity, diabetes and other diet-related conditions can reduce waste and ensure sustainable consumption and production (SDG 12). A significant proportion of the food produced is wasted, which requires around 1.4 billion ha of land. Since the SDGs are connected to each other in this manner through multiple targets, the targets are seen as a network of links to every target of the SDGs. Each target is also linked to other goals; for example, target 12.4 is linked to human health (SDG3); for example, SDG 12 and SDG 10 on inequality are closely connected. Target 3.8, under SDG3, is linked to SDG 10 and SDG 1. Table 2.3 shows the SDGs in terms of the number of interconnections with other goals. SDG12 on sustainable production and consumption has

Table 2.3 Interlinkages among the SDGs

Rank	Sustainable Development Goal	Number of other goals to which the goal is connected
1	12: Ensure sustainable consumption and production patterns	14
2	10: Reduce inequality within and among countries	12
3	1 : End of poverty in all its forms everywhere	10
4	8 : Promote sustainable economic growth and productive employment	10
5	2: End hunger and achieve food security	8
6	3: Ensure healthy lives and promote people's well-being	8
7	5 :Achieve empowerment of women and girls	8
8	4 :Ensure inclusive and equitable quality education and promote lifelong learning opportunities for all	7
9	6: Ensure availability and sustainable management of water and sanitation for all	7
10	11: Make cities and human settlements inclusive, sage, resilient and sustainable	6
11	13: Take urgent action to combat climate change and its impacts	6
12	15: Protect, terrestrial ecosystems, forests and reverse land degradation	6
13	16: Promote peaceful societies, access to justice and accountable institutions	6
14	7: Ensure access to affordable and sustainable modern energy	3
15	9: Build efficient infrastructure, promote sustainable industrialization and innovation	3
16	14: Sustainably use oceans and marine resources	2

Source: Blanc (2015)

14 interconnections with other goals. SDG 13 has six interconnections. The crux is that without recognizing these interconnections, achieving the SDG goals by 2030 is not possible.

2.4 SDGs and Sri Lanka

Sri Lanka is a developing country with a very high level of literacy, life expectancy and school enrolment rates. In the 1970s, it was a well-known example of a social welfare state. Nevertheless, despite continuous efforts by successive governments to alleviate food insecurity in the country, a quarter of the population is food-insecure. Poverty as the main cause for food insecurity is less tenable. As regards the agricultural production, Sri Lanka has achieved self-sufficiency in rice production, but it has not helped to reduce food insecurity, undernourishment, protein malnutrition and micronutrient deficiency in the country. The section below assesses the progress of several interrelated SDGs on food security and hunger, poverty, climate change, water and sanitation and health.

2.4.1 SDG 1: End Poverty in All Its Forms Everywhere

SDG 1 on poverty alleviation includes 7 targets and 14 indicators. Sri Lanka reduced income poverty from 22.7% in 2000 to 6.7% in 2012–2013.[1] Yet, the Batticaloa District had an incidence of poverty of 20.3% and Jaffna, Moneragala and Badulla are slightly behind. The Mullaitivu district had an estimated poverty of 12.7%. In the poorest estate sector, poverty has fallen from 20.5% in 1990 to 11.4% in 2009 (Table 2.4) (Nanayakkara 2018).

Sri Lanka's Gini coefficient has consistently ranged between 0.48 and 0.52 (0.4–0.6 considered high inequality) throughout most of its post-independence history.

Poverty interventions require progress in other SDGs such as access to electricity (SDG7), good infrastructure (SDG8) and climate change (SDG13) to improve the resilience of the poor against natural disasters.

Table 2.4 Poverty Statistics for Sri Lanka 2016

Sector/ province	Poverty head count index	Poverty gap	Number of poor population	Contribution to total poverty (percentage)
Sri Lanka	4.1	0.6	843,913	100.0
Urban	1.9	0.3	67,649	8.0
Rural	4.3	0.6	693,956	82.2
Estate	8.8	1.2	82,308	9.8
Western	1.7	0.3	101,342	12.0
Central	5.4	0.9	142,044	16.8
Southern	3.0	0.4	74,769	8.9
Northern	7.7	1.1	83,834	9.9
Eastern	7.3	1.2	118,061	14.0
North Western	2.7	0.4	64,638	7.7
North Central	3.3	0.5	43,191	5.0
Uva	6.5	0.7	83,885	9.9
Sabaragamuwa	6.7	1.1	133,149	15.8

Source: Household Income and Expenditure Survey-2016, Department of Census and Statistics, Ministry of National Policies and Economic Affairs Sri Lanka. Accessed from http://www.statistics.gov.lk/poverty/Poverty%20Indicators_2016.pdf

[1]However, the incidence of moderate poverty (i.e. the percentage of the population living below US $ 3.10 per day) was still high at 14.6% in 2012–2013.

Table 2.5 Baseline Data for SDG 2 (Eliminating Hunger)

Target/indicator	Percentage value	Year
Target 2.1: End hunger by 2030		
Indicator 2.1.2: Prevalence of moderate or severe food insecurity based on FIES	9.2	2013/2014
Indicator 2.2.1: Prevalence of Stunting (WHO child growth standard)	17.0	2006/2007
Indicator 2.2.2: Prevalence of malnutrition	17.5	2006/2007

Source: Department of Census and Statistics, Sri Lanka (2017)

2.4.2 SDG 2: End Hunger, Achieve Food Security and Improved Nutrition and Promote Sustainable Agriculture

Poverty alleviation is very closely related to SDG 2 on ending hunger. SDG 2 includes 8 targets and 13 indicators. Target 2.1 is to *end hunger and ensure access by all people, in particular the poor and people in vulnerable situations including infants, to safe, nutritious and sufficient food all year round by the year 2030*. Information on SDG 2, compiled by the Department of Census and Statistics (DCS), shows that data are available for three indicators. For Indicator 2.1.2, the latest data available are for 2013–2014, even though 3 years have elapsed since the adoption of the SDGs (Table 2.5).

Malnourishment is widely present and SDG 1 is linked with SDG 3 on health (ICFS 2017). Natural disasters, such as floods, in Sri Lanka, affected nearly 2 million people in 22 districts in the dry zone, such as Anuradhapura, Polonnaruwa and Kurunegala. This is despite the presence of the cascaded tank village system in the dry zone. These tanks were not properly managed using ecological principles which affected their sustainable use.

2.4.3 SDG 3: Ensure Healthy Lives and Promote Well-Being for All at All Ages

SDG 3 intends to promote universal health coverage and has 13 targets varying from reducing maternal mortality (<70 per 10,000 population) and halve the death and injuries by road accidents. Sri Lanka's health indicators were classified into four groups, namely (a) non-communicable diseases, (b) communicable diseases, (c) reproductive maternal and newborn health and (d) service capacity and access.

The infant mortality rate was 9.4 per 1000 live births in 2012. The maternal death rate has declined to 35 per 100,000 live births in 2010. However, in 2009, the Vavuniya district had an under-five mortality rate of 85.3. Mullativu, Kandy, Batticaloa and Colombo also had higher values exceeding the country average.

Communicable diseases (CDs) such as HIV, dengue and tuberculosis have shown an upward trend, making target 3.3 an important issue. Flooding led to a steep increase in the incidence of dengue with more than 110,000 affected and more than 350 deaths in the first 7 months of 2017 (Herath 2017).[2] In 2019, 78,000 were affected and 98 died due to dengue. In the plantation sector, poor housing and sanitation are starkly evident. About 40% of the babies born to estate worker families are underweight.

Coherent policy on non-communicable diseases (NCDs) is imperative to reduce their incidence and achieve SDGs 3.4–3.6 and 3.9.[3] From January 2010 to December 2015, there were 29,662 patients diagnosed with CKD/CKDu and in 2016, another 3820 cases had been registered. Nearly 2000 CKD/CKDu deaths occur annually mostly in the North Central Province (NCP).

2.4.4 SDG 5: Achieve Gender Equality and Empower All Women and Girls

SDG 5 on gender equality has nine targets that emphasize the elimination of violence against women and girls. Women play an important role in agriculture, energy use and reduction of hunger. Women play a crucial role in the agriculture value chain – cultivation/food production, food processing, etc. (Fig. 2.3) (Venkatramanan and Shah 2020). "Gender inequality challenges a) women's role in food production, b) achievement of food and nutritional security, and c) climate change mitigation through climate smart technologies" (Venkatramanan and Shah 2020). On the other hand, "gender equality enable household food security by strengthening a) women's voice in the family and household, b) women's role in subsistence agriculture and food production, and c) women's role in small livestock rearing" (Venkatramanan and Shah 2020). As a result, SDG 5 is closely interlinked with SDG 2, SDG 7, SDG 3, SDG 4, SDG 10 and SDG 13. Implementing gender-sensitive policies to foster women's participation and leadership will no doubt strengthen women's role in society. But in 2019, the gender gap for Sri Lanka dropped by two places from 100 to 102 according to the World Economic Forum. The Gender Development Index and the Gender Inequality Index for 2013 and 2014 were 0.69 and 0.38, respectively (Kumar et al. 2016). But Sri Lanka ranked 100th in the gender gap report of 2016 (Asian Mirror 2016).[4] In Sri Lanka and elsewhere, gender equality (SDG 5) is essential to achieve food and nutritional security, increase agricultural productivity and greatly aid in climate change mitigation in the agricultural sector (SDG 13) (Venkatramanan and Shah 2020).

[2]Gamini Herath, "The dengue menace: can Sri Lanka ever get this right" (*The Daily Mirror* July 21, 2017).

[3]Health and the SDGs in Sri Lanka, World Health Organization, Sri Lanka.

[4]Sri Lanka ranks 100th in the Gender Gap Index (Asian Mirror 2016). (https://www.facebook.com/english.asianmirror/)

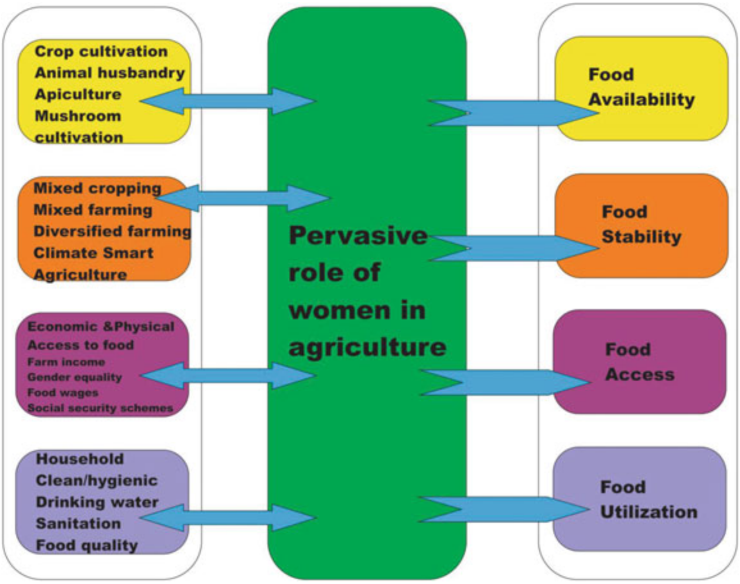

Fig. 2.3 Women in agriculture and their role in achieving food security. (Source: Venkatramanan and Shah 2020)

2.4.5 SDG 6: Ensure Availability and Sustainable Management of Water and Sanitation for All

SDG 6 is to "ensure availability and sustainable management of water and sanitation for all" and includes 8 targets and 11 indicators. SDG 6 is dedicated to clean drinking water, sanitation and hygiene, which are reflected, especially, in targets 6.1–6.3. Water is fundamental to life and to the surrounding natural environment and has become even more important due to lack of access to clean drinking water and water pollution. Climate change challenges the achievement of SDG 6 through its negative impacts on hydrological cycle. SDG 6 is also linked to reducing health risks (SDG 3) in targets 3.3 and 3.9. It must be noted that

Sri Lanka had not achieved universal access to piped water supply and water quality. Rural areas lack clean water and children suffer from diarrhoea and malnutrition. Water supply coverage in 2016 showed that 47.5% received pipe-borne water, while 36.4% used dug wells. Nearly, 12.2% of the population still do not have access to drinking water, and only 2.2% are connected to piped sewerage.

Water scarcity can negatively affect (SDG 2) food security and education (SDG 4). Universal provision of drinking water (Target 6.1) and sanitation coverage (Target 6.3) can be achieved by careful use and management of water resources and existing water bodies (SDG 12) and maintaining a high standard of water quality (Target 6.3).

Implementation of SDG 6 is a challenge because out of the 11 indicators, data are compiled by the Department of Statistics only for 1 indicator (Department of Census and Statistics 2017).[5] Data are to be compiled for another indicator through new censuses, surveys or special studies. For indicator 6.2.1 – the proportion of the population using safely managed sanitation services (Tier 1) – data are not available.

2.4.6 SDG 13: Take Urgent Action to Combat Climate Change and Its Impacts

SDG 13 deals with climate change, which can affect the Sri Lankan society seriously, especially the resilience of the poor (SDG 1). The frequency and intensity of floods and droughts have risen to dangerous levels due to climate change in recent years.

Sri Lanka clears about 8000 ha of forests every year. In 2015, the government agreed to conserve 21,800 acres of mangrove forest. The World Bank study in 2015–2016 identified the Colombo Wetland Complex as regulating heat related to climate change (SDG 13). The small tank system in Sri Lanka is a socio-ecological system which serves as a buffer against climate change. Further, climate change (SDG 13) can increase the incidence of dengue in Sri Lanka (Herath 2017).[6]In 2019, 85,000 cases were reported and nearly 100 people died of the disease.

There is a great degree of awareness of climate change, and Sri Lanka must pursue mitigation strategies in line with international agreements on climate change. Table 2.6, on the alignment of the SDGs with National Development Agenda, summarizes the poor state of affairs of the SDGs in Sri Lanka. The fully aligned targets are not many in number, and SDG 1, SDG 3, SDG 4, SDG 5, SDG 6 and SDG 7 had only two targets which are fully aligned with national development goals. For SDG 13, only one target is aligned with national goals, which reflects that SDGs and national goals are at variance with each other.

2.5 Sri Lanka's Path to Achieving SDGs by 2030: Challenges

Most policies initiated to support the specific SDGs failed to effectively integrate the key dimension of sustainability. As a result, there is a policy inconsistency and some policies negatively impacted other goals. Integration requires a proper evaluation of the interlinks among the SDGs. Policy coherence, integrated decision-making and understanding the interlinks are conspicuously absent. The government must ensure

[5]Department of Census and Statistics 2017 (pp. 36–44), Government of Sri Lanka, Colombo, Sri Lanka.

[6]Gamini Herath. The Dengue Menace: Can Sri Lanka ever get this right (*The Daily Telegraph* 21 July 2017).

Table 2.6 Alignment between SDGs and National Development Goals, Sri Lanka

	SDGs	Fully aligned targets	Moderately aligned targets	Slightly aligned target	Not relevant
1	No poverty	2	3	2	0
2	Zero hunger	3	3	2	0
3	Good health and well-being	5	2	6	0
4	Quality education	2	6	1	1
5	Gender inequality	2	4	3	0
6	Clean water and sanitation	2	5	1	0
7	Affordable and clean energy	2	3	0	0
8	Decent work and economic development	4	5	2	1
9	Industry innovation and infrastructure	3	3	0	2
10	Reduced inequality	4	4	4	0
11	Sustainable cities and communities	3	3	0	1
12	Responsible consumption and production	6	6	0	1
13	Climate action	1	2	0	2
14	Life below water	5	3	1	1
15	Life on land	6	4	1	1
16	Peace, justice and strong institutions	4	7	1	0
17	Partnership for the goals	6	3	2	8

Source: Voluntary National Review on the Status of Implementing Sustainable Development Goals (2018). Ministry of Sustainable Development, Wildlife and Regional Development. Accessed from https://sustainabledevelopment.un.org/content/documents/19677FINAL_SriLankaVNR_Report_30Jun2018.pdf

strict implementation of rules and regulations operating within the transparent systems of governance. The major challenges are summarized in Table 2.7.

Forest clearing still occurs for expansion of agriculture and food security (SDG2), but this may worsen water availability and alter rainfall patterns and add to climate change (SDG13). Land clearing in Wilpattu has been even implicated for climate change and drought, especially in the dry zone, by some professionals in Sri Lanka.[7] Sri Lanka moved into oil palm recently, but this is seriously flawed because oil palm can seriously affect biodiversity, soil stability and even climate change. This has now been reversed by the Gotabhaya Rajapaksa government in 2019, which is the correct vision.

Responding to climate change requires pragmatic adaptation and mitigation strategies. The question of how to adapt still remains an important issue for Sri

[7]MUA Tennekoon argues that the recent droughts in the dry zone are due to land clearing in the Wilpattu National Park.

Table 2.7 Issues, key trends and challenges in food, energy and water security and achieving SDGs in Sri Lanka

Drivers of change	Key trends	Future challenges
Increasing population. The population growth rate in Sri Lanka is about 1.5%. The present population of 23 million is projected to rise to 30 million by 2050.	Increasing demand for irrigation water, mechanical power and fertilizers, and energy in the next 25 years. Management of energy and water must be improved.	Increasing food supply and reducing the amount of irrigation water, fertilizer and pesticides. Soil erosion and land degradation will be a serious challenge in the long term.
Sri Lanka experienced a good economic growth rate, which made it a middle-income country with a large middle class. Growth is expected to rise to 6% in the next 4 years. Sri Lanka's GDP per capita was US$4102 in 2018. Fast economic growth has intensified food, water and energy demand use.	Changing food preferences towards more processed food, especially meat, wheat flour, coarse grain, animal products, which demand large quantities of energy and water.	Meeting the increased requirement for water and energy remains a critical issue.
Competing demand for land, water and energy resources. Urbanization requires more land, water and energy. Agricultural land conversion may occur for the expansion of cities. Clearing forests has led to human-elephant conflicts and damage of over US$10 million to crops and property. Climate change and water shortages force elephants to migrate to villages in search of food and water, causing severe crop damage and human deaths.	Growing competition for resources for different uses, loss of fertile land for agriculture and other crops can seriously affect millions of people. Nearly 75,000 people were displaced in 2017 due to worst floods. In stark contrast, severe drought in 2016 (worst in the last 40 years) affected over 16 districts in the country with over 900,000 people left with acute water and food shortage.	Disaster risk reduction, Managing man–elephant conflicts, must be more scientific.
Increasing intensification in agriculture. The irrigated area is growing by 1.7% and fertilizer use grew from 37 kg/ha NPK in 2005.	Loss of the village tank system, siltation and drought and lower water levels in major irrigation schemes. Dwindling forest area and loss of forests in water catchment areas. Lower quality of agricultural resource base. Slowing of agricultural growth rate.	Increasing food availability, accessibility and stability. Food insecurity and malnourished people.
Growing demand for water. Annual water demand is	Increasing pressure on water resources for multiple uses.	Meeting the competing demands for water from

(continued)

Table 2.7 (continued)

Drivers of change	Key trends	Future challenges
predicted to increase by 55% by 2030 compared to 2005.	Per capita water availability is declining at a rate of 2.1% per annum.	agriculture, domestic use, industry and energy sector.
Declining performance of canal irrigation. Subsidies on irrigation.	Poor management of canal water.	Enhance the efficiency of canal water use and distribution. Formation of water user associations.
Increasing costs for securing water availability. Groundwater pumping is costly due to fuel and machinery cost, which are often subsidized by governments.	Increasing pressure on the government budget.	Elimination of subsidies and creating better and efficient use of water.

Lanka. Farmers must adapt to water scarcity by using less water-intensive crops which save water. Sri Lanka must build capacity among both profit and not-for-profit organizations to respond to climate change. Weak organizational capacity and awareness are a hindrance to the success of climate change mitigation and adaptation. Gender policy is very important to alleviate food insecurity. Extant climate policy ignores this element. Governments must recognize women's interests and the centrality of gender in climate change mitigation and adaptation policy.

Achieving the SDGs for Sri Lanka will be a great challenge as the environmental problems like climate change exacerbate the resource constraints. Sri Lanka is recognized as a disaster hotspot and very vulnerable to climate change impacts. The progress in combating SDG 13 is not encouraging yet. From 2015 to mid-2018, Sri Lanka has developed some strategies and plans, but more serious attention to the SDGs and their interactions is imperative for their success. The weak political will and institutional capacity are yet another issue of concern. Further, institutional reform needs are more complex. However, alternative and efficient ways of delivering services need to be investigated. The state-society synergy is a very useful tool to encourage a bottom-up process. Civil society, the private sector, academia and the professionals can play a pre-eminent role in the implementation of the SDGs.

2.6 Conclusion

Around 40% of the population in Sri Lanka still lives in poverty earning less than 2 dollars per day. Hunger is still a feature in rural areas despite self-sufficiency in rice because other food items are still imported due to a shortage in local production. Environmental stress, particularly climate change, has put immense pressure on the resources, increasing risks associated with disasters such as droughts and floods. It is a known fact that climate change negatively affects the agricultural production. Sri Lankan agriculture is no exception. Rice cultivation is affected by climate change. Input-intensive rice cultivation is dominated by smallholders, whose livelihoods are vulnerable to climate change. Over one-fourth of the population do not have sufficient food to sustain a decent living. Many of the poor still consume low nutritional food, while 3.7% of households have insufficient food intake than what is required.

Achieving the SDGs for Sri Lanka will be a great challenge. Sri Lanka is recognized as a disaster hotspot and very vulnerable to climate change impacts. The weak political will and institutional capacity are yet another issue of concern. However, alternative and efficient ways of delivering services need to be investigated. The state-society synergy is a very useful tool to encourage a bottom-up process. Civil society, the private sector, academia and the professionals can play a pre-eminent role in the implementation of the SDGs. The Sri Lankan government must do some stocktaking to identify the priority goals from a national development perspective and localize relevant goals and targets. The targets are complex and interconnected. Therefore, there is a need for in-depth consultation with experts and stakeholders, and subsequently, the goals and targets can be prioritized. Further, this will help governments prioritize investments and create a common language and approach across sectors, fostering cross-sector collaboration. Institutions and actors must focus on their capacity to achieve progress on key nationally identified SDGs. It will also help to focus on SDGs wherein the synergies are particularly strong. Sri Lanka must develop cross-cutting coordination mechanisms to allocate resources, share data and information, facilitate research and innovation and build capacity to respond to climate change. Further, good local institutions result in a better management of the local and the natural resource base.

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3 The Status of Climate Variability and Food Accessibility: A Case of Households in Gauteng Province, South Africa

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Abstract

Globally, climate variability and change produces countless primary, secondary and tertiary consequences related to water supply including changes in quantity and quality of food. As South Africa is situated in one of the world's mid-latitude and semi-arid regions, a rise in temperature and decreased and more irregular rainfall can be projected for the country. During the last decade, the frequency of natural disasters in the Gauteng Province has increased significantly and the most common disasters were the occurrence of flash floods, veld fires, drought and rising temperatures. At the same time, South Africa is considered a 'food-secure' nation, producing enough calories to adequately feed every one of its 53 million people. However, national figures hide the reality at the household level. Household survey was conducted in the Gauteng Province by the Agricultural Research Council (ARC) and Gauteng Department of Agriculture and Rural Development (GDARD) to establish the status of climate variability and food accessibility. The following objectives were followed: (1) to identify and describe climate variability status in terms of rainfall and temperature, (2) to identify and describe household food accessibility and (3) to identify and describe the relationship of climate variability and households socio-economic characteristics. A total of 1150 households participated in the survey. Questionnaire, stakeholder's discussion and field observations were part of the data collection. The Standardized Precipitation Index (SPI) was used to monitor the occurrence of climate variability like droughts from rainfall data. A purposive sampling technique was used and data was coded, captured and analysed using the Statistical Package

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for the Social Sciences (SPSS). The results indicated that there is an overall decrease of rainfall in Gauteng Province and possible precipitation variability in the distant future. This limited water resource had a negative impact on household food security as a whopping number of Gauteng Province households interviewed were food insecure (860/75%) as compared to households that are food secure (290/25%). The majority of households indicated that they were not aware of environmental matters hence those households indicated that they could not adapt or mitigate against any climate variability and change, resulting in negative impact on household food production and high levels of food insecurity in the Gauteng Province. It is thus recommended that households need adequate knowledge about the importance of climate variability and change. Hence, the transfer of climate knowledge to support vulnerability and adaptation measures should be a priority for the government to contain household food security in the Gauteng Province.

Keywords

Climate variability · Climate change · Food security · Gauteng Province · South Africa

3.1 Introduction

"*Global climate change affects people, ecosystems and livelihoods across the world....Global climate change will exacerbate the agricultural risks through their effects on crop ecology, crop geography, crop environment, crop production, agricultural resources, agricultural supply chain and commodity prices*" (Venkatramanan et al. 2020a). So, it is essential to adapt the food system against climate change and minimize the negative impacts of climate change on agriculture (Venkatramanan et al. 2020b). "*The panacea to the climate risks in agriculture lies in the transformation of agriculture into a resilient and smart agriculture production system*" (Venkatramanan et al. 2020a) and achieve food and nutritional security. In Africa, temperatures are expected to increase, and Southern Africa is anticipated to receive lower levels of rainfall. As South Africa is situated in one of the world's mid-latitude and semi-arid regions, a rise in temperature and decreased and more irregular rainfall can be projected for the country. According to Durand (2006), South Africa is considered as a dry country with more than two-thirds of its area experiencing less than 500 mm average annual rainfall and as such, agriculture activities have been largely adapted to semi-arid conditions. Durand (2006) further emphasized that irrigated farming involves 1.3 million hectares of land and this places South Africa as the largest 'irrigation country' in the Southern African region. Most of the 22 major rivers in the country provide water for numerous activities including agriculture; however, it has been projected that water requirement in South Africa will exceed available water by 2025 (IISD 2011). According to Maponya and Mpandeli (2012), climate change will impact directly on agricultural production including household food gardens through the resources that are needed (Land, soil, water). Maponya and Mpandeli (2012) further emphasized that across most of the South African provinces, water resources are already stressed and climate change and variability is likely to increase water stress through more variable rainfall. During the last decade, the frequency of natural disasters in the Gauteng Province has increased significantly and the most common disasters were the occurrence of flash floods, veld fires, drought and rising temperatures. This situation has also affected some of the provincial fresh produce markets like Johannesburg as most hectares of land did not remain under production. According to Maponya et al. (2017), most of the farmers in Gauteng Province have also been severely affected by climate variability and change, but smallholder farmers were worse off as some commercial farmers had insurance to cover the impact of climate variability and change. It is reported that South Africa is producing enough food to feed one and all of its 53 million people and hence it can be construed as a food-secure nation (StatsSA 2018). Nevertheless, one in four people suffers hunger and the living conditions of more than half of the population are grim from the perspective of food security. It is interesting to note that South Africa fairs well in terms of total amount of food grain production and indeed it exceeds the global benchmarks. Nevertheless, the national statistics hide the household realities (Maponya 2019). According to StatSA (2014) the Gauteng Province is a home to over 12,272,263 million people who contribute to 23.7% of the total national population. Studies have shown that almost 20% of households in Gauteng Province go to bed hungry due to food insecurity and unsustainable income.

3.2 Aim and Objectives

The basic aim of this survey is to figure out the status of climate variability and food accessibility in Gauteng Province, South Africa.

The following objectives were established:

- *To identify and describe climate variability status in terms of rainfall and temperature in Gauteng Province.*
- *To identify and describe food accessibility under climate variability in Gauteng Province.*
- *To identify and describe the relationship between climate variability and households socio economic characteristics in Gauteng Province.* (Maponya 2019)

3.3 Methodology

Participatory action research was adopted in the present study. The participatory action research ensures active participation of 'researcher, collaborators, extension officers, households and funder', in all phases so as to achieve comprehensive deliverables. Backeberg and Sanewe (2010) opined that the participatory action research is more effective in the household survey. Studies construed the participatory action approach as an alternative to top-down "approach" particularly in the

Table 3.1 Gauteng Province households visited and interviewed

Province	Metropolitan or district	Number of households
Gauteng	City of Johannesburg	319
Gauteng	City of Tshwane	270
Gauteng	Ekurhuleni	141
Gauteng	Sedibeng	216
Gauteng	West Rand	204
Total		**1150**

domain of 'agricultural research and extension'. The research used quantitative and qualitative methods and purposive sampling from existing sample frame from the Gauteng Department of Agriculture and Rural Development (GDARD) database of the Homestead Food Garden project. The sample size in order to be statistically significant should be a minimum of 10% of the total population. Data was collected from 1150 households of Gauteng Province through a questionnaire survey (Table 3.1): City of Tshwane Metropolitan (270), City of Johannesburg Metropolitan (319), Ekurhuleni Metropolitan (141), West Rand District (204) and Sedibeng (216). It must be noted that the questionnaire incorporated both open- and close-ended questions. The qualitative data collection methods involved focus group discussions and field observations. The focus group discussions were conducted among 56 GDARD officials: City of Tshwane Metropolitan (24), City of Johannesburg Metropolitan and West Rand District combined (18), Ekurhuleni Metropolitan (7) and Sedibeng District (7).

The following approach was used to conduct standard precipitation index (McKee et al. 1993):

> The Standardized Precipitation Index (SPI) was developed to monitor the occurrence of droughts from rainfall data. The index quantifies precipitation deficits on different time scales and therefore also drought severity. It provides an indication of rainfall conditions per quaternary catchment (in this case) based on the historical distribution of rainfall. (Maponya 2019, p. 4)

The following approach was used to determine soil categories (ARC 2016):

Soils with humic topsoil horizons (soil forms Ia, Ma, Kp, No) 1
Freely drained, structureless soils (soil forms Hu, Cv, Gf, Sd, Oa) 2
Red or yellow structureless soils with a plinthic horizon (soil forms
Av, Gc, Bv, Pn) 3
Imperfectly drained sandy soils (soil forms/series Sp, Ct, Vf, Fw 10 & 20, Du) .. 4
Swelling clay soils (soil form Ar) 5
Dark clay soils that are not strongly swelling (soil forms Bo, Ik, Tk) 6
Soils with a pedocutanic (blocky structured) horizon (soil forms Va, Sw) 7
Imperfectly drained soils, often shallow and often with a plinthic horizon (soil forms/
series We, Cf, Lo, Wa, Kd 10–15, Kd 20–22) 8
Podzols (soil forms Lt, Hh) 9
Poorly drained dark clay soils that are not strongly swelling (soil form Wo) 10
Poorly drained swelling clay soils (soil form Rg) .... .11

Dark clay soils, often shallow, on hard or weathering rock (soil forms My, Mw) 12
Lithosols (shallow soils on hard or weathering rock) (soil forms Ms., Gs) 13
Texture contrast soils (sandy topsoils abruptly overlie clayey, structured subsoils), often poorly drained (soil forms/series Es, Ss, Kd 16–19) 14
Wetland soils (soil forms/series Ch, Fw 30, Ka) 15
Non-soil land classes 16
Rock 17

The following approach was used to determine correlations among variables:

> Correlation is a bivariate analysis that measures the strengths of association between two variables and the direction of the relationship. In terms of the strength of relationship, the value of the correlation coefficient varies between +1 and −1. When the value of the correlation coefficient lies around ±1, then it is said to be a perfect degree of association between the two variables. As the correlation coefficient value goes towards 0, the relationship between the two variables is weaker. The direction of the relationship is simply the + (indicating a positive relationship between the variables) or – (indicating a negative relationship between the variables) sign of the correlation. Usually, in statistics, four types of correlations are measured: Pearson correlation, Kendall rank correlation, Spearman correlation, and the Point-Biserial correlation. (Maponya et al. 2019, p. 297)

In this investigation, Pearson correlations were used and the following variables were found to be significant: climate change and variability; adaptation; language; level of education; source of weather information and water availability throughout the year (Tables 3.2, 3.3, 3.4, 3.5 and 3.6).

Table 3.2 Land suitability for cabbage, spinach and pea production under irrigation

	Suitability class		
	Class		
Land attribute	Suited	Marginally suited	Unsuited
T_{max} Annual (°C)	<31	<35	Other
T_{min} July (°C)	≥2	≥0	Other
Soil category[1]	2, 3	2, 3, 4, 12, Gs	Other
Soil depth (mm)	≥450	≥300	Other
Topsoil clay content (%)	12–35	Other	Other

Table 3.3 Land suitability for garlic and onion production under irrigation

	Suitability class		
	Class		
Land attribute	Suited	Marginally suited	Unsuited
T_{max} Oct–Nov (°C)	≤34	Other	
T_{min} July (°C)	≥3	≥2	Other
Soil category[1]	2, 3	2, 3, 4, 12, Gs	Other
Soil depth (mm)	≥450	≥300	Other
Topsoil clay content (%)	9–35	Other	

Table 3.4 Land suitability for sweet potato, pumpkin and butternut under irrigation

	Suitability class		
	Class		
Land attribute	Suited	Marginally suited	Unsuited
T_{max} Oct–Mar (°C)	24–31	Other	
Soil category[1]	2, 3	2, 3, 4, 12, Gs	Other
Soil depth (mm)	≥600	≥400	Other
Topsoil clay content (%)	≥9 ≤35	Other	

Table 3.5 Land suitability for tomato, chillies and green pepper under irrigation

	Suitability class		
	Class		
Land attribute	Suited	Marginally suited	Unsuited
T_{max} Oct–Mar (°C)	21–31	20-36	Other
Soil category[1]	2, 3	2, 3, 4, 12, Gs	Other
Soil depth (mm)	≥500	≥400	Other
Topsoil clay content (%)	12–35	Other	Other

Table 3.6 Land suitability for carrots and beetroots under irrigation

	Suitability class		
	Class		
Land attribute	Suited	Marginally suited	Unsuited
T_{max} Annual (°C)	<26	<31	Other
Soil category[1]	2	2, 3, 4, 12, Gs	Other
Soil depth (mm)	≥450	≥300	Other
Topsoil clay content (%)	9–26	Other	Other

3.4 Results and Discussion

3.4.1 Climate Variability and Crop Suitability in Gauteng Province

The main objective of this first part of the situation analysis was to conduct a desktop natural resources audit and to develop a set of crop suitability maps. The latter were aimed at determining the biophysical viability of food gardens in the identified districts and metropolitans. As indicated in Figs. 3.1, 3.2, 3.3, 3.4, 3.5, 3.6, 3.7, 3.8, 3.9 and 3.10, all household coordinates collected were plotted on the maps and different colours explained the suitability of different crops across the Gauteng Province. The figures are self-explanatory and gave an indication on which crops are suitable and can be grown under current climate variability in Gauteng Province.

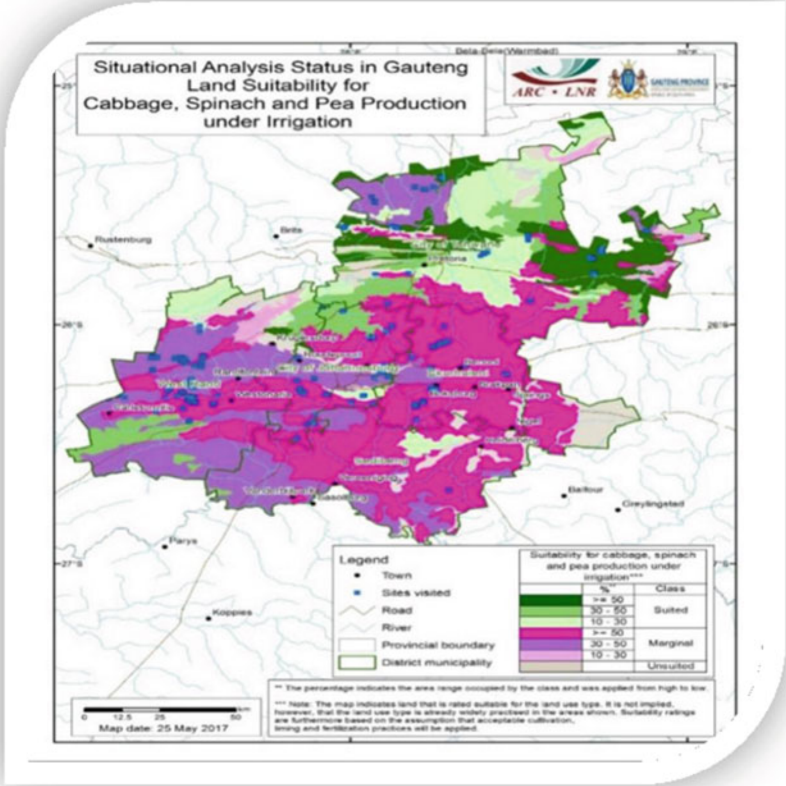

Fig. 3.1 Land suitability for cabbage, spinach and pea production under irrigation (ARC-ISCW 2017)

The approach taken in assessing crop suitability is primarily an adaptation and simplification of the Food and Agriculture Organization (FAO) methodologies as set out in their Framework (1976) and Guidelines (1983). It was also influenced by some of the approaches presented in various editions of the United States Department of Agriculture (USDA) National Soils Handbook. The results obtained take only the land-related aspects of sustainability into account, that is, technical feasibility and environmental sustainability. The aspects of social acceptability and economic viability are to be addressed separately.

The following are central concepts of the biophysical land use suitability process as pioneered by FAO:

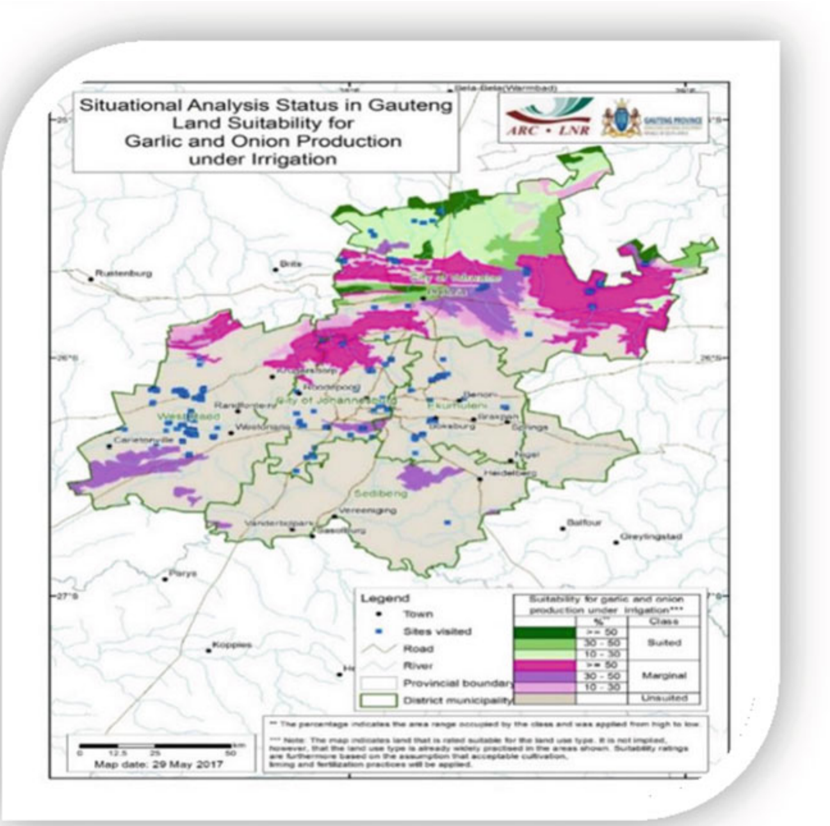

Fig. 3.2 Land suitability for garlic and onion production under irrigation (ARC-ISCW 2017)

- Land is evaluated separately for each land use type (LUT) of cluster of similar LUTs).
- Information on the environmental and land use requirements (LUR) of a land use type.
- Data/information on key land qualities and characteristics.

"*The Standardized Precipitation Index (SPI) was developed to monitor the occurrence of droughts from rainfall data (McKee et al.* 1993*). The index quantifies precipitation deficits on different time scales and also drought severity. It provides an indication of rainfall conditions per quaternary catchment based on the historical distribution of rainfall*" (Maponya 2019, p. 6). As depicted in Figs. 3.11, 3.12 and 3.13 by an arrow, the 24 SPI maps showed the extreme to mild drought conditions over some parts of Gauteng Province in 2016. Figures 3.14, 3.15, 3.16,

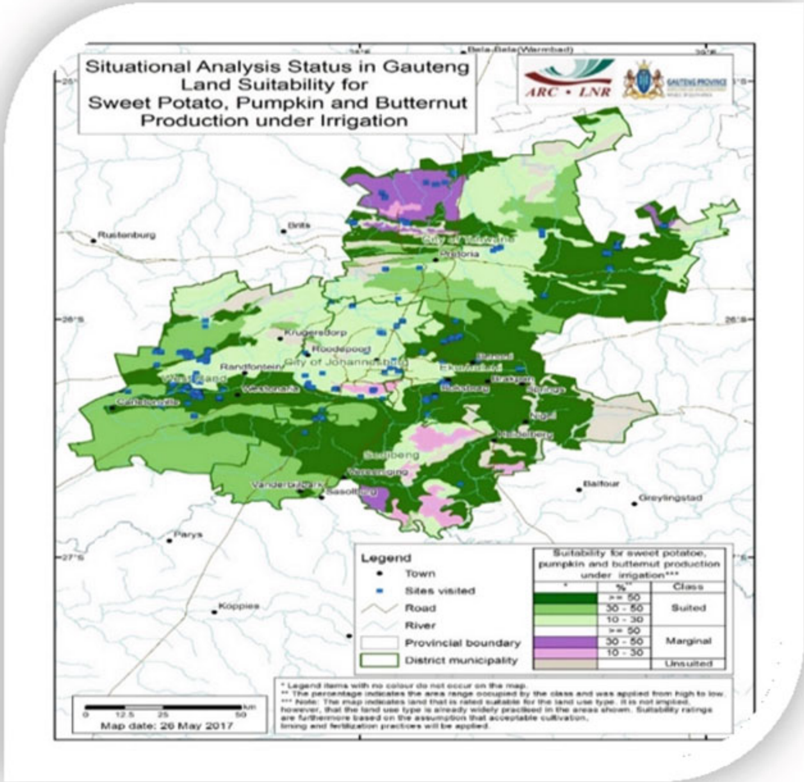

Fig. 3.3 Land suitability for sweet potato, pumpkin and butternut under irrigation (ARC-ISCW 2017)

3.17 and 3.18 reflect the current climatic variability in Gauteng Province. The climate variability is indeed a cause of concern, as it has negative impact on the water resources and food security of Gauteng Province. It has also been reported that the province may experience drier environmental conditions with increased frequency and intensity of drought (ARC-ISCW 2019). The study also indicated that with the current climatic variability, about 75% of households remained food insecure as limited water is available to engage in household food production and food prices skyrocketed in some of the Gauteng Province fresh produce markets. Farmers of Gauteng Province, indeed, have been experiencing the impacts of climate change and climate variability. Madima (2016) reiterated that the farmers in Gauteng Province have been facing the challenge of water scarcity and incidentally, and the smallholder/small farmers are more vulnerable. The fall in agricultural production results in the increase of agricultural product prices. This can be corroborated with

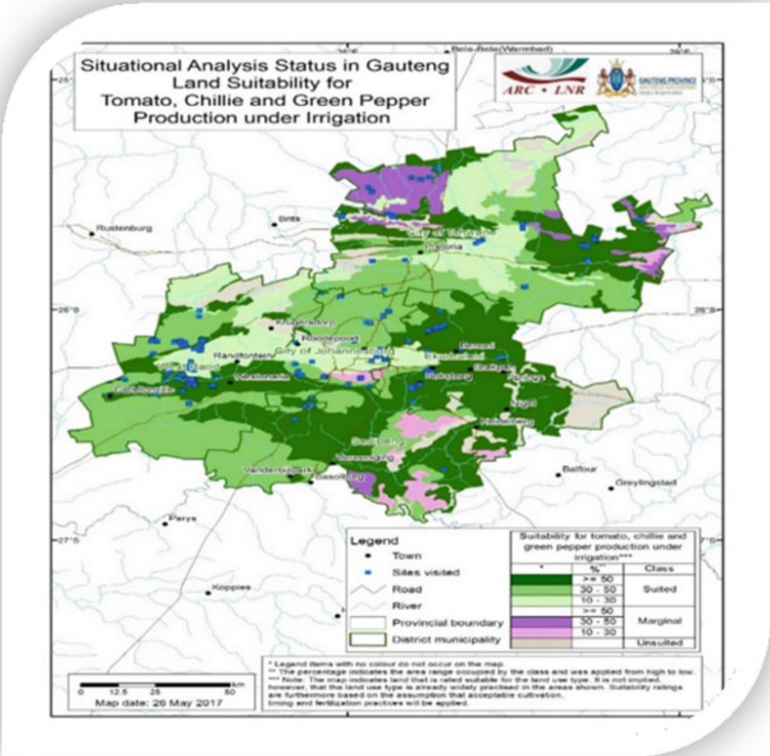

Fig. 3.4 Land suitability for tomato, chillies and green pepper under irrigation (ARC-ISCW 2017)

the increase in the prices of vegetables, namely, potatoes (95%), tomatoes (97%) and onions, by 41% (Madima 2016; Maponya 2019).

As indicated in Fig. 3.19, there was a general high minimum temperature across South Africa including Gauteng Province in 2016 when the project commenced (ARC-ISCW 2017). In addition, currently the minimum temperature in Gauteng Province is as high as indicated in Fig. 3.20 (ARC-ISCW 2019). The increases in temperature is always negative to agriculture production and hence affecting negatively on food security. According to Maponya and Mpandeli (2012), temperature increases can affect agriculture through its effect on cropping seasons, the increase in irrigation, the increase in evapotranspiration and the increasing effect of heat stress on crops.

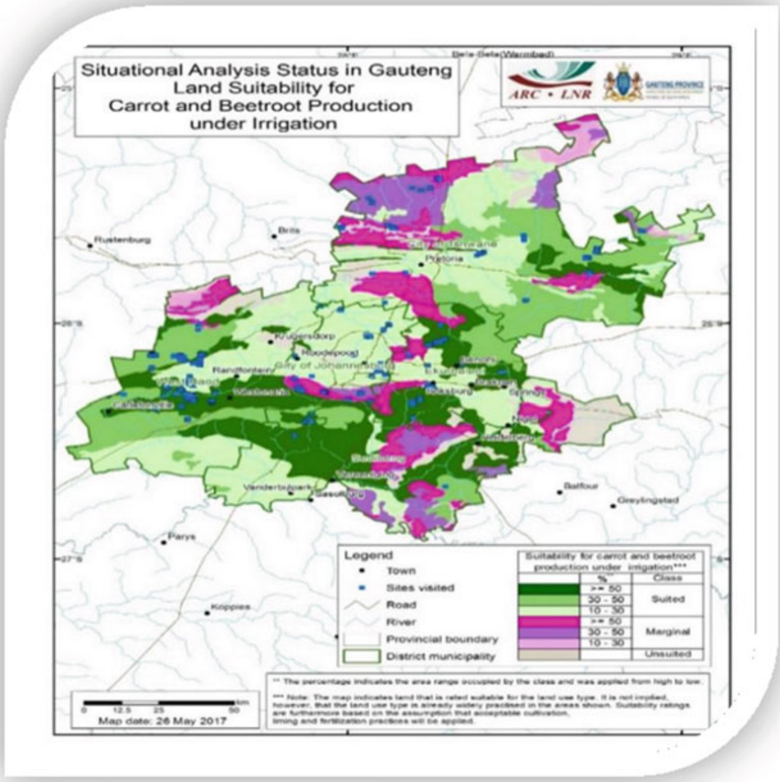

Fig. 3.5 Land suitability for carrots and beetroots under irrigation (ARC-ISCW 2017)

3.4.2 Climate Change Awareness Among the Households in Gauteng Province

As indicated in Fig. 3.21, about 933 households were not aware about the environment issues in the Gauteng Province. The GDARD should also take steps to create environmental awareness among their households. The focus group discussion indicated that the low levels of environmental awareness among households is because the mandate of environmental issues belongs to another department. If households were properly educated about environmental issues and importance, it would increase environmental benefits from recycling water and waste nutrients, controlling soil erosion, and maintaining or increasing local biodiversity. This would lead to a more sustainable environment and community as discussed during face-to-face interviews, observations and focus group discussion.

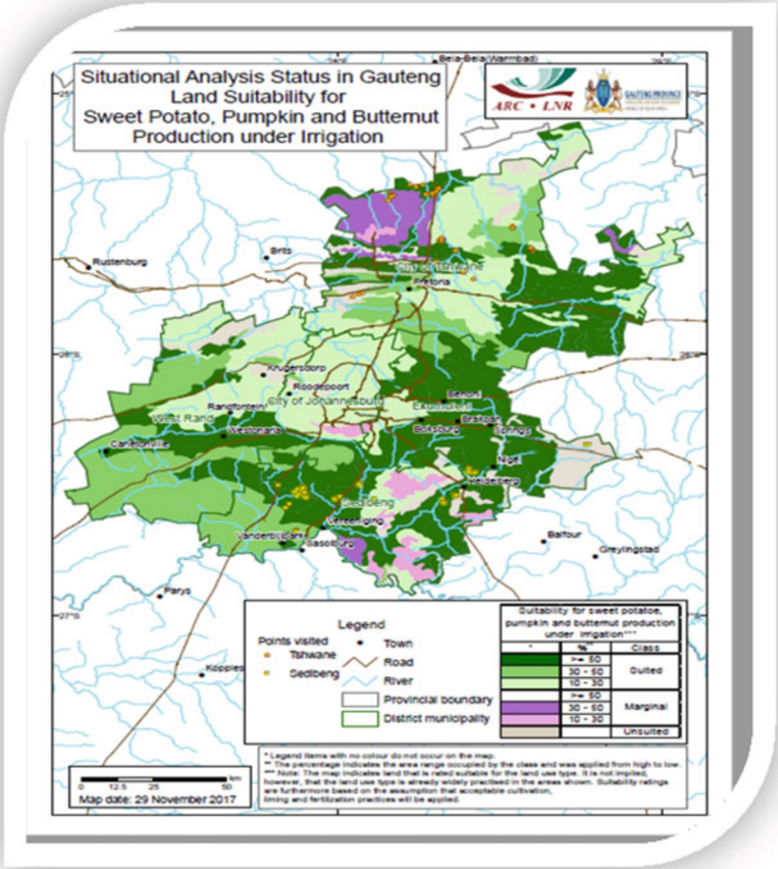

Fig. 3.6 Land suitability for sweet potato, pumpkin and butternut under irrigation (ARC-ISCW 2017)

Most of the households interviewed had no knowledge about climate variability and change (Fig. 3.22). This situation needs to be improved by the government extension service as knowledge of climatic perceptions and adaptations strategies are vital entry points for policy makers to know where to enhance the adaptive capacity of households and smallholders' farmers during the short rainy season and extended drought periods. According to Maponya and Mpandeli (2012), the study conducted in Limpopo Province found that access to weather information, resources and participation in government institutions are associated with households that have reported making farming changes in recent years. Maponya and Mpandeli (2012)

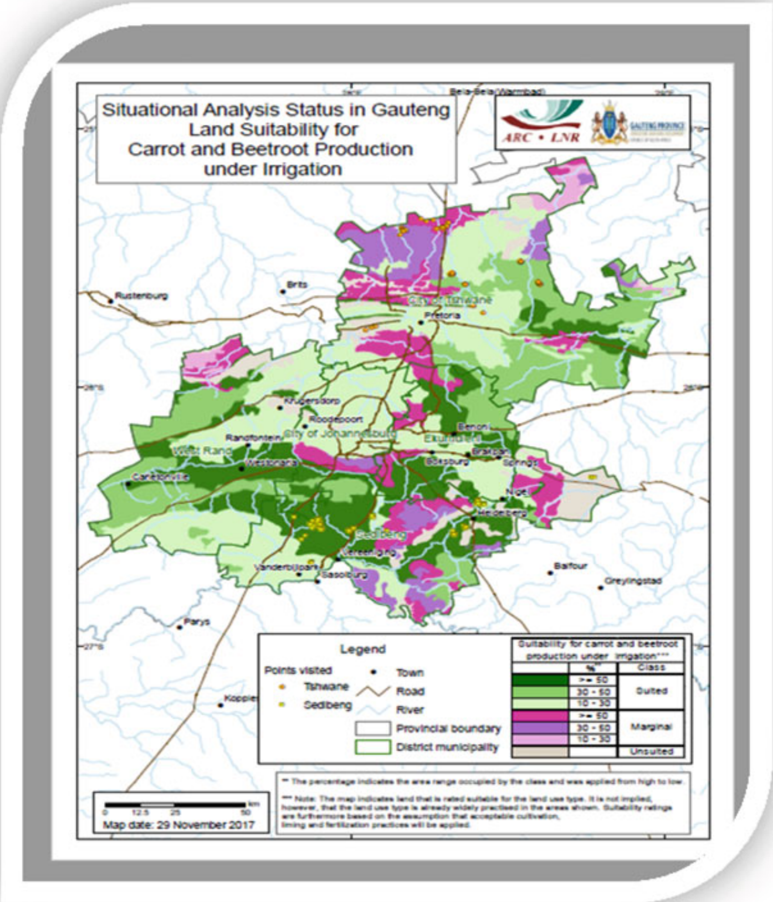

Fig. 3.7 Land suitability for carrots and beetroots under irrigation (ARC-ISCW 2017)

further emphasized that understanding these drivers and outcomes of farms/households associated changes across different socio-economic and environmental conditions is critical for ongoing dialogues for climate-resilient strategies and policies for increasing the knowledge capacity of smallholders and households under climate change and variability.

Climate variability is a major source of risk for agriculture and food systems. The increasing severity and frequency of extreme weather have extensively flawed agriculture (Maponya and Mpandeli 2012). As indicated in Fig. 3.23, risk management information remains a challenge in Gauteng Province. Figure 3.23 indicated

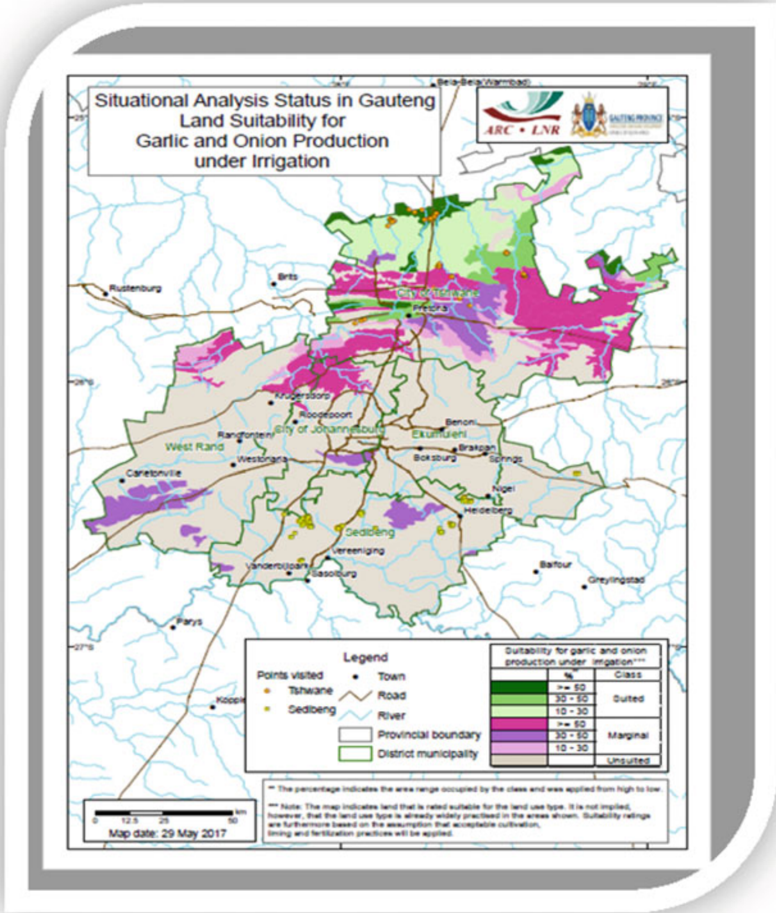

Fig. 3.8 Land suitability for garlic and onion production under irrigation (ARC-ISCW 2017)

that 875 households had no access to climate change and variability risk management information. The results also indicated that households in the city of Johannesburg Metropolitan had a high access to climate variability and change risk management information than other districts/metropolitan households. It is therefore advised that the following five major risk factors should be prioritized by the government and any other interested stakeholders: (1) Production risks linked with changes in crop yields and livestock from many sources (i.e., unpredictable weather conditions, disease incidence and pests), (2) financial risks, such as a farmer's capacity to pay their bills to sustain farming and avoid liquidation,

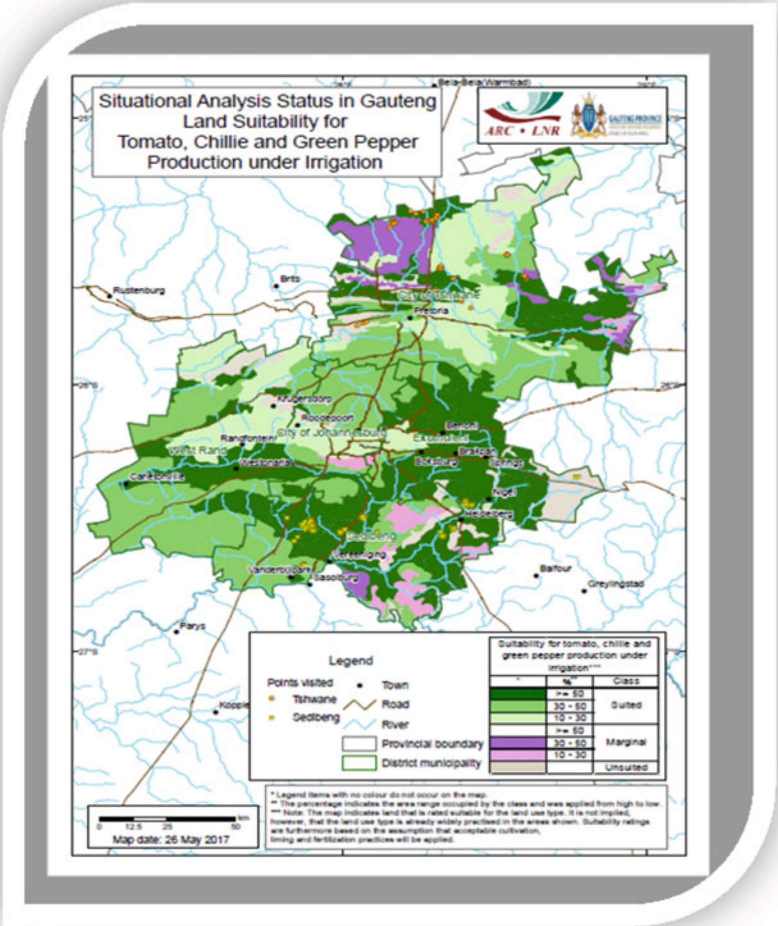

Fig. 3.9 Land suitability for tomato, chillies and green pepper under irrigation (ARC-ISCW 2017)

(3) marketing risks, which involve variations in the prices of agricultural products, (4) legal and environmental risks and (5) human resources (i.e., a lack of family members to play the role of labour and farm management).

According to Maponya and Mpandeli (2012), adaptation to climate change and variability is critical to reduce the negative impacts of climate change. Moreover, adaptation could be classified into spatial (both localized and widespread) and may be in the form of behavioural, technological, institutional, informational and financial adaptations. The results in Fig. 3.24 indicated that only 414 households are able

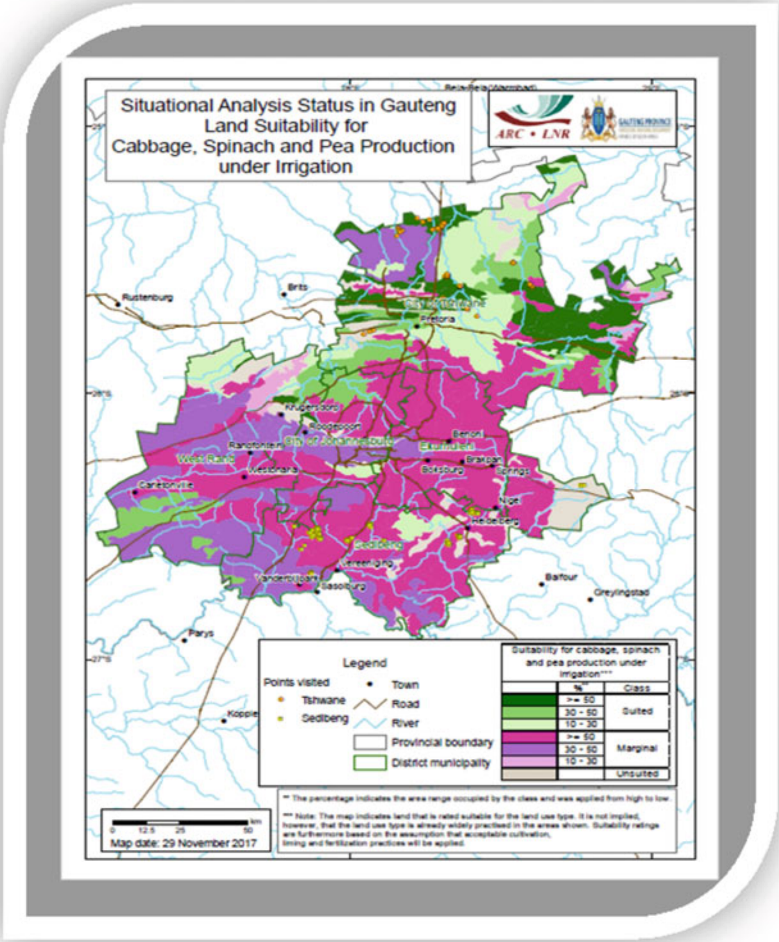

Fig. 3.10 Land suitability for cabbage, spinach and pea production under irrigation (ARC-ISCW 2017)

to adapt to climate variability and change in Gauteng Province. Some of their adaptation measures include

planting on raised beds and using garden tools to prepare the soil. The raised beds help to prevent irrigation water loss through run off and reduce soil loss from water erosion during heavy rains. To ensure minimal soil disturbance, less land degradation and compaction, hand garden tools are being used. Through this

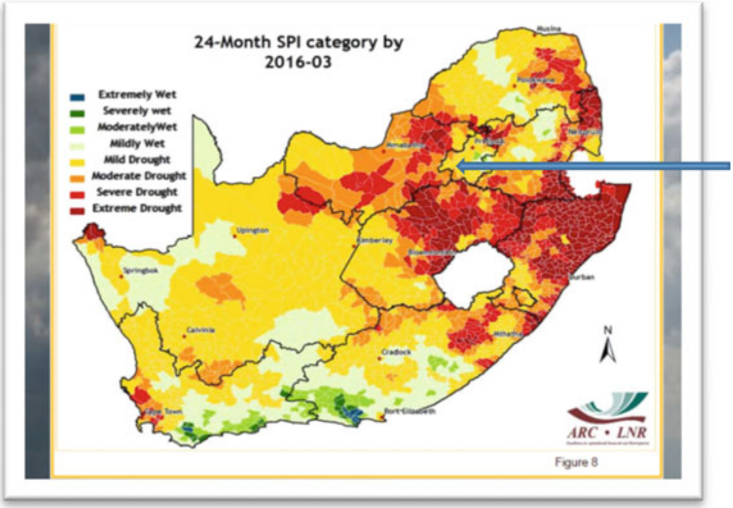

Fig. 3.11 South Africa 24 months standardized precipitation index for March 2016 (ARC-ISCW 2017)

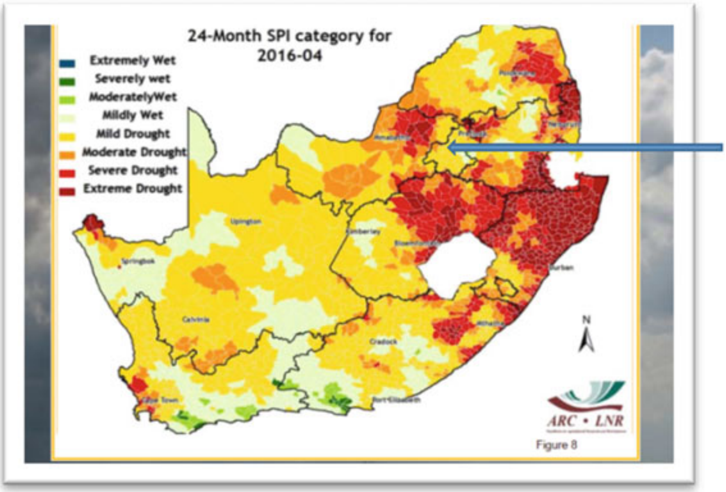

Fig. 3.12 South Africa 24 months standardized precipitation index for April 2016 (ARC-ISCW 2017)

practice, increased organic matter is also stored in the soil. Composting is practised so as to use compost as manure before planting. As shown in Fig. 3.25, some households practise mulching to enhance soil moisture. The

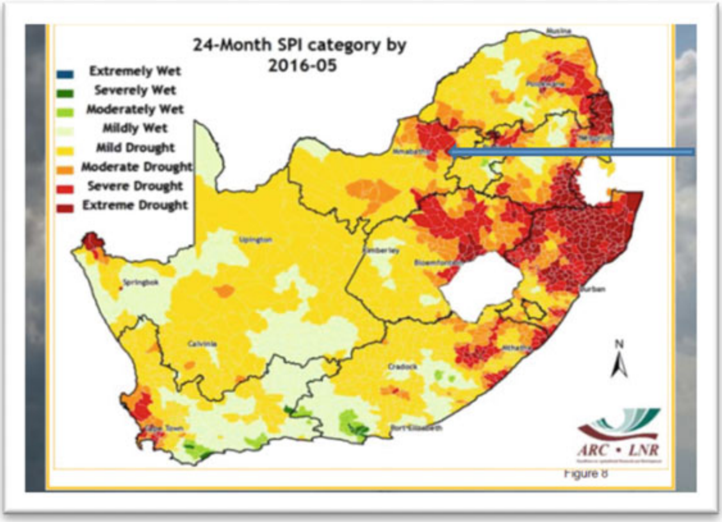

Fig. 3.13 South Africa 24 months standardized precipitation index for May 2016 (ARC-ISCW 2017)

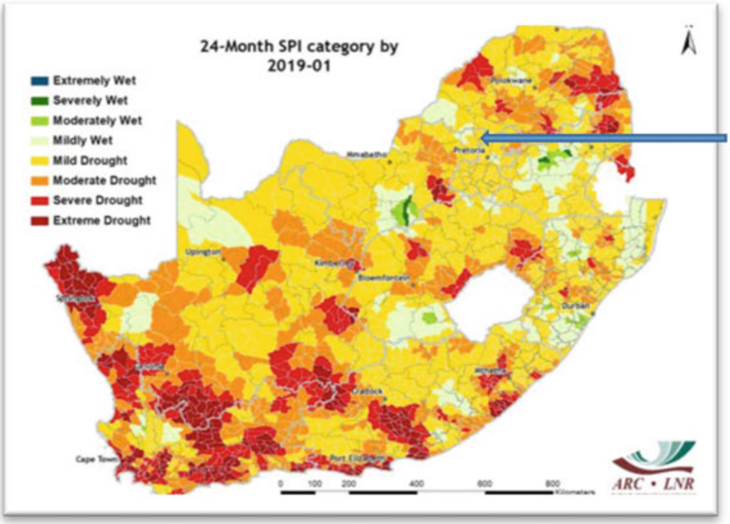

Fig. 3.14 South Africa 24 months standardized precipitation index for January 2019 (ARC-ISCW 2019)

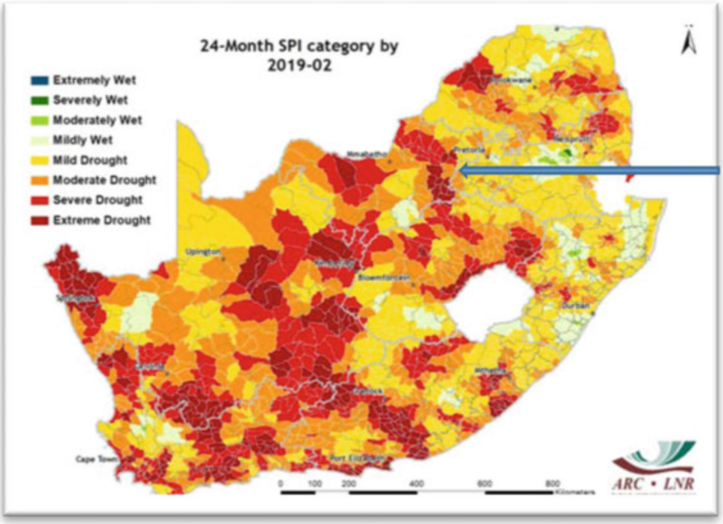

Fig. 3.15 South Africa 24 months standardized precipitation index for February 2019 (ARC-ISCW 2019)

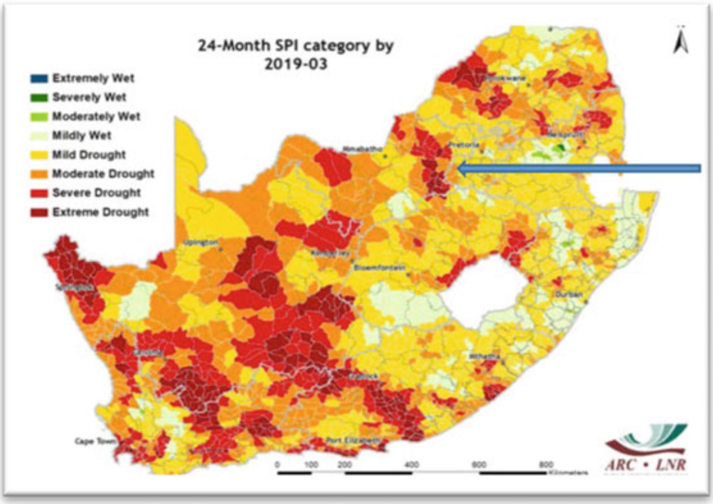

Fig. 3.16 South Africa 24 months standardized precipitation index for March 2019 (ARC-ISCW 2019)

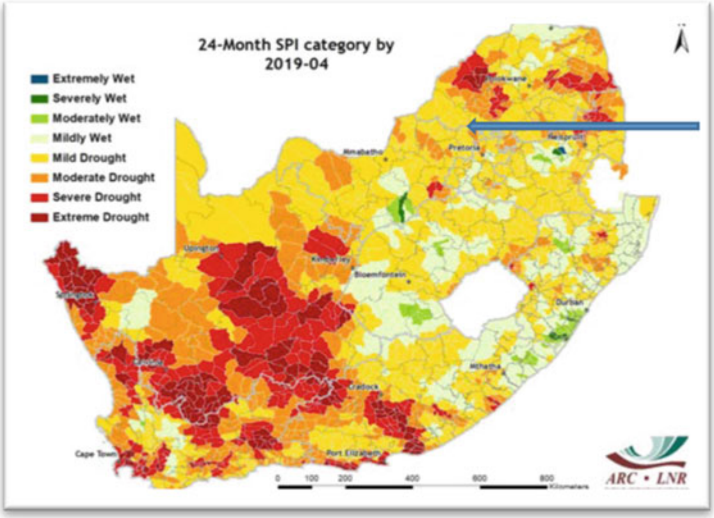

Fig. 3.17 South Africa 24 months standardized precipitation index for April 2019 (ARC-ISCW 2019)

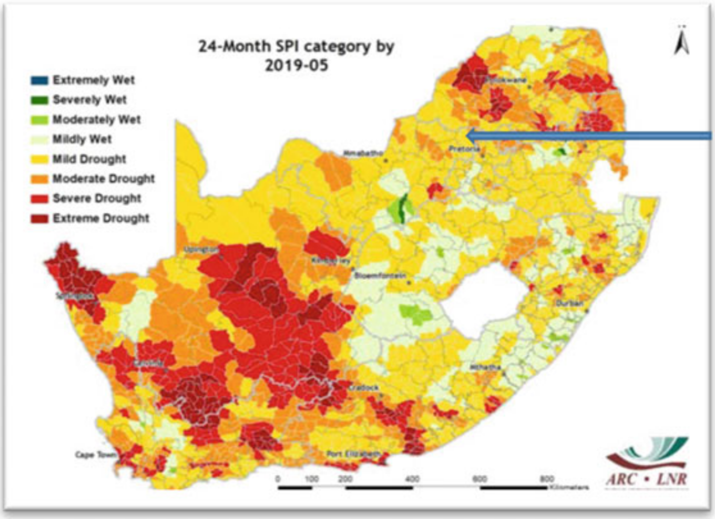

Fig. 3.18 South Africa 24 months standardized precipitation index for May 2019 (ARC-ISCW 2019)

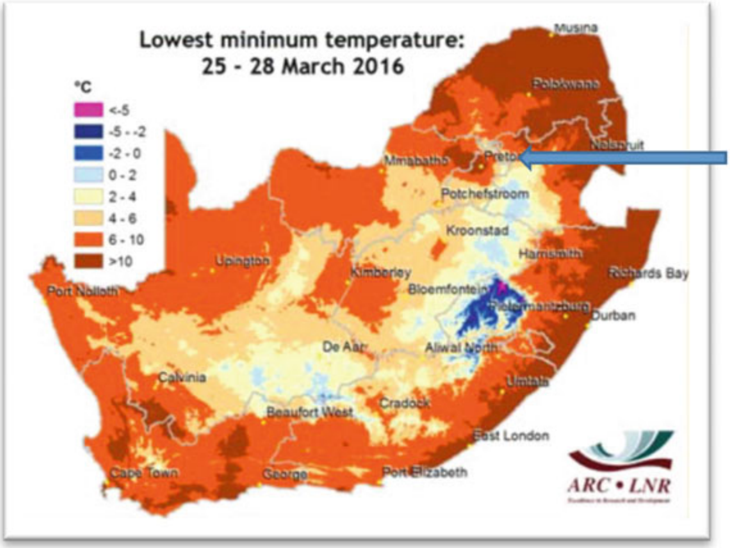

Fig. 3.19 South Africa minimum temperature for 25–28 March 2016 (ARC-ISCW 2017)

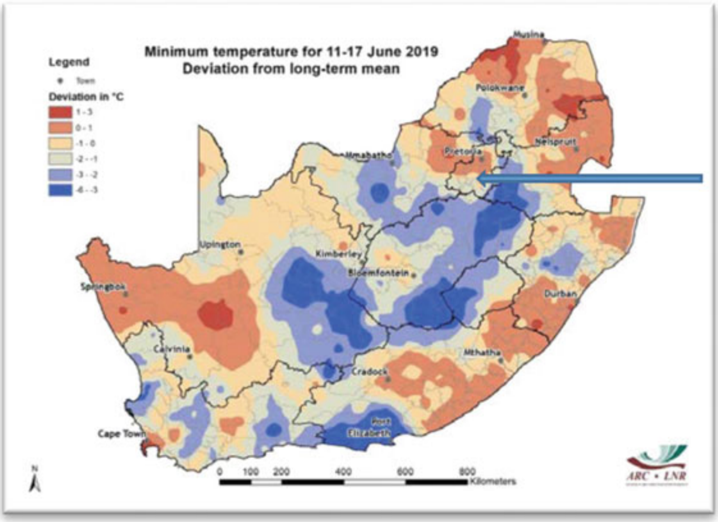

Fig. 3.20 South Africa minimum temperature for 11–17 June 2019 (ARC-ISCW 2019)

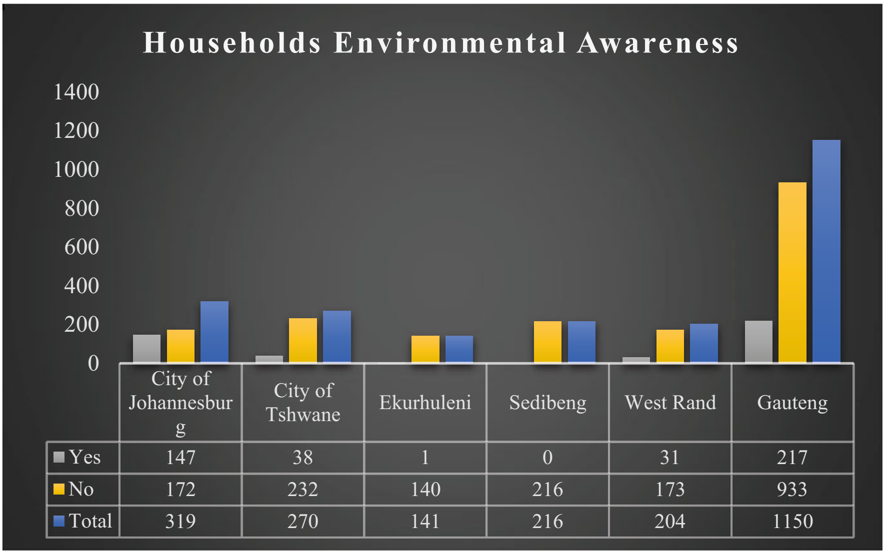

Fig. 3.21 Environmentally aware households in Gauteng Province

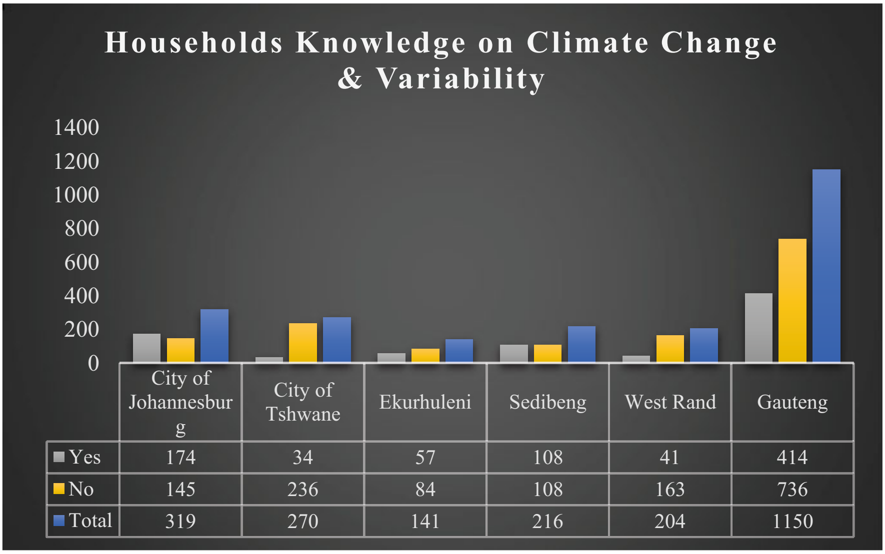

Fig. 3.22 Households' knowledge on climate change and variability

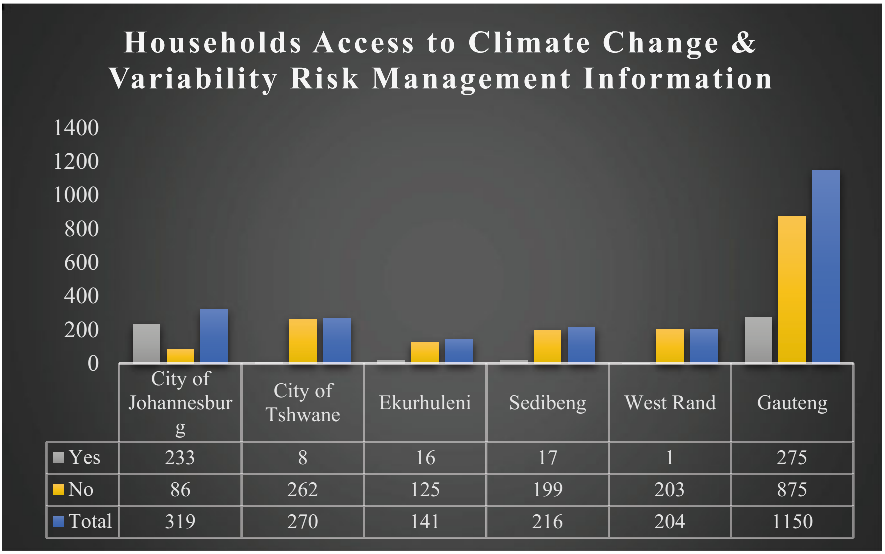

Fig. 3.23 Households' access to climate change and variability risk management information

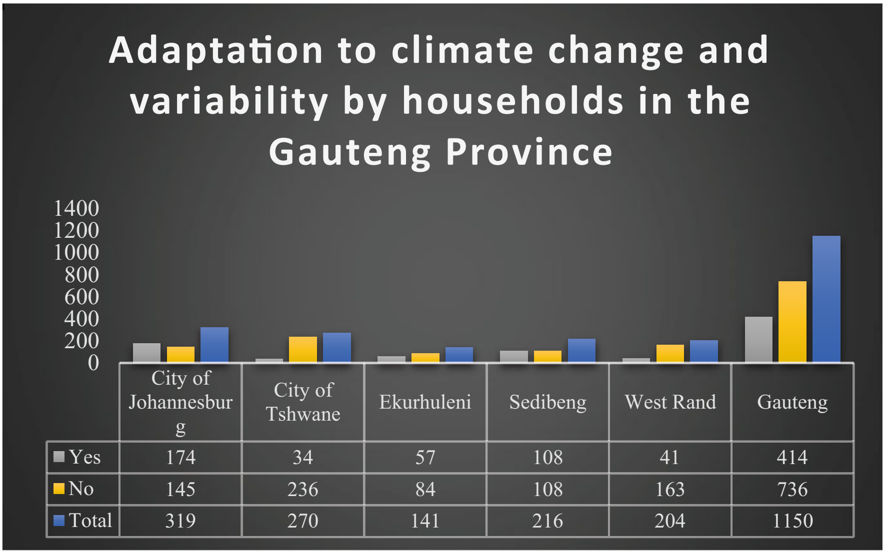

Fig. 3.24 Adaptation to climate change and variability by households in the Gauteng Province

Fig. 3.25 Households practising mulching in the Gauteng Province (survey data)

households also reduce municipal water utilization by harvesting rainwater from the building roof and therefore enhancing contribution towards sustainable water management.

3.4.3 Household Food Accessibility

> The majority of households interviewed were female (915) and similar trends were observed in the metropolitans and districts across the province. The results are also in line with Maponya and Moja (2012) study in Limpopo province which indicated that female households constitute a significant number of economically active populations and that the female-headed households usually fall within the vulnerable, marginal and food insecure categories. Most households fall in the age category >56 (454) and very few households fall in the age category <35 years (128). This shows an aging population of households, which could be critical to household food security. Similar trends were observed in metropolitans and districts. This indicates the need for youth involvement in agricultural food production as any future agricultural development in the districts and metropolitans should be tailor made to attract youth. In terms of educational attainment, most households received secondary education (574) with a few receiving tertiary education (34). The level of education is consistent in all districts and metropolitans across Gauteng Province. (Maponya 2019, p. 4)

Education is an agent to social change. Education has potential to augment the livelihood opportunities and reduce the poverty levels. Increase in employability has positive influence on the household food accessibility. Food security encompasses the dimensions such as food availability, accessibility, utilization and stability. The nutritional security component is essentially met through awareness, sanitation, gender equality and mainstreaming. In effect, the gender equality has positive influence on household food security (Venkatramanan and Shah 2020). Heckman (1999) attempted to highlight the role of education in 'poverty reduction', 'household food security' and 'livelihoods'.

> Most households fall in the income level R1001 – R2500 and quite a number of households had no income (248). Most of the households were spending >R601 of the monthly expenditure on food. There was not much difference in household members in Gauteng Province. Most of the household's size fell between 1–5 members and the same trend is seen across districts and metropolitans. (Maponya 2019, p. 4)

The role of household size cannot be overemphasized. Household size is a defining factor in food production, as the labour is an important factor in agricultural activity. The study by Ndobo (2013) too emphasized the significance of size of household size and its role in agricultural production, food accessibility and food security. Through the household survey, it was found that most of the households in the Gauteng Province experience constraints or challenges from the perspective of food accessibility (Table 3.7). As regards food accessibility, food secure households show minimum concern towards food access, as the food secure households can consume food three times in a day (Coates et al. 2007).

Figuring out the reasons for lack of food accessibility is a daunting task. However, in the Gauteng Province, it was found that 67% of the households were found to be food insecure due to a lack of resources which include the economic resources. Further, due to a lack of financial resources, households consume monotonous diets. Table 3.7 reveals about household food accessibility from the point of view of a

Table 3.7 Households' food accessibility in Gauteng Province (households who said YES)

An impression of food accessibility	R (%)	S (%)	O (%)	T (%)
In the past 4 weeks, did you worry that your household would not have enough food?	24	39	17	81
In the past 4 weeks, were you or any household member not be able to eat the kind of food you preferred because of lack of resources?	27	38	19	84
In the past 4 weeks, were you or any household member having to eat a limited variety of food due to lack of resources?	26	38	23	87
In the past 4 weeks, were you or any household member having to eat some foods that you really did not want to eat because of lack of resources to obtain other types of foods?	26	37	23	86
In the past 4 weeks, were you or any household member having to eat a smaller meal than you felt you needed because there was not enough food?	25	39	23	87
In the past 4 weeks, were you or any household member having to eat fewer meals in a day because there was not enough food?	25	38	24	87
In the past 4 weeks, was there ever no food to eat of any kind in your households because of lack of resources to get food?	21	29	16	67
In the past 4 week, did you or any household members go to sleep at night hungry because there was not enough food?	23	21	16	60
In the past 4 weeks, were you or any household member having go a whole day and night without eating anything because there was not enough food?	8	8	12	34

R rarely (once or twice), *S* sometimes (three to ten times), *O* often (more than ten times), *T* total (those households who said YES)

Table 3.8 Households food security levels and extent of food insecurity

Variable	Category	Household	Percent
Food security level	Food secure	290	25%
	Food insecure	860	75%
Extent of food insecurity	Mild	263	23%
	Moderate	367	32%
	Severe	223	20%

number of meals consumed/day, food preference, etc. (Maponya 2019). An interesting study by FAO (2012) reveals that households when challenged by food shortage consume less food. In effect, this study infers that the progress made by South Africa with respect to SDG 2 is less (Maponya 2019).

Coates et al. (2007) categorized households based on food security: *(a) 'Food secure households did not worry about food access; they were able to have a full meal three times in a day without food running out, in the past 30 days. (b) Mildly food insecure households were anxious about not having sufficient food. These households experienced food insecurity once or twice in the past 30 days. (c) Moderately food insecure households consume inadequate diet and eat less preferred food. These households experienced food insecurity three to ten times in the past 30 days. (d) Severe food insecure households experience high incidences of food security. These households experienced food insecurity more than ten times in the past 30 days'* (Maponya 2019, p. 6). Table 3.8 on 'Households Food Security Levels & Extent of Food Insecurity' reveals that about 75% of the households in Gauteng Province are food insecure. As regards the extent of food insecurity, about 20% of the households are in the severe category and 32% in the moderate category.

3.4.4 Correlation Between Climate Variability and Socio-economic Characteristics

There is a positive correlation between variables: climate change and variability, level of education, language, source of weather information and water availability throughout the year in Gauteng Province. It is expected that household members with a high level of education express willingness to undergo training, acquire new knowledge and understand the benefits of improved farm practices. Households prefer to access weather information from diverse sources but in their own language. According to Maponya and Mpandeli (2013), smallholder farmers and households in Limpopo Province became aware of climate variability and change through local radio stations, television, local agricultural extension officers, neighbours, village meetings, indigenous knowledge indicators of weather forecasts and local newspapers. The positive correlation between climate variability and change and water availability throughout the year is not surprising as water availability is very important for improving the agricultural production, reducing food insecurity,

Table 3.9 Pearson correlations coefficients among variables

	CCA[a]	LAN[b]	LEV[c]	SOU[d]	WAT[e]
CCA	1.00	0.01**	0.048*	0.050**	0.012**
LAN		1.00	0.006	0.141	−0.39
LEV			1.00	−0.96	−0.125
SOU				1.00	−0.47
WAT					1.00

*5% Significant level; **1% Significant level
[a]Adaptation to climate change and variability (CCA)
[b]Language (LAN)
[c]Level of education (LEV)
[d]Source of weather information (SOU)
[e]Water availability throughout the year (WAT)

increasing throughput and enhancing livelihood in the Gauteng Province. It must be emphasized that the adaptation to climate change and variability are a function of socio-economic and related factors such as changing to short cycle crop varieties, changing planting dates, crops diversification and use of drought-resistant crop varieties (Table 3.9).

3.5 Conclusion

In conclusion, Gauteng Province households differ in terms of the exposure and vulnerability to climate change and variability. Therefore, Gauteng Province households' ability to adapt to climate change and food security will depend on the understanding of risks and the vulnerability to food accessibility. Further, with the increase in climate change risks, the agriculture-based households must incorporate climate-resilient agricultural practices and technologies in their farm management framework, so as to increase agricultural production and ensure household food security. It is therefore important for the government to implement strategies to address food accessibility under current climatic conditions and to educate people on how to maintain their agricultural production during harsh climatic conditions.

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4 Climate Resilient Mariculture Technologies for Food and Nutritional Security

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Abstract

In India, marine fish production is achieved through capture fisheries and mariculture- culturing of finfish, shellfish, seaweed, etc., in the sea. Increasing protein demand has to be met through increased marine fish production. As marine capture fisheries is in a stagnating phase, the additional fish production has to be achieved through mariculture. Technologies like cage farming and seaweed farming are being promoted by the Indian Council of Agricultural Research (ICAR)-Central Marine Fisheries Research Institute (CMFRI) for more than a decade. These interventions assisted in enhancing the marine fish production and income of the fishers. One of the anticipated issues while expanding sea cage farming is the increased organic and inorganic load in the water and consequent disease problems. In this context, the concept of bio-mitigation along with increased biomass production can be adopted by integrating different groups of commercially important aquatic species that are having varied feeding habits. This concept is known as Integrated Multi-Trophic Aquaculture (IMTA). The environmental and economic stability and social acceptability is ensured through IMTA. The ICAR-CMFRI has successfully demonstrated IMTA under participatory mode with a fishermen group by integrating seaweed *Kappaphycus alvarezii* with cage farming of Cobia (*Rachycentron canadum*). Through demonstration, the total seaweed produced under IMTA was 2.2 times higher than the control. Similarly, the cobia yield was 1.3 times higher than the control. Additionally, the total amount of carbon sequestered into farmed seaweed was 2.2

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times higher than the control. At present in adoption stage, the total seaweed produced under IMTA was 3.1 times higher than the control. Integration of seaweed with cobia cages favorably generates additional revenue and is efficient in reducing both organic and inorganic matter from unutilized feed and excreta and thereby ensuring ecological balances. It is also one of the significant mitigating measures on the adverse impact of climate change and earns carbon credit to our country.

Keywords

Food and nutritional security · Resilient mariculture · *Kappaphycus alvarezii* · Cage farming · Cobia (*Rachycentron canadum*) · Integrated Multi-Trophic Aquaculture (IMTA)

4.1 Introduction

Aquaculture growth involves the expansion of cultivated areas worldwide, and density of aquaculture is determined by installations and species cultured with greater use of formulated feed resources. Poor and irregular management results in negative impacts on the environment and on the society. Increased environmental sustainability, economic stability through improved output, lower costs, species diversification with societal acceptability, risk reduction, and job creation are the prerequisites for "Engineered Aquaculture." The efficient use of nutrient resources, as well as the opportunity of diverse products and benefits while reducing impacts, and therefore integrated aquaculture, becomes a very important practical way to implement ecosystem approach to aquaculture (EAA) (FAO 2008). Farming of multiple species will effectively utilize the resources and bio-mitigate the production waste. This will increase the resilience of the operation with reduced risks which are the integral part of EAA.

Integration of fish and vegetation has been adopted for centuries. In the 1970s, John Ryther reignited interest in Integrated Multi-trophic Aquaculture (IMTA) in which advantages of synergistic interactions among species and the environment is appraised. He is considered as the grandfather of modern IMTA, his seminal work "integrated waste-recycling marine polyculture systems," for combining polyculture, integrated mariculture or aquaculture, ecologically engineered aquaculture, and ecological aquaculture. Later in 2004, Jack Taylor combined integrated aquaculture and multi-trophic aquaculture into the term integrated multi-trophic aquaculture. Integrated aquaculture not only provides food products but also many benefits to the ecosystem (Fang et al. 2018).

IMTA can be "applied to open-water or land-based systems, marine or freshwater systems, and temperate or tropical systems" (Chopin 2013a, b). Choices in the design of the IMTA systems can vary on different climatic, environmental, biological, physical, chemical, economic, historical, societal, and political governance conditions, prevailing in the parts of the world where they operate (Chopin 2013a, b). Culture organisms must be chosen from different trophic levels by factoring in (a) "their complementary functions in the ecosystem" and (b) "economic potential of the culture organisms." Usually, fed species such as finfish or shrimp are cultivated with extractive species, such as seaweeds and aquatic plants that recapture inorganic dissolved nutrients, and shellfish and other invertebrates that recapture organic particulate nutrients for their growth (Chopin 2006). There is tremendous opportunity to use marine macro algae as bio-filters, and to process them and produce products with commercial value. However, only a few countries are doing IMTA on a commercial scale, and globally most of the seaweed culture is taken up as open water monoculture, for example, in Asia, South America, South Africa, and East Africa.

Inorganic extractive components of IMTA farmed/being experimented in India are seaweeds such as *Kappaphycus alvarezii* and *Gracilaria edulis*. The culture of these organisms that are low in the food chain and that extract their nourishment from the sea involves relatively low input. The organic extractive components are the oysters and mussel. During recent years, fish-farming in floating cages has also been introduced in the open waters. It is then realized that the recycling of waste nutrients by seaweed and filter-feeding shellfish is the most likely way to economically improve mariculture sustainability.

4.2 CMFRI Technology – Sea Cage Farming of Cobia

In recent years, the availability of high value fish from sea is declining mainly due to over-exploitation of stocks. However, the demand for marine fish is increasing year after year, as it is an important source of protein, fatty acids, and it provides essential nutrients to the poorer sections of the society. Hence, the additional requirement of sea fish has to be met only by farming in seas, namely, mariculture. The Mandapam Regional Centre of "Central Marine Fisheries Research Institute" (CMFRI) is currently developing advanced technologies for the "seed production" and "farming of high value marine finfishes." One such technology is sea cage farming of cobia *Rachycentron canadum*.

The Mandapam Regional Centre of ICAR-CMFRI through intensive research on cobia has developed innovative technologies for (a) breeding, (b) seed production, and (c) cage farming of cobia. The technologies enable the fishermen to earn additional income and livelihood. Further, cobia farming can be undertaken on a small scale. Research findings as reported by Johnson et al. 2019 reveals that (a) cobia is a suitable species for sea cage farming and that (b) cobia quickly grows to attain a weight of 2–3 kg in about 6 months and 4–8 kg in about a year. Cobia is a popular table fish due to its high quality of meat. In India, cobia is sold as whole or as steaks in the domestic market. It has a very good demand in states like Kerala, Tamil Nadu, Maharashtra, West Bengal, Karnataka, and Goa. The present production level is not enough to meet the domestic demand. As the culture practice of the cobia is picking up momentum, it will also have export potential in the future. As a result of the initiation taken by the CMFRI–Mandapam, cage farming of cobia is being adopted by more than 100 groups in the coastal districts of Tamil Nadu with the support of central and state government agencies.

4.3 Integrated Multi-trophic Aquaculture

One of the anticipated issues while expanding sea cage farming is the increased organic and inorganic load in the water and consequent disease problems. In this context, the idea of bio-mitigation along with increased biomass production can be achieved by integrating different groups of commercially important aquatic species that have varied feeding habits. The ICAR-CMFRI has successfully conducted a demonstration of IMTA under participatory mode with a fishermen group at Munaikadu (Palk Bay), Ramanathapuram district, Tamil Nadu, India, by integrating seaweed *Kappaphycus alvarezii* with cage farming of Cobia (*Rachycentron canadum*). Since seaweed farming is being widely adopted on the coast of Tamil Nadu, integration of seaweed with cage farming of cobia was initially attempted (Figs. 4.1 and 4.2).

4.3.1 *Kappaphycus alvarezii* Farming

Kappaphycus alvarezii is a red alga, which is widely used as phycocolloids (carrageenan), food, fodder, and bio-fertilizer. *Kappaphycus alvarezii* farming methods include but are not limited to floating bamboo raft method, tube net method, and monoculture technique. Nevertheless, on the Tamil Nadu coast, India the floating bamboo raft method is widely adopted. Further, this method is ideal for coastal waters with moderate wave action and depth as well. The mainframe of the floating bamboo raft is 12 × 12 feet. As regards its construction, 4 bamboos (4 feet each) are

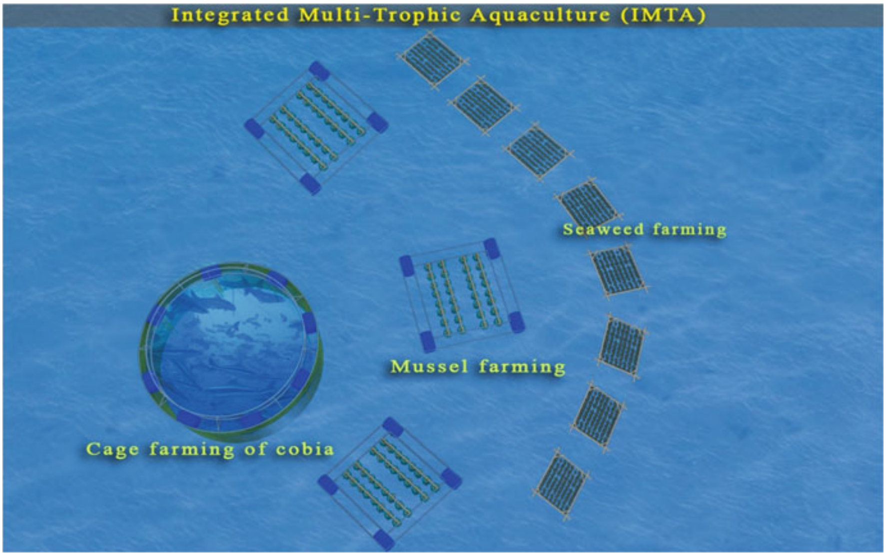

Fig. 4.1 IMTA (Schematic aerial view)

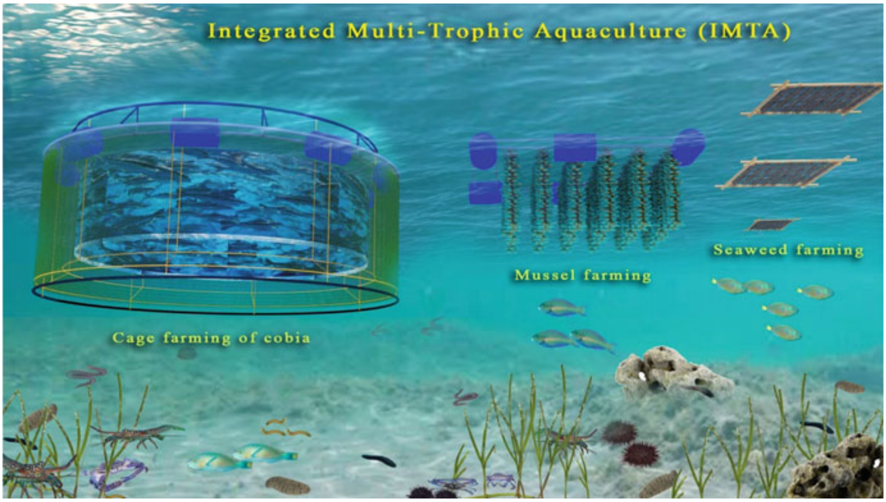

Fig. 4.2 IMTA (Schematic cross-sectional view)

Plate 4.1 Seaweed fragments are tied on the rope

fastened diagonally in the four corners of the mainframe (Plates 4.1 and 4.2). Approximately 20 polypropylene-twisted ropes along with seed materials are tied in the raft. Along the length of rope, about 150–200 grams of seaweed fragments are tied at a spacing of 15 cm in such a way that about 20 seaweed fragments are tied in a single rope. As regards the total seed requirement, it is about 60–80 kg/raft. In order to avoid grazing, a fish net with a dimension of 4 m × 4 m size is tied to the bottom of the raft (Johnson and Gopakumar 2011; Johnson et al. 2017). The crop duration is about 45 days. Annually, a gross revenue of ₹1,50,000 is being earned by a family in *Kappaphycus* farming.

Plate 4.2 Bamboo raft method – *Kappaphycus* farming

Plate 4.3 Cage farming of cobia

4.3.2 Demonstration of IMTA

A total of 16 bamboo rafts (12 × 12 feet) with 60–80 kg of seaweed per raft were integrated along with one of the cobia cages for a span of 4 cycles of seaweed farming (covering 180–210 days of cobia farming). The rafts were placed 15 feet away from the cage in a semi-circular manner, so as to enable the seaweed to absorb the dissolved inorganic nutrient wastes arising from the cage and that moves along the water current from the cage.

A GI cage of 6 m diameter and 3.5 m depth with 750–1000 cobia fingerlings was integrated with the above seaweed raft system. The fingerlings of cobia were fed @ 5% total biomass of fish with chopped low-value fishes (sardine, lesser sardine, rainbow sardine, etc.) twice a day. Net cages were changed based on the subjective assessment of fouling of the net in order to have sufficient water exchange. The crop period for cobia is 6–7 months (Plates 4.3, 4.4 and 4.5). As a control, a separate set of rafts of the same number were grown in a different location without any integration with the cobia farming cages.

Plate 4.4 Seaweed rafts

Plate 4.5 Seaweed rafts (16 Nos.) integrated with cobia cage

4.3.2.1 Economic Benefits Through Increased Seaweed Production Under IMTA

One complete cycle of seaweed extends for an average of 45 days. In one raft of 12 × 12 feet, the average yield without integration was 150 kg per raft, whereas in the raft integrated with a cobia rearing cage the average yield was 260 kg. The seaweed rafts were brought near the shore for harvesting. After retaining 60–80 kg as seed material for the next crop, the remaining material was sun dried near the shore for 3 days and sold in dried form. The average dry weight of the harvested seaweed is only 10% of the wet weight. Within 2 or 3 days from harvest, the rafts were seeded once again and integrated to the cobia rearing cage. Four cycles of seaweed farming were performed in a row for a period of 6–7 months.

The total dried seaweed production of the integrated rafts after 4 cycles was 1,280 kg, while that of non-integrated rafts was only 576 kg. An additional yield of 704 kg of seaweed was achieved through integration with cobia cage farming (Table 4.1). Also there was an increased number (average 90–100) of newly

Table 4.1 Comparison of cost and returns of seaweed cultivation by IMTA (16 rafts/1 cage/4 cycles) and non-IMTA

Particulars	IMTA	Non-IMTA	Difference
Dried seaweed production (for 4 cycles, 16 rafts)	1,280 kg	576 kg	704 kg
Price of dried seaweed (Rupees per kg)	37.50	37.50	–
Gross Revenue (Rupees)	48,000	21,600	26,400
Total Costs (Rupees) (16 rafts × Rs. 1000 per raft)	16,000	16,000	–
Net income (Rupees) (Gross Revenue – Total Cost)	**32,000**	**5600**	**26,400**
Profit margin (%) {(Net income/Revenue) × 100}	**67**	**26**	**41**

Plate 4.6 Comparison of seaweed yield both non-integrated (with cobia cage) (L) and integrated farming (R)

Plate 4.7 More numbers of newly emerged apical portion/tips from integrated rafts

emerged apical portion/tips in a bunch of harvested seaweed from the rafts integrated with the cobia cages, due to effective organic waste mitigation. However, the same was less (average 30–40 numbers) from the rafts that were not integrated. The bunches having more numbers of newly emerged apical portion/tips, when used for replanting, are ready for harvest within 40 days, whereas the seaweed with less numbers of newly emerged apical portion/tips, if used as seed, are ready for harvest only after 54 days (Plates 4.6 and 4.7). There was an additional revenue generation/additional net income of ₹26,400 with an increased profit margin of 41% through the integration of seaweed rafts to cobia cages with same operational cost for the rafts.

Table 4.2 Comparison of economics of sea cage farming of cobia with and without IMTA (for one cage and one crop of 6 months duration)

S. No.	Particulars	IMTA (Rupees)	Non-IMTA (Rupees)	Difference
750 cobia seeds were stocked in a 6 m diameter and 3.5 m depth GI cage				
1	Fixed cost (one cage)	61,600	61,600	0
2	Total operating cost	1,30,000	1,30,000	0
3	Total cost of production (6 months)	1,91,600	1,91,600	0
4	**Yield of farmed fish (in kg) (in 6 months average wt. 2.2 kg)**	**1220**	**960**	**260 kg**
5	**Gross revenue in Rupees (@₹290 per kg)**	**3,53,800**	**2,78,400**	**75,400**
6	Net income (Rupees)	1,62,200	86,800	75,400
7	Net operating income (income over operating cost) in Rupees	2,23,800	1,48,400	75,400
8	Farm gate price (Rupees)	290.00	290.00	0
9	Capital productivity (operating ratio) (Total operating costs/Gross revenue)	0.37	0.47	–
10	Cost of production in Rupees per kilogram (Total cost of production/Yield of farmed fish)	157	199	42

Plate 4.8 View of harvested cage farmed cobia fishes from the integrated cages

4.3.2.2 Economic Benefit Through Increased Cobia Production Under IMTA

The integration of cobia cage with seaweed rafts generated favorable returns for the farmers with respect to the finfish production. In a 6-month production cycle of cage farming of cobia under IMTA (along with 4 cycles for the integrated seaweed), an average yield of 1,220 kg was achieved whereas in the non-integrated cobia cage the yield was only 960 kg. The gross revenue generated from the cobia yield (with an average weight of 2.2 kg/fish and at the rate of ₹290/kg) was ₹3,53,800 for the integrated cages and ₹2,78,400 for the non-integrated cages. Hence, an additional

Plate 4.9 Harvested seaweed from integrated (with cobia cage) farming

net operating income of ₹75,400 was realized from the integrated cage (Table 4.2; Plates 4.8 and 4.9).

The decrease in operating ratio from ₹0.47 to ₹0.37 and cost of production per kilogram from ₹199 to ₹157 for non-integrated and integrated cages, respectively, increased the profit percentage.

The sequestration of the organic waste by seaweeds acts as a fertilizer for itself, and also decreases the organic load in the natural water body and helps the fish to save and minimize its energy expenditure toward warding off environmental stress, thus helping it to have a better growth rate over its counterpart cultured in a non-integrated manner.

4.3.2.3 Environmental Benefits

It was found that the organic waste mitigation was more efficient in the integrated system of *Kappaphycus* farming than the non-integrated system of farming. Biochemical analysis of water and sediments from the experimental rafts and cages indicated the mutual beneficial effect of seaweeds and cobia in the integrated aquaculture system. The analyses for organic matter load and water quality parameters indicated that the organic wastes from the feed waste and excreta of fish were sequestered by the integrated seaweed. This finding is in accordance with other works which reported that mussels/oysters and seaweeds can effectively remove fish wastes and increase the production when integrated with finfish (Chopin 2008; Jiang et al. 2010; Handå et al. 2012; Zhang et al. 2013).

Seaweeds absorb carbon-di-oxide (CO_2) and reduce global warming (Israel et al. 2010). Experimental studies were conducted at Munaikadu, Ramanathapuram district, Tamil Nadu, India, on “assessment of carbon sequestration potential of seaweed” (*Kappaphycus alvarezii*) and it was observed that the carbon-di-oxide sequestration rate is about 0.0187 $gday^{-1}$ (CMFRI Annual Report, 2015–2016). It is evident from Table 4.3 that the total amount of carbon sequestered into cultivated

Table 4.3 Comparison of carbon sequestration potential of seaweed cultivation through IMTA

S. No.	Particulars	IMTA	Non-IMTA
1	Seaweed production as wet weight (for 4 cycle, 16 rafts)	12,800 kg	5760 kg
2	Average dry weight percentage of the harvested seaweed (%)	8.75	8.75
3	Average carbon content (%)	19.92	19.92
4	**Total amount of carbon sequestered (1) × (2) × (3)**	**223 kg**	**100 kg**

seaweed (*Kappaphycus alvarezii*) in the integrated and non-integrated rafts were estimated to be 223 kg and 100 kg, respectively. This finding derives support from Tang and Fang (2012) who reported that IMTA contributes toward mitigation of the effects of climate change.

4.3.2.4 Adoption experience of IMTA in Tamil Nadu

At present in adoption stage at Munaikadu, Palk Bay, Tamil Nadu, seaweed through IMTA had a better average yield of 320 kg per raft, while in the non-integrated raft the yield was 144 kg per raft. An additional yield of 176 kg of seaweed per raft (122% additional yield) was achieved through the integration with the cage farming of cobia. Additional seaweed yield in the integrated rafts are due to the effective utilization of organic and inorganic wastes by the seaweeds. In each cycle, 60 kg of seaweed was retained as seed material and the remaining was dried. The total dried seaweed production (10 % of the wet weight) from the integrated rafts after 4 cycles was 1,664 kg (26kg × 16 rafts × 4 cycles). Whereas the production from non-integrated rafts was only 538 kg (8.4kg × 16 rafts × 4 cycles). Thus an additional yield of 1,126 kg of seaweed was achieved from 4 cycles through integration with cobia cage farming. An additional net income of Rs. 56,300/- (1,126kg × Rs.50/kg of dry weight) was realized through integration of seaweed rafts with cobia cage. The total amount of carbon sequestered into the cultivated seaweed (*Kappaphycus alvarezii*) in the integrated and non-integrated rafts was estimated to be 357 kg and 161 kg, respectively. Hence there is an addition of 196 kg carbon credit through the integration of 16 seaweed rafts (4 cycles) with one cobia farming cage (one crop). Similarly through cage farming of cobia under IMTA an average yield of 2,043 kg was achieved whereas in the non-integrated cobia cage the yield was only 1,750 kg. The gross revenue generated from the cobia yield was Rs.6,74,190/- (@ Rs. 330/kg) for the integrated cages and Rs.5,77,500 for the non-integrated cages. Hence, an additional net operating income of Rs.96,690/- was realized from the integrated cage. Therefore, the adoption of IMTA by farmers has proven increased economic returns and environmental sustainability than the trails and demonstration.

4.4 Conclusion

Integration of seaweed with cobia cages favorably generates additional revenue through increased yields of both cobia and seaweed. This is evident from the increased profit percentages in either case. Fishermen in Ramanathapuram district, Tamil Nadu, India, are being benefited through this technology and they are continuously adopting this technology with their own investment. Hence, integration of seaweed along with cage farming can be promoted for bio-mitigation. IMTA increased the profits and reduced the risk of crop failure through diversification, as *natural* crop insurance. Moreover, IMTA is efficient in controlling both organic and inorganic pollution in the natural open waters and thereby ensuring ecological balances. Thus, IMTA is an eco-friendly option with benefits including sustainable income to the coastal fishermen and livelihood security. It is also one of the significant mitigating measures that enable carbon sequestration and ecological sustainability of the marine ecosystem.

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5 Climate Change and Adaptation: Recommendations for Agricultural Sector

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Abstract

Agriculture is a climate-sensitive enterprise. Agricultural sector should also employ appropriate strategies and approaches to adjust to climate change. Due to the significance of this issue, the main purpose of this chapter is to explain the necessity of climate change adaptation strategies in the agricultural sector. In order to achieve this purpose, some specific objectives including "characterizing the meaning and different kinds of adaptation to climate change," "clarifying the relationship between adaptation to climate change and agricultural sustainability," "positioning adaptation theory in agricultural development theories and discourses," "introducing prerequisites and requirements of adaptation to climate change in developed and developing countries," "explaining approaches to climate change vulnerability assessment," and "introducing a comprehensive approach to climate change adaptation in agricultural sector" were defined. The main adaptation approaches to climate change include hazards-based and vulnerability-based approaches. The former focuses on gradual effects of climate change. That is, according to hazards-based approach, the assessment of agricultural adaptation to climate change is undertaken through predictions made in the field of climate change and designed on the basis of various scenarios, while the latter assesses future climate change trend by considering current climate risks. In other words, vulnerability-based approach places high emphasis on the social factors determining farmers' and systems' ability to combat climate damages. It is worth mentioning that one of the main drawbacks

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of these approaches is lack of emphasis on adaptation feedbacks. Furthermore, the results emphasized that although there is no a one-size-fits-all approach for adaptation to climate changes, being aware of the experiences of other countries (with similar climatic and geographical conditions) and adaptation strategies employed by them can definitely be useful for communities dealing with negative impacts of climate change.

Keywords

Climate change · Adaptation · Vulnerability · Agriculture · Resilient agriculture · Agricultural sustainability

5.1 Introduction

Climate is the average weather conditions during a 30–35 years' time period, while weather, whose elements consist of temperature, pressure, humidity, and precipitation, is atmospheric conditions during a day. In other words, climate is the average weather conditions in a certain area during a certain period of time. Based on the most basic definition of climate change, the phenomenon refers to changing weather conditions in an area consisting of average temperature, precipitation, and humidity conditions (Bradley et al. 1985). As a matter of fact, climate change refers to changes in meteorological conditions during a long period of time, namely centuries (Hageback et al. 2005). According to the definition presented by Intergovernmental Panel on Climate Change (IPCC), what is meant by climate change is, in fact, any changes caused by natural events and human activities during a certain period of time (Comoe et al. 2014). Also, long-term fluctuations in temperature, precipitation, wind, and other aspects of climate are related to climate change effects, which have major impacts on agriculture and food security (Molua 2002; Valizadeh et al. 2018).

The world's climate is changing with an unprecedented rapidity in the present era, having negative effects on the world's different areas (Adger et al. 2003; Bijani et al. 2017; Valizadeh et al. 2019). "*The global mean surface temperature has increased about 1 °C above pre-industrial levels and it is likely to reach 1.5 °C between 2030 and 2052 if it continues to increase at the current rate*" (Venkatramanan et al. 2020a). For instance, Table 5.1 presents predictions made by IPCC, concerning effects of climate change on various environmental elements in Asia. Given the variety of natural changes and human activities in the recent century, climate change is regarded as one of the main dangers, threatening sustainable development in various aspects such as environment, human health, food safety, economic activities, human resources, and infrastructures (IPCC 2001).

"*Agriculture is a climate-sensitive sector. Climate variability and climate change affects the agricultural production and productivity across the world*" (Venkatramanan and Shah 2019). Due to the prevailing condition of "poverty," "income instability," and lesser adaptive capacity, the developing countries are more vulnerable. The modern climate change demands transformation of present-day

Table 5.1 IPCC predictions concerning effects of climate change on various environmental elements in Asia

Area	Food and forest	Biodiversity	Water resources	Coastal ecosystem	Human hygiene	Settlement
Northern Asia	H-1	M-2	M-1	L-1	L-1	M-0
Dry and semi-dry	H-2	L-1	H-2	L-1	M-1	M-1
Temperate Asia	H-2	M-1	H-2	H-2	M-2	H-2
Tropical Asia	H-2	M-2	H-2	H-2	M-1	M-2

Table signs: *1*: High vulnerability, *2*: Moderate vulnerability, *0*: No vulnerability; *H*: High, *M*: Moderate, *L*: Low

agriculture sector to achieve food and nutritional security (Venkatramanan et al. 2020b). Integrating mitigation and adaptation strategies in agriculture sector paves way for resilient and smart agriculture (Venkatramanan et al. 2020b). Agriculture is a major source of revenue for rural communities and one of the main factors helping the economy of most developing countries. Meanwhile, it is the most vulnerable sector to dangers and global effects of climate change (Smit and Skinner 2002). According to Dinar and Mendelsohn (2011), climate variables influencing agricultural activities and natural resources are as follow:

- Change in temperature: this factor directly affects plant growth, livestock (reproduction, dairy productions), vermin spread, soil humidity, and evaporation of water resources.
- Change in precipitation: this factor impacts on the degree of water available for products, livestock forage, and river flows.
- Change in carbon dioxide: this factor affects plant growth by bringing changes in basic photosynthesis fuel and the degree of water needed for plant growth.
- Tragic phenomena (flood, conflagration, hurricane, etc.): factors like these affect production conditions, leading to destruction of agricultural products and drowning of livestock.

Currently, around the world, some climate change effects have been reported, including increase in levels of drought in dry and semi-dry countries (Keshavarz et al. 2013). Meanwhile, empirical evidence reveals that the degree of countries' vulnerability to climate change varies. In other words, inhabitants of developing countries depend for their livelihood on natural resources (e.g. water, soil, and pasture), causing them to be more vulnerable to climate change in these countries (Barak 2006). Therefore, if achieving sustainable development is among the main policies of developing countries, whose economy is dependent on natural resources, they need to adjust their agricultural sector to climate change (Stakhiv and Stewart 2010). Adaptation of agricultural sector to climate changes is of great importance,

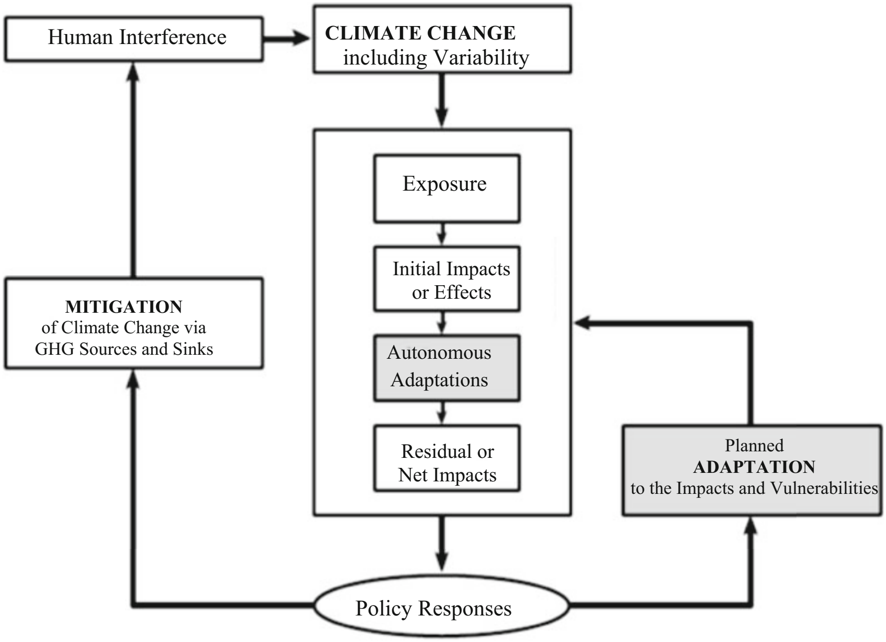

Fig. 5.1 Places of adaptation in the climate change issue. (Source: Smit et al. 2001. Available from https://www.ipcc.ch/site/assets/uploads/2018/03/wg2TARchap18.pdf. Accessed on 9 Apr 2020)

since it facilitates the selection of best policies and reduces the vulnerability of different groups. It should also be mentioned that the adaptation of agricultural sector to climate changes can decrease the costs (Grothmann and Patt 2005). Adaptation to climate change should be undertaken in such a way that (1) ecosystem stability is maintained, (2) food security is not endangered, and (3) the possibility of social and economic development of groups and communities, which are vulnerable to climate change, is provided (Smit et al. 1999). Therefore, the degree to which agriculture is exposed to damages inflicted by climate change is dependent on the degree of consequences and ability to adjust to climate change(Karimi et al. 2018a, b; Maleksaeidi et al. 2015; Keshavarz et al. 2014) (Fig. 5.1).

5.2 Concept of Adaptation to Climate Change

Adaptation refers to a system's characteristics and behaviors, which improve its ability to combat external pressures (Brooks 2003). It is a response to a shock caused by humans or nature before, during, or after it has occurred, resulting in the stability or improvement of social-ecological systems (Folke 2006; Renaud et al. 2010; Berrang-Ford et al. 2011). Modification in ecological and socioeconomic systems in response to effects and outcomes of actual or expected weather stimuli is called climate change adaptation (Plummer et al. 2013).

A review of the related literature reveals that there are different kinds of adaptations. Studies have classified adaptation into five categories: (1) farm and technology management, (2) farm financial management, (3) diversity in and out of farm, (4) government interference, and (5) knowledge and network management.

Also, Iglesias et al. (2007) divides adaptation into three groups, namely managerial, technical/instrumental, and infrastructural. Kinds of adaptation or, in other words, adaptation methods can be differentiated on the basis of various characteristics (Bryant et al. 2000). Different aspects of differentiating adaptation are as follow (Fussel 2007; Smit et al. 1999):

- Areas sensitive to climate change: adaptation should be undertaken in all areas under the influence of climate change, namely agriculture, forestry, water management, public health, and disaster prevention.
- The kind of climate threat: adaptation should be undertaken in a series of climate threats occurring at present or in the future, namely observed or expected changes in climate, climate fluctuation, or climate catastrophes.
- Climate change predictability: some aspects of future climate change can be predicted with high certainty (e.g., changes in average temperature), while with regard to some other changes such certainty is not present (e.g., changes in severity and occurrence of hurricane).
- Non-climate conditions: environmental, economic, political, and cultural conditions affect climate change adaptation as well. In should be noted that the non-climatic conditions vary from one area to another.
- Purposefulness: adaptation can be undertaken unconsciously, pre-planned, and purposefully. Unconscious or spontaneous adaptation is of that kind occurring as a response to climate stimuli. As shown in Fig. 5.1, this kind of adaptation happens when faced with early effects of climate change, and government institutions play no role in undertaking such an adaptation. On the contrary, planned adaptations can occur as a response or prediction.
- Timing: planned adaptation can occur as a response (aftereffects of climate change emerge), or proactive and prediction-oriented (before the effects of climate change emerge).
- Planning time limit: planned adaptation time limit can range from short period of time to decades as climate changes.
- Combination: adaptation encompasses different kinds of activities, namely structural, legal, institutional, financial, and technological.
- Activists: various groups of people might get involved in climate change during the adaptation process. Here, government and private institutions play a major role in adaptation.

Also, adaptation to climate change can be examined on the basis of people's responses to this phenomenon. As it is depicted in Fig. 5.2, climate change adaptation can be undertaken in the form of "bear losses," "share losses," "modify threats,"

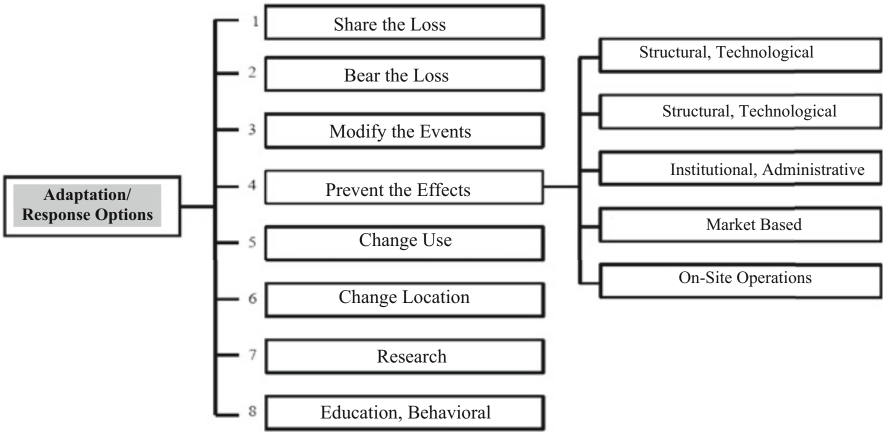

Fig. 5.2 Classification of adaptation options. (Source: Burton et al. 1993)

"prevent effects," "change in use," and "change location" (Burton et al. 1993). It is obvious that society structures, institutional arrangements, and public policies play a role in climate change adaptation (Fig. 5.2).

5.3 Agricultural Sustainability and Adaptation

Sustainability has been mainly defined as the capacity to meet today's goals without compromising the future capacity to achieve them (Maleksaeidi and Karami 2013). This definition stems from the definition of sustainable development presented by the Brundtland Commission in 1987. The concept of sustainability has varied throughout history, and authors have reported different dimensions about it (Keshavarz et al. 2010). It seems that the concept of sustainability is similar to "beauty in the eyes of viewer" (Swanson et al. 2005). This diversity, in turn, leads to diversification of sustainable agriculture. Nevertheless, sustainable agriculture is defined as an integrated cultivation and animal husbandry system that has a special situational application. The elements of this type of agriculture are (Hayati 2017):

- Providing human food needs
- Increasing environmental quality and natural resources, based on agricultural economy
- Leading to use of renewable and agricultural resources and integrating biological cycles in an efficient way
- Sustainability of agricultural functions
- Increasing quality of life of farmers and community as well

"Agricultural sustainability includes recognition of feedback interaction in ecosystems that enable the sytem to be controlled and self-regulated; maintaining

the stability and sustainability of the ecosystem through the use of free services of nature and increasing the species and landscape diversity" (Venkatramanan and Shah 2019). Sustainable agriculture involves economic, ecological, and social sustainability. While economic sustainability reflects the crop productivity, ecological sustainability refers to "the preservation and improvement of the natural environment" and social sustainability reflects self-reliance, equality, and improved quality of life (Hayati et al. 2011; Forouzani and Karami 2011; Forouzani et al. 2012). For instance, gender equality and gender mainstreaming play a significant role in improving agricultural productivity, natural resource management, and social sustainability (Venkatramanan and Shah 2020). It is obvious that each of the scholars concentrated on different dimension of sustainability and revealed new aspects of it. But the main commonality in all of these theories is "the role of human in managing the other aspects of sustainability."

The literature shows different understandings about concepts of adaptation and sustainability (Tendall et al. 2015). If we accept the definition of Brundtland Commission, and also define adaptation as the system's characteristics and behaviors that improve its ability to combat external pressures, it will be obvious that these two concepts could be complementary. Sustainability induces adaptation, and adaptation leads to sustainability (through capacity building of a system to properly function prior, during, and after the pressure). This type of association between adaptation and sustainability has been confirmed by Keenan (2016) and Maleksaeidi and Karami (2013). Based on Keenan (2016), adaptation may be dependent on the periodic sustainability of certain systems to provide the resources and capital for the adaptation processes that prevent the subject, host, and/or system from crossing the frontier that results in loss or failure.

Moreover, Table 5.2 highlights the different aspects that sustainability and adaptation share, including a broader framework oriented toward resource trade-

Table 5.2 Comparison of sustainability and adaptation

Comparison characteristics	Sustainability	Adaptation
Social construction	Triple bottom-line balancing	Manage risks and long-term hazards
Primary policy principle	Resource trade-offs (natural capital)	Resource trade-offs (human and financial capital)
Actors	Multi-actor	Multi-actor
Policy setting	Cooperation	Cooperation
Tasks	System solutions for individuals	Individual solutions for systems
Principle for action	Proactive	Reactive and proactive
Primary scope	Global	Local
Focus	Products and process networks	Products and process networks
Technology	Integrated processes and innovations	Integrated processes and innovations

Source: Keenan (2016)

offs, cooperation, and a focus on products, processes, and innovation. In more immediate terms, the ends to these common values are seemingly drawn only by the distinction between climate mitigation and risk mitigation. However, the conceptual conflict between sustainability and adaptation has been widely cited in various domains of scientific literature (Keenan 2016).

5.4 Adaptation in Agricultural Development Theories

In the evolution process of development, the concept of "sustainable development" was obtained, and this understanding is often considered to be an ideal development approach (Cobbinah et al. 2015). Sustainable agriculture has been developed as a response to the changes and problems of agricultural sector. But there are two theoretical perspectives, including De-Modernization (DM) theory and Ecological Modernization (EM) theory in this context, that are known as bases of coping with agricultural environmental challenges and provide a conceptual framework for sustainable agricultural development (Rezaei-Moghaddam et al. 2006). DM assumes that the environmental degradations stem from the modernization, and the solution is going back to the traditional systems of agriculture. In contrast, EM accepts that modernization has induced negative impacts on environment. It also assumes the reason for environmental degradation is inadequate advances in modernization. Therefore, based on this theory, the solution for all these problems is hyper-industrialization, modern technology, ecological economy, strong modern environmental state, reform ideology, and changing discourses (Asadi and Naderi 2015).

These theories have serious problems with regard to how transformation to sustainable agriculture occurs, and, therefore, they assume a linear mode of thinking about development that is heavily dependent on technology (highly modern or traditional) (Rezaei-Moghaddam et al. 2006). On the other hand, the emergence of adaptation theory in development debates has increased the problematic dimensions of EM and DM theories because adaptation uses different elements of EM and DM, in order to accomplish sustainability. In other words, this paradigm has a more flexible nature compared to EM and DM. For instance, in EM and DM, the traditional knowledge and scientific knowledge contradict each other. But adaptation paradigm may use both of them at the same time for attaining sustainable development. The research of Maleksaeidi and Karami (2013) is in line with this notion. Maleksaeidi and Karami (2013) argued that one of the most important strategies farmers adopt to deal with water scarcity is combination of different types of knowledge (local and science). Based on DM, when farmers are faced with an environmental problem such as water scarcity, they consider returning to agricultural practices based on local or traditional knowledge such as diversification of agricultural activities and/or creation of a multifunctional agriculture. Adaptation theory not only uses these diversifications of agricultural activities but also tries to use EM teachings (such as improvement in new agricultural irrigation systems) as a combined strategy to deal with water scarcity. However, the adaptation could be supposed as a paradigm that is not in conflict with EM and DM. In other words, attaining sustainable agriculture through adaptation is not impossible even during problematic conditions.

5.5 Requirements of Adaptation to Climate Change: The Experience of Developed and Developing Countries

Although climate change has gained recognition as a global phenomenon, the ability of various countries to adjust to climate change differs. Given that developed countries are in a more economically sustainable situation, possess more appropriate institutions and infrastructures, and have higher access to capital, information, and technology, they enjoy higher climate change adaptive capacity compared to developing countries (Toman and Bierbaum 1996). Moreover, countries, which have more powerful social institutions and support different groups and individuals at appropriate levels of capital and knowledge, enjoy higher adaptive capacity (Smit and Wandel 2006). On the other hand, although developing countries have adopted various climate change adaptation strategies, namely indigenous methods of adaptation to climate change, their ability to provide an appropriate and on-time response to climate change is limited as they do not possess infrastructure and economic power needed for confronting with climate change impacts and consequences (Smit and Wandel 2006). The biggest obstacles to adaptation in these countries are (Fussel and Klein 2006; Mizina et al. 1999):

- Financial obstacles (severe price changeability, lack of money supply, unavailability of budgets)
- Legal/institutional obstacles (poor institutional structures, institutional instability)
- Social/cultural obstacles (social conflicts, improper use of lands)
- Technological obstacles (existing technologies, accessibility to technologies)
- Informational/educational obstacles (lack of information concerning kinds and degrees of climate change vulnerability, lack of trained forces)

Moreover, a study conducted by Rosenzweig and Parry (1994) revealed that climate change effects differ in developed and developing countries in such a way that damages inflicted by climate change on developing countries' agriculture are higher than those that occur in developed countries. In addition, since developing countries and poorer countries are faced with more technological and institutional constraints when undertaking climate change adaptation, their adaptation incurs higher costs (Smit and Wandel 2006). Also, in comparison with industrialized countries, developing countries have lower levels of adaptive capacity since their economy is highly dependent on climate resources (Barak 2006).

Although climate change adaptation is a necessity for countries, the way in which different countries and areas adjust to climate change varies. That is, they should undertake climate change adaptation in accordance with their economic, human, natural, and social capacities. Table 5.3 reveals the variation in climate change impacts and strategies proposed to adjust to climate change in different countries

Table 5.3 Adaptation and capacity in the regions

Key findings	Sector
Adaptation potential in socioeconomic systems is relatively high because of strong economic conditions; stable population (with capacity to migrate); and well-developed political, institutional, and technological support systems.	Europe
The response of human activities and the natural environment to current weather perturbations provides a guide to critical sensitivities under future climate change.	
More marginal and less wealthy areas will be less able to adapt; so without appropriate policies of response, climate change may lead to greater inequities.	
Adaptation measures have potential to reduce climate-related losses in agriculture and forestry.	Latin America
There are opportunities for adapting to water shortages and flooding through water resource management.	
Adaptation measures in the fishery sector include changing species captured and increasing prices to reduce losses.	
Strain on social and economic systems from rapid climate and sea-level changes will increase the need for explicit adaptation strategies. In some cases, adaptation may yield net benefits, especially if climate change is slow.	North America
Stakeholders in most sectors believe that technology is available to adapt, although at some social and economic cost.	
Adaptations such as levees and dams often are successful in managing most variations in the weather but can increase vulnerability to the most extreme events.	
Potential for adaptation is limited in indigenous communities that follow traditional lifestyles.	Polar Regions
Technologically developed communities are likely to adapt quite readily, although the high capital investment required may result in costs in maintaining lifestyles.	
Adaptation depends on technological advances, institutional arrangements, availability of financing, and information exchange.	
Adaptive measures would enhance flexibility and have net benefits in water resources (irrigation and water reuse, aquifer and groundwater management, desalinization), agriculture (crop changes, technology, irrigation, husbandry), and forestry (regeneration of local species, energy-efficient cook stoves, sustainable community management).	Africa
Without adaptation, climate change will reduce the wildlife reserve network significantly by altering ecosystems and causing species emigration and extinctions. This represents an important ecological and economic vulnerability in Africa.	
Risk-sharing approach between countries will strengthen adaptation strategies, including disaster management, risk communication, emergency evacuation, and cooperative water resource management.	

(continued)

Table 5.3 (continued)

Key findings	Sector
Adaptations already are required to deal with vulnerabilities associated with climate variability, in human health, coastal settlements, infrastructure, and food security. The resilience of most sectors in Asia to climate change is very poor. Expansion of irrigation will be difficult and costly in many countries.	Asia
Adaptive capacities vary between countries, depending on social structure, culture, economic capacity, and level of environmental disruptions. Limiting factors include poor resource and infrastructure bases, poverty and disparities in income, weak institutions, and limited technology.	
Adaptation strategies would benefit from taking a more systems-oriented approach, emphasizing multiple interactive stresses, with less dependence on climate scenarios.	
Adaptations are needed to manage risks from climatic variability and extremes. Pastoral economies and communities have considerable adaptability but are vulnerable to any increase in the frequency or duration of droughts.	Australia and New Zealand
Adaptations will be viable only if they are compatible with the broader ecological and socioeconomic environment, have net social and economic benefits, and are taken up by stakeholders.	
Adaptation responses may be constrained by conflicting short- and long-term planning horizons.	

Source: Smit et al. (2001). Available from https://www.ipcc.ch/site/assets/uploads/2018/03/wg2TARchap18.pdf. Accessed on 9 Apr 2020

(Smit and Pilifosova 2003). For instance, adaptation methods used by European and American countries are different from those employed by African and Asian countries. While in Europe and America, favorable economic, technological, and infrastructural capacities have paved the way for reduction in losses caused by climate change, poor infrastructure in African and Asian countries has increased the degree to which different groups are vulnerable to climate change.

Adaptation to climate change is one of the most interesting topics for researchers in many countries, and many studies have been carried out on this subject. In order to clarify some of the most significant results of these studies around the world, we tried to summarize six of these studies in the following section.

Case 1: Adaptation to Climate Change in Afghanistan: Evidence on the Impact of External Interventions

In this study, Jawid and Khadjavi (2019) attempted to offer some evidence on the impact of the agriculture-related external support on farmers' adaptation to climate change in the central highlands of Afghanistan. To this end, authors collected primary data from 1434 farmers whom they interviewed across 14 districts in Bamiyan, Ghazni, and Diakundi provinces. Researchers applied quasi-experimental econometric methods, including an endogenous switching regression analysis, to estimate the treatment effects on various adaptation-related outcomes. The results of this study showed significant impacts of support interventions on the use of improved types of seeds and farmers' access to irrigation water. Further impacts on the risk of flood, and economic and financial, as well as government and institutional adaptation constraints appear to be significant, but sensitive to the existence of unobserved factors. The study concludes that farmers perceived changes in the climate, and most of them tried to adapt by employing measures available to them. The impact of external support has been partially effective in addressing immediate and short-term farming challenges related to climate change and extreme weather events. They, however, have not been effective in treating long-term fundamental climate change–related risks.

Case 2: Social Representations of Climate Change and Climate Adaptation Plans in Southern Brazil: Challenges of Genuine Participation
This study was carried out by Bonatti and her colleagues in 2019. The main objective of their study was to present a case study (Tapera da Base) within the context of the project, "Climate Change and Vulnerable Populations in Brazil," which discussed the problems associated with climate change adaptation and risk-reducing activities. The methodology adopted involved identifying local development organizations, focused group discussion, interviews, and survey among families in the most vulnerable areas. The main results showed that Tapera residents do not associate the possible increase in their vulnerability to climate dynamics. They pointed to areas such as education, sanitation, and social assistance, as their most important local problems, thus not including climate change. They recommend that to generate genuine participation, it is crucial to create initiatives that promote a social learning space for residents to evaluate their self-state of vulnerability and possibilities of development. Therefore, climate change can make sense, and the responses at the community level will be created in the context that shape how climate risk is perceived, prioritized, and managed.

Case 3: Spatial Planning and Climate Change Adaptation Assessment: Perspectives from Mdantsane Township Dwellers in South Africa
In their study, Busayo et al. (2019) adopted a mixed-method approach to examine township spatial planning and climate change adaptation in identifying potentialities for an integrated approach. Mdantsane case study as one of the largest townships in South Africa was assessed as a unique landscape that was reminiscent of apartheid legacies to improve the people's climate change adaptation under urban poverty, lack of basic facilities, and other environmental challenges. In keeping with a case study design, they collected the required data using open- and close-ended survey forms with an interplay of geographic information system (GIS) and remote sensing techniques. This study revealed that Mdantsane is extremely susceptible to the impacts of climate change due to their built-up and natural environment setup as well as the existing interrelations. Thus, comprehensive integration of spatial planning was recommended for proofing, health, well-being, and resilience. Consequently, recommendations to seek strategic intervention and planning were made to

sustain adaptation of residents to climate change in the future with specific focus to reduce climate and environmental risks in Mdantsane Township.

Case 4: Evaluating Participatory Techniques for Adaptation to Climate Change: Nepal Case Study
In this study, Khadka et al. (2018) mainly examined the role of participatory tools and techniques with the potential to identify the level of vulnerability and likely adaptation measures to increase the forest resilience capacities of communities where the community-based climate change adaptation plan of action (CAPA) has been prepared. In total, 13 participatory qualitative tools were evaluated against 15 criteria for identifying their performance in nine CAPA groups, representing three geographical regions of Nepal. The results of multivariate analyses indicated how CAPA groups evaluate the likelihood of climate change impact, determining the vulnerability of specific ecosystem services and understanding the possible local adaptation measures. These scholars also cited that the integration of adaptation planning in local institutions, in order to deal with different ecosystem-based adaptation options, along with identification of climate change scenarios, impacts, trade-offs, synergies, and the sensitivity of management problems, is highly recommended.

Case 5: Psychosocial Drivers for Change: Understanding and Promoting Stakeholder Engagement in Local Adaptation to Climate Change in Three European Mediterranean Case Studies
The goal of this work, which was directed by Luis et al. (2018), was to explore whether or not the intention of engaging could be understood (Study 1) and promoted (Study 2), by using an extension of the theory of planned behavior. In Study 1, stakeholders from three European Mediterranean case studies were surveyed: Baixo Vouga Lagunar (Portugal), Schéma de Cohérence Territoriale Provence Méditerranée (France), and the island of Crete (Greece) ($N = 115$). Stakeholders' intention of engaging was significantly predicted by subjective norm (which was predicted by injunctive normative beliefs toward policymakers and stakeholders) and by perceived behavioral control (which was predicted by knowledge of policy and instruments). Study 2 was conducted in the Baixo Vouga Lagunar and consisted of a two-workshop intervention, where issues on local and regional adaptation, policies, and engagement were presented and discussed. A within-participants comparison of initial survey results with results following the workshops indicated that these were successful in increasing stakeholders' intention of engaging. This increase was paired with (a) an increase in injunctive normative beliefs toward policymakers and, consequently, in subjective norm and to (b) a decrease in perceived complexity of planning local adaptation and an increase in knowledge regarding adaptation to climate change.

Case 6: Coastal Management and the Political-Legal Geographies of Climate Change Adaptation in Australia
This study, which was carried out by O'Donnell in 2018, connects critical legal geography and coastal climate change adaptation. This study was conducted in New South Wales, Australia. In attending to the political-legal nature of coastal manage ment through the lens of legal geography, this case study illustrated the complexities of law's role as both a driver and a barrier to coastal climate change adaptation, through a detailed review and analysis of repeated legislative reform between 2009 and 2018. This not-yet-documented analysis serves to highlight a shifting legal landscape and the politics of coastal climate change adaptation. It also illustrates how private property rights have been used as both a sword and a shield to advance dominant interests. The study offers specific examples of ways private property discourses have been used to muddy the waters of adaptation responses and how private property discourses can pervade, dissuade, and undermine land-use manage ment policies even as such policies aim to achieve more harmonious coastal management.

5.6 Approaches to Climate Change Vulnerability Assessment

Different national and international organizations have introduced a variety of approaches to the assessment of climate change effects and adaptation. The most important adaptation assessment guides include IPCC (Carter et al. 1994), international guidebook United States Country Study Program—USCSP (USCSP 1994), United Nations Environment Programme—UNEP guidebook, United Nations Development Programme-Global Environment Finance (UNDP-GEF) policy framework (Burton et al. 2005), and adaptation to climate change through integrated risk assessment (ADB 2005).

Hazards-based and vulnerability-based approaches are among the common approaches to the assessment of climate change effects and adaptation (Burton et al. 2005). The former focuses on gradual effects of climate change, according to which assessment of adaptation to climate change is carried out through predictions made on the basis of various scenarios in the field of climate change. Accordingly, little attention is paid to non-climate factors affecting adaptation. IPCC, USCSP, and UNEP have put considerable emphasis on hazards-based approach (Fussel 2007). Even though different studies have revealed that the assessment of adaptation to climate change on the basis of hazards-based approach is of high significance in identifying climate change risks, results obtained from these studies cannot be regarded as a useful tool for making purposeful policies to rapidly reduce effects of climate change (O'Brien 2000; Burton et al. 2002).

Excessive emphasis on modeled prediction of climate and climate change effects is one of the important constraints of hazards-based approach as the odds are that scenarios and various models of climate change do not exist for areas and locations, in which climate change adaptation programs are to be implemented. Also, most of the predicting models of climate change devote a long-term time period, which can prove inappropriate for many adaptation programs and farmers. For instance, long-term predictions cannot help farmers in making decisions regarding annual plantation and short-term use of water resources. Moreover, hazards-based assessments pay little attention to current risks, concerning natural climate fluctuation and non-climate stimuli. Also, this assessment approach disregards key uncertainties in policymaking and developing adaptation policies. Disregarding nontechnical aspects of climate change (e.g., adaptive capacity and social determinants of farmers' vulnerability) and wider aspects of climate change adaptation policy (e.g., developing sustainable economy and management of rural resources) are among other defects of hazards-based approach (Fussel 2007).

On the contrary, vulnerability-based approach assesses the future trend of climate change with regard to current climate risks with a considerable emphasis on social factors determining farmers' and systems' abilities to combat climate losses. Vulnerability-based assessments take into consideration past climate risk management and get farmers involved in assessment and adaptation from the beginning, directly connecting climate change adaptation with their activities. Therefore, even at the absence of a precise and reliable climate change prediction scenario, assessments conducted using this approach can yield fruitful results. Yet, the approach has disadvantages as well, including excessive dependence on views and judgments of agriculture experts, limited comparability in different areas due to qualitative nature of results obtained from assessments, and also lack of a certain methodology (Fussel 2007). Hazards-based and vulnerability- based approaches take into account different perspectives regarding climate change risks. The former is helpful in raising awareness of farmers about existing problems and identifying research priorities. Also, employing this approach in agriculture is recommended where current risks are effectively controlled, and long-term decision-making for agricultural adaptation are taken into consideration, resources needed for developing various scenarios are available, and also where future climate change is sufficiently predictable. On the contrary, vulnerability-based approach is helpful in identifying prioritized areas for implementing climate change adaptation programs and evaluating the degree to which activities carried out to adopt agriculture to climate change have been effective. In addition, applying the vulnerability-based approach is highly favorable in adjusting agriculture to climate change in cases where current climate risks cannot be brought effectively under control, non-climate factors play a significant role in intensifying effects of climate change on adjusting agriculture community to climate, adaptation planning horizons are not far, data and resources needed for developing climate change scenarios are limited, and, finally, where there is uncertainty with regard to effects of climate change in the future (Fussel 2007).

Accordingly, given that many developing countries do not possess data and resources needed for climate change prediction and modeling, and also take into consideration policies related to gaining short-term benefits resulting from controlling climate risks, employing vulnerability-based approach is highly recommended in these countries. It should be noted that grounds for assessing adaptation to climate change on the basis of hazards-based approach should also be provided in developing countries, as they are regarded as two complementary approaches (Burton et al. 2005). Therefore, selecting and employing agricultural adaptation approaches in developing and developed countries depend on climatic conditions of every area. That is, climate, environmental, social, and political conditions of different countries play crucial roles in the employment of agricultural adaptation approaches.

5.7 The Need for Development of a Comprehensive Approach to Climate Change Adaptation

Increased recognition of climate change effects and growing emphasis laid on climate change outcome by policymakers in different countries have led to changes in the global community's orientation and gradual development of theoretical discussions, concerning climate change adaptation. Currently, the theory of climate change adaptation has gained considerable attention and also a variety of approaches to, and methods of, adaptation assessment are taken into consideration (Burton et al. 2002).

Currently, according to a review of related literature, past studies regarding climate change adaptation have placed their emphasis on concepts such as complexity, adaptive social-ecological systems, and inadequacy of common approaches in explaining complexities concerning climate change adaptation (Cornell et al. 2010). Therefore, the need for a more precise and comprehensive assessment of climate change adaptation is felt. Accordingly, existing uncertainties regarding prediction of future climate changes and its effects should be effectively identified and also complex processes of climate change adaptation, which encompasses climatic and non-climatic stimuli, should be properly taken into account (Kalaugher et al. 2013). Mastrandrea and Schneider (2010) hold that assessments of climate change adaptation should be simultaneously conducted in the form of top-down and bottom-up approaches in such a way that various beneficiaries, climate scientists, and social sciences scholars can play a direct role in the assessment of adaptation to climate change.

As it was shown in part "A" of Fig. 5.3, top-down approaches, which are based on modeling (e.g., hazards-based approach), mostly reflect a mechanized view on adaptation of agricultural systems to climate change, on the basis of which it is thought that developed knowledge results from scientific methods, and, accordingly, it is objective and repeatable (Kalaugher et al. 2013). This approach seeks to exhibit causal relationships to provide the possibility of predicting the climate change adaptation process. According to top-down approaches, different scenarios of climate change are regarded as a basis for assessing future effects of climate change, and adaptation needs are determined on the same predictions. Moreover, in these approaches, adaptation to climate change is, to a great extent, separated from other processes and social activities, and adaptation needs are obtained through scientific analyses (Fussel 2007). It should be noted that top-down approaches are emphasized in IPCC technical guide (Carter et al. 1994). On the contrary, bottom-up approaches (e.g., vulnerability-based approach) make use of social sciences methodology,

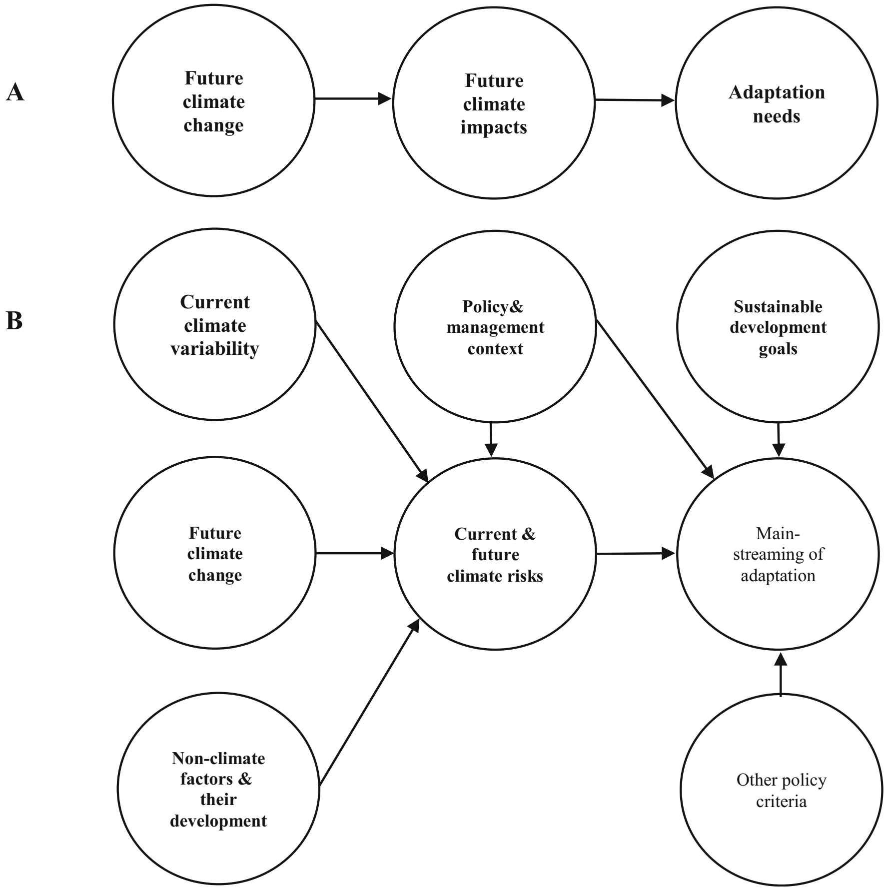

Fig. 5.3 Development of approaches to climate change adaptation: (**a**) linear hazards-based approach, (**b**) complex and comprehensive approach to adaptation. (Source: Fussel 2007)

according to which knowledge is developed in the form of narrative, commentary, and criticism.

The knowledge yielded from this approach is context-based and dependent on certain areas and conditions under examination (Miller et al. 2008). If top-down and bottom-up approaches are to be employed jointly to assess adaptation to climate change, a more complicated approach is required, a sample of which is depicted in part B of Fig. 5.3 (Füssel 2007). The new approach, which is extracted from current approaches to climate change adaptation, seeks to present a more comprehensive description, regarding present and future climate change risks. Not only does the new complex approach take into consideration present climate changes, but it also examines the future trends of climate change. In addition, the approach takes account of both climatic and non-climatic factors affecting adaptation to climate change.

Also, risk assessment is conducted through experiences obtained from past management regarding climate risks, and recommendations related to adaptation to climate change are presented on the basis of their potential for reducing present and future climate changes. It should be noted that recommendations should be in line with other policies such as sustainable development goals. This approach is emphasized in UNDP-GEF policy-making framework (Burton et al. 2002).

5.8 Conclusion

The main purpose of this chapter was to highlight the importance of climate change adaptation strategies in agricultural sector. As it was previously mentioned, agricultural sustainability and adaptation to climate change are strongly interdependent, and the concept of adaptation refers to a system's characteristics and reactions, which increase its capability to be able to cope with external pressures. Being able to cope with these pressures can pave the way for attaining sustainability in agricultural sector. The future of agricultural sector around the world depends on whether this sector is able to mitigate negative impacts of climate change and manage the resources, including water, soil, land, and so on, in a sustainable manner. This would require a set of actions that allow farmers access to the current technologies. Also, investing in research is necessary, in order to enable land and water management to cope with uncertain future. In this regard, more efforts should made toward investment in water conservation infrastructure, development of new technologies, investment in enhancing farmers' capacity to adapt to climate change, and investment in risk management. Furthermore, ensuring economic efficiency in the use of agricultural resources and taking measures to promote water and soil conservation at the farm level are priority areas for action. Also, assessment of the effectiveness and sustainability of water management strategies is needed. For instance, the excessive exploitation of groundwater during drought is not sustainable and should be prohibited.

Some of the policy measures, including educational programs, have no visible results in a short period of time. But they can have really significant effects on the mitigation of the effects of climate change. Lack of information and awareness has increased the risks and negative impacts of climate change in most countries around the world. In other words, many countries still have a partial and one-dimensional perspective about climate change and its impact and emphasize that the favorable changes should mainly be produced using technocratic approaches. Such views are not in line with the system-of-systems (SOS) perspective, which tries to give an integrated and multidimensional perspective about the problems. In this regard, it is recommended that the policymakers should try to pay more attention to social and informative dimensions of climate change programs. This information can help the inexperienced farmers to adapt more rapidly to climate variability and change and raise their agricultural productivity.

The other point in applying climate change adaptation strategies is that vulnerability to climate change impacts significantly varies among different groups of farmers and stakeholders. For example, Karimi et al. (2018a, b) mentioned that the effects of climate change on agriculture will be most severe for poor families and small-scale farmers with minimal adaptive capacity in different countries. Although policies that develop financial incentives may result in short-term gains, they can increase their vulnerability in the long term. Moreover, there is the possibility of public policies reducing the welfare of poor farmers, even as they benefit wealthier farmers with greater ability to respond effectively to climate change. Therefore, a set of actions will be required to relieve the expected severe pressures on poor farmers.

Although there are so many approaches for adaptation to climate change, it is worth mentioning that one of the main drawbacks of these approaches is lack of emphasis on adaptation feedback. Furthermore, according to experiences gained in developing and developed countries, adaptation to climate change depends, to a great extent, on conditions and characteristics of different areas. That is, climate, environmental, social, and political conditions play a key role in agricultural adaptation to climate change. This means that there is no one specific and fixed approach to climate change adaptation. There is no one-size-fits-all approach for adaptation to climate changes. However, being aware of the experiences of other countries (with similar climatic and geographical conditions) and adaptation strategies employed by them can definitely be useful for communities dealing with negative impacts of climate change.

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6 Integrated Farming Systems: Climate-Resilient Sustainable Food Production System in the Indian Himalayan Region

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Abstract

The Indian Himalayan Region (IHR) represents about 16.4% of the total area and 3.86% of the total population of India. The region supports extraordinary cultural, ethnic, and biological diversity. Vast variation in rainfall pattern was also noticed in the entire Indian Himalayan region. The Western Himalayan region had comparatively less rainfall than the Eastern Himalayas. Farmers of IHR, usually, adopt traditional agricultural practices and practice mono-cropping, which leads to soil degradation and poor farm productivity. The environmental degradation in the region reached an alarming proportion, necessitating urgent attention for their scientific management for the overall sustainable development of the region. This calls for an extra concentrated focus on the issue from the viewpoint of policy, research, development, and extension. Hence, policy reorientation and human resources development are the key areas that need special attention. Integrated Farming Systems (IFS) approach aims to enhance the farm income, promote the sustainable utilization of natural resource, and livelihood diversification. The IFS

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approach has multiple objectives of sustainability, food security, nutritional security, and poverty reduction towards the sustainable development goals (SDGs). Location-specific IFS modules have the potential to double the farmer's income besides providing year-round employment.

Keywords

Hill ecosystem · North-east India · Traditional farming · Indian Himalayan region · Integrated farming system · Climate resilient agriculture · Sustainable food production system

6.1 Introduction

Agriculture is an important segment of the Indian economy, accounting for 15.87% in India's gross domestic product (GDP) and employs more than 50% of the population. Small and marginal farmers constituted more than 86% of farm families in India (Kashyap et al. 2015). "*Technological advancements, industrial mode of production and ever-increasing urge of the industrious cultivators engendered green revolution*" (Venkatramanan et al. 2020a). During 1960, the green revolution was successful only in Punjab, Haryana, Western Uttar Pradesh, and some parts of Rajasthan. Most of the other regions, especially the hilly tracts of the Indian subcontinent, have not benefitted from the green revolution and continue to suffer from low crop productivity, unemployment, and insecure livelihood. Continuous chains of the mountain in the northern part of India are known as the Himalayan range. The Indian Himalayan Region (IHR) stretches over 2500 km from Jammu and Kashmir in the west to Arunachal Pradesh in the east, spreading between 21°57′–37°5′ N latitudes and 72°40′–97°25′ E longitudes. The IHR covers about 53.8 m ha, representing 16.4% total geographical area of India (Dadhwal et al. 2012), spread over 12 states of India, namely, Jammu and Kashmir, Himachal Pradesh, Uttarakhand, Sikkim, Arunachal Pradesh, Nagaland, Manipur, Mizoram, Tripura, Meghalaya, the hills of Assam, and West Bengal (Table 6.1). The IHR is broadly divided into Western, Central, and Eastern Himalayas. The region has rich forests, comprising various species. In general, the forests of Western Himalayan are diverse in both content and composition, whereas Eastern Himalayan forests are very rich in both flora and fauna (Dhar et al. 1997). The Eastern Himalaya is one of the 12 biodiversity hot spots in the world. About 3.86% of India's population lives in the IHR. *Nearly 56% of the total workforce is engaged in agriculture as it is the primary sector of the economy contributing 45% to the total regional income of the inhabitants* (Dadhwal et al. 2012). Out of the total 573 scheduled tribes of India, the IHR is home to more than 171 tribes (Samal et al. 2000). The availability of cultivated land is only 0.17 ha per capita as compared to 0.13 ha for the whole country. The net sown area comprises only about 12% of its total reported area of the IHR, and the growth rate of the human population is much higher than the national average. The Western Himalayan region has around 15.8% net cultivated area of

Table 6.1 Geographic indicators of IHR states

State	Geographical area (square km)	Latitude	Longitude	Percentage of the total area
Arunachal Pradesh	83,743	26°28′ to 29°30′ N	91°30′ to 97°30′ E	15.69
Assam	15,322	25°3′ to 26°35′ N	92°10′ to 93°50′ E	2.87
Himachal Pradesh	55,673	30°23′ to 33°13′ N	75°43′ to 79°4′ E	10.43
Jammu & Kashmir	222,236	32°17′ to 37°5′ N	72°40′ to 80°30′ E	41.65
Manipur	22,327	23°80′ to 25°8′ N	93°03′ to 94°78′ E	4.18
Meghalaya	22,429	25°1′ to 26°5′ N	85°49′ to 92°52′ E	4.20
Mizoram	21,081	21°58′ to 24°35′ N	92°15′ to 93°29′ E	3.95
Nagaland	16,579	25°6′ N to 27°4′ N	93°20′E to 95°15′E	3.11
Sikkim	7096	27°03′ to 28°07′	88°03′ to 88°57′ E	1.33
Tripura	10,486	22°56′ to 24°32′ N	90°09′ to 92°20′ E	1.97
Uttarakhand	53,483	28°43′ to 31°27′ N	77°34′ to 81°02′ E	10.02
West Bengal	3149	26°31′ to 27°13′ N	87°59′ to 88°53′E	0.59

Source: ENVIS Monograph Vol. 3 (http://censusindia.gov.in)

total geographical area, whereas the Eastern Himalayan region (EHR) has only 9.8% net cultivated area of total geographical area. Vast variation in rainfall patterns was also noticed in the entire Indian Himalayan region. Western Himalayan region had comparatively less rainfall (1530 mm per annum) than the Eastern Himalayas (3050 mm per annum). The entire Himalayan region of India mainly experiences two seasons (winter and summer). The average summer and winter temperatures in the southern foothills are about 30 °C and 18 °C. On the contrary, the middle Himalayan valleys have an average summer temperature of about 25 °C, while the winters are very cold. In the higher-middle Himalayas, the summer temperature generally remains around 15–18 °C and the temperature below freezing point can be observed during the winters. But at the higher altitude, temperature always remains below 20 °C. Regions above 4880 m remain always permanently covered with snow. The Himalayan alpine climate varies according to the altitude. In general, climatic condition changes very quickly in the Himalayan region due to change in the altitude. Hence, it can be concluded that the climate is very unpredictable in IHR.

The Himalayan soils are diverse, depending upon the altitude, vegetation cover, slope, structure, and stage. Brown hill soil, submountain soils, mountain meadow soil, and red loamy soils are the major soils in the IHR. Most of the soils in IHR are acidic. There are three main and 20 other river systems draining in the IHR. Due to climatic perturbations, changes in snow and glacier of the Himalayas may be a serious matter of concern in controlling monsoon, perennial water supply, and moderation of flood and drought in the plains.

6.2 Agro-Climatic Zones of the IHR

Broadly, the climatic zones in the Indian Himalayan Region (IHR) are based on the altitudinal gradient. Out of the total 15 agro-climatic regions of India, the IHR represents two agro-climatic zones, *viz*., Zone-I: the Western Himalayan region and Zone-II: the Eastern Himalayan region. Zone I is characterized by low-altitude sub-tropical region of the south to mid to high temperate region in the mid-hills, and extended to high hills on the north. Zone II had near tropical to alpine climatic conditions and characterized by hills and mountains of folded topography. The details of agro-climatic regions of IHR are given in Table 6.2.

Table 6.2 Agro-climatic zones of IHR and their characteristics

Agro-climatic zone	Climate	Rainfall (mm)	Regions	Major production systems
Zone I	Humid to cold arid	<1200	Jammu & Kashmir	Temperate fruits cultivation
Zone II	Humid to subhumid	1200–1800	Himachal Pradesh and Uttarakhand	Temperate fruits cultivation and subsistence terraced cereal farming
Zone III	Sub-tropical to temperate climate (humid during about 8 months of the summer and semi-humid during the 4 months of winter)	1800–2200	Nagaland, Mizoram, Manipur, and Tripura	Subsistence shifting cultivation
Zone IV	Sub-tropical to temperate climate (cold and frigid in Sikkim), humid during about 8 months of summer, and semi-humid during the 4 months of winter	2200–2800	Sub Himalayan West Bengal, Sikkim, Assam, and Meghalaya	Tea cultivation and subsistence shifting cultivation
Zone V	Temperate to cold and frigid humid to semi-humid	>2800	Arunachal Pradesh	Moderate temperate fruit cultivation and subsistence terraced cultivation

Source: Agro-Climatic Regional Planning, Planning Commission, 1989

6.2.1 Characteristics of Himalayan Agriculture

Farmers of IHR usually adopt traditional agricultural practices and generally prefer only mono-cropping and to some extent double cropping, and rest of the period, they leave the land as fallow, which leads to soil degradation resulting in poor farm profitability. The livelihood of the hilly farmers mainly depends on the availability of natural resources. Poor crop productivity and seasonal unemployment has led to a reduction in farm wages and enhancement in malnutrition. The environmental degradation in the region reached an alarming proportion, necessitating urgent attention to their scientific management for the overall sustainable development of the region. Shifting cultivation locally known as *Jhum* is still widely practiced, especially in the Eastern Himalayan region of India. Further to minimize the climate change risks and to ensure the production of food, it is necessary to implement strategies to increase sustainable food production and promote resilience, while reducing environmental impacts on agroecosystems. Besides, it is also important to integrate the different innovative solutions for sustainable crop production. Hence, conservation of natural resources—its optimum and effective utilization—is recommended for feasible and sustainable agricultural production systems. Fragility, marginality, and inaccessibility accompanied with the prevalence of shifting cultivation, lack of irrigation water, mixed and subsistence farming systems, low-input-based production systems, poor seed replacement ratio (traditional farming), small-sized farm often managed by women, and soil and nutrient loss are found to be major constraints in the IHR. As effective landholding is less in IHR, there is a need to increase land-use efficiency up to 65% so that the effective landholding becomes 0.50 ha, followed by cropping intensification, as a horizontal expansion of land-based enterprises is not possible. Integrated Farming Systems (IFS) have proven to be a promising option for several farmers to tide over the current imbroglio, especially with the climate change looming large. The global mean surface air temperature has increased about 1 °C above pre-industrial levels. Global climate change will augment the agricultural risks and so there is an urgency to adopt resilient and smart agricultural practices (Venkatramanan et al. 2020b). In this regard, adoption of climate smart agricultural technologies can checkmate the negative impacts of climate change (Venkatramanan and Shah 2019). Integrated farming practices are viewed as a sustainable alternative strategy to achieve economic and sustained agricultural production to meet diverse requirements of farm livelihood and seek to combine environmentally benign modern scientific methods with ecologically sound and time-honored farmers' practices. It is an appropriate combination of various farm enterprises and the means available to the farmer to raise the profitability of agroecosystem. The unique features of some farming families can also be incorporated in the IFS approach for increasing farm productivity and income. The vertical integration of land-based enterprises within the socio-economic environment of the farmers will make farming more profitable and resilient. The IFS approach includes multitier and multispecies cropping and effectively uses the horizontal and vertical space and harvest more crops per unit of resources used. The increased cropping intensity also helps as an insurance cover against various uncertainity, and the technologies and the crop mix involved are found to be climate-resilient. The IFS also provides scope for gender empowerment. Gender equality and empowerment improves the agricultural productivity, augments the farm income and improves household food security (Venkatramanan and Shah 2020). The advantages of IFS are the following:

- The cost of production of various agricultural commodities is lesser in IFS as compared to the modern farming system.
- The net annual returns per unit area and unit investment, land, and water are higher in IFS.
- IFS provides assured employment and year-round income for the farming family.
- IFS ensures sustainable soil health improvement and prevents/minimizes the various kinds of pollutions.
- IFS is an example of appropriate integration with of climate-resilient crops, livestock and other enterprises.
- IFS is an economically lucrative option for rural youth. Hence, it can minimize/arrest the rural-urban migration.
- IFS offers livelihood and nutritional security for farming families.

6.2.2 Cropping Systems in the IHR

Cropping patterns and their interaction with available farm resources, which determine its makeup, is called a cropping system. Crops and cropping systems in the Himalayas are diverse due to large agro-ecological and cultural diversity, which has led to variable cropping patterns (Yadav et al. 2019). About 80% of people of the Himalayan region practice subsistence agriculture (Maikhuri et al. 2001). In totality, around 85% of lands in IHR covered by small and marginal landholders are rainfed. The valley area covers 15% of agricultural land, which is generally irrigated. Generally, farmers of the IHR grow rice, but traditionally intercrop combinations involve cereals with millet, millet with legumes, and legumes with legumes. Intercropping finger millet with legumes and rice/maize with legumes often results in better resource utilization compared to sole/mono-cropping (Babu et al. 2016; Das et al. 2018). Millets are known for their high mineral content, and legumes fix nitrogen symbiotically. Rice and maize are the major livelihood crops of the Eastern Himalayas (Yadav et al. 2018; Avasthe et al. 2020). The Eastern Himalayan region is considered as a potential rice-growing region in India (Das et al. 2013; Yadav et al. 2017). Despite fertile soil and plentiful natural resources, mono-cropping of rice and maize is a common phenomenon in the Eastern Himalayas (Singh et al. 2016; Das et al. 2017; Babu et al. 2020a, b). After harvesting rice and maize, the land remains fallow, mainly due to moisture scarcity (Yadav et al. 2018). But zero-till lentil, vegetable pea and rapeseed-mustard after rice harvest in the system approach is gaining momentum in the region (Singh et al. 2016; Yadav et al. 2017). In IHR, especially in the Eastern and Western regions, farmers grow vegetables after rice under assured irrigation supply. However, the systems mainly prevalent in the valley to a limited extent are rice-pulse, rice-vegetable + pig, rice-vegetable + poultry, rice + fish + pig, and rice-rice-pulse + piggery. Some vegetable-based cropping systems are discussed in the following section.

Vegetables-Based Cropping Systems In harmony with the undulating topography, vegetable cultivation extends from foothills to elevations up to 2000 m amsl. Seasonal vegetables are cultivated in all the states of IHR. The important vegetables of the states are:

- ***Kharif* vegetables:** Brinjal, chilies, capsicum, French beans, cowpea, okra, cucumber, pumpkin, bottle gourd, sponge gourd, ridge gourd, snake gourd, bitter gourd, sweet gourd, balsam apple, chayote, etc.
- ***Rabi* vegetables:** Cabbage, cauliflower, broccoli, garden pea, French beans, radish, carrot, turnip, spinach, amaranths, fenugreek, leafy mustard, lettuce, celery, coriander, leafy onion, garlic, leek, potato, Colocasia, elephant yam, etc.
- **Off-season vegetables:** Cabbage, cauliflower, broccoli, Brussels' sprouts, radish, carrot, tomato, green pea, French beans, spinach, leafy mustard, chayote, cucumber, amaranths, leafy onion, summer potato, capsicum, asparagus, bamboo shoots, fern shoots, stinging nettles, mushroom, etc.

6.3 Integrated Farming Systems (IFS) in IHR

Geographically difficult terrain, adverse climate, scattered and small landholdings are the major factors that restrict commercialization of any single agricultural crop/enterprise in the hilly region (Singh et al. 2019). Traditional agriculture in hills is not very remunerative. Hence, livelihood security of hill farmers is under threat. Furthermore, ever-increasing production costs, poor crop productivity, soil degradation, and health risk of engaged workforce questioned the sustainability of conventional production systems (Reganold et al. 2001). A sustainable farm must be socially acceptable, and economically and environmentally sound in the long term. "To provide a sustainable source of production and income, farmers have to follow a different approach to farming in hills" (Singh et al. 2019). This calls for an extra concentrated focus on the issue from the viewpoint of policy, research, development, and extension. Hence, policy reorientation and human resources development are the key areas that need special attention. Integrated farming systems (IFS) ensure the "production of diversified produce at low prices through farm waste recycling" (Yadav et al. 2013; Das et al. 2019; Singh et al. 2019), which would be the best option for small and marginal landholders of the hilly tract. "IFS approach works on the principle that waste of one enterprise is wealth for other" (Babu et al. 2019; Singh et al. 2019; Das et al. 2019). IFS offers year-round employment and income, besides reducing production risks and costs through optimal use of natural resources (Yadav et al. 2013; Das et al. 2019). The integrated farming system, which requires lesser space and ensures higher productivity of the system, is the only option available for us. The integrated farming system includes dairy, poultry, goat rearing, and fruit trees. The IFS ensures judicious use of inputs and natural resources to provide the regular income and employment to small and marginal farmers. The IFS is considered as an approach to meet the multiple objectives of poverty reduction, food security, competitiveness, and sustainability of small and marginal farmers. The

Table 6.3 How IFS benefits the farm family?

S. no.	Advantages	How?
1.	Increased food supply and nutritional security	Horticultural and vegetable crops can provide 2–3 times more calories than cereal crops on the same piece of land. Inclusion of beekeeping, fisheries, sericulture, and mushroom cultivation under two- or three-tier systems of integrated farming gives substantial additional high-energy food without affecting the production of food grains.
2.	Recycling of farm residues	Proper collection and utilization of organic manures. Restoration of soil fertility. Use of crop residue as input for other enterprises, that is, its use for mushroom cultivation
3.	Use of marginal and wastelands	A combination of forestry, fishery, poultry, dairying, mushroom, and beekeeping can be combined with crop production, and all these activities can be undertaken on marginal wastelands also.
4.	Increased employment	There is a 200–400% increase in gainful employment and additional income to farm families to increase their standard of living.
5.	Multiple uses of resources	The appropriate mix of different enterprises and utilization of products within the system results in multiple uses of resources, thereby reduction in the total cost of inputs, leading to higher profitability.
6.	Risk reduction	The effect of climate variability on different crop/animal/fisheries enterprises will vary. So, the farmer will get assured income from any one of the enterprises during the extreme years.

approach aims at increasing income and employment from smallholdings by integrating various farm enterprises and recycling crop residues and by-products within the farm itself (Behera and Mahapatra 1999; Singh et al. 2006). Above all, the IFS is a practical way forward for agriculture that will benefit society, not just those who practice it. The significance of the IFS approach is supportive in enhancing productivity to meet the food, feed, fuel, and fiber requirement of the ever-increasing population. Devendra (1991) described different types of integrated farming systems: rice-fish systems; integrated pig-duck-fish-vegetable systems, integrated systems involving animals, and intensive integrated farming systems (Ewards et al. 1986; Prakash et al. 2015). Primary goals of IFS are yield maximization; improving the systems' productivity; pest management; reducing use of external inputs; and augmenting the resource-use efficiency. The IFS benefits to the hill farmers' in many ways (Table 6.3).

While designing IFS models for IHR, the following points must be taken into considerations:

- The model should be self-input generating, which means minimum requirement from the market.

- IFS model should be able to generate year-round employment and income akin to bank automated teller machine (ATM).
- Waste of one component should be wealth for another component; thus, complementarities should exist between the various components.
- The model should be energy efficient, economically viable, and socially acceptable.
- Rationality should be maintained between economic, ecological, and social dimensions of IFS models.
- IFS model should be capable to sustain the 'farm family needs'.
- Ecosystem services should be taken into consideration while designing the IFS models, and the model should effectively reduce the greenhouse gas (GHG) emission, and soil erosion.

6.3.1 IFS Options for Western and Central Himalayas of India

Agriculture is closely interlinked with traditional crop cultivation, animal husbandry, and forest-related enterprises in the Himalayan region (Saxena et al. 2005; Singh et al. 2018). Traditional farmers in the Indian Himalayas have observed significant climatic changes in recent years, reducing agricultural productivity. The cropping systems in the entire Western Himalayan region varied across the altitudes. Among the various food crops, maize and rice are very popular in the kharif season and wheat is a major dominant crop during the winter season. Under the fruit-based system in low hills, fruits are planted on the farmland either as a sole crop or on the bunds of field crops. In mid-hill altitudes, the vegetable crops become more popular due to the high profitability of off-season vegetables and the area under fruits is declining. The majority of people residing in the hills prefer nonvegetarian food. At Mandi district of Himachal Pradesh, Choudhary et al. (2012) demonstrated that *the integration of different field crops, vegetables, and practically feasible farm enterprises resulted in a B:C ratio of 4.92*, which is substantially higher than the prevailing farming practice in the region. Singh et al. (2019) demonstrated that *fish-poultry followed by fish-vegetable integrated farming systems are the most suitable for mid-hill conditions of Uttarakhand in terms of production as well as profit and also ensures nutritional security of rural people*. Hence, designing location-specific IFS model is required for enhancing the farmer's income and resource conservation. Dadhwal et al. (2012) suggested the following IFS models for the livelihood improvements of the hill farmers.

- Homestead farming along with backyard poultry
- Goat farming for landless and marginal farmers
- Beekeeping with agriculture
- Large animal-based integrations
- Small-scale poultry farming

Dadhwal et al. (2012) also suggested the rice-fish integration, watermill, and fish-based integrated farming systems for the mid-hill ecosystems of Uttarakhand. Some of the location-specific altitude-wise IFS modules suggested by Arnab and Uday (2018) are given as follows:

High altitude (2500–3500 msl)
- Livestock-based integration
- Neutra-Cereal-based IFS
- Protected cultivation (vegetables) and fruit-based IFS

Mid-high altitude (1750–2500 msl)
- High-value fruits and off-season vegetable-based IFS
- Livestock-based IFS
- Neutra-Cereal/food crop–based IFS
- Agroforestry-based IFS
- Integration of secondary agricultural activities with other agriculture enterprises

Mid-low altitude (1500–1750 msl)
- Food crop and vegetable-based IFS
- Livestock-based IFS.
- Intensified cropping-based IFS.
- Protected cultivation (vegetables) and fruit-based IFS and value addition.

Lower altitude (1200–1500 msl)
- Fruit, vegetables, and food crop–based IFS
- Livestock-based IFS
- Seed production–based IFS
- Secondary agricultural-based enterprises integration with Agri-Horticrops.

Foothills (1200-1000 msl)
- Fruits, vegetables, and food crop–based IFS
- Livestock (dairy, fishery, poultry, etc.)-based IFS
- Secondary agriculture–based IFS

6.3.2 IFS Options for Eastern Himalayan Region (EHR) of India

The EHR spreads over eight states of India and lies between 21°50′ and 29°34′ North latitudes and 85°34′ and 97°50′ East longitude. It represents a distinct agro-climatic area of our country. It is physically difficult, topographically differentiated, culturally diversified, socially isolated, and economically poor part of India. The region has a population of 40 million and a geographic area of 2,62,379 km^2, which is 3.85% and 7.97% of the population and area of the country, respectively. The hill, mountains, and undulating plateaus account for 72% of the total geographic area of the region. The region experiences heavy rainfall, causing 45–460 t/ha/ annum soil loss. Shifting cultivation is one of the prevailing and primitive agriculture practices in the region. The EHR occupies about 83% of the total shifting cultivation in India. Farmers cut and burn the fallow vegetation from November onwards up to January. Thereafter, they grow rice and vegetables in their *Jhum* land. Different types of mixed cropping have been observed in the *Jhum* areas like upland paddy + vegetables, etc. Sometimes, mixed cropping of 7–8 different types of crops has also been observed in a small *Jhum* land. About 85% of farmers of the EHR of India are small and marginal. Traditional agriculture is the major and dominant activity in the hill economy, which confronts multiple risks and uncertainty. The low yield of food and cash crops, fodder, fuel, and other minor forest produce and stagnant growth is the critical pull factor of the agrarian economy and, in particular, the household food security. Rather, a fast depletion of biodiversity is a matter of concern. The major challenge is to devise suitable location-specific solutions to restore and accelerate the economic process to ensure sustainable development. This requires a comprehensive strategy to understand the multifaceted hill and mountain regions. Yadav et al. (2013) suggested that *Integrated farming system (IFS) ensures efficient utilization of available farm resources, increases unit productivity, and income that are pre-requisite for the sustainable livelihood of small and marginal farmers*. Kumar et al. (2018) at Nagaland demonstrated that "agriculture + horticulture + poultry + fishery" in the IFS model gave the highest monetary net returns (Indian Rupees-INR 32,040), followed by "agriculture + horticulture + fishery + piggery + vermicompost" with net profits of INR 21,230. *The improved farming with various animal and crop components play a significant role in increasing manifold production, income, and nutrition and employment opportunities of rural populations* (Yadav et al. 2013). ICAR-National Organic Farming Research Institute, Sikkim, has developed and designed the Integrated Organic Farming Systems (IOFS) model for 1.25-acre land. The model comprising of cropping systems (rice-vegetable pea, rice-potato-Sesbania, rice-toria-Sesbania, rice-cabbage-Sesbania, maize-soybean-buckwheat, coriander-radish-broccoli-fenugreek, and cauliflower-pea-beetroot-spinach), 2 cows, and 50 poultry birds has been developed for Sikkim. Net income of INR 1, 37,000/year can be obtained from 1.25-acre land (PIB 2019). In the entire EHR of India, piggery is very popular and mainly reared by the tribal communities. Both in the valley and hill regions, farmers have adopted backyard poultry rearing to meet their household needs and supplement their income. The fodder supply for the livestock in the valley is met from locally available material, kitchen waste, etc. Spice crops like ginger, turmeric, large cardamom, Red cherry pepper, coriander, chilies, and bay leaf are also cultivated with the integration of other enterprises. To get more income, farmers have done vertical incorporation of the cucurbitaceous crop in turmeric and ginger field. Among the spices, large cardamom occupies the largest area in Sikkim and mainly cultivated with agroforestry plants. Paddy-cum-fish culture is also a prevailing practice, especially in Manipur and Nagaland. Das et al. (2019) at Meghalaya designed and developed Integrated Organic Farming Systems (IOFS) model for 1-acre land; the model comprises different enterprises such as "cereals, pulses, oilseeds, vegetable crops, fruits, dairy unit, fodder crops, central farm pond, farmyard manure/composting pits and vermicomposting unit." A farm pond with a dimension of 460 m^2 and 15 m depth is constructed for aquaculture and for providing life-saving irrigation. For the purpose of vertical intensification, climber vegetables are grown on a structure created on one side of the pond. On the other side, pumpkin is cultivated. The model was successful in terms of earnings (INR 73,903/year) and was also able to generate 80% of the seeds/planting materials and nutrients required within the system (Das et al. 2019).

6.3.2.1 Micro-watershed-Based Farming Systems for Livelihood Security

To address the alarming environmental degradation issues due to shifting cultivation in the Eastern Himalayas, ICAR Research Complex for the North-Eastern Himalayan (NEH) Region, Meghalaya launched a project entitled "Alternative Farming Systems to replace 'Jhuming'" at the State Government Farm of Soil Conservation Training Institute, Byrnihat, during 1975. The project was continued for 8 years in Byrnihat. The significant achievement of the research during this period was the identification of the "Agri-Horti-Silvi-pastoral" model as a viable alternative to shifting cultivation. In 1983, a full-fledged Farming System Research Project (FSRP) was initiated at ICAR Research Complex for the NEH Region, Barapani (Umiam), with eight different land-use models.

Eight micro-watershed-based land-use models under FSRP were established for evaluation on a long-term basis at ICAR Research Complex for the NEH Region, Umiam, Meghalaya. The models comprised dairy-based land use (FSW—1), mixed forestry (FSW—2), silvi-pastoral land use (FSW—3), agro-pastoral system (FSW4), agri-horti-silvi-pastoral system (FSW—5), silvi-horticultural system (FSW—6), natural forest block (FSW—7) and timber-based farming system (FSW—8). Three important farming systems are discussed in this chapter.

Dairy-Based Farming System

Dairy-based farming is an important land use for the livelihood and nutritional security of the rural people in northeast India. Besides producing milk, the farmyard manure (FYM) of the dairy animals is a good source of organic matter for improving physicochemical properties of soil, and it can also be used as farm draft power. In general, the dairy unit contributes more than 50% to the gross agricultural produce and plays a vital role in improving farmer's economic condition. Hence, dairy enterprise when combined with other compatible enterprises offers great opportunities for increasing farm income and employment, particularly to the weaker sections of the rural community. Generally, land up to 100% slope with the conversion of the hill slopes to bench terraces was found to retain 80–90% of annual rainfall and restrict soil losses substantially. The average slope of the watershed was 32.02%, and the lower terraces consisting of 1–5 were utilized for the production of annual fodder with maize + cowpea/soybean/rice bean/French bean-oat cropping sequence. The terrace risers area was utilized for the production of guinea grass, while 2500 m^2 slopy area was under broom grass. Guinea grasses were cut at an interval of 30 days from June to September to avoid competition with the main crops grown in the terraces. This was the noncompetitive strategy developed for fodder production and land stabilization. The green leaves and edible tender shoots of broom grass during the lean period also can be used as feed for cattle. Three milch cows along with their two calves were maintained in a cowshed of 12 m × 5 m × 4 m size. Forage crops/

grasses grown along the micro-watershed produced green fodder, which was made available for the dairy animals. The total dry matter (DM) requirement was 11.5 kg/ day/cow that amounted to 15.592 t/ annum, out of which 4.78 t was supplied through the concentrated feed. The dry matter (DM) supplied through paddy straw was able to meet the DM requirement of the dairy component. The system as a whole required 3480.96 megajoules (MJ) of net energy input and produced a net energy output of 81,871.41 MJ, resulting in an energy use efficiency of 26.19%. In terms of system profitability and employment generation, the system as a whole gave INR 323/day and generated 383 man-days. The system provided year-round income and employment generation for sustaining the farmer's need or livelihood.

Agro-Pastoral System

Agro-pastoral system was established in 0.64 ha area having an average slope of 32.42% with a forest land of 0.06 ha and a planned land-use area of 0.58 ha. Terracing was practiced across the slope and along the contours, which enhanced the surface area by 28.2%, resulting in 0.49 ha area of terraced land and 0.33 ha terrace risers, respectively. The topo-sequence study revealed that the growing of rice on lower terraces, groundnut (*Arachis hypogea*), ginger (*Zingiber officinale*) and turmeric on middle terrace, and maize on the upper terraces give the highest yield and income. About 75% of the total area was utilized for 200% cropping intensity. Production of guinea grass on terrace risers in the lower and middle part of the watershed and broom grass on the top portion of the watershed provided green fodder was sufficient for 8 months for the dairy unit without any extra input/ management cost. Production of grasses on terrace risers marginally reduced the yield of the main crop as, near the risers, crops suffered from shading and nutrient competition effect; however, this was compensated with the continuous availability of green fodder for the animals in the micro-watershed. The system as a whole required 4068.96 MJ of net energy input and produced a net energy output of 89,717.93 MJ, resulting in 38.14% energy use efficiency. The system profitability and employment generation of the system as a whole were INR 216/day and 395 man-days, respectively. The system provided year-round income and employment to the farmers. Concerning nutrient recycling, a total of 30.6 t/annum of green fodder and 3.5 t/annum of dry fodder were produced. Besides this, the system produced ~16 t/annum of various kinds of organic manure, which can meet about 75% nutrient requirement of the crops grown in the model.

Agri-Horti-Silvi-Pastoral System

Agri-horti-silvi-pastoral system was established in an area of 1.58 ha. Out of which, 0.55 ha was under forest, while 1.03 ha under planned land use, and the average slope of the micro-watershed was 41.77%. In this system, 0.10 ha of foothills was used for crops, 0.25 ha for horticultural crops, and 0.68 ha for silvi-pastoral crops. The distribution of area was done based on water requirement, soil condition, depth of soil, and slope of the land. In the lower terraces, crops like capsicum, French bean, radish, chilies, brinjal, and okra were grown during the kharif season and French bean, vegetable pea, broccoli, cauliflower, carrot, fenugreek, coriander (leaves), and cabbage were grown during rabi season. The middle portion of the system is utilized for fruit crops like Assam lemon, pineapple, orange, papaya, peach, and guava. In between the interspaces of the plants, Congo signal grasses are also planted to utilize the area. On terrace risers, guinea and Congo signal grasses are planted for green fodder production for the livestock and also to prevent soil erosion. Pineapples are planted in a double-row system as an intercrop with Assam lemon to conserve the soil and water and to get extra cash income. On the top portion of the land use, forest block consisting of *Alnus nepalensis* and *Schima wallichii* are maintained for timber and fuelwood purposes. Black pepper is allowed to climb on these trees, while *Ficus* spp. and *Symingtonia populnea* are used for green leaf fodder production during the lean period. In between the tree species, broom and guinea grasses are grown as a companion crop for soil and water conservation and fodder production. The system as a whole required 6607.52 MJ of net energy input and produced a net energy output of 14,177.81 MJ, resulting in an energy use efficiency of 29.66%. The system provided year-round income and employment to meet farmers' needs and sustain a livelihood. Regarding the recycling of nutrients, the system produced 7.6 t/annum of various kinds of organic manure, which met about 65% nutrient requirement of the model.

6.3.2.2 IFS for Sloping Land

A farming system is a viable approach for on-farm resource recycling, soil health improvement, food, and nutritional security. Keeping this in mind, a land-use model is envisaged for sloping lands (~30%), comprising cereals, pulses, oilseeds, fruits, spices vegetables, etc., for organic food production to enhance soil and crop productivity, and profitability of hill farmers. All India Coordinated Research Project on Integrated Farming Systems (AICRP-IFS) was started during 2009–2010 at the ICAR Research Complex for the NEH Region, Umiam, under this project. One-hectare area was earmarked for accommodating different components (crops+ livestock + fisheries + horticulture) of the Integrated Farming System. The IFS system from 1 ha area generated a gross return of INR 4,33,931/−, while the cost of production/rearing was INR 2,77,653/− and, hence, a net return of INR 1,56,278/ − ha/annum was estimated. Total dry matter production amounted to 8545.90 kg from the system. Out of this, 6938.90 kg was produced from field crops and 1500.6 kg from the livestock unit. The horticultural unit having orchard in 2000 m^2 area produced 106.35 kg dry biomass. The other dry biomass produced from ginger and turmeric was used to make composts after mixing properly with livestock excreta and farm waste materials.

6.3.2.3 Pond Dike–Based IFS

Babu et al. (2019) demonstrated that "the integrated pond management with poultry, fish, and vegetables on pond dike is an excellent approach for sustainable production as well as income and employment generation for the resource-poor rural households. Integrated fish production with poultry and pond dike intensification is a sustainable novel agricultural production system for sustaining the livelihood security and income of hill farmers and also maximize the utilization of the available limited resources. The major economic benefits of this technique are enhancement of food production and self-sufficiency, making farmers self-reliant and occupied through most part of the year which generally does not happen in conventional systems of farming. Hence, raising poultry directly above the fish pond in a low-cost poultry house in such a way that the poultry excreta should drop directly into the fish pond along with sequential cultivation of vegetables on the pond dikes is a profitable option for enhancing farm income in northeast India".

6.3.2.4 Intensive Integrated Farming Systems (IIFS)

IIFS systems have a good scope for the EHR, particularly in high rainfall areas, and livestock and fish can be the main sources of earning for the farmer. Keeping in view the scope and opportunities, IIFS models were developed and evaluated by ICAR RC for the NEH Region, at Meghalaya. As a pilot project, about 10 ha of the wasteland was taken up during the year 1999–2000. The average slope of the area ranged from 20% to 30% with a soil depth of < 1 m (Bhatt and Bujarbaruah, 2005). The five subsystems of IIFS were developed as detailed in Table 6.4.

6.3.2.5 Suggestive IFS modals for Tripura

The rural economy of Tripura is mainly driven by small and marginal farmers, as they constitute more than 80% of the total farming community. Important challenge in this region is declining per capita land availability. So, it would be beneficial to integrate farm enterprises such as dairy, fishery, poultry, duckery, apiary, field, and horticultural crops within the farm so that the livelihood of farming community, particularly small and marginal farmers, improves through sustainable income and employment opportunities. ICAR Research Complex for North-Eastern Himalayan region (Tripura Centre, India) designed and developed a series of location-specific integrated farming systems for the farmers having less than 1 ha land in the Tripura region of the Eastern Himalayas. All the developed farming system models enhanced the system productivity and farmers' net income and maintained soil health as compared to farmers' traditional rice farming systems. A brief description of important IFS models is given as follows:

FSR-1: Agri-Horti-Duckery-Fish-Based Farming System

Agri-Horti-duckery-fish-based farming system model was developed through the integration of crops, vegetables, fruit trees, duck, and fish over an area of 0.8 ha land (Fig. 6.1). The land was *tilla* type and slopy with 0.1-ha lowland, where water harvesting structure for irrigation, fish culture, and duckery was constructed. The total area for cultivation after excluding terrace, bund, and road areas (0.08 ha) was 0.72 ha. The area allocated and crops grown under different components are as follows:

Area allocation

- Agriculture and vegetable crops (*kharif*- Okra, cowpea, cucumber, upland rice, and maize; *Rabi*- Broccoli, cabbage, cauliflower, tomato, and capsicum): 0.52 ha

Table 6.4 Description of intensive integrated farming system models

Farming system	Land use component	Area (ha)	Description
Broiler chicken-crop-fish-duck-horticulture-nitrogen fixing hedgerow	Pond— 0.15 Pond dike—0.03 Duck shed—0.016 Broiler shed—0.006 Field crop—0.75	1.06	In the upland area, ragi (0.18 ha), maize (0.30 ha), and rice bean (0.12 ha) followed by ginger and turmeric were cultivated. In the lowland area, paddy (0.65 ha) and mustard 0.30 ha were cultivated. During rabi season, potato, tomato, cabbage, knolkhol, and radish were cultivated. Nitrogen-fixing shrubs were planted on contour bunds; fodder grasses and fruit trees were raised on pond dikes and farm boundaries. Ducks were reared (72 Nos) on pond dikes. The composite fish culture was practiced, and 900 fingerlings were stocked.
Crop-fish-poultry-multipurpose trees	Pond— 0.12 Pond dike—0.04 Poultry shed—0.01 Field crop—0.80	0.97	In the upland area, paddy (0.45 ha) and rice bean (0.05 ha) during *kharif* and buckwheat (0.50 ha) in the rabi season was cultivated. In the lowland area, paddy (0.30 ha) in *Kharif* and potato (0.25 ha) and French bean (0.05 ha) were cultivated. Fodder grasses and fruit trees were raised on pond dike and farm boundaries. Layer birds (52 nos.) were raised on pond dikes. The composite fish culture was practiced, and 720 fingerlings were stocked.
Crop-fish-goat-MPTs-hedge	Pond—0.10 Pond dike—0.035 Goat shed—0.008 Field crop—0.80 Hedgerow-—0.10	1.04	In the upland area, paddy (0.30 ha), ginger (0.30 ha), and turmeric (0.20 ha) during kharif and mustard (0.30), tomato (0.40 ha) and radish (0.10 ha) during rabi season were grown. Fodder grasses, MPTs, and fruit trees were cultivated on pond dike and farm boundary. Goats (6 nos) were reared on pond dike. The composite fish culture was practiced, and 600 fingerlings were stocked.

(continued)

Table 6.4 (continued)

Farming system	Land use component	Area (ha)	Description
Crop-fish-pig-bamboo-MPTs-fruit trees-hedge rows	Pond— 0.12 Pond dike—0.035 Pig shed—0.001 Field crop—0.80 Hedgerow—0.09	1.05	In the upland area, paddy (0.30 ha), Colocasia (0.10 ha) and maize (0.40 ha) during kharif and brinjal (0.10 ha), radish (0.05 ha), potato (0.30 ha), and buckwheat (0.15 ha) during rabi season were cultivated. MPTs and fruit trees were raised on pond dikes and farm boundaries. Edible bamboo species were also cultivated on farm boundary. Hedgerow rows were planted on contour bunds. Vermicompost was prepared in two units each of $12' \times 6' \times 2'$ size. Pigs (2 Nos) on pond dikes, the composite fish culture was practiced, and 720 fingerlings were stocked.
Crop-fish-dairy-MPTs-fruit trees-hedge rows-Vermiculture-liquid manure-broom	Pond— 0.12 Pond dike—0.06 Dairy shed—0.016 Field crop—0.80 Hedgerow—0.17	1.17	In the upland area, paddy (0.60 ha) was cultivated. Broom grass (0.10 ha) and Job's Tear (0.10 ha) were cultivated along the water channels. MPTs and fruit trees with fodder grasses were raised on pond dike and farm boundary. Cattle (2 milch cows and 2 calves) was reared. Oyster mushroom was cultivated in 8 m × 3 m × 2.5 m size unit. Liquid manure was prepared in 3 units $3' \times 3' \times 2.5'$ capacity. Vermicomposting was done in 6 units of 1 m × 1 m × 0.75 m. the composite fish culture was practiced in the ponds. The composite fish culture was practiced, and 720 fingerlings were stocked.
Upland crops, and fish farming without integration (control)	Pond—0.10 Pond dike—0.05 Crop area—0.80	0.95	In the upland area, paddy (0.40 ha) and maize (0.40 ha) during kharif season and buckwheat (0.20 ha) and French bean (0.30 ha) were grown. Fruit trees were grown on pond dike. The composite fish culture was practiced, and 600 fingerlings were stocked.

Source: Bhatt and Bujarbaruah (2005). pp. 24–26

Fig. 6.1 An overview of FSR-1 model Agri-horti-duckery-fish-based farming system developed by ICAR, Tripura Centre

- Fruit crops (Mango, litchi, and banana): 0.1 ha
- Duck: 0.001 ha
- Fishery: 0.1 ha

This farming system (0.8 ha of land) can get a net income of INR 1,440,00 with an investment of INR 45,300 only. This indicated that this system is more sustainable and profitable than traditional cultivation on this type of land.

FSR-2: Fish-Pig-Tuber Crops-Based Farming System
Fishery plays a significant role in livelihood. More than 95% of people of Tripura eats fish. Pig is one of the integral components' of tribal people's economy. They are highly interested in pig rearing. But they face the problem of feed. To overcome and solve the feed problem, the IFS with the incorporation of tuber crops and fish was designed in a 0.9-ha area (Fig. 6.2). The area allocation under different components is given as follows:

Area allocation-:
- Fishery— 0.2 ha
- Piggery— 0.005 ha

Fig. 6.2 An overview of FSR-2 model—Fish-pig-tuber crops-based farming system developed by ICAR, Tripura Centre

- Tuber crops- (*kharif*-Tapioca, Colocasia, elephant foot yam, Dioscorea); *rabi*-Potato, sweet potato)—0.6 ha
- Fruit crops (guava, mango, Indian jujube (ber), pineapple, papaya, citrus, areca nut, Napier, etc.)—0.08 ha (terrace, bund area)

FSR-3: Agri-Horti-Duckery-Fishery-Based Farming System (Organic Approach)

This FSR was designed and developed in a 0.83-ha area for efficient resources utilization. The basic approach was to utilize the entire crop residue through preparing vermicompost and without using any external inputs (Fig. 6.3). The area allocated under different components is given as follows:

Area allocation

- Agriculture (*kharif*—maize, cowpea, brinjal, Dolichos, okra; *rabi*- tomato, capsicum, cabbage, cauliflower, radish, carrot)— 0.5 ha
- Fruit crops—papaya, banana, pineapple, citrus—0.15 ha
- Duckery—0.001 ha
- Fishery—0.15 ha
- Vermicompost—0.002 ha

Fig. 6.3 An overview of FSR 3 model-Agri-horti-duckery-fishery-based farming system developed by ICAR, Tripura Centre

FSR-4: Rice-Duckery-Fishery-Based Farming System

This model was developed for improving the traditional lowland rice-based farming system, which also has an adjoining sloping area (Fig. 6.4). This system was developed on 0.88 ha total area. The allocation of the area under different components is given as follows:

Area allocation

- Agriculture—(kharif—lowland rice, groundnut; *rabi*—boro rice, mustard, potato)—0.13 ha; (*kharif*—0.2 ha under rice, 0.1 ha under groundnut; *rabi*—0.1 ha under rice, 0.1 ha under mustard and 0.1 ha under potato)
- Fruit crops—(papaya, banana, citrus, Bengal currant (karonda))— 0.4 ha
- Fishery—0.1 ha
- Duckery—duck house constructed above the pond

6.3.2.6 Hypothetical Integrated Farming System for Livelihood Security

To cater to the needs of a family of five members who are small and marginal farmers in the Eastern Himalayan region of India, the following type of area allocation can be adopted (Tables 6.5 and 6.6).

Fig. 6.4 An overview of FSR-4 model—Rice-duckery-fishery-based farming system developed by ICAR, Tripura Centre

Table 6.5 Hypothetical area allocation for a farmland of 0.5 ha to different components of IFS

S. no.	Components		Area (square meters)
1.	Field crops	Rice/maize-pulses/oilseeds/vegetables (intercropping/sequential cropping)	3000
2.	Nutritional homestead/kitchen garden	Indigenous vegetables (should be grown on beds in system mode) possible crops, beetroot, radish, fenugreek, chilli, broccoli, coriander, cowpea, spinach, lettuce, French bean, tomato, brinjal, okra, cabbage, cauliflower, cucumber, pumpkin, bottle gourd, bitter gourd, ridge gourd, Dolichos bean, knolkhol, and turnip	400
3.	Central water harvesting unit	Composite fish culture and pond dike utilization for vegetables/fruits (vertical intensification, diversion of cattle shed washing)	500
4.	Traditional crops	Location-specific traditional fruits (e.g., Sohiong (*Prunus nepalensis* L.), vegetables (e.g., sweet potato, local beans)	350
5.	Livestock	1 milk cow +1 calf /piggery/goatery, etc.	50
6.	Fodder	Perennial + annual fodder + MPTs (e.g., tree beans, etc.)	500
7.	Nutrient cycling	Vermicompost/FYM/hedge row planting/residue recycling/rock phosphate application/liming etc.	100
8.	Mushroom/farm-shed	Location-specific components, if any	100
9.	Boundary plantation and portable processing units	–	–
Total			5000

Table 6.6 Hypothetical area allocation for a farmland of 1.0 ha to different components of IFS

Details of module of the IFS model			
(a)	**Crop production**	**Area (ha)**	***Cropping system***
		0.23	Rice -Toria (*Brassica rapa* cv. toria)-French bean (grain + residue incorporation)
		0.25	Maize-Soybean, maize-Black gram, maize-Green gram soybean, maize-French bean, maize- Toria
		0.09	Vertical farming for dry terraces (turmeric/large cardamom/ginger + cucumber, turmeric/large cardamom/ginger + bottle gourd, turmeric/large cardamom/ginger+ sponge gourd, turmeric/large cardamom/ginger + squash)
		0.06	Oil seed–based (groundnut –Toria)
		0.07	Vegetable-based
(b)	**Horticulture**	0.20	Guava, papaya, pineapple, Assam lemon, peach, and orange
(c)	**Livestock**		
	Piggery	0.010	3 nos (Hampshire × Khasi local)
	Poultry	0.020	575–600 Nos. in 5 cycles
	Layer	0.010	130 nos. (Vanaraja)
(d)	**Complementary**		
	Fishery	0.05	500 nos. fingerlings
(e)	**Supplementary**		
	Vermicompost unit	0.0053	1 no.
	Farm boundary plantation	–	Papaya/guava/ or any other locally adaptable fruit plant
	Others (threshing floor and Misc.)	0.0047	
Total (including household and other areas)		1.00	

Note: Perennial fodder grasses should be planted on contour risers to check the soil erosion, and the fodder tree should be sandwiched between boundary-planted fruit crops

6.4 Conclusion

Agricultural productivity in IHR remains low as compared to plains, mainly due to variation in topography and rainfed condition. But the region has vast resource potential. The situation requires the promotion of an integrated farming system for year-round income generation and conservation of natural resources. Designing location-specific, socially acceptable, environmental friendly, and economically feasible integrated farming systems is the dire need to mitigate the impact of climate change and improve the livelihood security of hill farmers.

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Adaptation Mechanism of Methylotrophic Bacteria to Drought Condition and Its Strategies in Mitigating Plant Stress Caused by Climate Change

7

R. Krishnamoorthy, R. Anandham, M. Senthilkumar, and V. Venkatramanan

Abstract

Climate change–mediated drought stress has significant influence on sustainable crop production in many regions of the world. In recent years, occurrence of drought/higher temperature has increased as the result of continuous emission of greenhouse gases. Drought/high-temperature stress has severe effect on crop establishment, growth, and production. Microorganisms which have symbiotic relationship with plants exhibit various strategies in mitigating drought-induced damages in plants. Among different groups of plant microbiome, methylotrophic bacteria play a vital role in reducing greenhouse gas emissions and enhance plant growth under drought conditions. Methylotrophic bacteria are defined as "microbes which can utilize C1 compounds as the sole source of carbon and energy" (Iguchi H, Yurimoto H, Sakai Y. Interactions of methylotrophs with plants and other heterotrophic bacteria. Microorganisms 3:137–151, 2015. https://doi.org/10.3390/microorganisms3020137). Phyllosphere and rhizosphere are well-known habitats for methanol-utilizing methylotrophs, and larger populations of these bacteria are observed in plant phyllosphere, which include

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the genera *Methylobacterium*, *Methylophilus*, *Methylibium*, and *Hyphomicrobium*. Methylotrophic bacteria adapt to survive in stress conditions such as low nutrient, drought, and high temperature by producing biofilm, aggregate formation, and producing ultraviolet (UV)-protecting compounds. Under drought conditions, plants produce higher amounts of ethylene and reactive oxygen species and, in addition increase the frequency of stomata closure and membrane damages, which leads to yield loss. Methylotrophic bacteria produce 1-aminocyclopropane-1-carboxylate (ACC) deaminase and induce the production of antioxidant enzyme and osmolytes in plants, which helps in mitigating drought/high-temperature stress. This chapter summarizes the mechanisms involved in methylotrophic bacteria to survive under stress conditions and plant stress mitigating strategies.

Keywords

Climate change · Drought · Methylotrophic bacteria · ACC deaminase · Greenhouse gas · Xeroprotectants

7.1 Introduction

Human population growth is instrumental in causing global change (Venkatramanan et al. 2020a). Global change includes climate change, stratospheric ozone depletion, biodiversity loss and land degradation. Due to climate change, more variability occurs in drought frequency, elevated temperature, and precipitation. These climatic variables likely affect the ecosystem functioning. The effect of climate change on plant can be direct or indirect. The direct effect includes modifications in climate-sensitive plants. On the other hand, climate change indirectly alters the interaction of plants with its reciprocal partners such as insects, microorganisms, and pathogens (Jamieson et al. 2012). Among many biotic and abiotic factors that influence plant growth, drought plays a significant role. To tackle these climate variables and guaranteed food security, there is an urgent need for the development of novel techniques in crop production (Raza et al. 2019), and climate smart agricultural technologies (Venkatramanan and Shah 2019). There is a need to transform agricultural production system and checkmate the negative impacts of climate change (Venkatramanan et al. 2020b).

To overcome the problems in crop production, researchers have turned their attention to study the interactions of plants and microorganisms. Knowledge on the microbial-mediated morphological, physiological, and genetic modifications in plants to adapt to the climate change will be helpful in enhancing crop production. This chapter focuses on the microbial strategies in overcoming stress conditions and mechanisms adopted by the microorganisms that help in enhancing plant stress tolerance.

Climate change refers to a broad range of global phenomena created predominantly by burning fossil fuels, which add heat-trapping gases to the Earth's atmosphere. This climate change issues cannot be solved in 1 day and by few people; it requires the active involvement of each individual on the Earth. In nature, these climate changes may occur in hundreds or thousands of years; however, due to the increased anthropogenic activities such as industrialization, deforestation, etc., climate change occurs in a very short period. Most of the scientists agree that the main cause of the current climate change is due to the greenhouse gases, such as carbon dioxide (CO_2), methane, nitrous oxide, and fluorinated gases, which are mostly emitted due to human activities.

Among the greenhouse gases, carbon dioxide contributes to more than 60% of the man-made global warming; other gases such as methane and nitrous oxide contribute to 17% and 6%, respectively. Due to industrialization, CO_2 levels have increased in atmosphere up to 40%. Greenhouse gases' effect on agriculture may be grouped into three categories: (a) the increased atmospheric CO_2 concentration, which directly affects crop growth; (b) climate change, which can affect plant and animal productivity; and (c) sea level increase, which may lead to increase in the salinity of groundwater in coastal regions. Impact of climate change on agriculture will be one of the deciding factors which influences food production and the security of mankind on the Earth. Information on weather changes in a particular area and period helps in adjusting agricultural practices to get better crop growth and yield. However, adjusting agricultural practices based on unpredictable changes in weather condition due to climate change causes major problems in food production. Methane is a hydrocarbon gas emitted into the atmosphere from natural sources and human activities. When looking at the molecule level, methane is more active than CO_2, but the concentration in atmosphere is very less. Another powerful greenhouse gas is nitrous oxide, which is released into atmosphere during soil cultivation practices, fossil fuel combustion, and biomass burning.

7.2 Role of Microorganism in Greenhouse Gas Emission and Reduction

Microorganisms play an important role in greenhouse gas (CO_2, CH_4, and N_2O) emissions (Singh et al. 2010). Natural ecosystems such as ocean, forest, and agriculture are considered as ways of mitigating climate change. Microorganisms are the crucial entity in many biogeochemical cycles, and the role of microorganisms in climate change has to be studied (Walsh 2015). Microorganisms hold great significance in climate change since it is an important component of major nutrient cycles such as carbon and nitrogen; in addition, they are involved in emission and removal of methane.

Autotrophic microorganisms consume CO_2 by photosynthesis, whereas heterotrophic microorganisms release CO_2 by decomposition process; the balance between these two processes determine the net carbon flux in the ecosystem (Weiman 2015) (Fig. 7.1a). It has to be mentioned here that about 1.2×10^{14} kg (120 billion tons) of CO_2 is fixed by the autotrophs every year. At the same time, heterotrophic microorganism emit about 1.19×10^{14} kg (119 billion tons) of carbon (Singh et al. 2010).

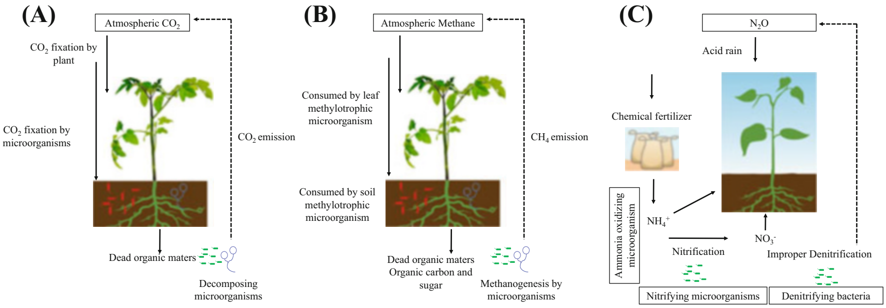

Fig. 7.1 Greenhouse gas cycle and the microbial role. (**a**) CO_2 is fixed by microorganisms and plants and released back to the atmosphere by decomposing microorganism; (**b**) methane is consumed by methylotrophic bacteria and released into the atmosphere by methanogenic bacteria; (**c**) nitrous oxide is mostly introduced as nitrogen fertilizer, and due to improper denitrification, nitrous oxide is released into the atmosphere. Dotted line indicates the emission, and black line indicates the fixation of greenhouse gas

While microorganisms are responsible for about 80% of the global methane emissions, they consume about 60% of the methane produced in the world (Fig. 7.1b). However, the disturbance of microorganisms and their diversity may cause adverse effects on carbon cycle, which lead to increased greenhouse gas (carbon dioxide and methane) in the atmosphere.

Nitrous oxide is another important greenhouse gas which is released into the atmosphere mainly by microbial nitrification and denitrification processes, which occur in the agricultural lands (Fig. 7.1c). Singh et al. (2010) reported that for every 1000 kg of chemical fertilizer addition, 10–50 kg of N_2O is emitted. Reduced use of chemical fertilizer in agricultural fields may be the better option to reduce the N_2O in the atmosphere. The role of microorganisms in both emission and reduction of greenhouse gases in the atmosphere is significant. Hence, microorganisms could serve as an indicator or key for managing the climate change (Budzianowski 2012). Therefore, there is an urgent need to deeply understand the microbial diversity in an ecosystem and their role in greenhouse gas emission/reduction processes (Pold and DeAngelis 2013). Singh et al. (2010) stated that for understanding climate change, it is important to study the climate and microbial/biological variability interactions on the greenhouse gas cycle (Fig. 7.2).

7.3 Bacterial Adaptation Strategies to Drought Condition

Climate change–mediated drought stress has displayed significant influences on agriculture in many parts of the world (Walck et al. 2011; Stone et al. 2012). In recent years, reports on temperature increases and number of drought incidences have increased (IPCC 2007). Intergovernmental Panel on Climate Change (IPCC) projected that land area affected by drought will increase and the water resources will decline up to 30% in the next few decades (Christensen et al. 2007). Generally,

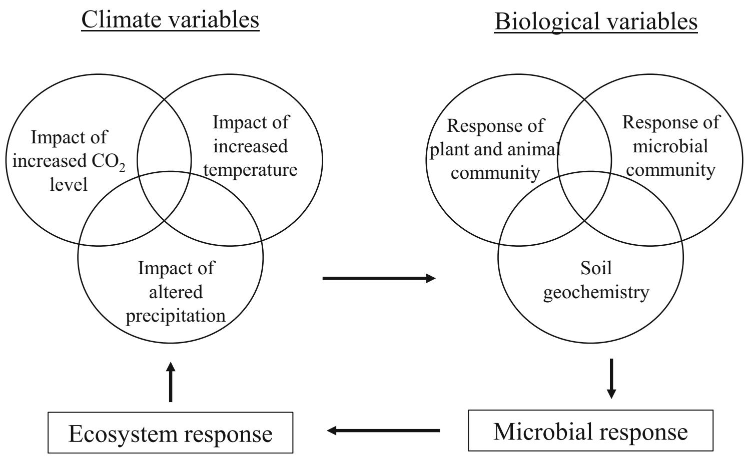

Fig. 7.2 Interaction between climate and biological variables on climate change (Modified from Singh et al. 2010)

drought stress occurs in soil when the available soil evaporates due to increased temperature. Drought stress is one of the major stressors which threaten the integrity of molecules and bacterial life on the Earth. However, some bacteria are able to overcome drought conditions by suspending their metabolism under adverse conditions and reactivating it once favorable conditions arrive. Under drought conditions, the bacteria use different molecular mechanisms, and it varies among different bacterial genera. But in general, most of the bacteria produce xeroprotectants to protect the cell biomolecules from the damage caused due to the lack of water (Julca et al. 2012). Xeroprotectants are the nonreducing sugar molecules, among which trehalose is most effective and found in many bacterial genera surviving under drought conditions. In addition, polyols, organic acid, and amino acids also act as xeroprotectants. Trehalose (a-D-glucopyranosyl-1, 1-a-D-glucopyranoside) is a nonreducing disaccharide present in bacteria. These trehalose are biosynthesized in five different pathways; in bacteria, trehalose-6-phosphate synthase (TPS) is used to form trehalose-6-phosphate from Uridine diphosphate-glucose and glucose-6-phosphate (Reina-Bueno et al. 2012). Suarez et al. (2008) illustrated that overexpression of OtsA gene (bacterial TPS production) in *Rhizobium etli* increases drought stress tolerance. Positive correlation between bacterial trehalose content and plant drought tolerance is illustrated by Vilchez et al. (2016).

Bacteria secrete exopolysaccharide (EPS) outside the cell to protect the cell under drought conditions (Nichols et al. 2005). The composition and concentration of EPS vary in different levels of drought stress and with different bacterial species. For example, composition of *A. brasilense* sp. 245 EPS is found to contain high-molecular-weight carbohydrate complexes (lipopolysaccharide–protein [LP] and polysaccharide–lipid [PL]), which enhance bacterial drought tolerance (Konnova et al. 2001). EPS is hygroscopic in nature and maintains higher water content in the colony microenvironments to improve the bacterial survivability in drought conditions. Reports proved that EPS protects *Pseudomonas* sp. and *Rhizobium sullae* KYGT207 under drought conditions (Susilowati et al. 2018; Khan and Bano 2019). Bacterial EPS helps in the formation of microbial aggregates that adhere to the soil surface and cement the soil particles together. Cation bridges, hydrogen binding, and van der Waals forces and anion adsorption mechanisms are used in the attachment of EPS with soil clay particles and form effective soil aggregates.

Production of ergothioneine (EGT) was found to be one of the survival mechanisms of the methylobacterium. EGT is known to absorb ultraviolet (UV) light, which may account for the ability to block UV damage (Bazela et al. 2014). Recent metabolomic analysis revealed that most of the methylobacterium cells accumulate a large amount of EGT, in order to protect the cell from UV rays (Alamgir et al. 2015). Since methylobacterium is a phyllosphere bacteria, their cell has developed UV-protecting mechanisms.

7.4 Microorganisms Associated with Plant and Soil

Microbial components of the plants are generally called as plant microbiome, which comprises of the microorganisms associated with rhizosphere and phyllosphere (Singh et al. 2019) (Fig. 7.3). Understanding of the plant microbe interactions may provide novel ideas to enhance plant growth. Nowadays, farmers face many challenges in crop production due to climate change. Microorganisms associated

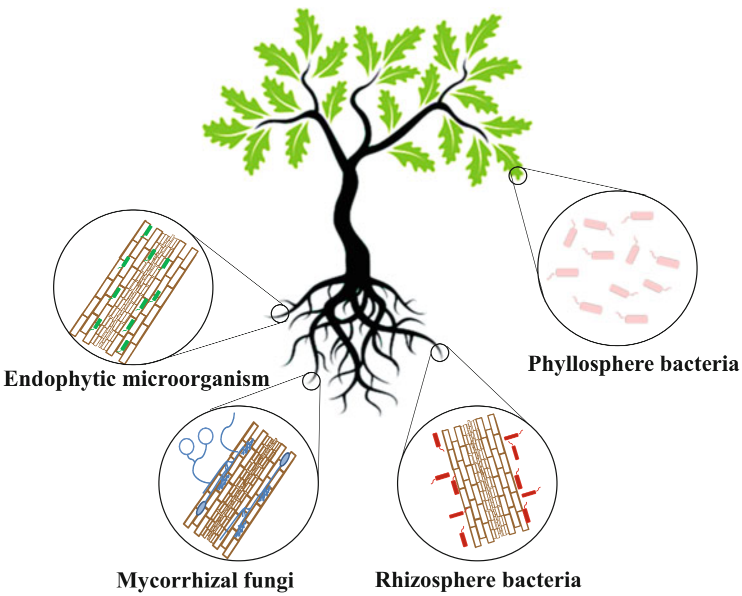

Fig. 7.3 Plant microbiome-microorganism associated with plants' rhizosphere and phyllosphere

with plants may play a significant role in plant growth promotion, mitigating the plant stress that occurs due to climate change. Having more information about the plant microbiota associated with plant grown under different biotic and abiotic stress and environmental conditions might be useful for the selection of efficient bio-inoculant for enhancing plant growth. More information is available regarding the belowground plant microbiome under different stress condition, and many plant growth–promoting rhizobacteria (PGPR) are available in the market. However, our knowledge on the aboveground plant parts–associated microbiome is much lesser compared to the belowground plant part–associated microbiome (Compant et al. 2019).

Microorganisms associated with the plant roots are mostly derived from the soil environment (Shrivastava et al. 2014), which is dominated by the genera of *Acidobacteria*, *Verrucomicrobia*, *Bacteroidetes*, *Proteobacteria*, *Planctomycetes*, and *Actinobacteria*. The rhizosphere region (soil influenced by the root exudates) is considered as a hot spot for the microbial activity and considered as one of the most complex ecosystems. Aboveground plant parts provide a niche for the endophytic and epiphytic microorganisms. It has been reported that phyllosphere microorganisms are diverse as that of the rhizosphere microbial population (Wallace et al. 2018). Kecskemeti et al. (2016) reported the dominance of *Pseudomonas*, *Sphingomonas*, *Frigoribacterium*, *Curtobacterium*, *Bacillus*, *Enterobacter*, *Acinetobacter*, *Erwinia*, *Citrobacter*, *Pantoea*, and *Methylobacterium* in the phyllosphere of grapevine.

7.4.1 Phyllosphere Microorganism

Methylotrophic microorganisms are defined as "microbes which can utilize C1 compounds as the sole source of carbon and energy" (Iguchi et al. 2015)

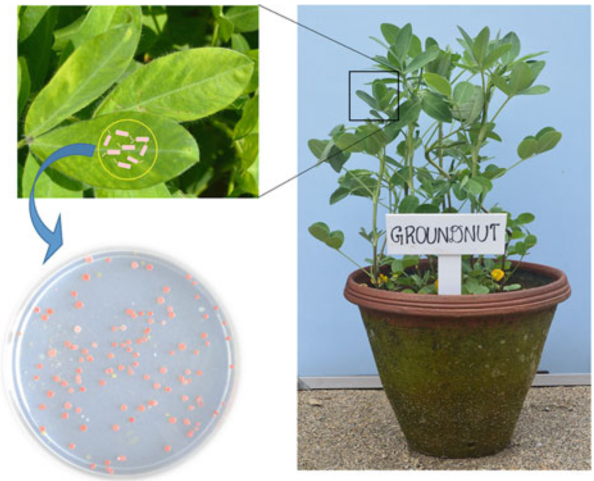

Fig. 7.4 Leaf phyllosphere methylotrophic bacteria associated with the groundnut plant

(Fig. 7.4). "The phyllosphere is found to be a well-known habitat of methanol-utilizing methylotrophs, and leaf surfaces are colonized by a large population of these bacteria, which include the genera *Methylobacterium*, *Methylophilus*, *Methylibium* and *Hyphomicrobium*" (Iguchi et al. 2015). *Methylobacterium* is known as pink-pigmented facultative methylotrophic (PPFMs) bacteria due to their pink pigment production. PPFMs are aerobic (required oxygen for growth), gram-negative bacteria, and they utilize formate, formaldehyde, or methanol as the sole carbon and energy source in addition to multicarbon compound. PPFMs can be easily isolated on a methanol-based mineral medium (ammonia mineral salt medium). Among the limited carbon sources present on plant leaves, methanol is assumed to be abundant (Kawaguchi et al. 2011), which provides an advantage for colonization of methanol-utilizing methylotrophs on plant phyllosphere (Sy et al. 2005; Iguchi et al. 2015). In addition, some methylotrophic bacteria can utilize C2, C3, and C4 carbon compounds.

7.4.2 Biodiversity of Methylotrophic Bacteria

The different classes of methylotrophic bacteria communities have been reported from diverse extreme habitats and as plant microbiomes. The methylotrophic bacteria communities belong to diverse classes of proteobacteria, namely α-, β-, and γ-proteobacteria. The class α-proteobacteria has been reported as most dominant followed by β-proteobacteria. On review, plant associated methylotrophic microbial diversity and of microbiomes of extreme environments, it was found that seven different families, namely Beijerinckiaceae, Hyphomicrobiaceae, Methylobacteriaceae, Methylococcaceae, Methylocystaceae, Methylophilaceae, and Rhodobacteraceae have been sorted out. The methylotrophic bacterial communities belong to 15 different genera, which are "*Hyphomicrobium, Methylarcula, Methylobacillus, Methylobacterium, Methylocapsa, Methylocella, Methyloferula, Methylohalomonas, Methylomonas, Methylophilus, Methylopila, Methylosinus, Methylotenera, Methylovirgula* and *Methylovorus*" (Kumar et al. 2016).

7.4.3 Methylotrophic Bacteria and Stress Mitigation

Plant growth–promoting rhizobacteria (PGPR) are important in agriculture, since their presence enhances plant growth and stress tolerance (Vilchez and Manzanera 2011; Prasad et al. 2015). Timmusk et al. (2013) gave the new terminology for the PGPR, which mitigates the plant drought as rhizobacterial drought-tolerance enhancers (RDTEs). Many RDTEs have been isolated from drought-affected areas (Dimkpa et al. 2009; Roca et al. 2013), and the isolates were found to augment plant growth under drought conditions. Similarly, the phyllosphere methylotrophic bacteria involved in the drought mitigation can be collectively called as phyllo-bacterial drought-tolerance enhancers (PDTEs).

7.4.4 1-Aminocyclopropane-1-Carboxylate Deaminase and Hormone Production

Ethylene in plant interrupts number of processes involved in plant growth and yield, and plays a major role in plant biotic and abiotic responses. In plant, ethylene synthesis occurs in three enzymatic pathways. First, methionine is converted into sadenosyl methionine (SAM), followed by the formation of ACC. Increased production of ACC activates ACC oxidase enzyme, which converts ACC to ethylene (Madhaiyan et al. 2006a; Chen et al. 2013). These enzymatic reactions are stimulated in the root system and increase ethylene concentrations in roots under drought conditions. Increased concentrations of ethylene in plants have detrimental effects (Glick 2014). Ethylene affects the photosynthesis process and stomata conductance; in addition, it interacts with other plant hormones such as auxin and abscisic acid. Plants that are treated with PPFMs that synthesize the enzyme 1-aminocyclopropane-1-carboxylate (ACC) deaminase break down the ACC to ammonia and alpha ketobutyrate (Fig. 7.5). Because of bacterial ACC deaminase enzyme, ethylene production in plants are reduced under stress conditions.

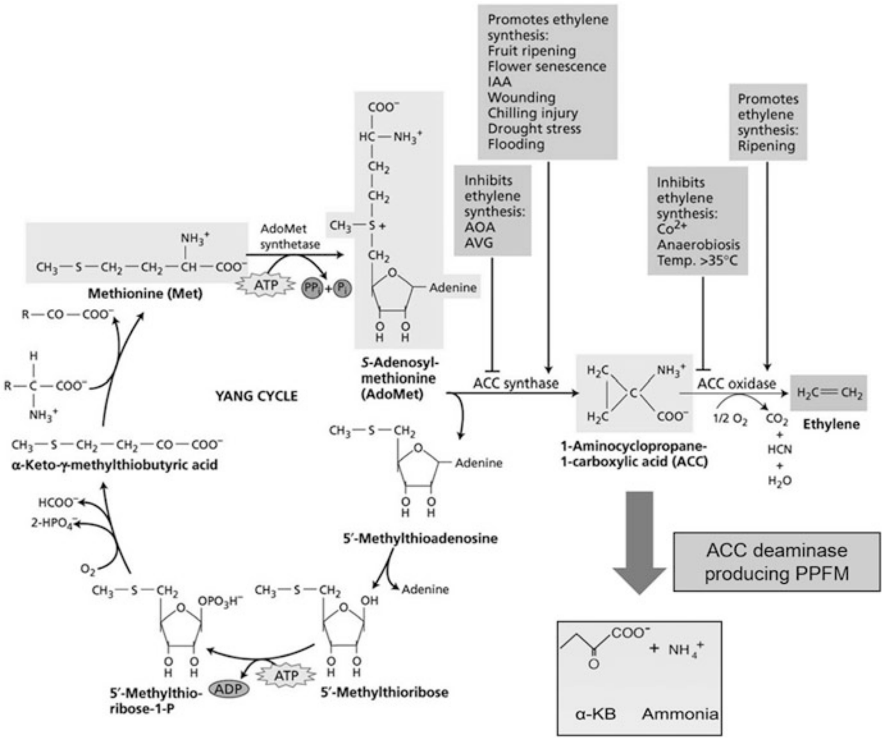

Fig. 7.5 Ethylene biosynthesis pathway and breakdown of ethylene precursor (ACC) by ACC deaminase produced by PPFM. (Modified from McKeon et al. 1995)

Saleem et al. (2018) reported that ACC deaminase–producing bacteria reduced leaf ACC levels by 41% compared to uninoculated plants under drought conditions. *Vigna mungo* L. and *Pisum sativum* L. treated with the ACC deaminase–producing plant growth–promoting bacteria enhances their drought tolerance by downregulating the ACC oxidase gene (Saikia et al. 2018). In rice plants, PPFM-mediated drought mitigation was reported by Kumar et al. (2017), where ACC deaminase–producing methylobacterium treatment reduced the plant ethylene stress under drought stress condition in rice plants. ACC deaminase–producing *Methylobacterium* spp. are able to modify the ethylene metabolism in plants during pathogen infection and enhancing plant tolerance against stress conditions (Yim et al. 2013).

Cytokinins are the class of plant phytohormones which promotes the cell division in shoots and roots. Methylobacterium was reported to produce higher amounts of cytokinin when it colonizes the plant as epiphyte and endophytes. Cytokinins produced by methylobacterium was found to improve bud formation in *Funaria hygrometrica* (Hornschuh et al. 2002). Recently Jorge et al. (2019) reported the drought stress mitigation by methylotrophic bacteria (*Methylobacterium oryzae*) through enhancing the plant cytokinin level.

7.4.5 Stomatal Regulation

Drought stress triggers the production of abscisic acid (ABA), which in turn induces the expression of various genes involved in stomatal closure and accumulation of compatible solutes. PPFMs control stomata closure through direct and indirect ways. As regards the direct ways, volatile compounds, or microbial-associated molecular pattern (MAMP), activate plant defense–related plant hormones, such as salicylic acid (SA) and jasmonic acid (JA), and trigger ABA-independent stomatal closure through nitric oxide (NO) and open stomata 1 (OST1) signal cascade. In case of indirect method, the negative effect of ethylene to the ABA in drought stress is reduced by ACC deaminase–producing PPFM.

Relative water content of plant tissue is considered as one of the tools to assess drought tolerance. It reflects the tissue water status and has direct relevance to photosynthetic rate and stomata opening. Plants treated with PPFM showed significantly higher relative water content in tissues compared to the untreated control plants under drought conditions (Sivakumar et al. 2017). Similarly, significantly higher relative water content in PPFM-treated rice plant was reported by Kumar et al. (2017) under drought conditions compared to control plants.

7.4.6 Prevention of Reactive Oxygen Species Accumulation

Plants produce reactive oxygen species (ROS) under stress, which react with proteins, lipids, and deoxyribonucleic acid (DNA) causing oxidative damage and affect the normal functions of plants (Kapoor et al. 2019). In order to overcome the negative effect of ROS, plants develop antioxidant defense systems, comprising both enzymatic and non-enzymatic components that serve to prevent ROS accumulation and alleviate the oxidative damage occurring during drought stress (Nath et al. 2016, 2017; Kapoor et al. 2019). PPFM spray induces the synthesis of various enzymatic and non-enzymatic components in plants against ROS and thereby relieves the plant from drought stress. The enzymatic components include "superoxide dismutase" (SOD), "catalase" (CAT), "ascorbate peroxidase" (APX), and "glutathione reductase" (GR). The non-enzymatic components include cysteine, glutathione, and ascorbic acid, which are induced by PPFM and prevent the plants from drought stress.

The enzyme catalase is involved in the detoxification of reactive oxygen species, especially hydrogen peroxide. The level of catalase enzyme in PPFM-treated tomato plants was increased up to 28% compared to control under drought condition (Sivakumar et al. 2017). Genes involved in the production of enzymes that are involved in the degradation of catalase and superoxide dismutase were identified in methylobacterium (Sanchez-Lopez et al. 2018).

Madhaiyan et al. (2004) reported the development of methylobacterium mediated induced systemic resistance development in rice against *Rhizoctonia solani*. Methylobacterium inoculation was found to increase the induced systemic resistance in groundnut plants by improving phenylalanine ammonia lyase (PAL), β-1, 3-glucanase, and peroxidase (PO) activities (Madhaiyan et al. 2006b). Plants inoculated with methylobacterium produced higher amounts of β-1,3-glucanase, PAL, PO, and PPO when challenged with *Ralstonia solanacearum* (Yim et al. 2013). Similarly, *Methylobacterium oryzae* CBMB20 increased activities of pathogenesis-related (PR) proteins and defense enzymes such as β-1,3-glucanase, phenylalanine ammonia-lyase, peroxidase, and polyphenol oxidase in tomato plants when plants were infected by *Pseudomonas syringae* pv. *tomato* (Indiragandhi et al. 2008).

7.5 Conclusion

Action has to be taken to face the global threat from rising temperature, inconsistent rainfall, and salinization of lands, which are the products of climate change. Emission of greenhouse gases and increased temperature affect plant growth and productivity. Corrective measures must be taken to reduce the greenhouse gases and, at the same time, research has to be focused on plant interactions with various biotic and abiotic factors. Knowledge on plant interactions with biotic factors, particularly with microorganisms, may be helpful in the development of eco-friendly solutions for the enhancement of plant growth under various adverse climatic conditions. Plants themselves recruit their beneficial microorganisms from the natural environment. The recruited plant microbiome helps in enhancing plant growth through various mechanisms. In future, we need to have in-depth knowledge on the habitat adopted plant microbiome of each crop and dominant microbiome in various ecosystems for sustainable crop production in the era of climate change.

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Synergies and Trade-offs Between Climate Change and the Sustainable Development Goals in the Context of Marine Fisheries

8

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Abstract

By 2050, humans will face the challenge of having to provide food and livelihoods to a population likely to exceed nine billion people. This challenge is well reflected in the United Nations Agenda 2030 for Sustainable Development, a global commitment to end poverty and hunger and to ensure that economic, social and technological progress occur in harmony with nature, through the sustainable management of natural resources. The goals of this agenda cover a wide array of critical areas in human development and socio-economic issues faced by humanity today, with many being interrelated. In particular, the goals of "Poverty Reduction," "Zero Hunger," "Decent Work and Economic Growth," Climate Action and "Life below Water" (Goals 1, 2, 8, 13 and 14) are especially impactful and relevant to the marine fishery industry and allied fields as well.

Globally, the fisheries and aquaculture sector supports the livelihoods of between 10 and 12% of the world's population, and in the last five decades, production has significantly outpaced population growth (FAO 2016), thus increasing its overall contribution to food security and nutrition (HLPE 2014). In India, a country which is home to 10% of the world's total biodiversity of fish and the world's second largest producer of fish, over 1.5 crore people directly depend on it for survival and it nets more than 5% of its GDP and over 10% of its foreign exchange earnings by exporting fish and marine products; yet fishermen and fisheries get little attention from either policy makers or the political class.

An additional consideration to the challenge of meeting the Sustainable Development Goals is that they will have to be met at a time when the effects of climate change will be increasingly prominent. The 2015 Paris Climate Agreement of the United Nations Framework Convention on Climate Change

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(UNFCCC) explicitly recognizes the fundamental priority of safeguarding food security and ending hunger when pursuing climate action. The Fifth Assessment Report of the IPCC concludes, with high confidence, that global marine species redistribution and marine biodiversity reduction in sensitive regions will challenge the sustained provision of fisheries productivity by the mid-twenty-first century (IPCC. 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 [Core Writing Team, R.K. Pachauri and L.A. Meyer (eds.)]. IPCC, Geneva, 151 pp, 2014) and preparedness is essential to translate changes into opportunities. Furthermore, the IPCC notes that adaptation is place- and context-specific, with no single approach for reducing risks that will apply across all settings (IPCC. 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 [Core Writing Team, R.K. Pachauri and L.A. Meyer (eds.)]. IPCC, Geneva, 151 pp, 2014).

This chapter will attempt to make a summary of the fishery industries of various key economic regions in terms of the efforts undertaken to fulfil the sustainable development goals in these areas, as well as focus on the synergies and trade-offs between the different sustainable goals, and examine the political and economic issues that pose challenges to the attainment of these goals.

Keywords

Sustainable development goals · Marine fisheries · Climate change · Mariculture · Food and nutritional security

8.1 Introduction

In 1972, governments met in Stockholm, Sweden, for the United Nations Conference on the Human Environment, to consider the rights of the family to a healthy and productive environment. In 1983, the United Nations created the World Commission on Environment and Development which defined sustainable development as "meeting the needs of the present without compromising the ability of future generations to meet their own needs." In 1992, the first United Nations Conference on Environment and Development (UNCED) or Earth Summit was held in Rio de Janeiro, where the first agenda for Environment and Development, also known as Agenda 21, was developed and adopted.

In 2012, the United Nations Conference on Sustainable Development (UNCSD), also known as Rio+20, was held as a 20-year follow-up to UNCED. Colombia proposed the idea of the SDGs at a preparation event for Rio+20 held in Indonesia in July 2011. In September 2011, this idea was picked up by the United Nations Department of Public Information 64th NGO Conference in Bonn, Germany. The outcome document proposed 17 sustainable development goals and associated targets. At the Rio+20 Conference, a resolution was reached by member states focusing on key themes such as poverty eradication, energy, water and sanitation, health and human settlement.

The Rio+20 outcome document mentioned that "at the outset, the Open Working Group will decide on its methods of work, including developing modalities to ensure the full involvement of relevant stakeholders and expertise from civil society, Indigenous Peoples, the scientific community and the United Nations system in its work, in order to provide a diversity of perspectives and experience."

In January 2013, the 30-member UN General Assembly Open Working Group on Sustainable Development Goals was established to identify specific goals for the SDGs. The Open Working Group (OWG) was tasked with preparing a proposal on the SDGs for consideration during the 68th session of the General Assembly, September 2013–September 2014. On 19 July 2014, a proposal for the SDGs was forwarded to the Assembly. After 13 sessions, the OWG submitted their proposal of 17 SDGs and 169 targets to the 68th session of the General Assembly in September 2014. On 5 December 2014, the UN General Assembly accepted the Secretary General's Synthesis Report, which stated that the agenda for the post-2015 SDG process would be based on the OWG proposals.

The Post-2015 Development Agenda was a process from 2012 to 2015 led by the United Nations to define the future global development framework that would succeed the Millennium Development Goals. The SDGs were developed to succeed the Millennium Development Goals which ended in 2015. Many of the gaps and shortcomings of MDG led to identifying a problematic donor-recipient relationship and instead, the new SDGs favour collective action by all countries.

Negotiations on the Post-2015 Development Agenda began in January 2015 and ended in August 2015, running in parallel to United Nations negotiations on financing for development, which determined the financial means of implementing the Post-2015 Development Agenda; those negotiations resulted in adoption of the Addis Ababa Action Agenda in July 2015. A final document was adopted at the UN Sustainable Development Summit in September 2015 in New York.

On 25 September 2015, the 193 countries of the UN General Assembly adopted the 2030 Development Agenda titled "Transforming our world: the 2030 Agenda for Sustainable Development." Paragraph 51 of this Agenda outlines the 17 Sustainable Development Goals and the associated 169 targets and 232 indicators.

Global climate change affects people. ecosystems, and livelihoods across the world (Venkatramanan et al. 2020a). The negative effects of climate change can be minimised through adoption of mitigation and adaptation strategies, and climate resilient development pathways (Venkatramanan et al. 2020a, b). Nevertheless, the poor or people who are dependent on nature for their livelihood or the people who inhabit the coastal regions and islands are vulnerable to climate change as they are devoid of resources. Vulnerable people include "indigenous peoples, minorities, women, children, the elderly, persons with disabilities, and other groups especially dependent on the physical environment" (Orellana 2010). Further the climate change also challenges human rights which encompasses the "rights to life, adequate food, water, health, adequate housing, and the right to self-determination" (Orellana 2010).

8.2 Marine Fisheries and Mariculture in the Context of Climate Change

India is endowed with a rich marine fishery resource base with a continental shelf area of nearly 0.53 million square kilometres. The sector has exhibited impressive growth over the past six decades with over six times increase in landings from 0.53 million tonnes in 1950–51 to about 3.81 million metric tonnes in 2017 (CMFRI 2018). Recent assessments suggest that through proper implementation of sustainable management options, it is possible to enhance the production potential in the Indian exclusive economic zone (EEZ) to the extent of 5 million tonnes per annum or more. Opportunities presented by mariculture are even more promising (Gopalakrishnan et al. 2017). Some of the more promising mariculture options include open sea cage farming, seaweed farming, integrated multi-trophic farming (IMTA), mussel and oyster culture, ornamental fish production, pearl culture, etc. Further, mariculture including finfish cage farming, molluscan farming, seaweed farming and open sea marine cage farming along the Indian coasts can augment marine food production.

Investigations carried out through the National Level NICRA project of CMFRI have identified several significant climatic effects on marine sector. Effect of climatic parameters on phenology of various marine fishes was studied and results indicate that sea surface temperature (SST), Chl-a, current speed, wind and rainfall have significant influence on the diet, spawning, maturity, distribution and catch. Additionally vulnerability assessment of fish and for long-term prediction of fisheries that changed along Indian coast, scientific criteria on exposure, sensitivity and adaptive capacity of Indian species in relation to climate variables were developed (Zacharia et al. 2016). Fish stock vulnerability assessment as per the developed criteria carried out at different zones indicated several low, medium and highly vulnerable species for which adaptation and mitigation options were suggested. Carbon footprint in life cycle of marine fisheries was analysed along Indian coast, and highest emissions were recorded in harvest phase in all cases. Adaptive capacity of Zoanthids and its distribution related to climate change was affirmed. The study provides information, first of its kind, on quantitative Zoanthid distribution and the dynamic changes exhibited by Zoanthids in relation to various environmental variables relevant in the context of climate studies. Analysis of phytoplankton community changes in sardine habitat off Kochi reveals unusual dominance of *Melosira sulcata* in 2015 along with high SST, which could be attributed to high tolerance of the species. Genetic stock structure investigations were carried out in Indian oil sardine, *Sardinella longiceps*, using microsatellite markers developed. Genetic distinctiveness detected points out that there are reproductively isolated subpopulations associated with local climate challenges, leading to a process of larval retention.

Experimental studies conducted on assessment of carbon sequestration potential of seaweed (*Kappaphycus alvarezii*) revealed the specific rate of sequestration (per unit mass of seaweed per unit time) of CO_2 by the seaweed as 0.0187 g/day. Experiments were carried out to find the impacts of temperature and salinity on potential mariculture species. In case of Cobia (*Rachycentron canadum*), many of the advantageous results in the hatchery were at a temperature range of 27.5–32 °C. It was found that 78.89 % of the fertilized cobia eggs hatched at 31 ppt salinity and a poor hatching percentage of 15.18 % was noticed at lower salinity ranges of 25 ppt. Temperature ranges of 29–31 °C were found to be advantageous in the larviculture of Silver pompano, *Trachinotus blochii*, for better survival as well as growth rate. The average increase of 2 °C in water temperature (i.e. 32 °C) resulted in reduced growth of larvae. However in cases when the increase was 2 °C beyond the ambient, it resulted in metaplasia of kidney cells. Experimental studies on the effect of different salinities on cell density of *Nannochloropsis oculata* and *Chlorella* sp. suggest that the growth rates are higher at the salinities of 30 and 33 ppt where the stationary phase was achieved on 15th and 11th day of culture, respectively. It was observed that rotifers maintained at 35 °C with *Nannochloropsis* sp. as feed have multiplied to a maximum of 360 numbers per ml at 48 h. Highest multiplication of rotifers was recorded in the range of 30 ppt followed by 25 ppt and least growth was recorded at 15 ppt.

8.3 National Policy on Marine Fisheries and Mariculture

National marine fisheries policy 2017 acknowledges the climate change as one of the biggest challenges that the fisheries sector is facing with necessity for time-bound adaptation and management plans. Climate change impacts with alternations in fish stock, abundance and vulnerability are profoundly evident in Indian EEZ and nearby high seas, which compels deviations on the fishing operations. The government will encourage focused studies on climate change impacts on fish stocks and fishing communities, besides implementation of adaptation options in a time-bound manner. As part of India's International commitments on climate change, the concept of green fisheries by reducing greenhouse gases (GHG) emissions from fishing and fishing-related activities will also be encouraged. As per National Marine Fisheries Policy 2017 the fisheries co-operatives will also be encouraged and strengthened in carrying out a science-based approach to address fisheries and climate-related issues.

8.4 Effect of Climate Change on Fisheries

Climate change in the near future will adversely affect the wild capture fisheries as well as aquaculture in India. With the increased frequency in extreme weather events such as cyclones, floods and adverse aquatic conditions, marine fisheries are often impacted, rendering a considerable reduction for active harvest operations. Aquatic resources face challenges in the form of diminishing resources due to over-exploitation and these vulnerable resources now face the potentially ruinous impacts of climate change. Additional focus needs to be made on increasing production to satiate the demand by promoting aquaculture. Natural water ponds inundated by floodwater for as many as 9 months in a year can be successfully seeded with fast-growing fishes by undertaking minimal alterations in the existing bunds and related infrastructure. In spite of this, policy support to govern the development of aquaculture in a sustainable manner is not in place in India.

8.5 SDG 2030 Agenda and Its Relevance to Marine Fisheries

Listed in order, 4 Goals out of the 17 of the 2030 Agenda are of particular relevance to the marine fisheries industry and its intersection with climate change. These 4 goals also include 42 separate targets, which are listed below.

Goal 1 – End Poverty in All Its Forms Everywhere
Targets for Goal 1 include:

- "*By 2030, eradicate extreme poverty for all people everywhere, currently measured as people living on less than $1.25 a day*
- *By 2030, reduce at least by half the proportion of men, women and children of all ages living in poverty in all its dimensions according to national definitions*
- *Implement nationally appropriate social protection systems and measures for all, and by 2030 achieve substantial coverage of the poor and the vulnerable*
- *By 2030, ensure that all men and women, in particular the poor and the vulnerable, have equal rights to economic resources, as well as access to basic services, ownership and control over land and other forms of property, inheritance, natural resources, appropriate new technology and financial services, including microfinance*
- *By 2030, build the resilience of the poor and those in vulnerable situations and reduce their exposure and vulnerability to climate-related extreme events and other economic, social and environmental shocks and disasters*
- *Ensure significant mobilization of resources from a variety of sources, including through enhanced development cooperation, in order to provide adequate and predictable means for developing countries, in particular least developed countries, to implement programmes and policies to end poverty in all its dimensions*
- *Create sound policy frameworks at the national, regional and international levels, based on pro-poor and gender-sensitive development strategies, to support accelerated investment in poverty eradication actions*" (Valeri 2019, pp. 43)

Many of the targets under Goal 1 can be at the very least partially fulfilled if the marine fisheries industry is utilized as a source of employment for coastal populations. These are synergistic with targets of Goal 2, providing food security and improved nutrition. However, this may result in trade-offs against the targets of Goal 14, Life below Water, as a result of promotion of over-extraction of marine living resources.

Goal 2 – End Hunger, Achieve Food Security and Improved Nutrition and Promote Sustainable Agriculture
Targets for Goal 2 include:

- "*By 2030, end hunger and ensure access by all people, in particular the poor and people in vulnerable situations, including infants, to safe, nutritious and sufficient food all year round*
- *By 2030, end all forms of malnutrition, including achieving, by 2025, the internationally agreed targets on stunting and wasting in children under 5 years of age, and address the nutritional needs of adolescent girls, pregnant and lactating women and older persons*
- *By 2030, double the agricultural productivity and incomes of small-scale food producers, in particular women, indigenous peoples, family farmers, pastoralists and fishers, including through secure and equal access to land, other productive resources and inputs, knowledge, financial services, markets and opportunities for value addition and non-farm employment*
- *By 2030, ensure sustainable food production systems and implement resilient agricultural practices that increase productivity and production, that help maintain ecosystems, that strengthen capacity for adaptation to climate change, extreme weather, drought, flooding and other disasters and that progressively improve land and soil quality*
- *By 2020, maintain the genetic diversity of seeds, cultivated plants and farmed and domesticated animals and their related wild species, including through soundly managed and diversified seed and plant banks at the national, regional and international levels, and promote access to and fair and equitable sharing of benefits arising from the utilization of genetic resources and associated traditional knowledge, as internationally agreed*
- *Increase investment, including through enhanced international cooperation, in rural infrastructure, agricultural research and extension services, technology development and plant and livestock gene banks in order to enhance agricultural productive capacity in developing countries, in particular least developed countries*
- *Correct and prevent trade restrictions and distortions in world agricultural markets, including through the parallel elimination of all forms of agricultural export subsidies and all export measures with equivalent effect, in accordance with the mandate of the Doha Development Round of 2001*
- *Adopt measures to ensure the proper functioning of food commodity markets and their derivatives and facilitate timely access to market information, including on food reserves, in order to help limit extreme food price volatility*" (Valeri 2019, pp. 43–44).

Marine living resources, if appropriately exploited, are an excellent source of healthy and nutritive food sources. The consumption of marine fisheries aid in the achievement of food and nutritional security.

Goal 8 – Decent Work and Economic Growth
Targets for Goal 8 include:

- *"Sustain per capita economic growth in accordance with national circumstances and, in particular, at least 7% gross domestic product growth per annum in the least developed countries*
- *Achieve higher levels of economic productivity through diversification, technological upgrading and innovation, including through a focus on highvalue added and labour-intensive sectors*
- *Promote development-oriented policies that support productive activities, decent job creation, entrepreneurship, creativity and innovation, and encourage the formalization and growth of micro-, small- and medium-sized enterprises, including through access to financial services*
- *Improve progressively, through 2030, global resource efficiency in consumption and production and endeavour to decouple economic growth from environmental degradation, in accordance with the 10-Year Framework of Programmes on Sustainable Consumption and Production, with developed countries taking the lead*
- *By 2030, achieve full and productive employment and decent work for all women and men, including for young people and persons with disabilities, and equal pay for work of equal value*
- *By 2020, substantially reduce the proportion of youth not in employment, education or training*
- *Take immediate and effective measures to eradicate forced labour, end modern slavery and human trafficking and secure the prohibition and elimination of the worst forms of child labour, including recruitment and use of child soldiers, and by 2025 end child labour in all its forms*
- *Protect labour rights and promote safe and secure working environments for all workers, including migrant workers, in particular women migrants, and those in precarious employment*
- *By 2030, devise and implement policies to promote sustainable tourism that creates jobs and promotes local culture and products*
- *Strengthen the capacity of domestic financial institutions to encourage and expand access to banking, insurance and financial services for all*
- *Increase Aid for Trade support for developing countries, in particular least developed countries, including through the Enhanced Integrated Framework for Trade-related Technical Assistance to Least Developed Countries*
- *By 2020, develop and operationalize a global strategy for youth employment and implement the Global Jobs Pact of the International Labour Organization*" (Valeri 2019, pp. 49–50).

Similarly, to Goal 1, many of the targets under Goal 8 can be at the very least partially fulfilled if the marine fisheries industry is utilized as a source of employment for coastal population. Synergies between Goal 1, 2 and 8 exist throughout many of the targets.

Goal 13 – Urgent Action to Combat Climate Change
Targets for Goal 13 include:

- *"Strengthen resilience and adaptive capacity to climate-related hazards and natural disasters in all countries*
- *Integrate climate change measures into national policies, strategies and planning*
- *Improve education, awareness-raising and human and institutional capacity on climate change mitigation, adaptation, impact reduction and early warning*
- *Implement the commitment undertaken by developed-country parties to the United Nations Framework Convention on Climate Change to a goal of mobilizing jointly $100 billion annually by 2020 from all sources to address the needs of developing countries in the context of meaningful mitigation actions and transparency on implementation and fully operationalize the Green Climate Fund through its capitalization as soon as possible*
- *Promote mechanisms for raising capacity for effective climate change-related planning and management in least developed countries and small island developing States, including focusing on women, youth and local and marginalized communities*" (Valeri 2019, pp. 54–55).

Goal 14 – Life Below Water
Targets for Goal 14 include:

- "*By 2025, prevent and significantly reduce marine pollution of all kinds in particular from land based activities including marine debris and nutrient pollution.*
- *By 2020, sustainably manage and protect marine and coastal ecosystems to avoid significant adverse impacts, including by strengthening their resilience, and take action for their restoration in order to achieve healthy and productive oceans*
- *Minimize and address the impacts of ocean acidification, including through enhanced scientific cooperation at all levels*
- *By 2020, effectively regulate harvesting and end overfishing, illegal, unreported and unregulated fishing and destructive fishing practices and implement science-based management plans, in order to restore fish stocks in the shortest time feasible, at least to levels that can produce maximum sustainable yield as determined by their biological characteristics.*
- *By 2020, conserve at least 10% of coastal and marine areas, consistent with national and international law and based on the best available scientific information.*
- *By 2020, prohibit certain forms of fisheries subsidies which contribute to overcapacity and overfishing, eliminate subsidies that contribute to illegal, unreported and unregulated fishing and refrain from introducing new such subsidies, recognizing that appropriate and effective special and differential treatment for developing and least developed countries should be an integral part of the World Trade Organization fisheries subsidies negotiation.*

- *By 2030, increase the economic benefits to small island developing States and least developed countries from the sustainable use of marine resources, including through sustainable management of fisheries, aquaculture and tourism.*
- *Increase scientific knowledge, develop research capacity and transfer marine technology, taking into account the Intergovernmental Oceanographic Commission Criteria and Guidelines on the Transfer of Marine Technology, in order to improve ocean health and to enhance the contribution of marine biodiversity to the development of developing countries, in particular small island developing States and least developed countries.*
- *Provide access for small-scale artisanal fishers to marine resources and markets.*
- *Enhance the conservation and sustainable use of oceans and their resources by implementing international law as reflected in the United Nations Convention on the Law of the Sea, which provides the legal framework for the conservation and sustainable use of oceans and their resources*" (Valeri 2019, pp. 55–56).

8.6 SDG Compliance in Different Nations

Success of the Sustainable Development Goals depends on an effective and robust monitoring system. The 2030 Agenda utilizes the sustainable development goals to set into place a global reporting structure at the local, national and regional levels, culminating in the UN High Level Political Forum. As part of the follow-up and review mechanisms, the 2030 Agenda for Sustainable Development encourages member states to "conduct regular and inclusive reviews of progress at the national and sub-national levels, which are country-led and country-driven." To that end, a review platform containing a database of the voluntary national reviews is stored in an online repository.

Compliance and adherence to self-set deadlines remains an issue, with many nations not providing updates on programmes that have been put in place to meet the targets of the Sustainable Development Goals.

8.6.1 India

8.6.1.1 Assisting Small and Artisanal Fishermen[1]

The National Policy on Marine Fisheries 2017 aims (a) to enhance their skill and livelihood and (b) to provide accidental insurance to them and their families through a series of schemes particularly for the small fishermen. Further, the National Scheme of Welfare of Fishermen through different activities aims "to enhance livelihood and quality of life of small fishermen below poverty line." Also under the scheme, grant-in-aid is provided for the creation of model fishermen villages.

[1]Assisting small and artisanal fishermen by India. Retrieved from https://oceanconference.un.org/commitments/?id=20664 (Accessed on 6-4-2020)

Such villages are bestowed with amenities like housing, drinking water, sanitation, community hall building (https://oceanconference.un.org/commitments/?id=20664).

India has shared its expertise and experience on oceanography with its partner countries. In the Indian Ocean region, the Indian National Centre for Ocean Information Services (ESSO-INCOIS) is one of the few centres providing value added and comprehensive ocean-service products to a vast array of users (from fishermen folk to marine industries).

8.6.1.2 Capacity Development of SAS Member Countries for the Preparation of Specific Policies to Implement Goal 14[2]

"South Asia Co-operative Environment Programme" (SACEP) is an inter-governmental Organization, established in 1982 by Governments of the eight South Asian countries – Afghanistan, Bangladesh, Bhutan, India, Maldives, Nepal, Pakistan and Sri Lanka, all of whom have ratified the articles of Association of SACEP. The basic aim of the programme is to promote and support protection and management of the environment in the region. SACEP is also the Secretariat for the South Asian Seas Programme (SASP), which is one of the eighteen Regional Seas Programmes of the United Nations Environment Programme (UNEP). SACEP is involved in the capacity development, experience sharing, policy formulation, action plan, strategic plan and task force for the member countries (https://oceanconference.un.org/commitments/?id=15445).

8.6.1.3 Designation of Marine Protected Areas

With over 7500-km-long coastline, 5400 km of which is on the mainland and over 2000 km is in the Andaman & Nicobar and Lakshadweep islands, India's coastline supports more than 30% of its population. Coastal fisheries are inextricably linked to economic and environmental health. Coastal vegetation habitats are important for the health of coastal ecological systems through their modulation of land-ocean interactions, providing nutrients for marine life, supporting biodiversity and preventing salt intrusion into ground water. Well-managed coastal beaches can also promote sustainable economic development such as ports and tourism.

A Marine Protected Area (MPA) is essentially a space in the ocean where human activities are more strictly regulated than the surrounding waters – similar to national parks on land. MPAs are given special protections for natural or historic marine resources by local, state, territorial, native, regional or national authorities.

The MPA network has been used as a tool to manage natural marine resources for biodiversity conservation and for the well-being of people dependent on it. MPAs are essential to safeguard biodiversity and to sustain vibrant seas and can increase biomass and biodiversity in tropical and temperate ecosystems. They help in

[2]Capacity development of SAS member countries for the preparation of specific policies to implement Goal 14. Retrieved from https://oceanconference.un.org/commitments/?id=15445 (Accessed on 8-4-2020)

increasing resilience against impacts of fishing and other activities that affect habitats. Scientific monitoring and traditional observations confirm that depleted natural marine resources are getting restored and/or pristine ecological conditions have been sustained in well-managed MPAs.

In India, there are 25 protected areas in the mainland and 106 in the islands. Detailed information in this regard is available at the website of the Environmental Information Centre (ENVIS) for Wildlife and Protected Areas under the Ministry of Environment, Forests and Climate Change. The designation and maintenance of these MPAs represent India's commitment to contribute to the maintenance and conservation of marine biological diversity and abundance which are relevant to sustainable fisheries and maintenance of coastal processes.

8.6.2 United States of America

8.6.2.1 Big Ocean

Big Ocean seeks to engage in a variety of activities and initiatives, as well as create products that produce tangible, practical outcomes. To date, the network has employed three general approaches to accomplish its purpose and aims: (a) Capacity Building – expanding the skills and professional experience of member site staff to improve operations at the site level and to enhance functioning of the network. Activities include business meetings, staff exchanges and joint research cruises. (b) Communication – enhancing the development, collection, analysis and sharing of information (and knowledge) internally and externally. Activities include membership surveys, outreach materials, maintaining a presence on the web and across social media, and presentations at international conferences. (c) Product Development – the creation of tools and services that enhance management efforts; improve the design, establishment and long-term management of large-scale MPAs; increase the effectiveness of management actions; and further professionalize the field. Examples of tools and services include: Learning Exchanges, the Shared Research Agenda for Large-Scale Marine Managed Areas, and Management Guidelines for Large-Scale MPAs.

Big Ocean is an informal network, in which members and partners participate voluntarily. As a non-binding entity, the activities and commitments made by the network (or subset of the network) are also non-binding and carried forward voluntarily by members and partners who find value in the effort.

8.6.2.2 Fisheries Conservation in the Wider Caribbean Region Through FAO's Western Central Atlantic Fisheries Commission (WECAFC)

The general objective of the commission is to promote the effective conservation, management and development of the living marine resources of the area of competence of the commission, in accordance with the FAO Code of Conduct for Responsible Fisheries (FAO-CCRF), and address common problems of fisheries management and development faced by members of the commission: 16 of WECAFC's 35 members are considered small island developing States.

Fishery scientists, experts, managers and decision-makers of member countries, regional partner organizations and NGOs participate in the working groups, which have specific terms of reference and are time bound. The data used by the working groups to generate fishery management advice and (non-binding) recommendations are collected by the participating countries and NGOs. Countries and relevant stakeholders are invited to make the non-binding recommendations binding at the national level by incorporating these in national laws, regulations, policies and management plans. Examples of goals include application of the 2010 FAO International Guidelines on Bycatch Management and Reduction of Discards by WECAFC members; capacity building among WECAFC members for implementation of the Port States Measures Agreement in the WECAFC region; establishment of a joint WECAFC/CRFM/OSPESCA Working Group on Illegal, Unreported and Unregulated Fishing; implementation of the strategy, action plan and programme proposal on disaster risk management and climate change adaptation in fisheries and aquaculture in the CARICOM region; organization of an FAO/WECAFC Training workshop for fisherfolk and fisheries managers on marine protected area (MPA) management; resource assessment carried out and a draft regional management plan Caribbean Spiny Lobster, *Panulirus argus*; development and endorsement of the Subregional Fisheries Management Plan for Flying fish in the Eastern Caribbean; development of a draft regional management plan for Queen Conch, *Strombus gigas*.

8.6.2.3 Global Coral Reef Monitoring Network

In 1995, the International Coral Reef Initiative called on many nations to commit to increasing research and monitoring of coral reefs in order to provide the data needed to inform policies of nations to sustain coral reefs and to strengthen management. Global reef monitoring was a major theme when ICRI was launched during the United Nations Global Conference on Sustainable Development of Small Islands Developing States in Barbados in 1994. It was during this time that the Global Coral Reef Monitoring Network (GCRMN) was established to support ICRI's Call to Action and Framework for Action. Today, the GCRMN works through a global network of stakeholders to support the management and conservation of coral reefs and is focused on the following major objectives – strengthen the scientific understanding of the status and trends of coral reef ecosystems at different places around the world. This scientific endeavour is to establish quantitatively rigorous baselines for earlier reef conditions and to document the extent to which different reefs have varyingly declined from a relatively more pristine to degraded state. This variability is important because some reefs are much healthier than others, and we need to understand why if we are to have any hope of preserving and restoring coral reefs and their ecosystem services in the foreseeable future. Strengthen communication among GCRMN members and provide information on network activities, identify opportunities to participate in regional and global reporting, share information on relevant meetings and involve GCRMN members in future monitoring (including the integration of biophysical monitoring with social, economic and environmental data) and assist Network members by the networking of technical assistance, problem-solving, participation in projects and to assist in seeking financial support.

Make coral-reef-monitoring data publicly available online in a timely fashion. In addition to these priorities, the GCRMN also works to link people and existing organizations to monitor the ecological, social, cultural and economic aspects of coral reefs within interacting regional networks. Strengthen the existing capacity across all regions for consistent and standard use of monitoring data that will effectively identify trends in coral reefs and will help discriminate between natural and anthropogenic climate change and allow this information to be compared in meaningful ways. Communicate results as widely as possible about the status and trends of coral reefs, and work with all levels of governance.

8.6.3 Eurozone

8.6.3.1 Blue Action Fund *by Germany, Federal Ministry for Economic Cooperation and Development*

The Blue Action Fund makes funding available for the activities of national and international non-governmental organizations in their efforts to help conserve marine and coastal ecosystems with the following objectives:

(i) The safeguarding of marine biodiversity by creating new protected areas and by improving the management of existing ones
(ii) The sustainable use of marine biodiversity: in fishery, aquaculture and in tourism

BMZ in cooperation with KfW Development Bank founded the Blue Action Fund as a response to the funding gap for the conservation of marine biodiversity. The initial endowment provided is worth 24 million Euro (approx. 26 million USD). The fund will work in Africa, Latin America, Asia and Pacific region. The Blue Action Fund will issue public tenders to which interested eligible organizations may submit their proposals.

8.6.3.2 Fostering the Conservation and Sustainable Use of Marine Biological Diversity Through the International Climate Initiative (IKI) *by Germany, Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety*

The German Government through the Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety (BMUB) facilitates via a range of bilateral, regional as well as global projects to the protection of coastal and marine areas in partner countries, their effective and sustainable management and long-term funding.

In addition to the focus on marine protected areas, other important aspects of cooperation include the support for sustainable artisanal fisheries and certification, combating of illegal fishing, reduction of pollution and the protection of coastal population from the consequences of climate change. The projects contribute substantially to the achievement of the SDGs especially SDG 14 as well as the Aichi

Biodiversity Targets, specifically related to coastal and marine challenges. The Funding volume for IKI projects in the field of coastal and marine biodiversity conservation ranges around 16 Million Euros in 2015 and 43 Million Euros in 2016.

8.6.3.3 French Initiative for Coral Reefs (IFRECOR)

IFRECOR's vocation is to promote the protection and sustainable management of coral reefs and their associated ecosystems, seagrasses and mangroves that are of major importance in the 9 concerned overseas territories.

Organization: The governance and the facilitation of the initiative are based on a national committee and a network of 9 overseas local committees, which meet every year to review the progress of the actions; its action relies on a 5-year working programme defined at both local and national scales.

Commitment: The plan of actions 2016–2020 adopted by France is the following:

- Strengthen knowledge and develop management tools on coral reef.
- Support the development of regulatory tools in order to protect them.
- Monitor and communicate on coral reefs, mangroves and seagrasses health.
- Contribute to the reduction of anthropogenic threats to coral reefs, mangroves and seagrasses.
- Contribute to a better consideration of coral reefs and associated ecosystems in the fight against climate change.
- Protect reefs by supporting Marine Protected Areas (MPAs).
- Diversify funding dedicated to the protection of reefs and associated ecosystems by developing public-private partnerships.

8.6.4 China

8.6.4.1 China's National Climate Change Program

According to China's National Climate Change Programme issued by the National Development and Reform Commission (NDRC), the country's first global warming policy initiative, the government will aim to adopt measures ranging from laws, economy, administration and technology which will combine to reduce greenhouse gas emissions and imbue the country with a flexible approach to climate change. The program focuses on energy production and use, agriculture, forestry and waste.

8.6.4.2 Sustainable Ocean Economy

To improve and strengthen the China's ocean economy, the following measures will be taken: promote transformation and upgrading of marine traditional industries such as marine fishery and offshore oil and gas industry; accelerate the development of newly emerging marine industry like marine equipment manufacture industry and marine renewable energy resources; improve the scale and level of marine tourism, shipping service industry, marine culture industry, marine-related financial service industries; develop ocean resources and protect marine ecological environment side by side and develop ecological, safe and environment-friendly industries.

8.6.4.3 Green Jobs in China

The Green Jobs Initiative is a partnership established in 2007 among the International Labour Organization, the United Nations Environment Programme and the International Trade Union Confederation. The International Organization of Employers joined in 2008.

As a rapidly developing country with a large population and a fragile eco-environment, China is vulnerable to the adverse effects of climate change. Global warming threatens both the ecosystems as well as the economic and social development of the country. The Green Jobs strategy offers a solution to the pursuit of growth, job creation, employment security and environmental protection. The primary objective of the green jobs programme in China is to help the country realize the potential for green jobs. The programme also aims to help China make a positive labour market transition in the face of climate change. Green Jobs reduce the environmental impact of enterprises and economic sectors, ultimately to levels that are sustainable, while also meeting the standards required of decent work. Areas of work that could respond to the challenges of climate change and other environmental problems include agriculture, food production, forestry, construction, energy supply and waste management.

8.6.4.4 Marine Observation and Early-Warning and Disaster Prevention and Mitigation Capacities

To effectively improve marine disaster prevention capacities of China, the following measure will be taken: build, upgrade and remould overseas observation stations, build a series of ground wave radar and buoys; advance comprehensive assessment of regional marine forecast ability and application of pilot work of marine risk investigation on large coastal projects; conduct monitoring, research and impact assessment on sea-level rise, ocean acidification, and climate change; evaluate impacts of climate change and human activities on economy, society, environment and resources, and make effective response solutions; strengthen cooperation with countries along the maritime silk road on building overseas observation stations and promote abilities responding to marine disasters.

8.7 Conclusion

The actions of individual nations with regard to the fisheries-related aspects of the Sustainable Development Goals are greatly lacking. Many major fishing nations have failed to submit timely reports in general, and the overall monitoring and progress in marine-fisheries-related goals is at best, insufficient. While many programmes have been started worldwide, steps to gauge their impact have not been taken in any significant form.

In India, the report on SDG progress contained a limited amount of information regarding Goal 14, though this may have resulted from the relatively recent (circa 2011) focus on the effects of climate change on marine fisheries. It may be possible for National Projects such as NICRA (National Innovations in Climate Resilient

Agriculture by ICAR) to begin the tracking of already established indicators as the new decade begins in order to more fully monitor the effectiveness of efforts to fulfil the Sustainable Development Goal Agenda in marine fisheries.

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Increasing Synergies Between Climate Change and Sustainable Development in Energy Policy

9

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Abstract

Viet Nam is currently one of the most dynamic economies increasing greenhouse gas (GHG) emissions. The country faces multiple challenges such as meeting energy demand, changing the energy mix as well as responding to climate change. In order to address how policies can contribute to creating synergies between climate change and the sustainable development goals (SDGs), this chapter focuses on SDG7 (affordable and clean energy). More concretely, key questions are how Viet Nam plans to achieve transition to green growth by scaling up renewable energy and where major barriers lie. Based on the recent progress in this policy area, it considers prospects for closer cooperation on sustainable development, climate change and renewable energy between the EU and Viet Nam.

Keywords

Viet Nam · Climate Change · Sustainable Development · Energy Policy · Renewable Energy

9.1 Introduction

In 2015, the UN adopted a new Agenda 2030 for Sustainable Development, setting 17 sustainable development goals (SDGs) with 169 targets. SDG7 is to ensure access to affordable, reliable, sustainable and modern energy. This goal has the following targets:

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- "7.1- By 2030, ensure universal access to affordable, reliable and modern energy services
- 7.2- By 2030, increase substantially the share of renewable energy in the global energy mix
- 7.3- By 2030, double the global rate of improvement in energy efficiency"[1]

Fuso Nerini et al. (2018) identified and characterised synergies and trade-offs between SDG7 on energy and other SDGs. A systematic assessment of SDG interactions concludes that in general, positive interactions between SDG7 and other SDGs outweigh negative ones (McCollum et al. 2018). Researchers agree that ensuring energy access for all (7.1), deployment of renewable energy (e.g. wind and solar) at scale (7.2), and energy efficiency improvements (7.3) will reduce greenhouse gas (GHG) emissions and therefore will have positive impacts on climate change mitigation under SDG13 (Fuso Nerini et al. 2018, 2019). However, a policy to promote universal access to energy for all (7.1) would keep the electricity price too low to reflect the production costs or the carbon content and risk increasing GHG emissions from fossil fuel energy with a negative impact on the climate (SDG13). This has been the case in Viet Nam, as explained in this chapter.
SDG13 is to take urgent action to combat climate change and its impacts with the following targets:

- 13.1- Strengthen resilience and adaptive capacity to climate-related hazards and natural disasters in all countries.
- 13.2- Integrate climate change measures into national policies, strategies and planning.
- 13.3- Improve education, awareness-raising and human and institutional capacity on climate change mitigation, adaptation, impact reduction and early warning.[2]

Climate action (SDG13) will require efforts to better plan and manage resources in an integrated way, thereby positively influencing renewable energy deployment (7.2) and energy efficiency improvements (7.3) (Fuso Nerini et al. 2019). On the other hand, SDG13 may negatively influence SDG7 in certain cases. Substituting fossil fuels such as coal and natural gas with renewable energy (7.2) might affect the delivery of affordable, reliable, modern energy services for all (7.1) (Fuso Nerini et al. 2019). Depending on the choice and design of a policy instrument, if distributional impacts of policies supporting renewable energy (7.2) and energy efficiency (7.3) are disproportionately large on low-income households, this could hinder progress towards universal access to energy (7.1) (Sovacool et al. 2016; Nilsson et al. 2018). Thus, renewable energy policies (7.2) that would risk increasing energy

[1] https://www.un.org/sustainabledevelopment/energy/ (last accessed on 28 July 2019)
Two other targets, 7.A and 7.B are outside the scope of this chapter.

[2] Ibid. Targets 13.A and 13.B are outside the scope of this chapter.

prices for low-income households (7.1) need to be accompanied by re-distributional fuel support mechanisms (McCollum et al. 2018).

To deliver the 2030 agenda, policymakers are recommended to mobilise additional resources and implement new laws and plans, taking sustainability into consideration when designing policy instruments (McCollum et al. 2018). In order to address the complexity of SDG interactions as described above, wider efforts to promote policy coherence across government bodies during policy planning and implementation (SDG 17.14) could be complemented by adaptation of institutional arrangements and governance to the needs for action.

Based on this background, this chapter starts with setting the broad context of Viet Nam's climate change mitigation in relation to economic development, demand and supply of energy, particularly in the electricity sector. This overview is followed by a summary of institutional arrangements and governance as well as a review of existing laws, plans, strategies and mechanisms in the areas of climate change, green growth and sustainable development, and energy. The review of policy instruments leads to identifying key challenges to Viet Nam in climate change mitigation and energy transition.

9.2 Context of Development and GHG Emission Growth in Viet Nam

Viet Nam is currently one of the most dynamic economies increasing GHG emissions, facing multiple challenges such as meeting energy demand, changing the energy mix as well as responding to climate change. To analyse the interactions between climate change and SDGs, particularly SDG7 on affordable and clean energy, Viet Nam offers an interesting example. The unique combination of geographical conditions and natural resource endowments frame Viet Nam's climate agenda. At the same time, the country's climate agenda shows barriers and opportunities that are common to neighbouring countries in Southeast Asia.

9.2.1 National Circumstances

In Viet Nam, climate change is increasing the number of extreme events, which affect levels of exposure and vulnerability (MONRE 2019). Viet Nam was ranked one of the five countries most affected by climate change (Bangalore et al. 2016), and ranked ninth among the countries most affected from 1998 to 2017 according to the German watch Climate Risk Index (Eckstein et al. 2018).

The country has a long coastline of 3260 km stretching from North to South with two major delta regions, the Red River Delta in the North with major cities such as Hanoi and Haiphong, and the Mekong River Delta in the South with the largest city, Ho Chi Minh City (HCMC) (MONRE 2019). Located in a tropical monsoon climate, these areas with a high concentration of population and economic assets are prone to risk of flooding. Based on the German watch Climate Risk Index score, Viet Nam was ranked third among the countries which were hit hardest by tropical cyclones in 2017 (Eckstein et al. 2018). Long-term trends of sea-level rise would increase the vulnerability. One metre sea-level rise would partially inundate 11% of the population and 7% of the agricultural land (World Bank and GFDRR 2011; GFDRR 2015; Bangalore et al. 2016).

Viet Nam has high potential for renewable energy sources which remain untapped: traditionally biomass and hydropower; more recently wind, solar and geothermal. As three-quarters of the land is mountainous with thousands of rivers and streams and the average annual rainfall is relatively high, the country has rich water resources. Yet, Viet Nam is exploiting only 10% of the total water volume. Long coastlines with strong seasonal winds due to the monsoon climate are considered desirable for wind power generation. Average annual sunshine hours are in the range from 1700 to 2500 hours (MONRE 2019). A number of the best locations for solar and wind power are in the southern third of the country which also has a relatively high share of offshore gas and hydropower (Dapice 2018).

The country also has rich mineral resources such as coal, crude oil and natural gas. Much of oil reserves and most of natural gas reserves are offshore (ADB and ADBI 2016). With significant coal reserves, Viet Nam was the second largest coal producer in Southeast Asia in 2016 (IEA 2017). In 2016, the country was self-sufficient in natural gas: its production was used for domestic use (IEA 2017).

9.2.2 Energy Demand Driving Development

Viet Nam has achieved rapid economic growth since the introduction of the economic and political reforms in 1986. The country has transformed itself from one of the poorest countries in the world to a lower middle-income economy over three decades. The economy continues to grow, driven by strong domestic demand and export-oriented manufacturing. Viet Nam is a member of the WTO, a party to the Comprehensive and Progressive Trans-Pacific Partnership (CPTPP), and a party to the Free Trade Agreement with the EU. Its GDP growth rates were 6.8% in 2017, 7.1% in 2018 and are estimated to be about 7% in 2019.[3] The emerging middle-class is expected to increase from 13% of the country's population (97 million in total) in 2018 to 26% by 2026.[4]

Viet Nam's energy intensity, that is, energy consumption per unit of GDP, is one of the highest among five countries in Southeast Asia that are also members of the Association of South East Asian Nations (ASEAN), DA5[5] (ADB 2015a). The country improved its energy intensity between 1990 and 1995, then largely

[3] https://www.worldbank.org/en/country/vietnam/overview#1 (last accessed on 28 August 2020).

[4] Ibid.

[5] DA5 may be also called ASEAN5. These five countries are Indonesia, Malaysia, the Philippines, Thailand and Viet Nam.

stagnated afterwards (ADB 2017). It has shown a strong coupling between economic development and energy consumption.

Main drivers for Viet Nam's energy consumption growth include industrial growth and residential energy use (MOIT 2017). Domestic energy consumption almost doubled the rate of the GDP growth between 2006 and 2016 (MOFA, Netherlands 2017). Between 2006 and 2015, Viet Nam's commercial energy consumption increased by 7.1% per year (MOIT 2017). It is estimated that domestic energy demand will have increased by three to eight times between 2015 and 2030 (MOFA, Netherlands 2017).

As the economic reform accelerated Viet Nam's industrialisation, use of primary energy sources shifted from traditional biomass to fossil fuels such as coal, crude oil, natural gas as well as hydropower. The share of renewable energy including biomass and hydropower in the total primary energy supply fell from 53% in 2000 to 24% in 2015 (MOIT 2017). The share of non-commercial biomass energy in the total primary energy supply also fell from 44.2% in 2000 to 16.9% in 2015 (MOIT 2017).

As commercial primary energy supply grew by 9.5% annually between 2001 and 2015, the annual growth rates of energy sources were 13.4% for natural gas, 12.2% for coal and 6.2% for oil products (MOIT 2017). In 2016, almost two-thirds of its energy supply came from fossil energy, namely, coal, oil and natural gas (Government of Viet Nam 2016; Nguyen et al. 2018).

Above all, the share of coal grew in the total primary energy supply from 15% in 2000 to 35% in 2015 (MOIT 2017). As coal reserves have been gradually depleted and domestic demand for coal was rapidly increasing, Viet Nam became a net energy importer in 2015 with a net import rate of about 5% of the total energy supply and is expected to continue increasing energy import, mainly coal with a smaller amount of oil (MOIT 2017; Nguyen et al. 2018).

Viet Nam changed from a coal exporter to a coal importer. In 2006, the country exported three quarters of its coal output mostly to China, yet its coal export fell rapidly afterwards (IEA 2017). Because of a significant increase in the volume of imported coal since 2014, Viet Nam became a net coal importer in 2015 with a net import of 12%. The country imported more than 10Mt of coal in 2016 and coal imports are expected to continue increasing in the coming years (Government of Viet Nam 2016; Nguyen et al. 2018; MOIT 2017). This trend has raised general concerns with the security of energy supply.

Gradual depletion of domestic energy sources, environmental impacts of large hydropower and coal-fired power plants (especially local air pollution from the latter), relatively slow development of natural gas industry, dependence on imported energy (imported coal and, in future, liquefied natural gas (LNG)), and suspension of nuclear power development would make renewable energy look like a viable alternative. Substituting fossil fuels with renewable energy could have additional merits of contribution to climate change mitigation. Thus, renewable energy deployment is considered essential to reduce the weight of coal-fired power generation. The ASEAN, of which Viet Nam is a member state, already set a target of reducing energy intensity by 30% from the 2005 level by 2025 and another target of achieving

Table 9.1 Projection of electricity supply

Year	2020	2025	2030
Installed capacity, MW	60,000	96,500	129,500
Electricity production, billion KWh	265	400	572
Annual growth rate in electricity generation, %	10.5	8.6	7.4

Source: Author created the table using data cited in PDP7 Revised (Decision No.428/2016/QD-TTg) (Government of Viet Nam (2016); Do and Hoffmann 2019)

the share of renewable energy to increase from 10% in 2015 to 23% in the primary energy mix by 2025 (IRENA and ACE 2016).

To meet surging demand for energy with the annual growth of 13%, Viet Nam needs huge investment in renewable energy which remains to be marginal despite its high potential. While annual new investment flowing into renewable energy projects remained modest below US$300 million from 2011 to 2015, new investment jumped to US$682 million in 2016 (Nguyen et al. 2018), presumably driven by the adoption of the revised Power Development Master Plan (PDP7 Revised) which took in effect in the same year.

9.2.3 Electricity Demand Driving Development

Rapid population growth with the government's policies to provide universal access to electricity throughout the country (ADB 2015b) led to surging demand for electricity in Viet Nam. The annual growth rate of its electricity demand was 12.1% on average between 2005 and 2014 (ADB and ADBI 2016), faster than other Asian countries, and is projected to be in the range of 8–9% through 2030 (Dapice 2018; Gerner et al. 2018).

Between 1995 and 2014, electricity consumption in Viet Nam increased by 11.3 times (World Bank 2015a; Hien 2019). Viet Nam's electricity intensity, that is, electricity consumption per unit of GDP, had increased by four times between 1995 and 2014, which made it the most electricity-intensive country in the Asia-Pacific region (Hien 2019). Its electricity intensity increased twice as fast as the GDP due to inefficiency in the economic structure and the government's policies (Hien 2019; Dapice 2018).

Viet Nam's electricity generation continued to grow by 11.6% per year between 2007 and 2017, and by 10.6% per year in 2018, achieving one of the highest growth rates in the world (BP 2019). The government envisages continuous expansion of total installed capacity of power plants and a significant increase in electricity generation through 2030 (Table 9.1).

The PDP7 Revised estimates that the total investment needed in power sources for electricity generation as well as grid expansion and upgrades will be approximately US$148 billion between 2016 and 2030 (Government of Viet Nam 2016). Based on the PDP7 Revised, the World Bank analyses that the total investment needed in the power sector between 2016 and 2030 will be in the range of US$152 billion to US$185 billion: US$118 billion to US$ 144 billion for electricity generation; and US$34 billion to US$ 41 billion for networks (transmission and distribution), respectively. Viet Nam will need new investment of US$8 billion to US$ 12 billion (including US$ 2 billion to US$ 3 billion for networks) annually from 2016 through 2030, shifting resources towards renewable energy, thermal generation and network infrastructure for transmission and distribution (Gerner et al. 2018).

9.2.4 Conventional Sources

Until the 1990s, the Vietnamese economy was dominated by the agricultural sector and for electricity generation largely dependent on hydropower and biomass especially in rural areas. In 2017, hydropower accounted for 38% of the installed capacity, followed by coal 34% and natural gas 18% (Gerner et al. 2018). Table 9.2 shows expected changes to structure of power sources in shares of total installed generation capacity and electricity production, respectively. Table 9.3 shows expected changes to the structure of conventional energy sources.

While a wide variety of electricity sources are available across the country, its regional distribution is not balanced. Viet Nam is roughly divided into three regions: North, Centre and South. Coal power plants, most of which are located in the North and Centre, accounted for 33% of the total installed capacity while natural gas power

Table 9.2 Structure of power sources in shares of total installed generation capacity and electricity production

Year	2020		2025		2030	
Source	Installed capacity %	Electricity production %	Installed capacity %	Electricity production %	Installed capacity %	Electricity production %
Hydro (large, medium, PSH)	30.1	25.2	21.1	17.4	16.9	12.4
Coal	42.7	49.3	49.3	55	42.6	53.2
Gas including LNG	14.9	16.6	15.6	19.1	14.7	16.8
Renewable energy including small hydro, wind, solar, biomass	9.9	6.5	12.5	6.9	21.0	10.7
Nuclear	–	–	–	–	3.6	5.7
Imported power	2.4	2.4	1.5	1.6	1.2	1.2

Source: Author created the table using data cited in PDP7 Revised (Decision No.428/2016/QD-TTg) (Government of Viet Nam 2016)
PSH Pumped storage hydroelectricity
LNG Liquefied natural gas

Table 9.3 Structure of conventional energy sources

Year	2020		2025		2030	
Source	Installed capacity, MW	Electricity production, %	Installed capacity, MW	Electricity production, %	Installed capacity, MW	Electricity production, %
Hydro including small, medium, PSH	21,600	29.5	24,600	20.5	27,800	15.5
Coal	26,000	49.3	47,600	55	55,300	53.2
Gas including LNG	9000	16.6	15,000	19.1	19,000	16.8

Source: Author created the table using data cited in PDP7 Revised (Decision No.428/2016/QD-TTg (Government of Viet Nam 2016) plants in the South accounted for 19% of the total installed capacity (Campbell et al. 2018).

9.2.4.1 Hydropower

Between 2006 and 2015, the generation capacity of hydropower in Viet Nam grew by 3.5 times (MOIT 2017; ACE and GIZ 2019). However, the share of hydropower in electricity generated in Viet Nam fell from over 60% in 1990 to only 30% by 2010 (ADB 2017). While the capacity of small hydropower can be still expanded, most of the hydro resource potential for large and medium hydropower plants will be fully exploited in 2020 (MOIT 2017). For a period up to 2030, shares of hydropower are expected to decline in both installed capacity and electricity production (Tables 9.2 and 9.3).

9.2.4.2 Coal

The share of coal in Viet Nam's power generation mix increased from 23% in 2005 to 30% in 2015 (IEA 2017). For a period up to 2030, shares of coal-fired thermal power in both installed capacity and electricity production are expected to increase and peak at 2025 (Tables 9.2 and 9.3).

9.2.4.3 Natural Gas

The share of natural gas in Viet Nam's power generation mix decreased from 42% in 2005 to 33% in 2015 (IEA 2017). For period up to 2030, shares of natural gas are projected to increase and peak at 2025 and return to roughly the same levels as 2020 (Tables 9.2 and 9.3).

9.2.5 Renewable Sources

In 2016, Viet Nam had the highest share (32.1%) of renewable energy in the total installed capacity among five countries in Southeast Asia (DA5), by adding 12.73GW between 2006 and 2016. For this period, most of its renewable energy installed capacity came from hydropower (ACE and CREEI 2018).

On the other hand, Viet Nam has fallen behind other countries in the region in non-hydro renewable energy deployment (MOFA, Netherlands 2017). In 2015, the share of renewable energy in its total electricity supply was only 3.7% (Nguyen et al. 2018). For a period up to 2030, however, renewable energy including small hydro, wind, solar and biomass is expected to achieve robust growth in both total installed capacity and electricity production (Tables 9.2 and 9.4).

9.2.5.1 Wind

In 2017, the total installed capacity of wind power in Viet Nam was estimated to be 190 MW (DEVI Renewable Energy 2017; Urban et al. 2018). In 2018, the country's annual growth rate of wind energy generation was 23.4% (BP 2019). For a period up to 2030, wind power is projected to increase multi-folds (Table 9.4).

Table 9.4 Structure of non-hydro renewable energy sources

Year	2020		2025		2030	
Source	Installed capacity, MW	Electricity production, %	Installed capacity, MW	Electricity production, %	Installed capacity, MW	Electricity production, %
Wind	800	0.8	2000	1	6000	2.1
Solar including large ground-mounted and small rooftop systems	850	0.5	4000	1.6	12,000	3.3
Biomass		1		1.2		2.1

Source: Author created the table using data cited in PDP7 Revised (Decision No.428/2016/QD-TTg) (Government of Viet Nam 2016)

9.2.5.2 Solar

In 2017, the total installed capacity of solar photovoltaics (PV) in Viet Nam was estimated to be over 7 MW (DEVI Renewable Energy 2017; Urban et al. 2018). In 2018, the country's annual growth rate of solar energy generation was 803.3% (BP 2019), even stronger than the growth of wind energy. For a period up to 2030, solar power is projected to increase multi-folds and overtake wind power by 2025 in both installed capacity and electricity production (Table 9.4).

9.3 State of GHG Emissions in Viet Nam

Viet Nam accounts for only a negligible amount of total global GHG emissions (0.5% in 2010) (Government of Viet Nam 2015). The amount of total GHG emissions in Viet Nam was 284MtCO_2e with Land Use, Land Use Change and Forestry (LULUCF) and 322 MtCO_2e without LULUCF in 2014 (MONRE 2019). The amount of GHG emissions from the energy sector, the largest source in Viet Nam, was 172MtCO_2e in 2014 (MONRE 2019).

In spite of its marginal contribution to global emissions, the country's GHG emission growth rate has been one of the highest in the world (World Bank 2014; MPI et al. 2015). Between 1990 and 2014, Viet Nam increased GHG emissions by 878%, which was the highest among ASEAN countries (WRI 2015; Urban et al. 2018). Table 9.5 shows an increase in GHG emissions between 2010 and 2014.

Viet Nam's rapid growth in CO_2e emissions can be attributed to energy (particularly the power sector, and other energy industries, manufacturing, transport) and to industrial processes (ADB 2017). Viet Nam's CO_2 emissions through consumption of oil, gas and coal for combustion-related activities (224.5MtCO_2 in 2018) increased by 14.8% per year in 2018, one of the highest growth rates in the world, and increased by 9.5% per year between 2007 and 2017 (BP 2019).

Due to a gradual shift in use of energy sources from hydropower and traditional biomass to fossil fuels, Viet Nam has become more carbon-intensive over the last three decades. Between 1985 and 2014, a strong coupling had been observed between economic growth and CO_2 emission growth (World Bank 2015b; Nguyen et al. 2018). Between 1990 and 2011 driven by a growing dominance of coal in the energy mix, Viet Nam had the fastest growth in CO_2e emissions intensity in Asia: its

Table 9.5 Viet Nam's GHG emissions under the business-as-usual (BAU) scenario

	2010	2014	2020	2030
	MtCO_2	MtCO_2	MtCO_2	MtCO_2
GHG emissions	246.8	283.97	474.1	787.4

Source: Author created the table using data cited in Nationally Determined Contribution (NDC) (Government of Viet Nam 2015; MONRE 2019)

Note: Viet Nam's BAU scenario for GHG emissions was developed based on the assumption of economic growth in the absence of climate change policies. At the time of NDC submission in 2015, 2010 was the latest year of the national GHG inventory. 2010, 2020, 2030 data include the energy, agriculture, waste and LULUCF sectors and excludes industrial processes carbon intensity of GDP increased by 78% (ADB 2017). Between 2006 and 2015, the country's carbon intensity per unit of GDP still increased by 48% (MOIT 2017).

At present, Viet Nam has the highest share of fossil fuel generation assets in Southeast Asia with 198 carbon emitting power units and 116 planned units (Caldecott et al. 2018). Three out of top ten power utilities in Southeast Asia come from Viet Nam. Vietnam National Oil and Gas Group (PetroVietnam), which operates gas-fired thermal power plants, has 10 current emitting units and 14 planned units. Electricity of Vietnam (EVN) has 6 current units and 11 planned units. EVN Genco 3, an EVN subsidiary for electricity generation, has 27 current units and 3 planned units (Caldecott et al. 2018). While CO_2 emissions from sources other than coal-fired power plants would increase by 14%, CO_2 emissions from coal-fired power plants, including those planned, are projected to increase by 948% between 2012 and 2030 (Edenhofer et al. 2018).

As the government is updating the Nationally Determined Contribution (NDC) and the Power Development Master Plan, it is important to ensure more coherence between climate and energy policies (SDG 17.14). Table 9.5 includes projections up to 2020 and 2030, respectively.

9.4 Institutional Arrangements and Governance Architecture

Viet Nam has attempted to integrate climate change, sustainable development or green growth and energy goals through both institutional arrangements and policy coordination. The experts appointed by the UN Framework Convention on Climate Change acknowledged that the country has made significant efforts to formulate policies and strategies including the formation and development of the institutional system in accordance with sustainable development objectives. The experts' review concluded that although Viet Nam is still in the process of defining and establishing its systems, it has taken significant steps to create institutional arrangements (UNFCCC 2018).

The National Climate Change Committee (NCCC) was established in 2012 to lead, coordinate, harmonise and monitor climate change and green growth (MPI et al. 2015). It is chaired by the prime minister and involves ministers of all the relevant ministries as members, which enables coordination between the ministries and oversight of the implementation of the National Climate Change Strategy (NCCS) and Vietnam Green Growth Strategy (VGGS) (MPI et al. 2015). The committee is supported by the Ministry of Natural Resources and Environment (MONRE) which serves as the National Focal Point to the UNFCCC, the Kyoto Protocol and Paris Agreement. The Viet Nam Panel on Climate Change (VPCC) was established in 2014 and is chaired by the Minister of Natural Resources and Environment (MONRE 2019).

MONRE, primarily the Department of Climate Change, presides and cooperates with other line ministries such as the Ministry of Industry and Trade (MOIT), Ministry of Planning and Investment (MPI), Ministry of Finance (MOF), Ministry of Transport (MOT), Ministry of Agriculture and Rural Development (MARD), Ministry of Construction (MOC) and Ministry of Science and Technology (MoST). Among others, the following ministries play particularly important roles in the mitigation of GHG emissions from energy-related activities.

MOIT, principally the General Directorate of Energy, takes responsibility for overall energy planning and policy formulation, appraisal of power and energy development plans, and supervision of the national electricity utility, Viet Nam Electricity (EVN) (Maweni and Bisbey 2016; ADB and ADBI 2016; GIZ 2015). MPI coordinates overall development strategies, planning and investments, including management of Official Development Assistance (ODA) as well as climate finance. MPI is responsible for developing mechanisms or policies for investment mobilisation and rational use of ODA sources to facilitate the sustainable development of the electricity sector, which is specified in PDP7 Revised (Government of Viet Nam 2016). MPI also serves as the focal point for the Viet Nam Green Growth Strategy (VGGS) and the SDGs, and has directed provincial green growth action plans based on the VGGS at the national level (Trinh 2018). Under PDP7 Revised, MOF is responsible for leading and coordinating with line ministries in establishing mechanisms for investment capital mobilisation for power development (Government of Viet Nam 2016).

Viet Nam has developed a hierarchical top-down administrative system. Below the central government level, there are three sub-national government levels: provinces, districts and communes (Government of Viet Nam 2016; Morgan and Trinh 2016; Strauch et al. 2018; Phuong et al. 2018).

- 63 provinces and five centrally managed cities
- 710 district-level cities, towns and districts
- More than 11,000 wards, townships and communes

At the provincial level, the Department of Natural Resource and Environment (DoNRE) and the Department of Industry and Trade (DoIT) advise on land use and on implementation of energy master plans, respectively, to the People's Committee of provinces and centrally managed cities (PC) for final decisions (GIZ 2015). Moreover, under the National Green Growth Action Plan and guided by MPI, they are responsible for developing provincial green growth action plans. Similarly, under the National Action Plan on Climate Change and guided by MONRE, they are responsible for formulating provincial climate change action plans (Strauch et al. 2018).

To date, ministries and provincial governments have made progress in developing and implementing a variety of action plans. 10 line ministries and 60 out of 63 provinces and centrally managed cities developed action plans to respond to climate change. As of October 2016, five line ministries and 30 provinces and centrally managed cities developed and started implementing green growth action plans (MONRE 2017). By October 2018, 50 out of 63 provinces and centrally managed cities developed their plans to implement the Paris Agreement while 26 out of 63 provinces and cities issued their green growth action plans (MONRE 2019). For a successful example, the Thanh Hoa province in the north central coast region developed a green growth action plan in 2016, setting a target of reducing GHG emissions by 14% by 2020 and 23% by 2030 and a target of having more than 140 MW of renewable energy (solar and wind) installed by 2030 (USAID 2017).

Based on a multi-level governance architecture, Viet Nam has translated national policies into sub-national plans and actions, setting in place mechanisms to mobilise domestic and international finance. Moreover, efforts have been made to achieve participatory and inclusive development through integration of top-down and bottom-up approaches to governance. Lack of effectiveness in horizontal and vertical coordination is another challenge (Strauch et al. 2018).

9.5 Regulatory and Policy Frameworks

Since the early 2000s, the government of Viet Nam has developed regulatory and policy frameworks to address climate change. Although the importance of integration of climate change into strategies and plans (SDG 13.2) has been well recognised, its implementation is at an early stage, which is mainly related to a lack of capacity. The government has prioritised mainstreaming climate change into Socio-Economic Development Strategy and Plan (MONRE 2019) and aligning climate change and development planning (Trinh 2018). It is suggested that a more holistic and integrated approach would improve planning and implementation of these strategies that involve multiple sectors and multi-level institutions (Urban et al. 2018).

The key components of the current frameworks are summarised and categorised by theme (climate change, sustainable development or green growth, energy) and by document type (law, strategy, plan, programme).

9.5.1 Climate Change

Viet Nam tends to ratify international climate change agreements without delay. Viet Nam ratified the United Nations Framework Convention (UNFCCC) in 1994, the Kyoto Protocol in 2002 and the Paris Agreement in 2016. The country submitted Intended Nationally Determined Contribution (INDC) in 2015, which became its Nationally Determined Contribution (NDC) to the UNFCCC in 2016 (MONRE 2019).

9.5.1.1 Law

Law on Environmental Protection (No.55/2014/QH13), enacted in 2014, includes a chapter with provisions on response to climate change including assessment of climate change mitigation and adaptation measures (MONRE 2019).

9.5.1.2 Strategies

National Strategy for Climate Change or *National Strategy on Climate Change (NSCC)* (Decision No.2139/2011/QD-TTg) was adopted in 2011. The strategy aims to carry out climate change adaptation and mitigation measures to ensure safety for people and properties for the sustainable development goals towards low-carbon and green growth (MONRE 2019; MONRE 2017). Mainly focusing on climate change adaptation with most measures related to adaptation, this strategy has a strong mitigation component such as developing and deploying advanced energy technologies (MPI et al. 2015; ADB 2017).

9.5.1.3 Action Plans

National Action Plan on Climate Change for the period from 2012 to 2020 was approved in 2012 to implement the NSCC (MONRE 2017). *Action Plan for Implementation of the Paris Agreement on Climate Change* for the period from 2016 to 2020, and to 2030 (Decision No.2053/2016/QD-TTg), was adopted in 2016. Among others, the Action Plan aims to review existing regulations and develop a decree on the roadmap and modality for GHG emission mitigation, to adjust climate response strategies, GHG mitigation and climate change adaptation regulations in accordance with NDC, and to continue integrating GHG mitigation and green growth into priority policies, plans and programmes (MONRE 2017, 2019).

9.5.1.4 Programmes

Support Programme to Respond Climate Change (SP-RCC) (Decision No.5613/VPCP-QHQT) set in place a financing mechanism that enables scaling up climate change response and coordination of policy development and dialogue between the government of Viet Nam and development partners (MPI et al. 2015; Nguyen et al. 2018; Strauch et al. 2018).

National Target Programme to Respond to Climate Change (NTP-RCC) for the period from 2012 to 2015 (Decision No.1183/2012/QD-TTg) was adopted in 2012. The programme aimed at mainstreaming climate change response into social and economic development (MPI et al. 2015). Although it also aimed at reducing GHG emissions and developing a low-carbon economy (MONRE 2019; Strauch et al. 2018), the programme mainly focused on climate change adaptation.

9.5.2 Green Growth Strategies

"Socio-Economic Development Strategy" (SEDS) for the period from 2011 to 2020 aims to lay the foundation for Viet Nam to become a modern industrialised society and well-integrated into the international economy through policies that maximise long-term welfare through rapid and sustainable development by 2020. It recognises the need for social equity and macro-economic stability, inclusive growth and sustainable development with emphasis on improving the efficiency of resource utilisation and technological progress (ADB and ADBI 2016).

"Viet Nam Green Growth Strategy" (VGGS) for the period from 2011 to 2020 with a vision to 2050 (Decision No.1393/2012/QD-TTg) was adopted in 2012. The overall objective of the strategy is to lead the country to green growth, sustainable development and low-carbon economy (MONRE 2017). To this end, it aims to

achieve GHG emission reductions and increase the capacity to absorb GHGs (MONRE 2019). This strategy has been regarded in most of the literature reviewed as the centrepiece for Viet Nam's climate change mitigation (MPI et al. 2015; Audinet et al. 2016; ADB 2017; Trinh 2018). It also sets mandatory targets for climate change mitigation (ADB 2017):

- To reduce GHG emissions intensity by 8% to 10% between 2011 and 2020 compared with 2010 levels (see also MPI et al. 2015)
- To reduce energy consumption per unit of GDP (energy intensity) by 1% to 1.5% per year between 2011 and 2020 (see also MPI et al. 2015)
- To reduce GHG emissions by 1.5% to 2% per year by 2030 and also by 2050
- To reduce GHG emissions from energy activities by 10% by 2020 compared to Business-As-Usual (BAU) with additional 10% (i.e., up to 20%) if international support is received, and to reduce GHG emissions by 20% by 2030 with additional 10% (i.e., up to 30%) if international support is received (see also Audinet et al. 2016)

9.5.2.1 Action Plans

"Socio-Economic Development Plan" (SEDP) for the period from 2016 to 2020 provides a policy framework and direction for line ministries to develop their own action plans (ADB and ADBI 2016). Sustainable development has been thoroughly mainstreamed into SEDP.[6] However, criteria and targets for environmental protection and green growth are generic in SEDPs. It is hard to monitor, report and verify the country's progress, which leads to limitations in the budget allocation process (Trinh 2018).

"National Action Plan on Green Growth" (Decision No.403/2012/QD-TTg) for the period from 2014 to 2020 was adopted in 2014. The focuses of the Action Plan include local institutional development and planning for green growth, reduction of the intensity of GHG emissions, and promotion of the use of clean and renewable energy (MONRE 2019).

"National Action Plan to Implement the 2030 Agenda for Sustainable Development" (Decision No.622/2017/QD-TTg) was adopted in 2017. This Action Plan aims to implement the SDGs in the 2030 Agenda of the United Nations from 2017 to 2020 and from 2021 to 2030, including integration of climate change and green growth. In the Action Plan 17 global SDGs have been nationalised, in line with national development conditions and priorities, into 115 Vietnam SDGs.[7] The implementation of the VGGS systematically links to and supports implementation of 57% of Vietnam SDGs and 55% of the tasks in the NDC, all of which will contribute to climate change mitigation (Trinh 2018).

[6] https://sustainabledevelopment.un.org/memberstates/vietnam (last accessed on 31 July 2019).
[7] Ibid.

9.5.2.2 Programmes

"National Target Programme for Responding to Climate Change and Green Growth" (Decision No.1670/2017/QD-TTg) for the period from 2016 to 2020 was approved in 2017. The programme aims to implement the NCCS and the VGGS, and to reduce GHG emissions in order to achieve NDC after 2020 (MONRE 2017; MONRE 2019).

9.5.3 Energy

"Electricity law", which was enacted in 2004 and amended in 2012, regulates the power sector planning and development investment, electricity saving and the electricity market (MOIT 2017). The original law was specifically enacted to reform the electricity sector in order to meet the demands of the rapidly growing economy and to remedy the inefficiencies in pricing (ADB 2015b).

"Law on energy efficiency and conservation" (Law No.50/2010/QH12), which was enacted in 2010, stipulates the energy efficiency and conservation as well as the associated policies and measures for their implementation. This law creates a regulatory framework to promote energy efficiency and conservation activities in all the economic sectors (MOIT 2017; ADB 2017).

9.5.3.1 Strategies

National Energy Development Strategy until 2020 with a vision to 2050 (Decision No.1855/2007/QD-TTg), which was adopted in 2007, aims to ensure energy supply, to develop electricity generation sources and grid, to complete rural electrification, and to develop competitive markets for electricity, coal, oil and gas industries (MOIT 2017).

"National Renewable Energy Development Strategy" (NREDS) for the period to 2030 with a vision to 2050 (Decision No.2068/2015/QD-TTg) was adopted in 2015. One of the main objectives of the strategy is to develop and use renewable energy sources in line with sustainable development and development of green economy (MONRE 2019). It sets in place mechanisms and policies for the development of renewable energy such as the creation of a market for renewable energy, electricity pricing policy, investment guarantee as well as a variety of incentives (MONRE 2017). Moreover, this strategy sets concrete targets for climate change mitigation and for a shift from fossil fuels to renewable energy sources.

- To reduce GHG emissions in energy activities compared to Business-As-Usual by 5% by 2020, 25% by 2030 and 45% by 2050 (MOIT 2017; MONRE 2017)
- To reduce fossil fuel imports: 40Mt of coal and 3.7 Mt of oil products by 2030; and 150Mt of coal and 10.5 Mt of oil products by 2050 (MOIT 2017)
- To increase the share of renewable energy in total primary energy consumption from 31.8% in 2015 to 31.0% in 2020, 32.3% in 2030, then to 44.0% in 2050 (ADB 2017)

- To increase the share of renewable energy sources (including large hydropower) in total national electricity production from 35.0% in 2015 to 38.4% by 2020, 31.5% in 2030 and 43% by 2050 (MONRE 2017; ADB 2017)

The Seventh National Power Development Master Plan in 2011–2020 with a vision to 2030 (Decision No.428/2016/QD-TTg) was approved in 2011 and amended in 2016. The current plan is the 2016 amendment, called PDP7 Revised (Government of Viet Nam 2016). As *electricity law* requires the government to formulate a national power development master plan every 10 years, the next power development master plan, PDP8, is under preparation.

PDP7 Revised outlines a master plan for power source development in which renewable energy such as wind, solar and bioenergy will be prioritised with a view to increasing the share of electricity generated from renewable energy sources (GIZ 2016). General objectives include promoting the use and exploitation of renewable sources for electricity production, and steadily increasing the share of renewable electricity in order to reduce dependence on imported coal-fired electricity, thus contributing to national energy security, climate change mitigation, environmental protection and sustainable socio-economic development (Government of Viet Nam 2016).

The original plan (PDP7) regarded fossil fuels (mainly coal) and hydro as the main sources of energy and projected their significant growth (MOFA, Netherlands 2017). Although the share of coal in domestic electricity generation in 2030 was reduced from 56.4% in PDP7 to 53.2% in PDP7 Revised (GIZ 2016), the revised plan foresees consumption of domestic coal to continue increasing through 2030, reaching 63Mt of coal in 2020, 95Mt of coal in 2025 and 129Mt of coal in 2030 (Government of Viet Nam 2016). In addition to reduction of the weight given to coal, the main change in PDP7 Revised from PDP7 is a stronger emphasis on renewable energy development and on power market liberalisation (GIZ 2016; ADB 2017). The share of renewable energy (small hydro, wind, solar and biomass) in electricity production in 2030 was increased from 6% in PDP7[8] to 10.7% in PDP7 Revised (GIZ 2016). PDP7 Revised also sets a specific objective to carry out and enhance the National Target Programme for energy efficiency and conservation (Government of Viet Nam 2016).

9.5.3.2 Programme

"National Target Programme on energy efficiency and conservation or *National Target Programme on economical and efficient use of energy"* for the period from 2012 to 2015 (VNEEP2) (Decision No.1427/QD-TTg) was adopted in 2012. The programme aims to create a regulatory framework for implementation at both national and local levels (MONRE 2019). The programme sets several targets:

[8] The original plan sets a target to increase the share of electricity generated by renewable energy from 3.5% in 2010 to 4.5% by 2020, then to 6% by 2030 (ADB 2015b).

- A target of saving 5% to 8% of total consumption between 2012 and 2015 compared to the forecasted energy demand in the PDP7, that is, BAU (MOIT 2017)
- Sector-specific targets of energy savings for energy-intensive industries such as cement and steel (MOIT 2017)

The current programme sets a target on commercial electricity savings of more than 10% of total electricity consumption for the period from 2016 to 2020, which is specified in PDP7 Revised (Government of Viet Nam 2016). While efforts have been made to control electricity consumption through the National Target Programme on Energy Efficiency, it is argued that this programme with a main focus on technical aspects has not sufficiently addressed economic, especially financial, problems as well as compliance and capacity building issues (MOIT 2017; Dapice 2018; Hien 2019).

9.5.4 Public Finance

National Target Programmes (NTPs) in Viet Nam are part of the system for the national government to transfer financial resources to local governments. Through conditional grants from the state budget and international grants and loans, the NTPs aim at achieving national socio-economic development objectives in a wide range of policy areas including climate change and energy use (Morgan and Trinh 2016). Climate actions are mainly implemented through NTPs such as the NTP-RCC, which was later integrated with green growth. SP-RCC is another instrument to mobilise international grants and loans to support climate action, and to direct donor contributions to the national budget on an annual basis (Strauch et al. 2018).

MOF and MPI have overall responsibilities for financing decisions and monitoring across NTPs. Line ministries are responsible for budget allocations to and oversight of the relevant NTPs or relevant parts of NTPs (Morgan and Trinh 2016). Although allocation of financial resources for climate change response used to be heavily oriented towards climate change adaptation, financial resources were slightly shifted to climate change mitigation: the share of mitigation increased from 2% to 3.9% between 2010 and 2013 (MPI et al. 2015).

9.6 Climate Change Mitigation Under International Agreements

Having ratified the UNFCCC and the Kyoto Protocol, Viet Nam shares the long-term objective of the convention and has access to policy instruments and mechanisms which are set in place to assist developing countries to meet the objective. The country has benefited from hosting projects that can reduce GHG emissions and carrying out actions that aim at reducing GHG emissions compared to BAU in 2020. Moreover, Viet Nam ratified the Paris Agreement and presented an unconditional goal which it intends to meet with domestic resources and a goal which is conditional upon its receipt of international resources.

9.6.1 Implementation of the UNFCCC and the Kyoto Protocol

The Clean Development Mechanism (CDM) allows projects in developing countries to earn Certified Emission Reduction (CER) credits,[9] which industrialised countries can use to meet a part of their emission reduction commitments under the Kyoto Protocol for the period from 2008 to 2020. Viet Nam has been among major beneficiaries from implementation of the CDM. As of June 2018, Viet Nam had 255 CDM projects and 10 Programme of Activities (PoAs)[10] accredited and registered with total annual estimated reductions of 18.0MtCO_2e and 2.0MtCO_2e, respectively. 21.7 million CERs have been issued from 70 CDM projects and one PoA (MONRE 2019). As of June 2019, 274 CDM projects in total were registered for Viet Nam. The energy sector has the largest number and share of CDM projects in Viet Nam, including 210 hydropower projects (76.6%), 19 biomass projects (6.9%) and 4 solar projects (1.5%).[11]

Developing countries can also participate in Nationally Appropriate Mitigation Actions (NAMAs) in the context of sustainable development in accordance with the UNFCCC. NAMAs refer to any actions that aim at reducing emissions in developing countries compared to BAU in 2020 and that are prepared under the initiative of a national government.[12] One of the registered NAMAs is a support programme which aims at promoting wind power development in Viet Nam by removing barriers on policy, capacity and technology and sets several targets:

- Increasing the share of wind power to 0.7% of total electricity in 2020 and to 2.4% in 2030[13]
- A reduction of 282,700 tonnes of oil equivalent (TOE) converted from imported coal by 2020 and 2,011,400 TOE by 2030 (MONRE 2017)
- An emission reduction of 5.2MtCO_2e by 2020 and 66.6MtCO_2e by 2030 (MONRE 2017)

[9] One CER is equivalent to one tonne of CO_2. https://cdm.unfccc.int/about/index.html (last accessed on 1 August 2019).

[10] A Programme of Activities (PoA) allows a developing country to register the coordinated implementation of a policy, measure or goal that leads to emission reductions. https://cdm.unfccc.int/ProgrammeOfActivities/index.html (last accessed on 1 August 2019).

[11] CDM project distribution within host countries by region and by type (last updated on 1 June 2019) http://cdmpipeline.org (last accessed 28 June 2019).

[12] https://unfccc.int/topics/mitigation/workstreams/nationally-appropriate-mitigation-actions (last accessed on 1 August 2019).

[13] http://www.nama-database.org/index.php/Wind_NAMA_in_Vietnam; https://unfccc.int/files/focus/mitigation/application/pdf/viet_nam_nama_poster_presentation.pdf (last accessed on 24 July 2019).

The country is seeking international financing for the total budget of the programme estimated to be US$34 million.[14]

9.6.2 Implementation of the NDC

For the period from 2021 to 2030, Viet Nam announced both unconditional and conditional goals in the NDC to the Paris Agreement (Government of Viet Nam 2015; MONRE 2019):

- Its unconditional goal: to reduce GHG emissions by 8% (equivalent to 62.65MtCO_2e) by 2030 compared to BAU with domestic resources.
- To meet the unconditional goal, Viet Nam's emission intensity per unit of GDP will need to decline by 20% compared to 2010 levels and its forest coverage will need to increase up to 45%.
- Its conditional goal: to reduce GHG emissions by up to 25% (equivalent to 197.94MtCO_2e) by 2030 compared to BAU, if the country receives international support.[15]
- To meet this goal, Viet Nam's emission intensity per unit of GDP will need to decline by up to 30% compared to 2010 levels.

Total domestic financial needs to meet the unconditional goal of an 8% emission reduction are estimated to be US$3.2 billion. Additional US$17.9 billion would be required to achieve the conditional goal of a 25% emission reduction, for which the government is seeking international financing (MONRE 2017).

The VGGS and provincial green growth action plans are considered to be the main instruments for Viet Nam to implement the mitigation goals in the NDC (Trinh 2018). The country has developed 45 GHG mitigation options, of which 25 measures will be implemented with domestic resources and 20 measures require international support. The energy sector will have 17 mitigation options (equivalent to 65.93MtCO_2e) (MONRE 2019). Despite the overall positive assessment, the UNFCCC experts pointed out that Viet Nam's NDC did not provide information about the contributions of the individual mitigation actions to achieving the broader policy target (UNFCCC 2018). For example, the Asian Development Bank (ADB)

[14]http://www.nama-database.org/index.php/Wind_NAMA_in_Vietnam (last accessed on 24 July 2019).

[15]International support may be provided through bilateral and multilateral cooperation as well as the implementation of new mechanisms under the Paris Agreement. Although these mechanisms were stipulated in Articles 6.2 and 6.4 of the Paris Agreement, their modalities and rules remain to be decided at the Conference of Parties. Media reported that the Prime Minister approved the updated NDC in July 2020 and the MONRE would submit it to the UNFCCC secretariat. According to this report, Viet Nam under the updated NDC will reduce GHG emissions by 9% by 2030 and by up to 27% with international support. https://en.vietnamplus.vn/vietnam-raises-contributions-to-global-effort-to-respond-to-climate-change/179861.vnp (last accessed on 30 August 2020).

evaluated 63 mitigation measures that can reduce GHG emissions by over 4600 $MtCO_2e$. The greatest mitigation contribution of about 500$MtCO_2e$ is expected to come from the power sector, which contributes more than 70% of the total mitigation potential over 2010–2050 through efficiency measures and renewable low-carbon electricity generation (ADB 2017).

9.7 Policy Instruments and Processes to Support Renewable Energy Development

In Viet Nam, MOIT is responsible for leading and coordinating with line ministries and localities in formulating incentive mechanisms or policies for investments in the development of renewable energy projects, according to PDP7 Revised (Government of Viet Nam 2016). The main instruments for promotion of renewable energy in Viet Nam are the standardised Power Purchase Agreement (PPA) for power plants less than 30 MW, a standard tariff for small generators based on the avoided costs of EVN, and Feed-In-Tariffs (FITs) for grid-connected renewable energy projects (ADB and ADBI 2016).

9.7.1 Pricing Instruments

Electricity purchasing prices in the form of Avoided Cost Tariffs (ACTs)[16] and FITs have been regarded as a major supporting mechanism for renewable energy development in Viet Nam (MOIT 2017; ACE and CREEI 2018). EVN is obliged to purchase all on-grid wind power produced for 20 years from the date starting commercial operation with provision for extension. Similarly, EVN is obliged to purchase all on-grid solar power produced for 20 years from the date starting commercial operation based on a standard PPA. The same tariff as on-grid solar power plants also applied to excess electricity which was generated from rooftop solar installations and sold to EVN (Campbell et al. 2018). The obligation for EVN to purchase the electricity generated from the wind or solar project for a period of 20 years is stated in the law as well as the contract (PPA).

Viet Nam has taken steps to increase private sector participation in electricity supply by preparing a regulatory framework including PPAs that allows Independent Power Producers (IPPs) to provide electricity to EVN (IEA 2017). The new Decision on solar power development entering into effect from 1 July 2019 provides an option of Direct Power Purchase Agreement (DPPA) which allows a seller and a buyer to negotiate their own prices for electricity without connecting to the EVN grid. In this way private power consumers can directly purchase electricity from IPPs.

[16]An ACT is set and adjusted annually based on the estimated cost of the marginal thermal generator on the system (ADB 2015b).

Table 9.6 Avoided-cost tariffs (ACTs) and feed-in-tariffs (FITs) in Viet Nam

Generation sources	Technology types	Tariff	Electricity sale price US¢/KWh	Legal basis
Small hydropower (<30MW)	Electricity production	ACT annually adjusted by MOIT	5.0	
Wind	On-shore	FIT for 20 years	7.8 (excluding VAT until 2018); 8.50 (from 2018 until October 2021)	Decision No.39/ 2018/QD-TTg amending No.37/ 2011/QD-TTg
	Near-shore		7.8 (excluding VAT until 2018); 9.80 (from 2018 until October 2021)	
Solar	On-grid	FIT for 20 years, adjusted according to PPA	9.35 (excluding VAT until June 2019)	Decision No.11/ 2017/QD-TTg
	Rooftop	FIT for 20 years, annually reviewed by MOIT	9.35 (excluding VAT until June 2019)	
Biomass	Co-generation	FIT for 20 years; ACT (from 2016)	5.8	Decision No.24/ 2014/QD-TTg
	Electricity production		7.5551 (North)	
			7.3458 (Centre)	
			7.4846 (South)	

Source: Author created the table using data cited in MOIT (2017) with additional data cited in ACE-CREEI (2018), Gerner et al. (2018), Nguyen et al. (2018), Do and Hoffmann (2019), Campbell et al. (2018), and ADB (2015b)
Note: This table excludes solid waste and does not include new tariff for solar power applicable from July 2019

The PPA sets a specified price for the sale of every kilo-watt hour (KWh) of electricity generated and structured with a specific contract period and often differentiated based on technology type, project size, resource quality and location (ACE and CREEI 2018). In Viet Nam, a uniform tariff was introduced to support wind and solar power development, and later differentiated by technology type, project size and location (Table 9.6). For wind power, a 2018 Decision sets higher tariffs for near-shore than those for on-shore. For solar power, a new Decision entering into effect from 1 July 2019 differentiates tariffs by technology type and irradiation regions.

In principle, a lower tariff is set for regions with higher irradiance mainly in the South while a higher tariff is set for regions with lower irradiance, mainly in the North. The main points of consultation include the number of irradiation regions: MOIT appeared to opt for establishing four regions with a higher tariff in the North in order to rebalance the distribution of solar projects, which are currently concentrated in the South. The Prime Minister and EVN preferred limiting the division to only two regions and continuing investments in the South to reduce pressure of increasing the retail electricity tariff (Buzenet et al. 2019; Cooper 2019).[17] This debate reveals different approaches to and priorities for SDGs: to gradually replace coal by renewable energy (SDG 7.2) even in regions where the latter is more costly with possible consequences for raising electricity tariff (SDG 7.1); and to target renewable energy expansion (SDG 7.2) at regions where generation and transmission costs can be kept low, thereby maintaining affordable electricity supply (SDG 7.1).

In Southeast Asia, the levels of FITs in Viet Nam are at the lowest among five countries (DA5) in both wind and solar power (ACE and CREEI 2018), which fails to attract potential investors. On the other hand, the levels of electricity purchase prices for renewable energy sources in Viet Nam are set higher than the average cost of electricity in the country. In Viet Nam, onshore and nearshore wind as well as solar FITs (US¢ 8.50/KWh, US¢ 9.80/KWh and US¢ 9.35/KWh, respectively) exceed the average cost of wholesale power purchase of US¢ 7.2/KWh (Gerner et al. 2018). Therefore, it is possible that the current FIT mechanism for solar power will be replaced by competitive bidding or auction regime after the expiry of the 2019 Decision on 31 December 2021. The government (MOIT) is currently preparing and designing a competitive auction regime to attract foreign private investment in solar PV development at scale and to meet the target of 12 GW by 2030 (Gerner et al. 2018).

9.7.2 Non-pricing Instruments

Renewable energy projects such as wind and solar power will be also entitled to non-pricing incentives such as import duty exemption on equipment, corporate income tax exemption and reduction, and land-based incentives. First, goods, which are imported to construct or form fixed assets such as raw materials, manufactured materials and other components, will be subject to exemption from import duty. Second, income from new investment projects for renewable energy production will be subject to corporate income tax at 10% for the first 15 years compared with the lowest corporate income tax at 20% (Campbell et al. 2018; Nguyen et al. 2018).

Third, land-based incentives include land fee exemption (MOFA, Netherlands 2017; Nguyen et al. 2018). In Viet Nam, there is no private property but the state's ownership of land. According to advice from DoNRE at the provincial level, the PC makes decisions to lease land by allocating land-lease titles of max. 50 years to individuals. Land-lease title holders may sell the certificate to other individuals or

[17] Although experts' updates and summaries of three drafts were available, the author was not able to obtain information about the final decision during this research.

companies (Urban et al. 2018). Investors may be entitled to exemption from the land use fee that would apply for 11 years or in a poor region for 15 years. During the period of construction of a new building or plant for up to three years from the date of the land lease contracts, they are entitled to exemption from land rents and water surface rents (Campbell et al. 2018).

9.7.3 Approval, Compensation and Capacity for Project Development

Viet Nam's policy framework for renewable energy development does not only depend on the above-mentioned incentives but also on the enforcement process, particularly related to approval by local authorities and compensation for land loss.

For renewable energy projects, developers have to request site approval and land use rights at the provincial DoNRE. The latter reviews the requests and sends them to the PC for final decisions (GIZ 2016). The PC is responsible for approvals and permits during the construction phase and the operation (GIZ 2015; Government of Viet Nam 2016). It is criticised that the current approval process is confusing, opaque and circuitous, which requires an unusually large amount of stakeholder engagement with government agencies (Breu et al. 2019). Other barriers include lack of consistency across provinces with regard to licensing and permitting procedures as well as the multiplicity of licenses and permits required for a project (Gerner et al. 2018).

There is another claim that PCs have allocated certificates or licenses to too many local developers without a track record or finances to build large solar or wind projects. It is reported that actual developers with expertise and finances will have to buy land licenses from those title-holders who charge up to 20% of the ownership share for having the best site (Dapice 2018). Strict application of existing laws means that if a project developer fails to implement the signed project within one or two years since the license is granted, the provincial authorities should recall the land for auction (Dapice 2018).

In some cases, tensions may arise between conflicting interests over project development. Site selection for a wind farm or a solar park can be affected by land availability, land use rights or competition over land use purposes related to different SDGs, for example, between land for agriculture (SDG2) and land for energy generation (SDG7). In such a case, farmers, who have the rights, may be granted compensation for their loss due to land clearance for energy infrastructure projects. To mitigate the negative impacts, efforts have been made to ensure due-processes that are transparent and accountable. Government-fixed compensation rates are applied, and some projects offer additional benefits as well as a living allowance (Urban et al. 2018). PDP7 Revised stipulates that MOIT is responsible for working with the PC to agree on the land funds for power projects (Government of Viet Nam 2016).

9.8 Key Challenges to Energy Transition

Since the 1980s, Viet Nam has come through dual transition processes. One is a transformation from a largely agricultural economy with a lack of access to energy to a rapidly industrialising economy driven by surging demand for energy, currently moving towards low-carbon economy. Another is a transition from a centrally planned economy led by the government to a market-oriented economy, pursuing for an open competitive market. These processes would be interrelated. For example, delay in the transformation of the energy mix may be partly explained by incompleteness of changes to the roles of the state and the market in energy industry.

9.8.1 Structure of the Energy Industry in Viet Nam

Like other centrally planned economies, Viet Nam has dominance of State-Owned Enterprises (SoEs) in the energy sector. MOIT supervises SoEs such as PetroVietnam, Vietnam National Coal and Minerals Industry Group (Vinacomin), and EVN. PetroVietnam, an SoE for exploration and production of oil and gas, owns and operates significant power plants as described earlier (ADB and ADBI 2016; Caldecott et al. 2018). Vinacomin, an SoE in the mining sector and one of the largest employers in the country, is responsible for exploration, exploitation, processing and sales of coal and minerals, and operation of coal-fired power plants (GIZ 2015; ADB and ADBI 2016). Despite significant reserves and surging domestic demand, its coal production has stagnated over the last decade (IEA 2017).

EVN with its subsidiaries has been a dominant player in the electricity generation market in Viet Nam as the largest producer and a single buyer (GIZ 2015; ADB 2015b; Maweni and Bisbey 2016). In 2017, EVN and three generation companies (GENCOs) owned 64% of the installed generation capacity in Viet Nam (Gerner et al. 2018).

Power transmission and distribution systems in Viet Nam are exclusively operated by EVN subsidiary companies, that is, the National Power Transmission Corporation (NPTC) and five distribution companies (ADB 2015b). The government regards transmission as a strategic asset and keeps it entirely in the public sector with EVN (Gerner et al. 2018).

EVN is privileged to receive state support specifically in access to land and capital (Hien 2019) even though guarantees and other forms of support from the government are gradually diminishing through recent reforms (Maweni and Bisbey 2016; Gerner et al. 2018). MOF borrows concessional and foreign currency denominated (e.g., US dollar) resources from international financial institutions and development partners, lends them to EVN at less than concessional rates, and also guarantees EVN's direct borrowing from local and international commercial banks (Gerner et al. 2018). Fossil fuel subsidies in Viet Nam varied between US$ 1.2 billion and US$ 4.49 billion, including spending on electricity, per year from 2007 to 2012 (Nguyen et al. 2018).

9.8.2 Electricity Tariffs

In Viet Nam, electricity prices have been highly regulated and kept artificially below cost-recovery levels through subsidies. The IEA defines that "fossil-fuel consumption subsidies artificially lower end-user prices to below international market levels and lower consumer electricity prices to below the full cost of supply by subsidising the price of fossil fuel used to generate power" (IEA 2017).

Fossil fuel subsidies take the form of ceilings on domestic coal prices, refined petroleum prices or tax exemptions. The current tax rates in Viet Nam do not reflect the thermal basis. Domestic natural gas production, especially that of offshore gas, is heavily taxed while imported coal including coal from the US is hardly taxed (Dapice 2018).

Electricity prices are differentiated by consumer categories and regions. First, electricity tariffs have been set lower for industries than service and commercial sectors (Perera 2018; Hien 2019). Viet Nam's cheap electricity tariffs attracted investments in electricity-intensive industries, which made them less energy-efficient and less competitive than neighbouring countries in the region (Hien 2019). Second, rural electrification is a national priority to ensure universal access to all across the country (SDG 7.1). PDP7 Revised states that electricity selling price should take into account the regional and population characteristics in couple with regulated price or tax or subsidies to narrow the gaps and that the cross-subsidy mechanism will be gradually removed among different consumer categories and regions (Government of Viet Nam 2016).

9.8.3 Implications of Electricity Tariffs for EVN

In Viet Nam, electricity tariffs were set lower than production costs: the average electricity retail tariff in 2015 covered 73% of the long-run marginal cost (ADB and ADBI 2016). If electricity tariff does not compensate for production costs, it will not ensure a high rate of return on investments. This has seriously undermined EVN's financial health (ADB 2015b; ADB and ADBI 2016; Nguyen et al. 2018; Gerner et al. 2018). Therefore, EVN's creditworthiness depends on whether it can establish retail electricity tariffs that adequately match the costs of service such as operational expenditure, capital expenditure, debt service plus a profit margin (Gerner et al. 2018). EVN's overall revenues were not sufficient for operational maintenance and investment needs. The losses of EVN were therefore compensated by the government through indirect subsidies such as preferential access to financial resources and special tax treatment (ADB 2015b).

In order for EVN to reflect cost-recovery levels, that is, to recover all costs of electricity including production, transmission and distribution as well as guarantee reasonable profits (GIZ 2015), electricity prices need to be regularly and continuously adjusted (Maweni and Bisbey 2016; ADB and ADBI 2016; GIZ 2015). The PDP 7 Revised up to 2020 aims to gradually increase the price of electricity. The pricing regulation amended in 2017 enables EVN to increase the price by 3% to 5%

without the government's approval but requires its approval for any rise above 5% (IEA 2017). Although the government raised electricity tariffs in 2017 to US¢7.6/KWh after having frozen them since 2015, it has had difficulties with further increasing them to US¢12/KWh, full cost-recovery levels (Gerner et al. 2018). Those difficulties are social, macro-economic and political reasons, including macro-economic spill-over effects and distributional impacts (Gerner et al. 2018; see also Coxhead and Grainger 2018).

There remain uncertainty and lack of transparency about how much electricity prices will increase in Viet Nam (Perera 2018). Adoption of a multi-year tariff trajectory on a path towards full cost-recovery would give an important positive signal to potential investors (Gerner et al. 2018), as it could improve predictability. EVN is recommended to raise the price of retailed electricity in the range of US¢ 10–12/KWh, which is close to the above-mentioned level and equivalent to the price level in Thailand (Dapice 2018). It is estimated that to keep pace with planned investments, electricity tariffs would need to continue increasing towards US¢14/KWh by the early 2020s (Gerner et al. 2018). It is also important to ensure that any trajectory towards full cost-recovery for electricity tariffs is accompanied by suitable policies to mitigate macro-economic and social impacts on low-income households and small and medium-sized enterprises (SMEs) (Maweni and Bisbey 2016; Gerner et al. 2018).

9.8.4 Tariffs of Electricity Generated from Renewable Energy

As costs of solar and wind technologies are rapidly declining, renewable energy has become the lowest source of new power generation on a global scale (IRENA 2019). In general, wind or solar power plants are considered expensive to build, but require less time to build, and have low costs to run once they are built (Dapice 2017). As a result of significant decreases in capital costs of solar and wind energy over the last 5 years, renewable energy in Viet Nam has become the cheapest form of new power generation on a Levelised Costs of Energy (LCOE)[18] basis (Breu et al. 2019). Viet Nam's LCOEs for solar PV and land-based wind power were the lowest among 10 countries in Southeast Asia. Its equipment installation costs for these technologies were the lowest as well (World Bank 2019; Lee et al. 2019). However, its operation and maintenance (O&M) costs were relatively higher than those in other countries (Lee et al. 2019).

To ensure cost-recovery for renewable energy projects without increasing burden on the state budget via the Viet Nam Environment Protection Fund (VEPF),[19] a

[18]Generation costs are expressed as the Levelised Cost of Energy (LCOE). It is a commonly used metric of generation costs to represent the net present value of the unit cost of electricity during the lifetime of a particular electricity generation technology (Lee et al. 2019).

[19]Until 2018, FIT for wind power was set at US¢7.80/KWh of which EVN paid power producers US¢ 6.80/KWh and the VEPF paid them US¢ 1.0/KWh (ADB 2015b). From 2018, with a fixed price of electricity at US¢6.8/KWh paid by EVN, power producers receive US¢1.7/KWh for

small surcharge may be added to the electricity tariff. For example, a recent study suggests that estimated values of renewable electricity surcharge can be US¢0.10/KWh in 2020 and US¢1.07/KWh in 2040, and transferred to electricity consumers instead of the state (Do and Hoffmann 2019).

9.8.5 Bankability of Renewable Energy Projects

Generation capacity expansion as well as grid upgrades in Viet Nam's power sector would require a huge amount of investments. It is estimated that a half of the total investments in renewable energy projects needs to come from the private sector (Nguyen et al. 2018). One key policy option would be adoption of competitive bidding or auctioning to replace FITs. Another option would be improvement on the bankability of PPAs in line with the government's direction towards creation of a competitive electricity market (GIZ 2015; Maweni and Bisbey 2016; ADB and ADBI 2016; Gerner et al. 2018). Bankability of renewable energy projects has been the main concern for international investors in search for opportunities in Viet Nam (Gerner et al. 2018; Campbell et al. 2018).

The current PPA model set in place in Viet Nam requires project developers or electricity sellers to shoulder the majority of the risk, which makes it difficult for them to raise capital. The cost of equity for renewable power projects is higher than traditional coal power projects (Breu et al. 2019).

Under the PPA, EVN is able to curtail assets with no financial repercussions and may not be obliged to *take and pay* power generated, but need to only pay for electricity which was received (Breu et al. 2019; Burke et al. 2019). The present electricity tariff is set below the price at which EVN is expected to purchase electricity from new renewable electricity generation (Gerner et al. 2018). Due to loss-making FITs and the limited grid capacity, EVN is reluctant to buy a large amount of solar or wind power at prices which are higher than coal or higher than its retail tariff of electricity (Dapice 2018). Unlike conventional thermal projects, the current PPA model for renewable energy projects in Viet Nam leaves developers little room for negotiation (a *take it-or-leave it* option) by limiting the ability of project developers to offset main project risks (Breu et al. 2019).

In cases where EVN does not buy all the electricity generated, the seller has to bear the liabilities of interruption or disruption in transmission and the costs and risk with connection to the grid. This could especially affect the seller whose project is located in a remote area in the need of running transmission lines over a long distance (Campbell et al. 2018). Project developers will have to build transmission lines from the project site to the national grid, negotiating with each land holder along the route (Dapice 2018).

Such PPAs currently in place have been acceptable to only local banks and not to international financial institutions or investors. Local Vietnamese loans charge

onshore wind and US¢3.0/KWh for near-shore wind from the government (Do and Hoffmann 2019). See Table 6.6.

higher interest rates and require a faster payback period than foreign loans (Dapice 2018). Due to the limited ability to provide large finance and lack of technical expertise to evaluate projects in the sector, local commercial banks are inclined to increase their perceived risks (Gerner et al. 2018), which may be reflected in the terms and conditions.

In effect, although there is no restriction over foreign ownership under existing laws, there was no precedence of international financing for renewable energy projects in Viet Nam as of 2018. Private local investments through equity financing or local bank financing have been limited to small and medium hydro power plants as well as wind power plants while foreign investments have flowed in independent large thermal (coal and gas) power plants (Campbell et al. 2018; Gerner et al. 2018).

In summary, the current structure of PPAs and reliance of renewable energy projects on commercial finance together with uncertainty about the approval process and land use rights would incur additional costs of electricity generation and transmission (Dapice 2018), which has become less attractive to potential foreign investors (Nguyen et al. 2018).

9.9 Roles of International Cooperation

To date, the regulatory environment in Viet Nam's energy industry has been major concerns for potential investors or developers and the biggest barrier to their attempts at financing renewable energy projects. The EU and Viet Nam bilateral cooperation framework could contribute to improving conditions for supporting renewable energy in the latter. The following two approaches could complement each other and provide some solutions. One is to consolidate the inter-governmental cooperation frameworks in line with the UN 2030 Agenda and Viet Nam's SEDS. The other is to commit themselves to removal of restrictions on trade and investments for goods and services which can be used to promote energy efficiency and renewable energy.

9.9.1 Intergovernmental Cooperation

The EU and Viet Nam established diplomatic relations in 1990 and broadened the scope of their relations through the Framework Cooperation Agreement (FCA) entering into force in 1996, followed by the Partnership and Cooperation Agreement (PCA) entering into force in 2016. The PCA provides a framework for cooperation in the areas of trade, environment, energy, science and technology among others.[20] Guided by the UN 2030 Agenda for Sustainable Development, the EU-Viet Nam PCA stipulates Sustainable Development (EC 2016).

[20] https://eeas.europa.eu/delegations/vietnam_en/1897/Vietnam%20and%20the%20EU (Last accessed on 3 August 2019).

In development cooperation, the EU regards Viet Nam as one of the main partners in Southeast Asia. Between 2007 and 2014, the EU and member states committed €5.8 billion for grants and concessional loans to support Viet Nam. Between 2014 and 2020, the EU will mainly focus on sustainable energy (max. €346 million) in line with Viet Nam's SEDS by promoting efficient, clean and renewable energy available to all in Viet Nam (EC 2016).

Moreover, the levels of the bilateral relations were advanced with the signature of the EU-Viet Nam Free Trade Agreement (EVFTA) in June 2019 and its entry into force in August 2020. The EVFTA is the most comprehensive FTA between the EU and a developing country, and dedicates Chapter 13 to trade and sustainable development of the agreement, which was framed by the UN 2030 Agenda. The chapter includes commitments to the effective implementation of all the multilateral environmental agreements (MEAs) ratified including the UNFCCC and the Paris Agreement and an article on climate change (EC 2016). The EVFTA requires each Party to ensure that the measures to implement the MEAs, which it ratified, are not applied in a manner which would constitute a means of arbitrary or unjustifiable discrimination between the Parties or a disguised restriction on trade (EVFTA 2018). On climate change, both parties reaffirm commitments to reaching the ultimate objective of the UNFCCC and effectively implementing the Convention, the Kyoto Protocol and the Paris Agreement. The areas of priority or of mutual interests for consultation and information-sharing include carbon pricing mechanisms, carbon markets, energy efficiency, low-emission technology and renewable energy. Each party affirms its commitment to enhance the contribution of trade and investment to the goal of sustainable development and to that end attempts to facilitate trade and investment in goods and services that can be used for climate change mitigation such as renewable energy and energy efficiency (EVFTA 2018).

9.9.2 Enabling Conditions for Private Investments

The regulatory environment in Viet Nam's energy industry, particularly related to approval for land use, risk allocation defined in the current PPA model, and financing conditions have caused major difficulties in project development for renewable energy. The current standard risk allocation in the wind, solar and hydro power PPAs is generally considered unacceptable to international investors and therefore inefficient to scale up investment to the desired level (Gerner et al. 2018).

In addition to risks that are particularly relevant to solar and wind power generation projects (e.g., curtailment, transmission, connection or connectivity), other major risks are associated with foreign exchange convertibility, consequences of termination, force majeure and its consequence, change in law and dispute settlement (Gerner et al. 2018; Campbell et al. 2018; Breu et al. 2019). Among these risks, it is considered critical to develop a bankable PPA that contains three essential elements: sufficient payments from EVN for compensation upon termination of the

PPA; adequate compensation to the project for curtailment by EVN; and arbitration of disputes under the PPA in a neutral, international jurisdiction (Gerner et al. 2018).

In this context, international investors could benefit from potential improvements in the regulatory environment in Viet Nam resulting from the EVFTA with Chapter 7 on non-tariff barriers to trade and investment in renewable energy generation. In line with global efforts to reduce GHG emissions, the Parties share the objectives of promoting, developing, increasing the generation of energy from renewable and sustainable sources, particularly through trade and investment. In 5 years after the date of entry into force, each party will have to refrain from measures for local content requirements and those for local partnership requirements (EVFTA 2018). Regarding interpretation and application of the agreements, both the EVFTA and the EU-Viet Nam Investment Protection Agreement (EVIPA) provide international investors safeguards by allowing dispute settlement by consultation and arbitration (Chapter 15 of the EVFTA and Chapter 3 of the EVIPA, respectively) (EVFTA 2018; EVIPA 2018; Nguyen and Turksen 2019).

9.10 Conclusion

As one of the most dynamic economies in needs to meet energy demand, to change the energy mix and to respond to climate change, Viet Nam offers an interesting example of coping with interactions between climate change and Sustainable Development Goals (SDGs), particularly SDG7 on affordable and clean energy. In spite of its marginal contribution to global climate change, the country has been growing GHG emissions at the highest rate in the world and has become more carbon-intensive over the last three decades. At present, Viet Nam has the highest share of the fossil fuel generation assets in Southeast Asia.

Viet Nam has attempted to integrate climate change, sustainable development or green growth and energy goals through institutional arrangements and policy coordination. Based on a multi-level governance architecture, the country has translated national policies into sub-national plans, setting in place mechanisms to mobilise domestic and international finance. While there remains an implementation gap in aligning climate change and development planning, the government has developed regulatory and policy frameworks and mainly framed them by themes such as climate change, sustainable development or green growth, and energy.

Having ratified the UNFCCC and the Kyoto Protocol, Viet Nam has benefited from existing instruments and mechanisms which are set in place to assist developing countries to meet the long-term objective. Viet Nam further ratified the Paris Agreement and presented a goal to meet with domestic resources and a more ambitious goal based on its receipt of international resources. The main instruments for the promotion of renewable energy in Viet Nam are the standardised PPA for smaller power plants, a standard tariff for small generators based on the avoided costs, and FITs for grid-connected renewable energy projects.

Delay in the transformation of the energy mix resulting from rapid industrialisation and need for decarbonisation may be partly explained by incompleteness of reforms on SoEs in energy industry. To date, the regulatory environment in Viet Nam's energy industry has been major concerns for potential investors or developers and the biggest barrier to their attempts at financing renewable energy projects. Consolidation of the inter-governmental cooperation frameworks and commitments to removal of restrictions on trade and investments for energy-efficient and renewables-related goods and service could contribute to reducing uncertainty and easing investors' concerns. Nevertheless, adequacy of electricity tariffs and choice of support measures would be crucial in preparation for the next power development master plan and implementation of Viet Nam SDGs.

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Ensuring Domestic Water Security for Cities Under Rapid Urbanisation and Climate Change Risks

10

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Abstract

There has been an exponential growth in the number of people living in urban areas since the middle of the twentieth century, and by the end of 2018, more than half of the world population lived in cities. This rapid urbanisation has created unprecedented challenges, among which the provision of domestic water has received increasing attention. Water is a basic need for humans and is the basis for socio-economic development. However, in many developing countries, governments have difficulties keeping pace with the fast rate of urbanisation due to limited financial resources and a lack of technical expertise. This ultimately results in a number of water-related problems, such as the lack of provision of an adequate water supply and improper sanitation, degradation of ecosystems and stormwater management failures. Moreover, climate change is exacerbating these water-related problems by influencing the hydrological cycle.

Today, there are 400 million urban dwellers worldwide affected by water scarcity and 250 million people are without improved sanitation services, causing

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an estimated 3.4 million deaths annually through water-borne diseases. These figures will inevitably increase, as an 80% increase in water demand is projected by 2050. According to the American Meteorological Society, accessibility to a sufficient supply of clean water is one of the critical issues facing society in the twenty-first century. Such issues are now receiving greater attention from politicians and policymakers, leading to increased research in this direction. This chapter provides insights into the problems leading to an unreliable and unsecure domestic water supply in cities and identified future water challenges that cities will face. Moreover, indicators used to measure domestic water security are explained and an index based on the amalgamation of those indicators is presented to facilitate a better understanding of urban water security.

Keywords

Climate change · Domestic water · Urbanisation · Water security

10.1 Introduction

Urbanisation refers to an increase in the population living in urban areas. Since the middle of the twentieth century, the world has experienced a rapid increase in the number of people living in cities as a result of industrialisation. From about 30% in 1950, the percentage of people living in urban areas worldwide increased to more than 50% by the end of 2018 (Fig. 10.1). This shift from rural to urban areas is unparalleled in history and is causing important socio-economic changes, notably outside Europe and North America where this trend is more pronounced (Satterthwaite 2005). Globally, the number of cities with more than one million inhabitants recently reached 561, with 33 of them classified as mega cities with more than ten million inhabitants (United Nations 2018). Population data from the United Nations[1] show that during the period 1950–2018, the number of people living in cities increased by over three billion worldwide with this exponential growth in the number of urban dwellers projected to continue in the future (Fig. 10.1). This increase in urban population is the result of a combination of factors, particularly migration from rural areas, the spatial expansion of cities and hence the conversion of rural into urban areas, and the high growth rate of the urban population. This trend in urbanisation is not uniform across countries, as it is affected by socio-economic development and political stability, with the most rapid rate of urbanisation found in developing countries (Satterthwaite 2005; Srinivasan et al. 2013).

Around 50% of the world's urban population now lives in Asia (United Nations 2018), with Africa and South America also having an increasing proportion of their population living in urban areas. The world's largest cities, which were once found only in Europe (e.g. London) and North America (e.g. New York City) are now

[1] https://www.un.org/en/development/desa/population/theme/urbanization/index.asp

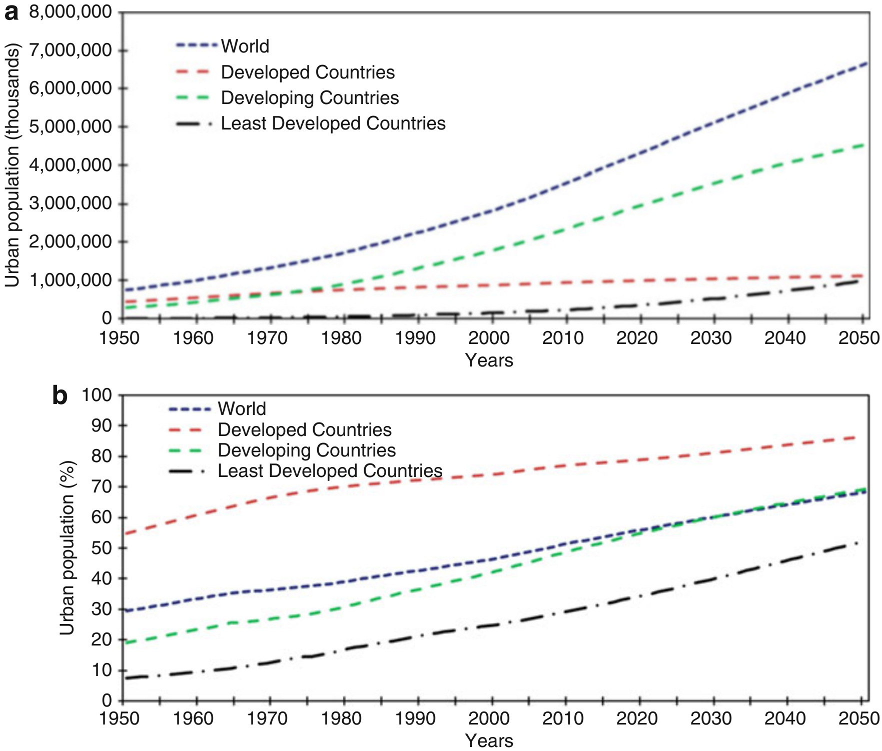

Fig. 10.1 Growth in urban population from 1950 to 2050. The share of the urban population to the total population is shown in number (**a**) and in percentage (**b**) for the world and the developed, developing and least-developed countries

located in Asia; for example, London and New York City were one of the largest urban centres in the early 1950s, with a population of approximately 8 and 7.8 million inhabitants[2,3] respectively. However, in the late twentieth century, Tokyo (Japan) became the world's largest city, with its population reaching 34.5 million inhabitants at the turn of the century. Moreover, this trend in urbanisation is expected to continue into the twenty-first century with the addition of more than 2.6 billion urban inhabitants worldwide by 2050 (United Nations 2018). By that time, urban dwellers will account for nearly two-thirds of the world population (~85% in developed countries and ~65% in developing countries), and it has been estimated that such an increase in population will require more than 3000 new big cities (Koop and Leeuwen 2017).

[2]https://data.london.gov.uk/dataset/historic-census-population

[3]http://physics.bu.edu/~redner/projects/population/cities/newyork.html

10.2 The Challenges of Urbanisation

Rapid urbanisation has created unprecedented challenges with the provision of clean water gaining particular attention. Domestic water consumption, for instance, has increased more than four times in the last 60 years (Richter et al. 2013). However, in developing countries, governments, due to their limited resources and lack of technological knowledge, are unable to respond to this fast rate of urbanisation, which ultimately results in a variety of water-related problems, such as inadequate water supply, improper sanitation, degradation of ecosystems and stormwater management failures (Assefa et al. 2019).

New developments as a result of population growth are putting pressures on the urban environment, which contribute to the pollution of freshwater resources. According to CDP (2017), water quality issues affect 132 cities worldwide. This compares with 196 cities at risk of water stress (defined as per capita water availability of less than 1700 m^3 per year) or scarcity (defined as per capita water availability of less than 1000 m^3 per year). The majority of the approximately 400 million urban dwellers facing water scarcity live in Asia and Africa, (Bakker 2012; Sperling and Sarni 2019), and 250 million are also without improved sanitation facilities, causing 3.4 million deaths annually due to water-borne diseases (Leeuwen 2013). An improved sanitation facility is one that is connected to either a public sewer or a septic system. These figures are likely to become more severe in the future, as the demand for water is projected to rise by 80% by 2050, leading to a water crisis for about one billion urban dwellers worldwide (Amarasinghe and Smakhtin 2014).

Although cities occupy approximately only 2% of the surface area of the Earth, nearly 10% of the global water consumption takes place in cities (Hoekstra and Mekonnen 2012). Furthermore, one-fourth of urban areas are located in drylands where there are many cities with a population of more than one million inhabitants (Guneralp et al. 2015; Koop and Leeuwen 2017). In these water-deficient regions, more than 90% of the water is used for agriculture, which leaves very limited water for domestic usage (Richter et al. 2013). Hence, these cities suffer from periodic droughts and during those droughts, the population relies on groundwater resources. This results in extensive pumping of groundwater, leading to a decline in the volume of groundwater in the aquifers and, in some cases, the depletion of the aquifer (Flörke et al. 2018). Figure 10.2 depicts the groundwater footprint of the world together with the location of the world's major cities. This map was prepared using data obtained from the World Resources Institute.[4] Groundwater footprint is the ratio of groundwater withdrawals to the estimated recharge in an area over a specific period of time. It is a unitless ratio representing groundwater stress.

Moreover, most cities do not have their own water supply locally, and water is transported from surrounding regions. Surface water comprises an essential component of this water supply, accounting for approximately 80% of the total supplied

[4] https://www.wri.org/resources/data-sets/aqueduct-global-maps-21-data

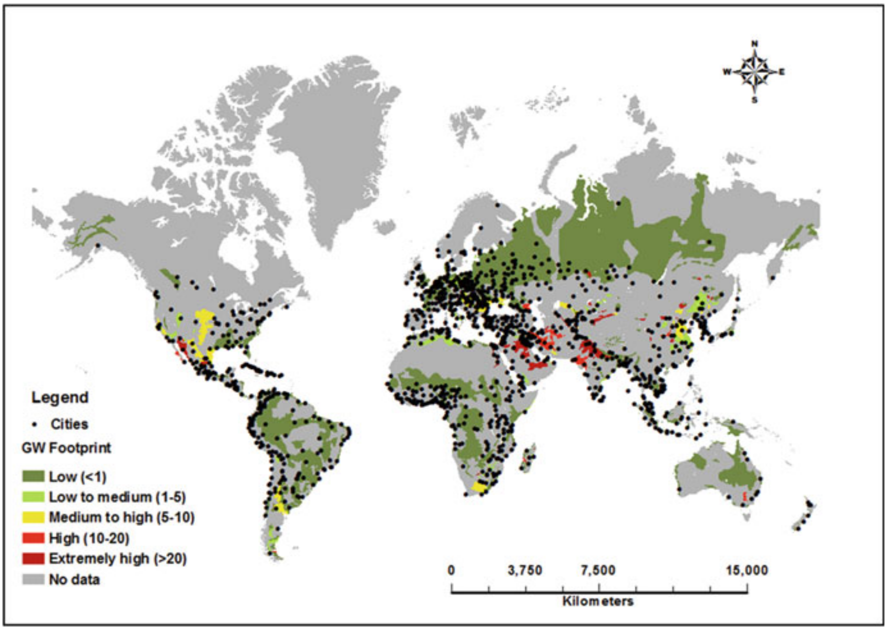

Fig. 10.2 Global groundwater footprint (1958–2000) showing cities with a population greater than 250,000 inhabitants falling under different categories of groundwater stress

water (McDonald et al. 2014). According to McDonald et al. (2014), 504 billion litres of water are supplied daily to big cities by covering a total distance of 27,000 ± 3800 km, of which a significant proportion is lost because of leakage from water distribution networks. The situation becomes more critical during droughts, as the extremely dry soils affect the water supply distribution network by exerting pressure on pipes and joints (Guneralp et al. 2015). Figure 10.3 depicts cities located in water stress regions. The baseline water stress is found to be very high for cities located in Southeast Asia, southern Europe and western North America. Furthermore, Guneralp et al. (2015) predicted an expansion of urban areas into drylands by approximately 300,000 km^2 by 2030. In these environments, cities are already short of water supply, and this will cause even more stress on existing available water resources in the future.

The estimated upstream storage of water for major cities across the world is shown in Fig. 10.4. It assesses the potential of storing water upstream of a place with respect to the total water supply at that place. It is represented in the form of an index, which was obtained by dividing storage capacity by the mean of total blue water during the period 1950–2010. The figure clearly shows that cities in the eastern parts of Australia, North America and Asia and the western parts of South America and Africa are characterised by poor upstream water storage capacity. These cities are thus more exposed to the seasonal or long-term scarcity of water.

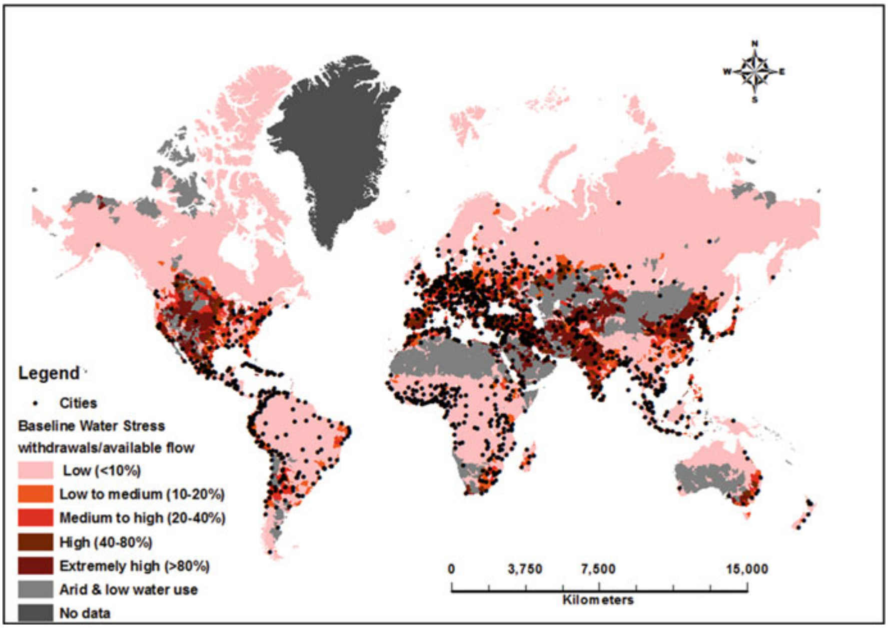

Fig. 10.3 Global water stress index (1950–2010) showing the vulnerability of cities with a population greater than 250,000 inhabitants to fresh water. (Source of data: https://www.wri.org/resources/data-sets/aqueduct-global-maps-21-data)

In addition to water management issues facing cities in relation to improved sanitation and water supply, there are other issues complicating the situation in cities of developing countries, notably an increasing population living in slums, the presence of various non-point pollution sources, a large percentage of the water supply lost through leakage and an aging distribution network. In a recent report, the United Nations (2015) revealed that around one billion people worldwide live in slums, of which the majority are found in developing countries where they account on average for about 30% of the population of a city. Based on current trends, this figure is projected to increase to two billion people by 2030 and three billion by the middle of the century (United Nations-Habitat 2010). The lack of proper maintenance of the water infrastructure results in the loss of about 25% of the total water supply through leakage and evaporation. Additionally, only 10% of wastewater is being treated prior to being released back into the environment because of the non-availability of low-cost treatment and lack of technological knowledge (Sperling and Sarni 2019).

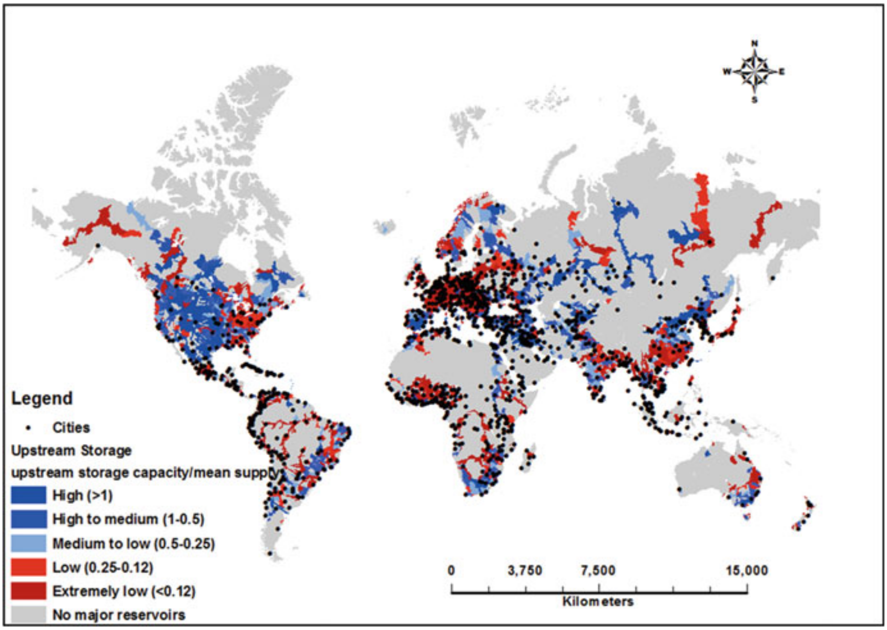

Fig. 10.4 Global upstream water storage index (1950–2010). (Source of data: https://www.wri.org/resources/data-sets/aqueduct-global-maps-21-data)

10.3 Climate Change and Water Scarcity

The impact of climate variability, including extreme events, on water availability has long been an issue of concern and the focus of scientific research (e.g. Allen and Ingram (2002) and Barnett et al. (2005)). This is because fluctuations in temperature and precipitation influence water resource availability in addition to long-term climate change (Afzal et al. 2015, 2016). Global mean surface temperature has risen by 0.74 ± 0.18 °C throughout the twentieth century (IPCC 2013), while climate change has affected the amount, intensity and frequency of precipitation (Barnett et al., 2005; Singh et al. 2015). For instance, there has been an overall decrease in precipitation over land between 30°N and 10°S during the past few decades of the twentieth century, with inevitable impacts on hydrologic parameters such as runoff and groundwater recharge. These climatic changes have resulted in a decrease in water availability, notably from glaciers, rivers, lakes, springs and reservoirs, leading to water shortages in many cities across the world (Guneralp et al. 2015; Li et al. 2015).

CDP (2017) stated that 63% cities worldwide consider climate change as a threat to their water supply, with such perception of vulnerability higher in cities across Asia (84%) and Africa (80%) than in Europe (34%). Globally, a correlation has been reported between climate change and the water crisis in cities (Wada et al. 2016;

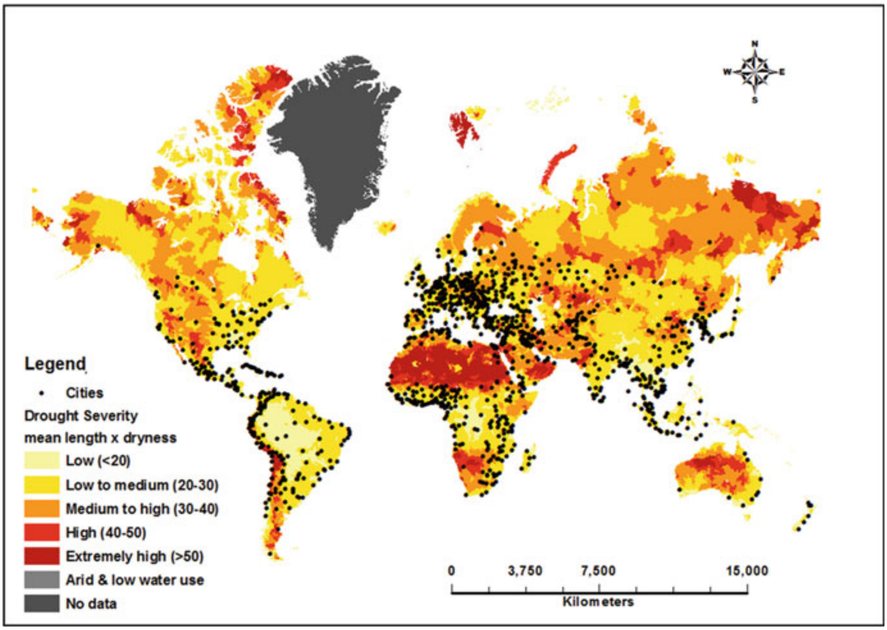

Fig. 10.5 Drought severity map averaged over the period 1948–2008. (Source of data: https://www.wri.org/resources/data-sets/aqueduct-global-maps-21-data)

Flörke et al. 2018). Guneralp et al. (2015) modelled the future expansion of urban areas and their exposure to climate change worldwide and predicted a substantial expansion of urban areas into drought-prone areas, which is expected to increase from 0.17 million km^2 in 2000 to 0.5 million km^2 by the end of 2030. The study, based on 482 large cities, reveals that the surface-water deficit will be in the range of 1386–6764 million m^3 for the 2050s depending on the used scenario of climate change and socio-economic pathway. Approximately 27–40% of cities will face surface water shortages, escalating the urban groundwater footprint (Flörke et al. 2018) described above.

Climate change also increases the risk of extreme events (Easterling et al. 2000). According to the latest report published by the Intergovernmental Panel on Climate Change (IPCC), global surface temperature is likely to increase by 1.5°C under a business-as-usual scenario by the end of the twenty-first century, with an associated increase in the number and frequency of extreme events (IPCC 2013), with potential severe consequences for water resources. The rise in global air temperature and extreme climatic events has led to an increase in the frequency and intensity of droughts and has caused water crises in several cities across the world. This was exemplified by the recent water crisis of California (2012–2017), Cape Town (2015–2018) and Melbourne (1996–2010), when these cities recorded their highest temperature and lowest annual rainfall on record. Figure 10.5 depicts the severity of droughts averaged over the period 1948–2008, as calculated by multiplying the average length of droughts (in month) by the dryness of the droughts.

10.4 Urban Water Security

A reduction in the availability of water resources in cities has escalated conflicts in the distribution of water among users, including for the maintenance of ecosystems (Kurian 2017). This also negatively affects the productivity of urban systems, which may have serious implications on Gross World Product (GWP). Currently, cities provide approximately 80% of the total GWP (Dobbs et al. 2011). Therefore, the urban water crisis needs to be investigated with a broader perspective by considering the relationships among water resource sustainability, ecosystem health and economic development with water as the central determining factor (Chen and Shi 2016). The first attempt in this direction was made during the Second World Water Forum and Ministerial Conference held at The Hague in 2000, where the term *water security* was introduced explicitly concerning the above-discussed challenges.

Water security is defined differently depending upon the subjectivity of the problems, but the notion of balancing the water requirements of human and environment remains the central objective of each definition (Bakker 2012). According to Hoekstra et al. (2018), water security aims to achieve long-term sustainability by minimising the risks associated with water, improving economic welfare and enhancing social equity. Thus, water security refers to a social state where everyone has access to a safe and clean water supply, and the water meets the demand of domestic users in addition to the demand of the agricultural and industrial sectors, as well as to meet the minimum environmental flows required to maintaining ecosystems (Assefa et al. 2019). Bakker (2012) propagated water security as an emerging concept that adds value to the urban water management discourse. However, this notion of urban water security is somewhat distinct from the generalised concept of water security as it establishes the parameters that are explicitly applicable for the urban environment and may not be useful for measuring water security at the global or country level. Romero-Lankao and Gnatz (2016) presented the concept of urban water security as a paradigm where developmental domains such as socio-demographic, economic, technological, ecological and governance are mutually interrelated (Fig. 10.6).

There are a limited number of studies on urban water security despite its immense significance in urban ecology, which might reflect the difficulty in measuring urban water security. The identification of relevant variables and defining indicators that are truly representative of the different facets of urban water security is challenging as these are governed by the level of scale, for example, local, national or global (Jensen and Wu 2018). "Measuring the water security (urban) at the global or national level will only provide the universal scenario of the problem from a countrywide standpoint, not from a local perspective" (Assefa et al. 2019). However, "local indicators are helpful to show the variations that exist in water challenges between different localities within a single country or river basin, allowing for a more effective identification of the problem, and to provide more relevant indicators for decision-makers, as responsibility for many aspects of water policy is widely devolved to the local level" (Jensen and Wu 2018). Furthermore, "water security is highly dynamic (Srinivasan et al. 2017), suggesting the need for

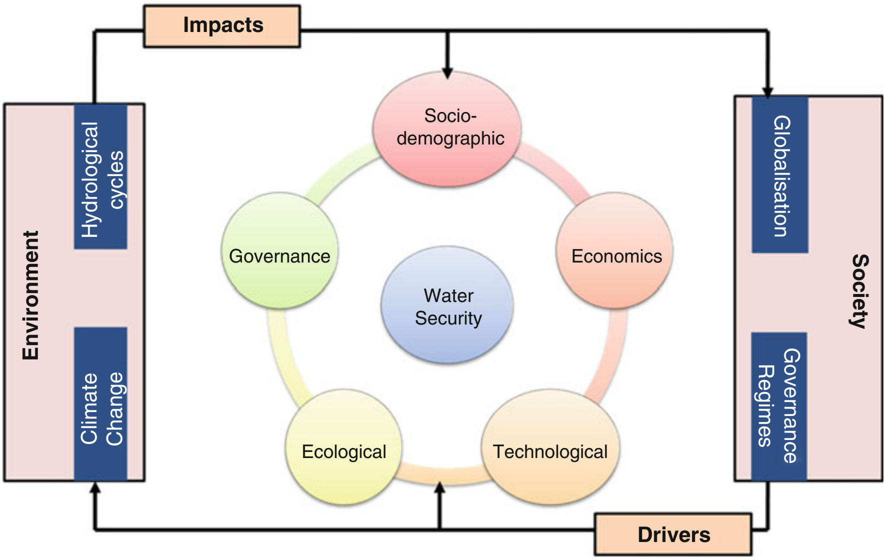

Fig. 10.6 Influence of environmental and societal components on urban water security and its interaction with developmental domains. (Source: Modified after Romero-Lankao and Gnatz 2016)

indicators that can reflect such changes at the local level" (Jensen and Wu 2018). The assessment of urban water security is the foundation for establishing the strategy of water security and making management decisions.

10.5 Dimensions and Indicators of Urban Water Security

This section describes the indicators used to develop an index to measure domestic urban water security. The indicators and the three dimensions they are grouped in are based on the criteria of Sustainable Development Goal (SDG 6) - Ensuring availability and sustainable management of water and sanitation for all. "The adopted dimensions include: water supply, sanitation and hygiene" (Assefa et al. 2019), with the indicatos underlying each dimension described below.

10.5.1 Water Supply Dimension

This dimension of the domestic urban water security is concerned with freshwater availability, its consumption and distribution, and the availability of piped water during the days as well as its quality an affordability. The following paragraphs elaborate on the indicators comprising this dimension of urban water security.

10.5.1.1 Per Capita Freshwater Availability

Water availability is an important indicator; it is calculated by dividing the size of the available water resource in a given year by the total population (Eq. 10.1). If the availability of fresh water is less than 1700 and 1000 m^3/capita/year, the city is said to be in the state of water stress and water scarcity, respectively.

$$\text{Per capita water availability} = \frac{\text{Total available freshwater resources } (\text{m}^3) \text{ in the year}}{\text{Total population of the year}} \tag{10.1}$$

10.5.1.2 Per Capita Water Consumption

Per capita water consumption is also considered an indicator of the urban water supply dimension. It is represented by a variable known as per capita water consumption, which can be derived by dividing the total amount of water consumed by the total population (Eq. 10.2). "This variable is used to determine the current state of water consumption for routine household activities. It has been calculated that with a consumption of 100 litres/capita/day, all basic human needs are met, including hygiene" (Howard and Bartram 2003; Assefa et al. 2019).

$$\text{Per capita water consumption} = \frac{\text{Total amount of water consumed (L)}}{\text{Total population}} \tag{10.2}$$

10.5.1.3 Proportion of the Population with Piped-Water Supply Users in Relation to Total Population

The improved water supply refers to a facility or a delivery point that safeguards water from contamination such as faecal coliforms (Hsu et al. 2014; Assefa et al. 2019). Hence, the proportion of the population with piped water supply should be calculated to evaluate the status of improved water supply coverage of the city. This is measured as follows:

$$\text{Proportion of piped water supply} = \frac{\text{Number of piped water supply users} \times 100}{\text{Total population}} \tag{10.3}$$

10.5.1.4 Duration of Piped Water Supply Service Duration Per Day

This is factored in to determine the reliability of water supply through (a) determining the duration of accessing improved water supply and (b) continuity of the water supply service of the city. It can be stated that a city with secured water supply will provide access to water to all its citizens round the clock (Assefa et al. 2019).

10.5.1.5 Proportion of Safe Drinking Water Supply Based on Drinking Water Quality Standards

It is essential to assess or evaluate the quality of the supplied water, as water quality influences human health. As regards the drinking water quality, the parameters that are important are *Escherichia coli* (*E. coli*), pH, residual chlorine and turbidity (WHO 2011). The following are WHO's (2011) standards for water quality: *E. coli* must be nil, residual chlorine must be greater than or equal to 0.2 mg/L, pH value must be between 6.5 and 8.5 and turbidity must be less than or equal to 5 Nephelometric Turbidity Units (NTU) (Assefa et al. 2019).

10.5.1.6 Affordability of Domestic Water Supply Tariff

Affordability refers to provision of domestic water supply to all of the community at affordable tariff, so that the low-income people also get access to water supply. Through their study, Banerjee and Morella (2011) proposed a benchmark tariff of about 0.40 US$/m^3 in developing countries. However, this may not be appropriate for developed countries (Assefa et al. 2019).

10.5.1.7 Percentage of Non-revenue Water

Particularly in the developing countries, water loss occurring in the water supply system is a cause of concern. Water loss results in water shortage to the consumers and also higher operating cost for the operators. Hence, the water loss of the city must be assessed so as to figure out the water security status of the city (Assefa et al. 2019). Non-revenue water (NRW) reflects the difference between the amount of water supplied through the water distribution system and that billed to customers. This percentage includes real or physical losses like water leakage and apparent losses such as illegal connections and meter inaccuracies.

10.5.2 Sanitation Dimension

Hsu et al. (2014) define improved sanitation as access to a connection to a sewer system, a septic system, a ventilated pit latrine and a pour-flush latrine.

10.5.2.1 Proportion of Customers Connected to the Sewer System

The proportion of sewer line system users is considered "to evaluate improved sanitation access". The proportion of the customers connected to the sewer system or the extent of improved sanitation is calculated as the number of customers connected to the sewerage system in relation to the total population of the area (Eq. 10.4) (Assefa et al. 2019).

$$\text{Proportion of sewer line users} = \frac{\text{Number of sewer lines users} \times 100}{\text{Total population}} \quad (10.4)$$

10.5.2.2 Percentage of Treated Wastewater

It is assumed that about 80% of the freshwater provided to the customers will reach the drainage system as wastewater. Essentially, only the treated wastewater should be released so as to safeguard human beings and protect the environment. Hence, the assessment of the treated wastewater will reflect on the water security status of the city (Assefa et al. 2019).

10.5.2.3 Proportion of Wastewater Effluent Quality Based on Wastewater Discharge Quality Standards

It is essential to maintain the quality of the treated wastewater within the recommended standards so as to safeguard the human beings and protect the environment (Assefa et al. 2019).

10.5.2.4 Affordability of Domestic Wastewater Collection Tariff

The domestic wastewater collection tariff should be in the affordable range. Hence, it is important to assess the affordability of wastewater collection and disposal. A questionnaire surveying the population can be adopted to assess affordability (Assefa et al. 2019).

10.5.3 Hygiene Dimension

Availability of water is fundamental to human health. Under the hygiene dimension, the three indicators, namely water availability, percentage of the population with diarrhoea, and education level, are evaluated.

10.5.3.1 Water Availability for Hygiene (Per Capita Water Consumption)

Howard and Bartram (2003) stated that a consumption of 100 L/capita/day would meet all the basic human needs. This metric is calculated in a similar fashion as that of per capita water consumption (Eq. 10.2) (Assefa et al. 2019).

10.5.3.2 Percentage of Population with Diarrhoea

The availability of proper toilet system including water availability and cleanliness can improve the hygiene status. It has been reported that diarrhoea can be an indicator of unhygienic conditions. Also, diarrhoea is a common disease in developing countries. Hence, assessment of people affected with diarrhoea can be a good indicator of water security of a place. The assessment can be done through household surveys and also from the secondary data (Assefa et al. 2019).

10.5.3.3 Education Level

It is reported that awareness is a fundamental requirement of the hygienic condition. It can be stated that the educational background can be correlated with hygienic condition. Hence, the assessment of educational level can be an indicator to reflect the hygienic condition of the people living in a particular area (Assefa et al. 2019).

10.6 Measuring Domestic Urban Water Security

In order to obtain the index of water security, the values of the different indicators comprising each of the above three dimensions of urban water security should be aggregated. Onsomkrit (2015), through his study on "water security assessments at the city scale", proposed the aggregation equations.

The first step in the calculation of the domestic urban water security index is to give a score for each of the variables (*v*) according to their values. After all the variables (*x*) are assigned with their respective scores, the next step is to calculate the indicators (*y*), dimensions (*z*) and overall domestic urban water security index (*DUWSI*).

The value of an indicator (P_{zy}) is calculated with respect to scores given to variables as below:

$$P_{zy} = \sum_{y=1}^{n} \sum_{z=1}^{m} w_{zyx} \times V_{zyx} \tag{10.5}$$

P_{zy}: the value of indicator *y* for dimension *z*; *n*: number of indicators in dimension *z*; *m*: number of variables in indicator *y*; w_{zyx}: weight given to variable *x* of indicator *y* of dimension *j*; V_{zyx}: score of variable *x* of indicator *y* of dimension *z*. The total of weights given to the variables equals 1.

The value of a dimension (Z_z) is calculated with respect to values of indicators:

$$Z_z = \sum_{y=1}^{n} w_{zy} \times P_{zy} \tag{10.6}$$

where Z_z is the value of dimension *z*, w_{zx} is the weight given to indicator *y* of dimension *z*. The total of weights given to indicators equals 1.

DUWSI is calculated with respect to values of dimensions:

$$DUWSI = \sum_{z=1}^{n} w_z \times Z_z \tag{10.7}$$

where *DUWSI* is domestic urban water security index, *n* is the number of dimensions, w_z is the weight given to dimension *z*. The total of weights given to dimensions again equals1.

In case the measured value of *DUWSI* is greater than or equal to 3.5 (on the scale of 0–5), then the city is said to possess a satisfactory system and a water-secure environmental set-up. However, if it is less than 2.5, it raises concerns on every dimension of water security and calls for developing service-specific action plans on the water to begin streamlining adaptive responses (Assefa et al. 2019).

10.7 Conclusion

The provision of a secure supply of water to urban areas is one of the most important challenges of the twenty-first century. This chapter provided insights into the problems leading to an unreliable and unsecure domestic water supply in cities and identified future water challenges that cities will face. Several cities worldwide are facing the risk of water insecurity due to rapid urbanisation and climate change impacts. It is projected that the number of people living in cities will increase by approximately 2.6 billion by 2050, and the demand for water will increase globally by 55% from its current level due to the increased consumption of water in manufacturing, energy and domestic sectors. At the same time, a 40% decrease in supply in global water is predicted due to climate change and the collapse of existing water resources. This will cause a risk to the water supply systems of cities and alter urban ecology, jeopardising urban resilience systems. Hence, it is essential to define and quantify urban water security, so that necessary measures can be taken in advance to better mitigate the forthcoming risks. This chapter discussed different aspects of urban water security and showed how it is interlinked with various developmental domains. Furthermore, dimensions and indicators used in measuring domestic water security index have been explained in detail. This chapter elaborates on the notion of domestic urban water security and provides a holistic but simplified description to facilitate its understanding.

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Improving Water Productivity for Smallholder Rice Farmers in the Upper West Region of Ghana: A Review of Sustainable Approaches

11

Mawuli Y. Boadjo and Richard J. Culas

Abstract

Water productivity remains a challenge in the Upper West Region (UWR) and Ghana as a whole. Population growth and change in lifestyle of most Ghanaians, especially the city dwellers, have increased the demand for cereal foods like rice and maize. Rice production requires significant water resources. Low productivity is widespread in the production of rice and this has accentuated Ghana's need to import this staple crop. Rice is traded internationally in the United States Dollar, and so the importation of rice to meet the nation's rice appetite has contributed to the weakening of the Ghanaian Cedi over the years, affecting the entire economy. That is the economic context in which this study explores the complex story of Ghanaians' relationship to rice and how rice industry stakeholders, in particular, smallholder rice growers in the UWR and beyond, see their future, a future imperilled by global climate change. What is the country to do to shape a sustainable and doable rice industry?

In this regard, this study aims to identify ways of improving water productivity within the sector to lift crop production and improve farmer livelihoods and reduce the country's reliance on imported rice. Water resources identified in this study included rainfall, rivers, dams and dugouts. The results indicated that Ghana has abundant water resources that need to be utilized in a manner that will reduce wastage. The findings also revealed that rice production in the UWR and Ghana generally is not well organized. Supplemental irrigation (SI) was observed to be a highly efficient water use practice which, if more broadly adopted, could

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improve water productivity in the UWR since farmers in the region rely heavily on inefficient rainfed agriculture. This study therefore recommends SI to steer agriculture towards a more sustainable future, ultimately improving rural livelihoods and communities.

Keywords

Sustainable agriculture · Water productivity · Irrigation practice · Rice production · Supplemental irrigation

11.1 Introduction

About 60% of the population in Sub-Saharan Africa are smallholder farmers in rural areas (FAO 2006). The agricultural sector in Ghana is dominated by such smallholder farmers who contribute close to 80% of the total agricultural production (AQUASTAT Survey 2005). According to the Ministry of Food and Agriculture (MOFA) (2009), the value of Ghanaian agricultural production rose by 4% in 2000 and by 6% in 2005, achieved largely by the contribution of smallholder farmers. But the contribution of agriculture to the gross domestic product (GDP) reduced from 44% in 1990 to 37% in 2005. This suggests that agricultural activities by smallholders need some improvements to continue to contribute to the GDP now and the future.

According to the FAO, there is the need to lift production of food and fibre in the face of entrenched land tenure, deteriorating soil and water quality, and changing weather conditions (FAO 2015). This is because population increase is creating the demand for food and fibre. For example, there is a high demand for rice in the country since rice has become a staple food for many Ghanaians, much of which is imported (Dogbe et al. 2016; Asuming-Brempong and Osei-Asare 2007). The growing demand for rice creates an opportunity to expand domestic production by the dominant smallholder sector. Farmers must therefore adapt agricultural practices to increase rice production in a manner that will ensure environmental and economic sustainability for smallholder farmers.

However, sustainability involves technologies and practices that use environmental and human resources without causing permanent damage (Pretty 2008). Additionally, sustainability focuses on the use of natural processes, reduction in the use of external inputs and full participation of farmers in the farming processes. It is therefore essential that agricultural practices adhere to sustainable practices that will ensure a viable ecosystem now and for future generations. Generally, rice is a water-dependent crop and water usage for agricultural production is on the increase due to the intensification of rice production along with other crops in Ghana. This is the reason why water productivity is highly essential for smallholder rice farmers to ensure sustainable rice production in the Upper West Region (UWR) of Ghana.

The UWR is in the northern savanna zone which experiences a hot, dry and wet climate (Buah et al. 2011). The region is characterized by a short precipitation period between April and October and the rest of the year is dry. This tends to halt agricultural activities for the rest of the year and brings hardship to farmers. It is for this reason that the sustainable practice of irrigation is important. Irrigation practices are sustainable when their effects on water, land and other elements of the environment are kept within limits such that the ecosystem can regenerate itself overtime (Wichelns and Oster 2006).

Rainfed agriculture which is widespread in Ghana (Place et al. 2002) can assist in ensuring food security in various parts of the country. The increasing population has spurred the expansion of irrigation despite the sometimes-unattainable investment required (Barkley and Barkley 2016). In the year 2000, of 8587 ha in 22 public irrigation schemes only 5600 ha of land were irrigated (AQUASTAT Survey 2005). Miyoshi and Nagoya (2006) observed that the shrinking proportion of irrigated land is due to the declining capacity of the facilities to be able to distribute water. In some cases, the total neglect of the facility is due to the inability of the pump to start and farmers' unwillingness to pay for the operational costs of the infrastructure. Too many farmers think that the irrigation facilities are to be repaired and maintained by the Government, since they are tax payers (Mensah and Ibrahim 2017).

Rice production yields in Ghana have remained low, between 1.2 and 1.5 tons/ha especially with rainfed-upland production (Oladele et al. 2010) due to the methods used in the production process. In other areas of the world, irrigation has been utilized to increase rice yields and proved that it is the best method for rice production in terms of yields. The aim of the study was to promote sustainable irrigation for rice production and to enhance water productivity to improve rice yields for smallholder farmers.

Section 11.2 of this chapter describes the agricultural sector in Ghana and its contribution to the economy, including the importance of rice production. Section 11.3 provides an overview of the water resources available in Ghana and the institutional aspects of the irrigation management in the country. Section 11.4 explores the ways to enhance the effectiveness of water resources management in the country. Rice production methods in particular in the UWR of Ghana is discussed in Section 11.5. Section 11.6 details the possibilities of the practices, learning and water management options that can be available for improving rice productivity of the farmers in the UWR.

11.2 Agriculture in Ghana

Agriculture continues to play a vital role in the economies of African Union (AU) member states. This reality underpinned the Maputo Declaration, which encouraged member states to use 10% of their budgets to support the agricultural sector (NEPAD 2003). The main intention of the agreement was to improve agricultural productivity yearly by 6% for the next 20 years starting from the year 2003. This encouraged the Government of Ghana to increase agricultural investments by the provision of subsidized agricultural machinery to farmers and offer support for research and extension stakeholders and for public–private partnerships (PPPs) (Al-Hassan 2008).

In Ghana, agriculture is practised by rural communities on a small scale, family-operated farms using simple tools. The Food and Agriculture Sector Development Policy II (FASDEP II) document indicated that an estimated 2.74 million households in Ghana practise agriculture. Most of these farmers farm on land areas less than two hectares and have contributed significantly to the agricultural sector. The FASDEP II document, which is the main policy and planning document for the Ministry of Food and Agriculture, also aims to attract the younger generation into agriculture by introducing the use of machinery and irrigation facilities to remove drudgery in farming activities. There are few commercial farms in the country representing about 10% using machinery and irrigation in farming producing cocoa, oil palm, rubber, coconut, maize, rice and pineapples (Namara et al. 2011) (Tables 11.1, 11.2 and 11.3).

Most of the rice produced in Ghana is from the Volta and Northern Regions where farmers cannot afford machinery of their own (Houssou et al. 2013) and so they rely on machinery service providers. This strategy underpins the industry and helps explain the performance of the sector in the top five rice-producing regions (Fig. 11.1).

11.2.1 Rice in the Agriculture Landscape of Ghana

The high nutritional composition of rice – starch (80%), water (12%), protein (7.5%) and ash (0.5%) (Chandler 1979) – makes rice an important grain. Chandler also indicated that starch in rice is normally due to factors including weather, rice variety, the nature of soil and the quantity of fertilizer application. According to Grist (1986), paddy rice from the farm contains up to 75% starch, 2.6% glucose and 0.5% sucrose. Additionally, a grain of rice contains protein, carbohydrate and amino acids (Juliano 1993), which people depend on for their daily nutrition. Figure 11.2 shows the characteristic nature of rice produced under valley conditions in Ghana.

The trends from Fig. 11.3 show an increase in production over time. This is due to the increase in demand for rice from the change in lifestyle and because of population increase which is expected to keep rising (Pingali et al. 1997). The trend for rice production indicated a steady production between 1991 and 2007 and rose from then to 2012. The growing consumption of rice among city dwellers (Al-Hassan 2008) is putting pressure on the Ghanaian economy. Because the demand for rice is greater than the country's production capability, rice is being imported to meet the shortfall. The international rice trade is transacted in US dollars, which puts downward pressure on the exchange rate of the Ghanaian Cedi (Rogers 2012).

11.2.2 Contribution of Agriculture to the Economy of Ghana

One sector that contributes significantly to the economy of Ghana is the agricultural sector through job creation mainly in the rural areas. The agricultural sector has some relation with other sectors of the economy. The sector contributed about 22% to the

Table 11.1 Major crops by area cultivated per annum ('000ha)

Crop/year	Maize	Millet	Rice	Sorghum	Cassava	Cocoyam	Plantain	Yam	Soy bean	Groundnut	Cowpea
2006	793	200	125	320	790	260	299	325	52	480	185
2007	790	163	109	208	801	258	305	324	47	342	139
2008	846	182	133	276	840	252	312	348	62	351	161
2009	954	187	162	267	886	225	325	379	77	337	163
2010	992	177	181	253	875	205	328	385	91	333	167
2011	1023	179	197	243	889	204	336	204	86	357	182
2012	1042	172	189	231	869	196	337	426	85	345	169
2013	1023	161	216	226	875	194	340	422	85	329	162
2014	1025	162	224	227	889	200	357	428	87	335	166
2015	880	162	233	228	917	200	363	430	86	336	163

Source: MOFA, SRID (2016)

Table 11.2 Other selected crops by area cultivated from 2010 to 2015 ('000ha)

Crop/year	2010	2011	2012		2013	2014	2015
Cocoa	1600.20	1600.30	1600.80		1650.80	1683.77	1717.44
Oil palm	367.1	381.8	397.1		409.1	349.04	425.6
Cashew	77	82	86.5		89	90.78	92.6
Coconut	25.2	25.3	25.3		26.1	26.6	27.15
Rubber	25.5	25.8	26		26.8	27.35	27.88
Citrus	16	16.2	16.5		17	17.34	17.69
Coffee	0.4	0.4	0.4		0.5	0.46	0.47
Mango	6.9	7	7.2		7.4	7.55	7.7
Banana	7.3	7.5	7.6		7.8	7.96	8.12
Pawpaw	1	1.2	1.5		1.6	1.5	1.61
Pineapple	9.5	9.8	10		10.3	10.5	10.72
Tomato	44.2	44.5	44.8		46.1	47.02	47.96
Pepper (chilli)	13.2	13.4	13.7		14.1	14.4	14.68
Shallot	5	5.2	5.2		5.4	5.46	5.57
Okra	2.6	2.8	3		3.1	3.16	3.23
Onion	7	7.5	8		8.3	8.42	8.58
Garden eggs	5	5.5	6		6.2	6.33	6.45

Source: MOFA, SRID (2016)

GDP in 2014 or 23,640 million Ghana Cedis (ISSER 2015). In the first decade of the 2000s, the sector made a strong contribution to the economy, recording the significant growth rates of 6% and 6.1% in 2008 and 2009, respectively. But in recent years, the growth rate of agriculture has moderated up to 2.8% in 2015 and 3.0% in 2016 (Ghana Statistical Service 2017).

Additionally, the contribution of agriculture to GDP in 2015 was 20.3% but reduced to 19.1% in 2016. In 2017, the expected growth rate for agriculture was 3.7% (Ghana Statistical Service 2017). This expanded role for agriculture in the economy reflected the aspirations of the sustainable development goals (SDGs). According to the United Nations sustainable development charter, the second goal embraces the aim to stop starvation, attain food availability, enhance population nutrition and encourage sustainable farming. Promoting sustainable agriculture must be knowledge-based, which can be local knowledge and practices that ensure less non-renewable resource use (Pretty 1998). Figure 11.4 models water movement in a valley landscape with good agricultural soils.

Andriesse et al. (1994) indicated that a valley is a seasonal wetland which naturally gives precipitation a runoff and good agricultural production potential because of high water and soil fertility availability. This implies that the major food crop able to thrive on the intermittent flooded area is rice. These valleys are very important ecosystems for rural farmers as they are used not only for agricultural production but also support fishing, hunting and forest ecology (Adams 1993). Ghana has good agricultural soils especially in the south and middle sector of the country which has aided in the production of rice and other crops (MOFA 2009). But

Table 11.3 Yearly production ('000Mt) of major crops in Ghana for a period of 10 years

Crop/year	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Maize	1188.80	1219.60	1470.10	1619.60	1871.70	1684.00	1949.90	1764.50	1768.54	1,691,643
Rice (paddy)	250	185.3	301.9	391.4	491.6	464	481.1	569.5	604.04	641,492
Millet	165	113	193.8	245.5	219	184	179.7	155.1	155.32	157,369
Sorghum	315	154.8	331	350.6	353	287.1	280	256.7	259	228,400
Cassava	9638.00	10,217.90	11,351.10	12,230.60	13,504.10	14,240.90	14,547.30	15,989.90	16,523.66	17,212,756
Cocoyam	1660.00	1690.10	1688.30	1504.00	1354.80	1299.60	1270.30	1261.50	1298.97	1,301,188
Yam	4288.00	4376.00	4894.90	5777.90	5860.50	5855.10	6638.90	7074.60	7118.89	7,296,123
Plantain	2900.00	3233.70	3337.70	3562.50	3537.70	3619.80	3556.50	3675.30	3828.01	3,952,437
Groundnuts	520	301.8	470.1	485.1	530.9	465.1	475.1	408.8	426.63	417,199
Oil palm	1737.90	1684.50	1896.80	2103.60	2004.30	2125.60	2196.10	2326.92	2443.27	2529.51
Cowpea	167	118.9	179.9	204.8	219.3	236.7	223.2	200.4	201.26	203,317
Soybean	54.3	49.8	74.8	112.8	144.9	164.5	151.7	138.7	141.47	142,360

Source: MOFA, SRID (2016)

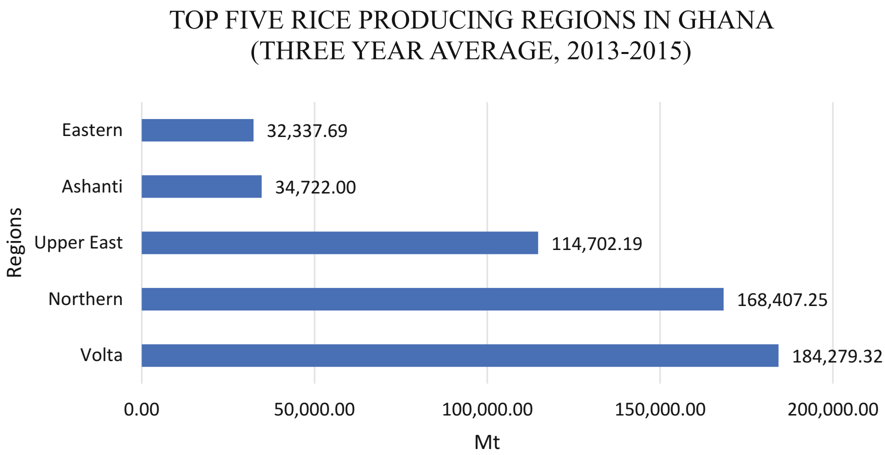

Fig. 11.1 Top five rice-producing regions in Ghana (three-year average, 2013–2015). (*Source*: MOFA, SRID 2016)

Fig. 11.2 Rice cultivated under the valley system in UWR, Ghana

the soil type of the Savannah zone (northern parts of Ghana) is savannah Ochrosols which does not drain well and is characterized by low fertility (Buah et al. 2011). Additionally, the soils in the Savannah are less leaching and acidic but are shallow and are prone to occasional waterlogging.

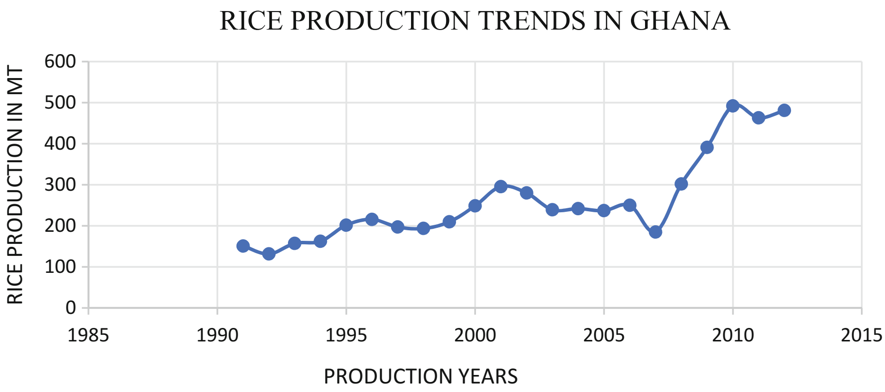

Fig. 11.3 Rice production trends in Ghana from 1991 to 2012. (*Source*: MOFA, SRID 2016)

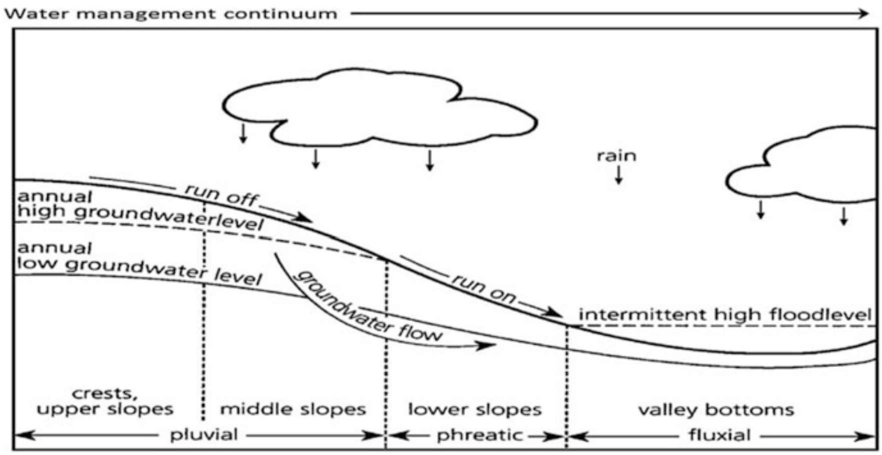

Fig. 11.4 Valley landscape for the cultivation of rice. (*Source*: Rodenburg et al. 2014)

11.3 Water Resources in Ghana

11.3.1 Rainfall Pattern in Ghana

The amount and timing of rainfall significantly affect a river's flow, which in turn directly affects the quantity of water available for agricultural and domestic purposes. Easterling et al. (2007) stated that climate change is a factor that affects precipitation patterns. This therefore makes climate change a significant factor when considering agricultural sustainability.

Water is available throughout the rainy season in Ghana, but rare in the dry season. Table 11.4 shows regional rainfall for a period of ten years in millimetres.

Table 11.4 Ghana's rainfall information in mm for a 10-year period

Regional rainfall information (in mm) for a 10-year period											
Region	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	10-Year average
Western	1350	1678	1518	1385	1749	1445	1298	1025	1654	1144	1456
Central	1462	1330	1361	1195	1359	1144	1029	920	1447	1051	1250
Greater Accra	689	863	914	805	871	812	646	365	777	689	749
Eastern	1410	1328	1454	1211	1477	1337	1204	1080	1271	999	1142
Volta	1093	1195	1436	1212	1009	928	1061	1075	1368	1213	1319
Ashanti	1384	1542	1412	1380	1397	1170	1224	1215	1381	1025	1346
Brong Ahafo	1310	1312	1366	1148	1251	823	1049	1814	1239	1048	1257
Northern	1014	999	1223	1292	1361	1083	1002	1066	1084	870	1122
Upper East	925	1320	902	884	984	665	956	997	707	918	927
Upper West	982	1089	1171	1086	630	523	1136	434	300	724	817
Total	11,619	12,656	12,757	11,598	12,088	9929	10,605	9992	11,228	9679	11,385

Source: MOFA, SRID (2016)

The Western Region has the highest amount of rainfall throughout the period, highly suitable for farming activities to boost the agricultural sector of the country. The average rainfall over the period was 1456 mm for the region. The south and middle sectors of the country in general have very good rainfall levels compared to the north. The UWR on the other hand observed 817 mm of average rainfall over 10 years. The region with the lowest average rainfall was Greater Accra with 749 mm over the period.

Unimodal rainfall (only one peak in the annual rainfall pattern) is experienced in the northern parts of Ghana, with a rainy season from May to October, peaking in September (Gyau-Boakye and Biney 2002). But the effective rainfall that supports agricultural production lasts for 4 months (Namara et al. 2011). The dry season is characterized by little or no rain and is between November and March. In the south of Ghana, there is bimodal distribution of rainfall with major and minor seasons. The major season is between March and July and the minor is between September and November (Kankam-Yeboah et al. 2005). The dry season in the south is between December and February (Opoku-Ankomah and Amisigo 1998). Since the 1970s, rainfall patterns indicate a reduction in the quantity in West Africa (Aka et al. 1996). Considering the rainfall situation between 2006 and 2015, there was no significant change for the period for Ghana, though there were some fluctuations.

11.3.2 Irrigation Development in Ghana

Irrigation started about a century ago in Ghana (Smith 1969), however, small-scale irrigation agriculture can be traced to the 1880s, around Keta in the Volta Region. This system of farming had to be used because the prevailing conditions of the area did not allow shifting cultivation practice. Shifting cultivation was the system being practised throughout the country at the time. Irrigation and the use of manure was the mode of practice for the area. Around the 1930s, shallow tube well irrigation was being practised around the current day Volta Region of Ghana (Agodzo and Bobobee 1994). Also, in the 1950s and the 1960s, there was the development of water schemes which resulted in the construction of 240 earth dams and dugouts in the north and 66 around the Ho and Keta areas in the Volta Region.

These structures provided water for domestic, animals and irrigation purposes. The first irrigation project at Dawhenya was started around 1959, but information available indicates that the Asutuare irrigation scheme was first to be completed in 1967 (Namara et al. 2011). Formally, the construction of irrigation structures started in the 1960s and up to 22 government irrigation facilities had been constructed by 2003 nationwide.

11.3.3 Irrigation Infrastructure

Namara et al. (2011) found that there are different methods by which irrigation schemes distribute water to crop fields in Ghana. Though dugouts do not have canals they are equally used for domestic and livestock purposes, but in some instances they are used for watering crops in the dry seasons using watering cans and buckets (Obuobie et al. 2006). Small reservoirs are created by digging, but in this case they have water intake structures like canals for in-flow and out-flow of water. Irrigation under these systems of dugouts and small reservoirs amounts to 6116 ha. According Namara et al. (2011), groundwater has been used for irrigation in Ghana. The groundwater usage is through the shallow well-based irrigation systems and borehole-based irrigation systems. The construction of shallow well is done manually with the use of axes, shovels, buckets and ropes. Different technologies are used in drawing water from these wells and ranges from the use of buckets to ropes to machines. The communal borehole irrigation systems are systems that were developed with the use of windmill technology to lift water from a borehole site to a reservoir and allow by gravity to flow to irrigable land with the help of valves (Namara et al. 2011).

Some farmers have resorted to the use of irrigation pumps with pipes to convey water to the crop field (Obuobie et al. 2006). Here, an irrigation pump is placed at a safe area around the water source and pipes are connected to both the suction and delivery ends. The suction end pulls water from the water source and the delivery end conveys the water to the field, distributing water to plants by drip system, while others use the furrow system which is wasteful. This has increased the cost of production since pumping is linked to the cost of fuel (MOFA 2009).

As part of the maintenance and sustainable use of irrigation structures, the regular removal of sediments from canals is necessary to prevent heavy accumulation. This is to avoid huge maintenance and rehabilitation costs (Depeweg et al. 2014). The majority of Ghanaian farmers (80%) are smallholders and find irrigation expensive (Carr and Strauss 2001) and so rely mostly on Government-built schemes for dry season farming. This makes the role of the Government very important in expanding the use of groundwater.

11.3.4 Water Reservoirs in Ghana

According to Namara et al. (2011), Ghana's small reservoirs are mostly constructed by the Ghana Irrigation Development Authority (GIDA) or private contractors which are sponsored by donors. In the communities where these reservoirs are constructed, water user associations (WUAs) have been formed for management and maintenance activities. Small reservoirs can be sub-classified into small dams and dugouts. A dugout is usually small in surface area, has a small capacity and a small group of people relying on it. Dugouts are created by digging to increase the depth for more water capture. On the other hand, Appiah-Nkansah (2009) found that in the UWR of Ghana, an irrigation scheme involves a small reservoir behind an earth dam which collects water during the rainy season. There is an emergency spillway which releases excess water. The dams are designed to deliver water directly from the dam to the crop field through concrete canals and others through ditches with valves.

Table 11.5 Small dams and dugouts in Ghana in 2008

		Number of			
S. no.	Region	Small dams	Dugouts	Total no. of small dams and dugouts	Farming area (HA)
1	Greater Accra	35	218	253	120.0
2	Eastern	149	115	190	438.0
3	Volta	167	136	303	103.0
4	Central	23	265	288	342.0
5	Ashanti	22	219	241	677.0
6	Western	50	783	833	820.0
7	Brong-Ahafo	50	289	339	1360.0
8	Upper West	84	54	138	712.0
9	Upper East	149	129	278	895.0
10	Northern	131	398	529	640.0
	Total	786	2606	3392	6116.0

Source: GIDA-MOFA (2008)

In other areas of the region, water delivery is by gravity through conduits into storage tanks of 2.5 m^3 and about 20 m away (Appiah-Nkansah 2009).

Dugouts are constructed to serve a maximum of two villages and are usually planned for domestic and livestock usage with limited use for irrigation. Dugouts in some communities are constructed by the District Assembly for places where domestic water supply is limited, and due to topographical difficulties other forms of water supply are not possible. According to Birner (2008), detailed studies have been done on small dams and dugouts in the Upper East Region. The construction of small reservoirs has been carried out by Non-Government Organisations (NGOs) and donor funding agencies including International Fund for Agricultural Development (IFAD), Plan Ghana, Red Cross and Action Aid.

Around the 1970s and the 1980s, these donors have been promoting the small reservoir systems, and recently the Ghana Irrigation Development Authority (GIDA) of the Ministry of Food and Agriculture (MOFA) conducted a survey to obtain an inventory of small reservoirs in Ghana. Table 11.5 shows the current situation of small reservoirs comprising small dams and dugouts in Ghana. Small reservoirs have the capacity to irrigate 6116 ha. The Volta Region of Ghana has the highest number of small dams, followed by Upper East and Northern Regions.

11.3.5 Institutions/Farmer Organizations

Irrigation policies exist in Ghana to regulate water usage for irrigation activities and to facilitate sustainable irrigation performance in the country. At the top of the policy framework is the MOFA with its subsidiary arm, the GIDA, which is responsible for addressing the constraints and opportunities of all irrigation practices. MOFA and GIDA collaborate hand in hand, but GIDA takes the lead role in coordinating with other institutions such as the local government, NGOs, regulatory bodies, researchers and research institutions such as the Council for Scientific and Industrial Research (CSIR) and academia to advance better irrigation and rice production practices.

Some of the NGOs include World Food Programme (WFP), Alliance for Green Revolution in Africa (AGRA), International Fund for Agricultural Development (IFAD), Plan Ghana, Red Cross and Action Aid. Some of the educational institutions involved in research and improving irrigation and rice production are Kwame Nkrumah University of Science and Technology (KNUST), University of Ghana (UG), University of Cape Coast (UCC) and University for Development Studies (UDS). MOFA and GIDA organize farmers into groups in the various communities and offer them training to ensure better management of agricultural facilities such as dams and irrigation technologies. Such groups include water users associations (WUAs).

11.4 Enhancing Effectiveness of Water Management in UWR, Ghana

11.4.1 Water Productivity

According to Sadeghi and Rahimi (2003), water productivity is the value of product over the volume of water utilized. The value used can be denoted by different terms such as biomass, grain in kilograms or metric tons and money. Brauman et al. (2013) defined water productivity (kg/m^3) as the amount of food produced in kilograms per unit of water used. Brauman et al. (2013) found that in Sub-Saharan Africa, there is a large range of crop water productivity for various crops compared to other parts of the world like the United States and China. For instance, the crop water productivity for maize in Sub-Saharan Africa was below 0.3 kg/m^3 compared to 1.7 kg/m^3 in the United States (Zwart and Bastiaanssen 2004; Rockstrom et al. 2009; Zwart et al. 2010).

This variability accords with the picture reported in Brauman et al. (2013), who argued that crop water productivities are influenced by climatic and location factors as well as the type of crop. Primary producers and other stakeholders in the agricultural sector need to look at such contextual factors when evaluating crop water productivities and making production decisions. Smallholder farmers in the UWR of Ghana, for example, can resort to using low water rice cultivars in producing rice since the region experiences low precipitation (Table 11.4).

11.4.2 Causes of Low Water Productivity

The technical know-how of farmers in Ghana, according to Cornish et al. (2001) is minimal and farmers lack basic information on land preparation needed for good water management. Schraven (2010) argued that the Ghanaian smallholder farmers' practising irrigation are not sustainable, given the complex environment in which they operate. It is reported that rising soil salinity affects the crop development and water productivity. Low water productivity can also be caused by climate change and the inability of farmers to adjust to the changes.

11.4.3 Measures to Improve Water Productivity

11.4.3.1 Crops with Low Water Requirement

Water productivity can be improved by choosing varieties that thrive in low moisture conditions (Catlett and Libbin 2007). Drought-tolerant varieties require less water, which can reduce a farmer's irrigation costs. In Ghana, rice production has evolved and the use of Degang rice variety is highly conducive for use in the dry conditions in most areas. The use of drought-tolerant varieties of rice is a major way of reducing production costs in dry conditions in most cases (Catlett and Libbin 2007).

11.4.3.2 Mulching Practice

Another means of improving water productivity is by means of appropriate mulching practices. Crops perform better in soil that are well managed and have good water retention capacity, temperature and weed control measures. The use of mulches maintains the soil moisture, temperature and weed control mechanisms to boost crop performance (Gliessman 2004). The use of biodegradable materials helps retain fertility of the soil which ensures subsequent performance of crops on the same tract of land. To reduce costs, mulching can be introduced to retain the existing moisture in the soil thus reducing the amount of water needed from irrigation. Mulching is important for soil, water and nutrient conservation (Pretty 2013). Pretty concluded that the spread of organic material on the surface of soil provides some form of protection and cover to retain soil moisture from evaporation and reduce erosion.

The application of mulch gives the opportunity for the use of varied materials that can benefit plant, soil and water utilization. The importance of mulching also includes the reduction of soil surface evaporation, improvement of soil temperature and soil water conservation. According Khurshid et al. (2006), mulching with crop residue at soil surface affects the infiltration of precipitation. The crop residue reduces the flow of rainwater as runoff giving more time for the water to infiltrate the soil. Erenstein (2002) drew similar conclusions from experience in Zimbabwe – that mulching significantly reduces surface runoff to allow infiltration which is slow.

11.4.3.3 Adaptation to Climate Change

Climate change adaptation gives the opportunity to manage the effects that it poses by changing forms of agricultural activities and to take advantage of the emerging opportunities while reducing the monetary value of the harmful effects (Walthall et al. 2013). Strategies that will mitigate the harmful effects of climate change are mostly related to conservation practices (Delgado et al. 2011). Adaptation to climate change, according to Walthall et al. (2013), include the development of drought, pest and high temperature resistance in crops and animals. They added that to check climate change, there is the need to diversify crop rotations and mixing livestock with crop production methods. Since land is a fixed asset and population is increasing, improvement of soil quality is essential to combat climate change effects. To minimize the effects of climate change, farmers, students, researchers, government institutions and the public will have to adapt to systems that encourage sustainability by which the environment will be protected for now and the future generations. "Further, linking the climate mitigation and adaptation in the agricultural production system per se paves way for resilient agriculture". The resilient and smart agricultural practices sustain the agricultural production, ensure food security and decarbonize the agricultural production (Venkatramanan et al. 2020).

11.4.3.4 Supplemental Irrigation (SI)

For the next fifty years as reported by Molden (2007), gains can be achieved if water productivity can be increased from less water to reduce future demand for water in crop production. Smallholder farmers with careful targeting can make gains in water productivity which can reduce poverty and increase their incomes. This can be achieved with the use of supplemental irrigation. Supplemental irrigation as stated by Oweis and Hachum (2012) is the supplying of small amounts of water to mostly rainfed crops when rainfall fails to give enough moisture for normal growth to ensure good yields. Rainfed agriculture or dry land farming is the most practised agriculture in the world and is most common in Sub-Saharan Africa and some parts of Asia where the poorest people reside (Oweis and Hachum 2012).

During the sudden halt of rainfall which is a common occurrence in the UWR of Ghana, supplemental irrigation will be an effective action to be taken to respond to the adverse effects of soil moisture stress affecting crop yields. The sudden halt of rain in some cases happens when the crops need moisture for flowering and grain development. During such times of breaks in rainfall, supplemental irrigation can reduce the moisture stress. There is scope for the UWR to develop tube wells and sell underground water to farmers at a near production cost to boost the rice industry in Ghana. This could be through water pricing mechanism where water is priced and released to the farmers' fields for irrigation to improve sustainability.

11.4.3.5 Water Pricing

Water is an essential natural resource. Water is renewable due to its ability to be reused when not intensely contaminated and recirculated through the water cycle. Water cycle refers to the process by which moisture is drawn by evaporation from rivers, lakes, plants, trees and the sea into the atmosphere to form clouds which fall

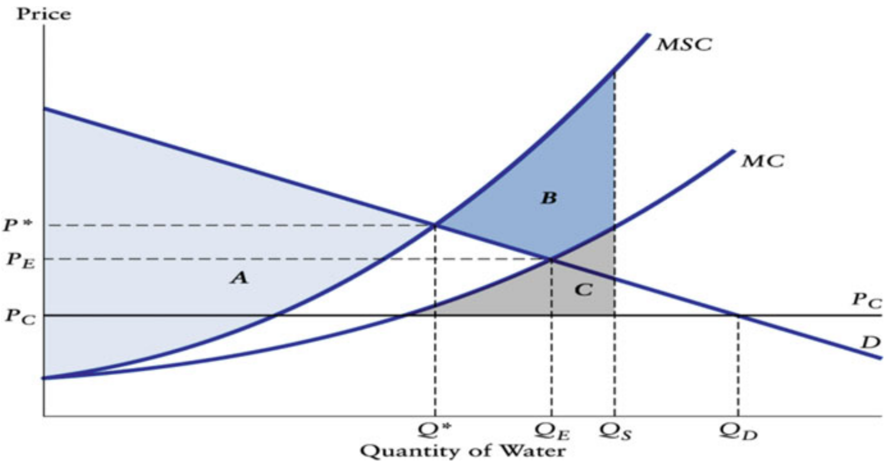

Fig. 11.5 The characteristics of subsidized pricing of water. (*Source*: Adopted from Harris 2006)

back as rain (Harris 2006). Groundwater on the other hand is water beneath the earth surface which can be drawn from shallow wells or deep wells for irrigation and domestic purposes. If groundwater is harvested at a higher rate than the rate at which it is replenished, it becomes a non-renewable resource (Tietenberg and Lewis 2012).

The principal markets for water are agricultural, industrial and domestic. The sector that consumes more water globally is agriculture which uses about 67% of the planet's fresh water supplies. While about 83% of total agricultural land is under rainfed production and only 17% is irrigated land, more than 40% of the global food supply is produced using irrigation (Harris 2006). Irrigation is therefore the most important means to food security in the world.

In this context, the role of the government is to use the pricing mechanism to manage national water use, encouraging uses that are more, not less, efficient. This would mean that in Ghana, for example, the Government would apply pricing pressure to discourage the use of inefficient furrow and flooding systems of irrigation. Careful use of pricing can encourage adoption of more efficient technologies which has the effect of consuming less water for a given crop output. Industries and individuals who recycle used water should be given subsidies to encourage them to continue (Harris 2006). Figure 11.5 illustrates the way pricing policies affect the demand and supply of water. In the Fig. 2.5, total water demand = D; marginal cost for water supply = MC; marginal social cost = MSC.

The MSC takes into consideration aspects that tend to harm the environment and activities that drain the water reservoirs. Water price at P_c which is below the amount for supplying MC will favour more people using the resource which might add to demand and even cause overload, with interruptions to supply. This implies that the government will have to supply at Q_D (Fig. 11.5). The price at P_E shows the full cost that users of the water can pay for quantity Q_E to avoid losses. The price at P* will give a benefit at quantity Q* which should benefit the supply at some cost to the user.

Governments can use such mechanisms to actively intervene in water pricing to achieve optimal efficiency and minimize waste, where the areas C, B and A (Fig. 11.5) represent, respectively, the cost of subsidy by the Government, user (external or social) cost and net benefit (welfare) by the pricing policy (Harris 2006).

11.5 Rice Production Systems in UWR of Ghana

According to Abe and Wakatsuki (2011), rice is being cultivated in Sub-Saharan Africa under three systems, namely, irrigated, rainfed lowland and rainfed upland. This aligns with earlier findings of Kranjac-Berisavljevic et al. (2003) that three main systems of rice cultivation exist in the UWR of Ghana: irrigated, valley and rainfed upland rice production. These systems practised by farmers are largely based on costs of production of the commodity because most farmers are resource poor. Therefore, most of these farmers use the upland rainfed system which involves rain watering, no bunds and natural drained soils without water build-up. In this production system, yields depend on good and regular rainfall. The expenditure for this system is low hence the interest by farmers.

The other system that is gaining acceptance in the UWR and beyond is the valley rice production system where the Government with other organizations construct water retaining structures in the field for the various communities to enable them to produce rice in the rainy season. Though this system is rainfed, because of the infrastructure installed in the field, the system can produce higher yields of rice than the upland rice system. Participating smallholder farmers are positive about the system, but it is quite expensive without the support of the Government and NGOs. Irrigated rice production systems require water supply and are expensive and more technology dependent, but they offer high yields. The monetary aspect of this system makes this solution unattractive for smallholder farmers unless support is available.

11.5.1 Irrigated Rice Ecology

Irrigated rice ecology tends to produce high yields because high technological approaches are used much more than in rainfed and upland rice farming (Abe and Wakatsuki 2011). In this system, enhanced land preparation with tractors, enhanced seed varieties from the Crop Research Institutes (CRI), fertilizer application and weed control measures through water management are used (MOFA 2009). Under the irrigated ecology, land preparation is carried out by ploughing followed by harrowing which is essential in breaking, loosening and levelling of compact soil (Culpin 2013).

Fig. 11.6 Transplanted rice in a valley in the Upper West Region of Ghana

11.5.2 Valley Rice Production

Valley rice production is practised primarily by bunding of land and allowing rain to flood the area which supports the growing of rice throughout the season (MOFA 2009). Bunding is an earth embankment raised above the ground level to avoid the escape of water from a field or within a drain. The valley system of rice production in the Northern Regions of Ghana include the construction of bunds with graders (MOFA 2009) which can be highly expensive for rural farmers. The drains and bunds in valleys are used to control water during the rainy season. The purpose of the drain is to allow water to move freely through the fields. The process involves opening a side of the bund and closing it when enough water enters the field. The land is prepared using tractors with mounted plough and harrow. Some farmers are unable to afford the cost involved with the use of machines like graders and tractors (Houssou et al. 2013), therefore the Government of Ghana and other organizations and countries support with the provision of infrastructure such as bunding and irrigation facilities.

About 20% of today's global rice harvest is achieved using the flooded lowland production system (IRRI, AfricaRice and CIAT 2010). Swain et al. (2005) indicated that rainfed lowland production of rice in Asia constitutes about 26% of their total production in the region. Typical yields are presently around 1–2.5 tons per ha. Some lowlands have much water available for rice production. Growers in these areas need to select rice varieties that will perform well in such conditions. Some varieties are more capable of adapting to prevailing moisture conditions than others. The plant develops adventitious roots that can absorb nutrients from the water directly while the normal roots are bound firmly to the soil (Balasubramanian et al. 2007).

Rice cultivation in Ghana is mostly carried out using the rainfed system. In the northern part of Ghana, fields have been allocated and worked with machinery like

Fig. 11.7 Bund created for water control measure

Fig. 11.8 Rice ready for harvest

graders to construct bunds, mini-bunds, laterals and levelling. The bunds are created for the easy control of water in the field. When water is needed in the field, the bunds to the drain holding water is cut open to allow water into the field and then closed to stop the flow (Figs. 11.6 and 11.7). The laterals created in the field are to ensure even distribution of water, fertilizer and manure.

The Rice Sector Support Project (RSSP) is a French and Ghana Governments' project which is substantially financed by the French Government. This project is assisting in the increasing production of rice in a sustainable manner to reduce poverty and increase food availability in four regions. Figure 11.8 shows RSSP rice in the UWR ready for harvesting.

11.5.3 Sawah Technology

The sawah system on the other hand is being practised in rainfed valleys in the south of Ghana. The sawah system involves bunding, puddling and levelling manually to achieve good water and nutrient management (Wakatsuki et al. 1998). It is a cheaper solution than other systems. Bunds are formed in the field to retain water and fertilizer. Puddling is the tilling of a rice field when flooded with a power tiller. This buries weeds in the soil to prevent them from growth (Das et al. 2014). The sawah system is an ecologically friendly system that can ameliorate pest disturbances and sustainably improves the fields (Oladele et al. 2010). Bunding, puddling, levelling and supplementary irrigation are land management practices that offer higher yields of rice (Becker and Johnson 2001). The main aim of the introduction of sawah was to overcome low rice productivity (yields of 4 tons/ha) and to achieve a sustainable production system (Oladele et al. 2010) by using environmental resources like land and soil without causing damage.

According to Abe and Wakatsuki (2011), the bunding and levelling features of the sawah system are effective in that they permit the rice field to be flooded, covering the base of the rice plant with water, which reduces the growth of weeds and reduces the need for labour for weed control. During the submergence of the rice crop, macro and micro-nutrients are replenished, encouraging rice growth and breeding of microbes that aids nitrogen fixation (Greenland 1997). The sawah system naturally replenishes soil fertility which is important for the sustainable production of lowland rice (Eswaran et al. 1997).

The sawah system yields between 2 and 3 tons/ha without the use of fertilizer and can continue for years without fallow which is not the case for other systems. It can be concluded that if organic fertilizer is applied, yields can exceed the values stated. The upland rice produces yields of 1 to 2 tons/ha which practises fallow of up to 10 years (Wakatsuki et al. 1998). Bam et al. (2010) concluded from results of on-station trials between 2006 and 2009 in southern Ghana that there is the possibility to double yield notwithstanding the type of rice with the 'sawah system'. Buri et al. (2012) added that valley rice farming in the 'sawah system' will lead to a substantial enhancement in soil and water management in the country.

11.5.4 Upland Rice Production

With this system, the land is prepared before the rains come and rice is broadcast at the onset of rain (Seck et al. 2012). This is the most popular system being practised in most parts of Ghana and is responsible for about half of the country's rice production (Kranjac-Berisavljevic et al. 2003). However, this system has not yielded the expected results due to erratic rainfall patterns, lack of good extension services, wrongful fertilizer applications and poor weed and disease control (MOFA 2009). The lack of good weed control measures is the main factor reducing rice yields. Other factors reducing yields include blast (a rice disease), drought, soil acidity and general decline in productivity. Some farm activities like slash and burn have compounded problems by destroying living organisms that aerate the soil (Oldeman and Hakkeling 1990). Some farmers use longer growing season varieties. Because the rainy season is short, these plantings are inadequately watered in drier months and have poor growth.

11.5.5 Rice Productivity (Opportunities and Challenges)

The agricultural sector is the largest consumer of fresh water because water is a key component in crop production (Rosegrant et al. 2009). Rice has long been the dominant crop in terms of water consumption. In the context of growing scarcity of water, rice producers have a challenge in improving their water use efficiency (Molden 2007). It is becoming increasingly obvious that society is looking to the farm sector to improve its productivity for reasons of national food security given the expanding population (Hoff 2010).

According to Molden (2007), agricultural activities have increased over the past 50 years due to population increase and will continue to increase for the next 50 years. An obvious priority is to improve land and water productivity for crop production. The greatest potential according to Molden (2007) for improved yields is within the rainfall areas where the majority of poor rural people live. In Sub-Saharan Africa, there is a need for infrastructural development through investment in irrigation and the opportunities that are available, reallocating supplies and rehabilitating ecosystems.

In the Upper West of Ghana, there is a need for more infrastructure development, although there was previously certain infrastructure in some districts that have been poorly maintained. Most of that infrastructure now needs massive rehabilitation if it is to be kept in use. In areas where infrastructure exists, the need to improve productivity is recognized, especially in well-endowed districts like Jirapa and Wa Municipality. Supporting the various institutions that are engaging with this challenge is important for the sustainability of the country's agricultural enterprise.

Supplemental irrigation (SI) which involves limited water applications to crops during critical growth periods will result in considerable enhancement of yield and crop water productivity. According to Oweis and Hachum (2012), supplemental irrigation is important for increasing yields of crops like rice in most regions of the world and can be an influence in reducing low productivity of rice and other cereals when used with proper production inputs. Field visits to some rice farms in 2015 in the UWR revealed that rice fields were affected by sudden dry spells and for those farms that had received water at the resumption of rain recovered and yielded well.

This result supports Oweis and Hachum's (2012) position on supplemental irrigation. In other parts of the region, valleys are being utilized for growing rice. These valleys hold substantial reserves of water because the water table for groundwater is close and readily available for SI application. The main sources of water for supplemental irrigation include groundwater and surface water like rivers, lakes and streams but water harvesting for dams and dugouts is also available in the region.

Research from the International Centre for Agricultural Research in the Dry Areas (ICARDA) indicates that when a cubic meter of water is used at the correct time when the crop is water stressed in combination with good management practices can produce 2.50 kg of grains which is greater than when using rainfed (0.50 kg of grain) and full irrigation (0.75 kg of grain). The high productivity of water is due to the effectiveness of reviving water-stressed crops with a small amount of water during the critical stage of the crop growth and seed development (Oweis and Hachum 2012).

When the physical and economic conditions are favourable, water resources are best utilized within an SI regime. It is important that before the application of SI, the farmer wait for soil moisture to drop to the critical level. This means that a constant measuring of soil moisture is required. In this instance, farmers will have to use their experience to determine the amount of precipitation that the crops receive and the appearance of the crop to know when to apply SI. As soil moisture drops, it is important to know when and how much water to apply to obtain the maximum yield.

11.5.6 Practices, Learning and Water Management Options for Rice Production

11.5.6.1 Alternative Practices

There is strong alignment between the principles of supplemental irrigation (SI), as propounded by Oweis and Hachum (2012) in relation to cereal production in Asia, and the sawah eco-technology approach (Oladele et al. 2010; Abe and Wakatsuki 2011). Sawah eco-technology involves environment-friendly use of valley landscapes, land management and water use efficiency (irrigation) to produce rice. This approach has already benefitted smallholder farmers in some areas. These systems can be adopted and propagated by extension staff for farmers to use to ensure sustainability. The land management techniques involved in sawah fields according to Oladele et al. (2010) are bunding, puddling, levelling and transplanting.

The main difference in the addition of water for both technologies is that the water is applied to submerge the rice plant in the sawah system but in the case of SI small quantities of water are applied at the critical stage of rice production. While SI requires significantly less water than the sawah approach, other inputs like fertilizers are required to support crop growth. By contrast, the sawah approach requires that the rice plant is submerged in water to the stem, and during this submergence microbial interactions increase soil fertility and boost rice yield (Oladele et al. 2010). Fertilizer is expensive for smallholder farmers and availability is not always assured, so the sawah approach is seen by these producers as an attractive strategy for increasing yields.

The sawah technology's only challenge is the involvement of manual labour which these farmers are willing to invest especially when they are in groups. The sawah solution which is recognized for its strong sustainability credentials could be implemented in the UWR. The application of this approach could improve biodiversity because the natural environment is accepted as an essential element in project

Table 11.6 Smallholder farmers adopting sawah technology in the south of Ghana between 2001 and 2005

Farmer groups	2001	2002	2003	2004	2005
Adugyama A	4.0	4.7	3.8*	5.0	4.5*
Adugyama B	4.4	4.8	5.5	5.5	4.8*
Biemso A	4.8	4.7	4.8	5.5	–
Biemso B	4.7	5.7	5.9	6.5	5.4
Biemso C	–	4.5	5.4	5.5	5.5
Mean	4.5	4.9	5.1	5.6	5.1
SE	0.18	0.21	0.36	0.24	0.24
Traditional system	0.9	1.0	1.0	1.1	1.1

Source: Oladele et al. (2010)
*Fields partially destroyed by floods

design and improving biodiversity is a valued outcome. The adoption of the sawah approach is growing in the south of Ghana and Table 11.6 shows the impact created in the yields of the farmers between 2001 and 2005. More than 4 t/ha of grain on the average was achieved by smallholder farmers for the period, which has been a demonstration of the merits of the sawah solution.

11.5.6.2 Participatory Learning, Training and Extension Programmes in Farming

According to Al-Hassan (2008) and Mensah and Ibrahim (2017), there are high illiteracy rates among farmers in most parts of Ghana and this has resulted in low adoption of agricultural technologies and continuing low productivity. This need not be the case. According to Community of Practice (COP) theory, smallholder farmers can work with an expert or extension officer as a community of learning, considering proposals for change in a language that is understood by the farmers. In this environment, lack of literacy need not be an obstacle to innovation nor to improved farm performance. To prevent low rice productivity and low yields, rice production experts must engage with farmers to learn, develop innovation and share knowledge using the local language of the farmers. These approaches and ideas are in line with the COP that agroecology proponents seek to promote. If Ghana is going to change the way agriculture is conducted towards a more sustainable future, the Government must give priority to and support the adoption of COP approaches.

Learning is the accumulation of knowledge to make meaning. According to the experiential learning cycle, learning involves real world experiencing, reflective observation, idea building and ideas in action. In the real world experiencing stage, participants interact with others. This stage involves reliance on senses, feelings and instincts more than on applying standard principles to situations. Wenger (1998) noted that institutions of learning are using reductionist approaches for acquiring knowledge and that they concentrate on individualized sessions and see collaboration as cheating. As a result, most learners and would-be learners see institutional learning as boring and difficult. Learning is inevitable; it arises from our experience of participating in the world we belong to. Learning should be part of our human nature, just like eating or sleeping, and just as life sustaining.

Innovation is the process by which a new idea or invention is translated into a good or service that creates value. The word signifies that something new has occurred which could be a change in practice or adjustment of some old concepts. According to Cross and Ampt (2016), farmers adapt technologies, techniques, behaviours and attitudes and innovate these values in partnership with other farmers and experts rather than adopting inventions alone. This view aligns with earlier works by Allan (2005) and McKenzie (2013). As noted by McKenzie (2013), an important aspect of innovation is not just the acquisition of new knowledge but also the processes of interaction by which new understandings are developed and applied together. Traditionally, farmers have used many methods to innovate on their farms to grow crops, but in these changing times the tried and true methods will need new kinds of innovative thinking. Such new thinking can be achieved by bringing farmers together with extension professionals and governments to holistically address the challenges in farming today.

11.5.6.3 Water Management Options

In water-stressed areas like the UWR of Ghana, agricultural water for supplemental irrigation (SI) must be used to ensure water productivity. As previously canvassed, SI represents a conservative, economical approach to water use. Research in other parts of the world has shown significant improvement in water productivity from SI. When water is scarce for rice production, a farmer can use an incremental approach to SI. He may, for example, apply full SI to half of the farm and leave the other half to rainfed watering; or, he may apply deficit (reduced) supplemental irrigation to the entire farm. Under such conditions, applying 50% of full SI to irrigate the entire farm has been seen to be the best option for farmers. Oweis and Hachum (2012) indicated that a farmer having a 4 ha farm can produce 33% more grain by adopting deficit irrigation for the whole farm rather than applying full SI to half of the farm. From Fig. 11.9, applying full SI ensures greater yield of 4.5 t/ha and

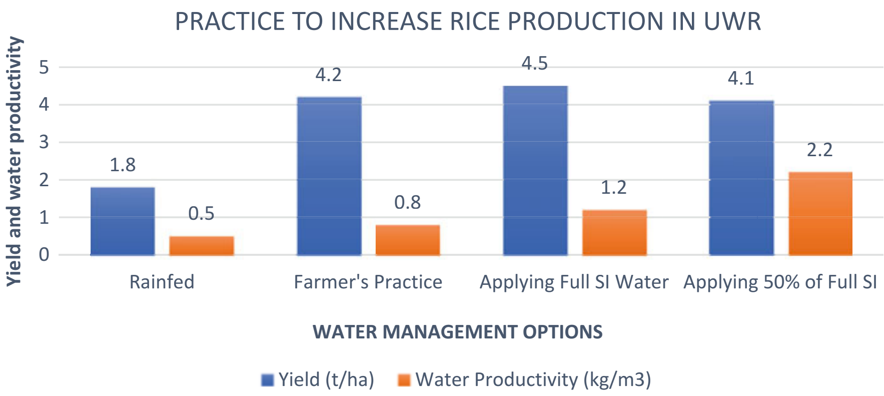

Fig. 11.9 Practices that can increase yield of rice per drop of water. (*Source*: Oweis and Hachum 2012)

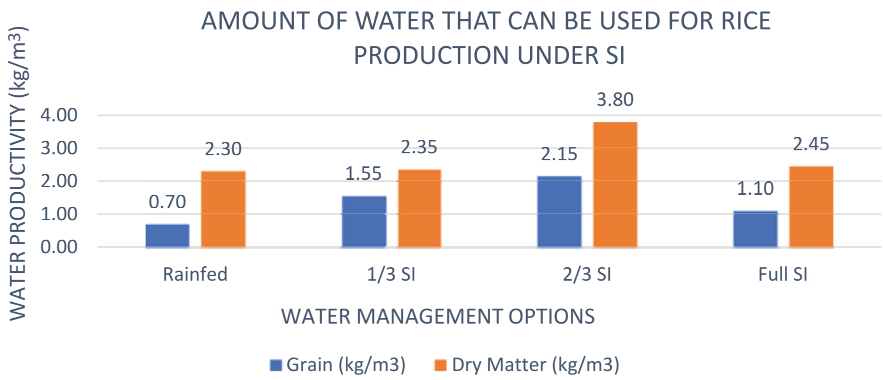

Fig. 11.10 Possible water supplemental options for increased yield of rice. (*Source*: Oweis and Hachum 2012)

uses less water to ensure water productivity of 1.2 kg/m^3 as compared to the other methods of water conservation practices.

Maximum water productivity can be achieved when smallholder farmers are able to supply water to their rice fields between 1/3 and 2/3 of full SI water, especially during times of water stress (Oweis and Hachum 2012). In most cases, farmers either under- or over-irrigate the field due to the difficulty of identifying the best time to supply the water. Considering the achievement of rainfed agriculture (Fig. 11.10), when good water management is applied the rainfed system can make a worthwhile contribution to food production. The grains produced (2.15 kg/m^3) for 2/3 SI water option (Fig. 11.10) is the highest option for cereal production and can be beneficial to smallholder farmers since the main aim is to maximize profit with little water and other inputs. Rainfed showed the lowest performance followed by full SI. The substandard performance of full SI might be due to oversupply of water to the crop at the critical stage or perhaps farmers could not identify the proper timing for applying SI. On the other hand, the dry matter produced under full SI showed similar development compared to that of 1/3 SI and rainfed trials. This might be because dry matter develops with ease compared to grain development process.

11.5.6.4 Improving Economic Policies and Trade for Rice Production

Asuming-Brempong and Osei-Aare (2007) noted that Ghana is a member of the international community controlled by policies and trade relations which are bounded by rules and regulations. Among them are World Trade Organization (WTO), African Union (AU), Economic Community of West African States (ECOWAS) and others. Though Ghana is supposed to participate in different trade negotiations to protect the national interest to secure great opportunities for development, the overall regime of these international obligations are impacting negatively on local rice production in the country (Kranjac-Berisavljevic et al. 2003).

There is no denying of the fact that trade agreements are important for the country but when these obligations result in making the Ghanaian rice industry less

Table 11.7 Quantity and value of rice commodity imports in Ghana between 2006 and 2015

Year	Quantity (Mt)	Value ($ Million)
2006	389,660	159.47
2007	442,073	157.86
2008	395,400	187.28
2009	383,985	218.5
2010	320,152	200.88
2011	543,465	391.17
2012	508,587	319.8
2013	644,334	392.3
2014	413,609	221.09
2015	620,811	285.32

Source: MOFA, SRID (2016)

competitive on the international market, they appear to be causing more harm than good and they are not in tune with the benefits for which Ghana joined the world community. The Group of 20 (G20) summit held in May 2017 recognized that in terms of trade, countries involved must gain ‘reciprocal and mutually advantageous’ benefit and that countries with trade issues can resort to ‘legitimate trade defence instruments’ if they feel they are at a disadvantage. The legitimate trade defence instrument is the WTO’s current mechanism for regulating international trade. Between 2006 and 2015, there was a steady increase in rice importation into Ghana (Table 11.7).

This is the main reason the Government of Ghana set up about 89 machinery service centres between 2003 and 2010 in the country to benefit smallholder farmers. The main aim of the Government was to set up an agricultural machinery service station in every district in the country, but the logistic constraint has not allowed the aim to be materialized.

11.6 Conclusion

Rice is an important crop in the world and does well in tropical and sub-tropical areas, including the UWR in Ghana. Production systems vary due to weather conditions, landscape, the ability to adopt technology by farmers, the cost of production and many more. Smallholder farmers consider the cost of production as the major consideration in the systems that they utilize rather than the yields obtained. Production levels and yields can improve with the extent of water control measures which is the significant factor needed to enhance yield levels in the UWR.

Whereas sophisticated irrigation schemes have the edge to control water and other inputs to produce higher yields, farmer practices on the other hand produce stagnated yields using an upland rice production system with less technologies. Rice production systems based on cropping systems like crop rotation (mostly vegetables and legumes) is highly beneficial, as seen from some of the irrigation schemes in

Ghana. Smallholder farmers must adopt such systems on their fields by integrating long-lasting crop production systems.

Smallholder farmers in UWR can contribute to the economy of Ghana by adopting more sustainable production systems. The utilization of supplemental irrigation (SI) can be a highly important addition with the use of simple irrigation pumps and accessories to boost crop development in times of water stress. The Government of Ghana should ensure that machinery services are available in every district and municipality in the country. Many young people are jobless and are a potential labour force for machinery services. It would also improve the availability of food and reduce hunger and poverty for a majority of the Ghanaian people, thereby helping Ghana to achieve some of the UN sustainable development goals (SDGs).

As more young people elect to stay in the regions, the migration of youth to the cities will be reduced. Ghana's need to import rice has grown and continues to grow. This does nothing to improve the local rice industry. The solution to the challenge is for the UWR and Ghana more broadly to make improvements in rice production through the utilization of technologies to make sure that locally produced rice can compete with the quality and quantity of the imported rice.

It is hereby recommended that the Government must review certain neglected elements of the rice industry such as irrigation facilities that were never completed and others that were completed but not properly maintained. Some of the facilities need simple repairs while others need huge capital investments or replacement. In this way, the UWR will use the new and rehabilitated facilities to increase its production of rice and other food crops. The target-based production approach for increasing rice production together with a commitment to retain some of the wealth generated in the regions to support the local economy should be adopted as a national survival strategy.

Multiple voices need to be heard to tap into the collective experience of rice industry stakeholders in pursuit of a sustainable future. The efficient utilization of water is needed in times when irrigation water has become scarce and all sectors are competing for water. The use of supplemental irrigation (SI) will help farmers to efficiently use water which is becoming less available and more expensive. The yield target will be a valuable tool for maintaining a formidable rice industry to enable smallholder farmers in the region to achieve good living standards for their families and communities.

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Synergies Between Climate Change, Biodiversity, Ecosystem Function and Services, Indirect Drivers of Change and Human Well-Being in Forests

12

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Abstract

Climate change is having impacts on the biodiversity and structure of many ecosystems. In this chapter, we focus on its impacts on forests. We will focus on how the potential climate change impacts on forest biodiversity and structure will have a reflection on the ecosystem services provided by forests, and therefore on the capacity of these ecosystems to support the Sustainable Development Goals set by the United Nations. The chapter will be organized in three sections,

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considering boreal, temperate, and tropical forests along each section. The first section will deal with the synergies or interactions between climate change, biodiversity, and ecosystem function with emphasis not only on plants but also on fungi, animals, and prokaryotes. Synergies between climate change and ecosystem services will be described and analyzed in the second section. To better link the first two sections, we will explore the relationships between ecosystem function, species traits, and ecosystem services. Finally, case studies for boreal, Mediterranean, and tropical forests will be presented, emphasizing the synergies between the above factors, the indirect drivers of change (demographic, economic, sociopolitical, science and technology, culture and religion), and human well-being (basic materials for a good life, health, good social relations, freedom of choice and actions) in forests.

Keywords

Climate change · Biodiversity · Ecosystem · *Larix gmelinii* · Boreal forest · Sustainable development goals

12.1 Introduction

The terrestrial and aquatic ecosystems of the Earth are connected by cycles of water, carbon, and nutrients controlled by the dynamics of climate, which is powered by solar energy. The interactions between these cycles and climate are modulated in part by forests both at the local and global scales. These interactions result in various synergies, as we shall see in this chapter, that generate complexity and dynamic stability which can make difficult to predict dynamics of ecosystem attributes and services (Perry et al. 2008). Forests cover about 30% of the world's land area (Shvidenko et al. 2005). Through their low surface albedo, high carbon storage capacity (~ 45% of terrestrial carbon), high CO_2 uptake (~50% of terrestrial net primary production), and by changing their evapotranspiration rates that cool the climate and affect rain patterns, forests can influence climate and the hydrological cycle (Bonan 2008). Forests also can regulate streamflow and influence water quality (Perry et al. 2008). Additionally, they provide provisioning (e.g., water and timber), regulating (e.g., carbon sequestration), supporting (e.g., biogeochemical cycling), and cultural (e.g., recreational) services to humans (MEA 2005).

The importance of the above functional attributes and ecosystem services generally vary depending on the type of forest. Among these, three forest types predominate on the Earth's continents. Thus, boreal, temperate, and tropical forests represented 26.5, 16.1, and 57.2% of total forest cover in 2010, respectively (Hansen et al. 2013). According to Bonan (2008), boreal forests have moderate climate control through moderate carbon storage, weak evaporative cooling, and lower albedo (i.e., sun absorption); temperate forests have moderate climate control through strong carbon storage and moderate evaporative cooling; and tropical forests have strong climate control through strong carbon storage and strong evaporative cooling. Although boreal forests have very low human population density and a low number of tree species, more than 33% of the lumber and 25% of the paper of the global export market originate from this biome (Gauthier et al. 2015). Human boreal communities benefit from ecosystem services provided by the forest for fishing, hunting, leisure, spiritual activities and economic opportunities. In the temperate zone, tree biodiversity is intermediate and human population density is generally high and concentrates in rural areas and especially in cities. Forests close to these population centers are often utilized intensively as a source of recreation and other non-forestry activities (e.g., hunting, fishing, and mushroom picking). However, temperate forests constitute a source of industrial roundwood of the same magnitude as boreal forests (FAO 1999). Tropical forests hold the highest biodiversity on Earth, which provides a wide range of ecosystem services on which 1.2–1.5 billion people benefit directly (Lewis et al. 2015). From them, almost 820 million people live in forests, savannas, or their surroundings, and 250 million of them are under the thresholds of extreme poverty (FAO 2018).

During the period 2000–2012, the tropics were the only domain to exhibit a significant trend in annual forest loss due to the prevalence of deforestation dynamics. Boreal forest loss followed, due largely to fire and forestry. Temperate forests, however, showed relatively low losses mainly due to fire, logging, and disease (Hansen et al. 2013). Indeed, temperate and boreal forest cover has stabilized and even increased in the last decades, but their quality is still threatened by air pollution, fire, pest and disease outbreaks, continued fragmentation, and inadequate management (Shvidenko et al. 2005). In general, it appears that these patterns will be maintained or accentuated in the near future (e.g., Seidl et al. 2011) and pose a real threat not only to forest health and the delivery of ecosystem services, but also to the overall functioning of the global system (Prăvălie 2018). Furthermore, climate change threatens forests in all biomes, both directly and through synergies with natural and other anthropogenic disturbances.

In this chapter, we will focus on how the ongoing and potential climate change impacts on forest biodiversity and function will have a reflection on the ecosystem services provided by forests, and therefore on their capacity to support the Sustainable Developing Goals set by the United Nations. First, we will deal with the synergies or interactions between climate change, biodiversity, and ecosystem function putting emphasis not only on plants but also on fungi, animals, and prokaryotes. Then, synergies between climate change and ecosystem services will be described and discussed. Next, to better link the previous two sections we will explore the relationships between ecosystem function, species traits, and ecosystem services. Finally, case studies for boreal, temperate (in its Mediterranean version), and tropical forests will be presented, emphasizing the synergies between the above factors, the indirect drivers of change (demographic, economic, socio-political, science and technology, culture and religion), and human well-being (basic materials for a good life, health, good social relations, freedom of choice and actions) in forests.

12.2 Synergies Between Climate Change, Biodiversity, and Ecosystem Function

12.2.1 Climate Change Impacts on Forest Biodiversity

Global climate change affects ecosystems across the world. The global warming trend in the recent past is unprecedented (Venkatramanan et al. 2020a). Earth's forest biomes are facing a rapid and increasingly profound stress associated with climate change. Global trends attributable to climate change include latitudinal and elevational range shifts, phenological advances in growth or reproduction, and changes in disturbance patterns (i.e., tree pest and diseases, fire and drought), resulting in changes in community structure and function and delivery of ecosystem services.

Distribution of species has recently shifted to higher latitudes at a median rate of 16.9 kilometers per decade and to higher elevations at a median rate of 11.0 meters per decade (Chen et al. 2011). Northern boreal forests are migrating northward into tundra while southern boreal forests shift to shrub lands or grasslands in response to global warming (Allen and Breshears 1998). Likewise, tropical species are increasingly incorporated into temperate communities affecting food webs and resulting in new species interactions (Scheffers et al. 2016). For example, populations of insect defoliators and bark beetles are expanding to northern latitudes and higher altitudes in response to climate change affecting novel host species (Pureswaran et al. 2018). The rates of diversity turnover for microbes across temperature gradients from tropical to boreal forests are substantially lower (i.e., 2–8 times lower) than those recorded for trees and animals, suggesting that the diversity of plant, animal, and soil microbial communities show differential responses to climate change (Zhou et al. 2015), and that latitudinal shifts of microbes might be proceeding at lower rates. However, a warming threshold might be reached in how trees interact with fungi, so the existing forest transition from low-latitude arbuscular mycorrhizal through N-fixer to high-latitude ectomycorrhizal forests (Steidinger et al. 2019) can be disrupted, resulting in different types of ecosystems. Elevational range shifts caused by climate warming have been described in boreal, temperate, and tropical forests. For instance, bird distributions (Kischman and van Heuren 2017) and tree lines (Cazzola et al. 2019) have shifted upward 83 m in 40 years and 150 m in 52 years, respectively, in two boreal forests. Similarly, summer drought increase has caused a 70 m upward shift of European beech in a 50-year period through progressive replacement of cold-temperate ecosystem by Mediterranean ecosystems (Peñuelas and Boada 2003). Likewise, upslope shifts of moths (i.e., 67 m in 42 years) and bird distributions (i.e., 95–152 m in 50 years) have been found in tropical mountains (Chen et al. 2009, Freeman and Class Freeman 2014). Although higher latitudinal areas are undergoing the largest increases in temperature (Diffenbaugh and Field 2013), at least for birds, tropical montane species are responding more strongly to climate change than temperate-zone species, apparently due to higher sensitivity to warmer temperatures of tropical species (Freeman and Class Freeman 2014). The impacts of species redistribution will affect at least 11 of the United Nations

Sustainable development goals (e.g., SDG3 Good Health and Well-Being). However, current global goals, policies, and international agreements do not sufficiently take into account species range shifts in their formulation or targets (Pectl et al. 2017).

Longer growing seasons of plants are occurring predominantly via warming of the coldest days in late winter and early spring (Cleland et al. 2007), potentially contributing to an increase in carbon sequestration. Forest vegetation phenology changed dramatically between 1981 and 2012, especially in the boreal and northern temperate regions (Buitenwerf et al. 2015). These changes appeared to be regulated by temperature and photoperiod cues (Delpierre et al. 2016), while tropical ecosystems appear to be more influenced by precipitation variability (Cleland et al. 2007). Differential phenological shifts can cause mismatches between plant and pollinator population and lead to the extinctions of plant and pollinator species (Lavergne et al. 2010), with expected cascading effects on community structure and function.

Evidence of climate change effects on pest and diseases in boreal (Boyd et al. 2013) and temperate forests (Millard and Stephenson 2015) is mounting. This is relevant because tree pest and diseases can affect the ability of forests to sequester and store carbon, reduce flood risk, and purify water, damaging also provisioning and cultural services (Boyd et al. 2013). Global climate models predict an increase in fire frequency and intensity under climate change (Moritz et al. 2012). However, in some parts of the world like the western US forests, this is already a fact and it has resulted in reductions in forest productivity, greater tree mortality, and increased opportunities for colonization by plants (Grimm et al. 2013). These anticipated and ongoing changes in fire patterns along with the fact that bacteria appear to be more resistant to fire than fungi, and both of them less resistant than mesofauna, translates into important changes in ecosystem structure and function. The impacts are further exacerbated by the lack of resilience to fire of these biological communities (Pressler et al. 2018). In temperate forests, interactions between increasing temperatures resulting in "hotter droughts," native insects, and pathogens and uncharacteristically severe wildfires are resulting in unprecedented forest mortality (Millard and Stephenson 2015). In tropical forests, synergistic effects between fragmented forests and climate change are provoking important changes in plant and animal species composition (Brooks et al. 2008; Laurance et al. 2014). Disturbance recovery time of leaf area and transpiration (i.e., water regulation services) is decades, while carbon storage functions take from decades to centuries, while biodiversity, coarse woody debris, and nutrient mineralization can take even longer (Blanco 2012; Trumbore et al. 2015). These trade-offs have an impact on people with a reduction in timber supplies and carbon sequestration, and changes in water quality (Scheffers et al. 2016).

12.2.2 Climate Change Impacts on Forest Ecosystem Function

Anthropogenic climate change is due to the economic activities including but not limited to industrial activity, agriculture and urbanization (Venkatramanan et al. 2020b). Primarily, the increase in atmospheric concentration of greenhouse gases causes climate change. Among those gases, carbon dioxide (CO_2) is the most important producing greenhouse effect. CO_2 is also a growth-limiting factor for plants as they use it to create carboxylates during the photosynthesis. Increasing levels of atmospheric CO_2 concentration (*Ca*) enhance the rate of carboxylation by the photosynthetic enzyme system and reduce photorespiration (Norby et al. 1999). Likewise, rising *Ca* will decrease stomatal conductance, which results in an increase of water-use efficiency (WUE), that is, the ratio of the carbon gain to water loss (Fig. 12.1a) (Farquhar et al. 1989; Körner 2000). In addition, soil moisture savings due to reduced transpiration and changes in leaf area index have been associated with increasing *Ca* (Fatichi et al. 2016). The combined direct and indirect effects have been commonly referred as CO_2 fertilization (Holden et al. 2013). Consequently, an improvement of forest productivity is expected (Gedalof and Berg 2010). However, although some studies reported positive growth responses (LaMarche et al. 1984; Martínez-Vilalta et al. 2008), neutral and negative responses have also been found (Peñuelas et al. 2011; Silva and Anand 2013; Lévesque et al. 2014; Camarero et al. 2015). Such inconclusive results reveal that there are other factors controlling the growth-rising *Ca* relationship (Lo et al. 2019).

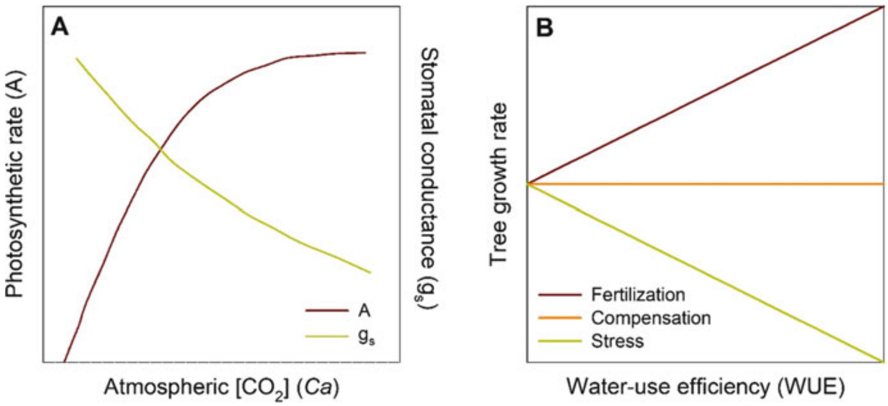

Fig. 12.1 (**a**) Relationship among photosynthetic rate (A), stomatal conductance (gs), and atmospheric CO_2 concentration (*Ca*) for unstressed trees (own elaboration based on Regehr et al. 1975); (**b**) expected relationships between water-use efficiency (WUE) and tree growth (own elaboration based on Silva and Anand 2013). When increased WUE, resulting from rising *Ca* and/or water stress, can override physiological response to stress, CO_2 fertilization effect of growth is expected (*Fertilization*). Conversely, if water stress is too strong, a negative growth-WUE would occur (*Stress*). No change is expected when CO_2 stimulation compensates for stress (*Compensation*)

Climatic conditions play an important role in modulating forest responses to rising *Ca*. Warming likely enhances tree growth through the positive influence on xylogenesis activity (Rossi et al. 2008), or the lengthening of growing season (Poulter et al. 2013). Despite the combined effect of increased temperature and improved WUE, global growth response patterns in relation to rising *Ca* have been proposed to be dependent on water stress (Fig. 12.1b) (Silva and Anand 2013). In regions where water is not a limiting factor (i.e., high latitude or altitude), growth stimulation has been observed (Salzer et al. 2009, Silva et al. 2010). The growth–WUE relationship becomes progressively more negative as the climate develops into warmer and drier conditions, such as the drought-prone Mediterranean regions (e.g., Peñuelas et al. 2008; Linares and Camarero 2012; González de Andrés et al. 2018). The physiological basis of such a pattern is linked to strong reductions of stomatal conductance resulting from water deficit (Waterhouse et al. 2004), which reduces cavitation risks at the expense of reducing photosynthesis and growth (McDowell et al. 2008). If drought is long or intense enough, drought-induced mortality could occur as a consequence of hydraulic failure or hydraulically-mediated carbon starvation, and subsequent predisposition to attacks from biotic agents (McDowell 2011).

An important issue when analyzing climate change impacts on forests is their composition and structure, as forest response at both tree and stand levels is greatly modulated by competing neighbors and stand structure (e.g. Coomes et al. 2014; González de Andrés et al. 2018; Grossiord 2019). In forests, trees compete for light, water, and nutrients, and the effect of such tree-to-tree interactions may be more important than climate factors (Primicia et al. 2013; Fernández-de-Uña et al. 2016). In mixed-species forests, biodiversity effects can modify the performance of communities compared to individual species. Two main processes are thought to contribute to positive biodiversity effects: facilitation (positive effect exerted by one species on the functioning of cohabiting species, Bertness and Callaway 1994) and resource partitioning (differences in functional traits that reduce competition for resources, Hooper 1998). Facilitation and resource partitioning involve multiple mechanisms, including nutrient, water, and light-related processes. A thorough list of such mechanisms can be found in Forrester and Bauhus (2016) and in Ammer (2018).

There is increasing evidence that biodiversity promotes various ecosystem functions and services (Cardinale et al. 2012). Tree species richness has been shown to foster productivity at both regional (e.g. Jucker et al. 2014; Vilà et al. 2013; Fichtner et al. 2018) and global scales (Zhang et al. 2012; Liang et al. 2016; Jactel et al. 2018). Mixed forests have been also found to be more stable in terms of biomass production (Morin et al. 2014; Aussenac et al. 2017; del Río et al. 2017) and resistant against disturbances (Jactel et al. 2017). However, mixing effects are modulated by environmental conditions (Ratcliffe et al. 2017; Mina et al. 2018), and special attention has been paid to climate (Forrester et al. 2016; Jucker et al. 2016; González de Andrés et al. 2017; Jactel et al. 2018). In fact, selective effects have been proposed to drive long-term forest responses to climate change, so that changes in competitive balance and species composition are expected to occur

(Morin et al. 2018). It is noteworthy that positive biodiversity effects would take place as long as tree species interactions improve the mobilization of the limiting resource (Forrester 2014). In the context of climate change with predicting increasing aridity, mixtures will not display greater drought resistance unless net water-use partitioning or water-related facilitation processes occur (Grossiord et al. 2014a, b). Hence, adaptation of forest stands to rising water deficit depends on functional traits – and thus identity – of species involved (Forrester et al. 2016; Metz et al. 2016; Tobner et al. 2016; Vitali et al. 2018; Yuan et al. 2018).

Apart from species composition, climate change impacts on forest functioning depend on nutrient availability (Lévesque et al. 2016). On one hand, elevated nutrient availability makes trees susceptible to suffer greater water stress as they likely increase water demand and reduce uptake capacity (Dziedek et al. 2016; Lim et al. 2017) due to higher investment to foliage biomass and increased shoot-root ratios (Marschner et al. 1996). Under high nutrients' trajectory, intensive droughts increase risks of cavitation and mortality due to hydraulic failure (Gessler et al. 2017). On the other hand, decreased nutrient availability and uptake, which take place during a drought event (Kreuzwieser and Gessler 2010), are worse if nutrient content in forest soils is low, increasing the likelihood of C starvation and biological infections under long-term water deficit (Gessler et al. 2017).

At the same time, climate change also affects cycles of nutrient in forest ecosystems (Fig. 12.2). Litterfall constitutes a major proportion of nutrient cycling between plant and soils in forests (Prescott 2002). Climatic conditions are closely linked to variations in production, seasonal patterns, and composition of litterfall (e.g., Aerts 1997; Blanco et al. 2006, 2008; Yuan and Chen 2009; Zhang et al. 2014; González de Andrés et al. 2019). Hence, projected increasing temperatures and alterations of precipitation regimes will have striking consequences on litterfall dynamics.

Stoichiometry (i.e., proportion of elements) of organisms and resources determine rates at which metabolic reactions take place (Sterner and Elser 2002). Elemental stoichiometry can be associated with important ecological processes and ecosystem traits, such as the ability of trees to adapt to environmental stress (Sardans et al. 2013, 2017), or composition of decomposer communities and litter decomposition rates (Güsewell and Gessner 2009; Mooshammer et al. 2014). Indeed, litter quality has been identified as the most important factor controlling decomposition (Cornwell et al. 2008; Zhang et al. 2008), which has been negatively related with high litter nitrogen:phosphorus (N:P) ratios (Güsewell and Freeman 2005; Mooshammer et al. 2012). Litter stoichiometry is the product of many processes, including nutrient uptake and allocation, growth, or resorption, which are modulated by climatic conditions (Fig. 12.2). In general, warming and drought have been proposed to increase tree N:P ratios (Yuan and Chen 2015), whereas N and P resorption efficiencies are reduced and enhanced, respectively (McGroddy et al. 2004). In addition, water availability largely determines the effect of rising *Ca* and N deposition on stoichiometry of nutrient recycling (Zechmeister-Boltenstern et al. 2015).

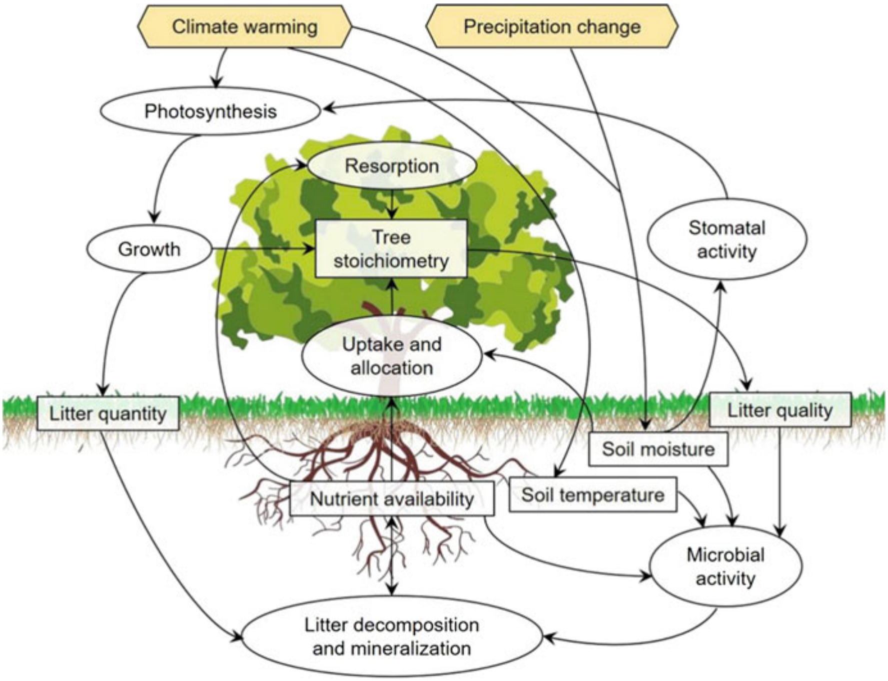

Fig. 12.2 Conceptual diagram of the impacts of climate change on processes controlling stoichiometry of trees and nutrient cycling in forests ecosystems. Yellow hexagons are climate change drivers, rectangles represent nutrient pools, and ellipses indicate biogeochemical processes (own elaboration)

Decomposition and nutrient mineralization rates are also driven by climate (Parton et al. 2007; Zhang et al. 2008). For instance, drought decreases microbial activity and ion mobility in soils (Kreuzwieser and Gessler 2010). Moreover, warming increases net N mineralization and nitrification and reduces soil P availability (Melillo et al. 2011; Dijkstra et al. 2012). Therefore, climate change is expected to have significant impacts on different processes controlling nutrient cycling in forests (González de Andrés 2019).

In short, climate change will influence productivity, species interactions, and nutrient cycling of forest ecosystems, all of which interact among them in a complex way. Understanding how climate factors affect different aspects of forest functioning is essential in order to predict forest responses on ecosystem services, and therefore how such services can contribute to reach the UN's Sustainable Development Goals.

12.2.3 Climate Change Impacts on the Relationship Between Forest Biodiversity and Ecosystem Function

UN's Sustainable Development Goal 14 is "Life Below Water" and SDG 15 is "Life on land." Therefore, the maintenance of biodiversity in both water and land systems is a priority for development to be considered sustainable. The effects of environmental conditions on the relationship between biodiversity and ecosystem functioning (B-EF) are poorly understood. Most research on this topic has been carried out in grasslands although it is rapidly increasing in forests. However, studies on plants predominate but research on other kingdoms is almost absent. Climate change may alter to which degree complementarity (i.e., niche partitioning and facilitation) and/or dominance effects underlie the B-EF relationship (Pires et al. 2018). Ratcliffe et al. (2017) explored the B-EF relationship along gradients of tree species richness using a European research platform that included boreal, temperate, and Mediterranean forests. They found that water availability was the most important factor in changing B-EF. In general, B-EF relations tended to be more positive in water-limited forests (e.g., Mediterranean) and to turn neutral or negative in forests with high water availability (e.g., boreal). Similar B-EF relations have been found in boreal forests when comparing limiting and non-limiting water conditions (Grossiord et al. 2014a, b). These results add more evidence supporting that niche partitioning is an important mechanism in water-limited forests. Furthermore, as water limitation increases under climate change, biodiversity may become even more important to support high levels of functioning in European forests. However, biodiversity effects can also be negative in mixed boreal stands relative to pure ones in the sense that water availability can be more intensively used through niche partitioning in the former leading to lower tree growth (Grossiord et al. 2014a, b). Also, if only a subset of species is resistant to the climatic stressors, and this selection or dominance process becomes increasingly important under climate warming, the complementary effects will probably diminish (Pires et al. 2018; Steudel et al. 2012).

It is also important to point out that changes in biodiversity and ecosystem functioning can affect global climate change (Hisano et al. 2018). Thus "losses in biodiversity can directly reduce ecosystem functioning (e.g., losses in carbon stocks) which can accelerate global change (e.g., increased carbon emission). Moreover, increased biodiversity can mitigate the negative impacts of climate change on ecosystem functioning" (Hisano et al. 2018).

12.3 Synergies Between Climate Change and Ecosystem Services

12.3.1 Ecosystem Services in Forests

Ecosystem services are the benefits humans receive from the environment, and a concept useful to explain beneficial functions provided by ecosystems to the society (Dai et al. 2017; Nolander and Lundmark 2016). In particular, forest ecosystems provide multiple and diverse services, resources, goods, and products for human well-being and a great variety of purposes. The demand for ecosystem services is dynamic and influenced by societal transformations, political preferences, and changing environmental conditions (Peters et al. 2015).

Traditionally, forest owners had a main economic interest in provisioning services such as manufacturing of wood products, timber supply, and pulp and paper production at the expense of other services (Duncker et al. 2012; Nolander and Lundmark 2016). Thereby, forests provide further services (e.g., preservation of biodiversity, carbon sequestration, water regulation, nutrients cycling, hydrological functions, and recreation), and at the same time have to face increasing and recent environmental problems (e.g., global climate change, biodiversity loss, pollution, land degradation, and desertification). Thus, current forest management options should provide economically valuable products or services and promote a good living environment (Dai et al. 2017), as well as mitigate environmental pressures and improve long-term human well-being (e.g., socio-cultural or economic benefits such as health, employment, and income).

Current sustainable forest management practices are expected to lead to beneficial trade-offs or synergies between different ecosystem services. Therefore, knowledge and awareness of interactions between ecosystem services are necessary for taking decisions regarding appropriate forest management. Trade-offs or synergistic relationships between the same ecosystem services will differ among forests due to different ecological processes at different scales (Dai et al. 2017). In recent years, there has been an increasing interest to use woody resources as an energy source and substitute for fossil fuels (Nolander and Lundmark 2016). However, there is also the need to analyze the effects of energy wood production and use in policy development and forest management in order to address current and future trade-offs and to take advantage of the full potential of synergies related to other forest ecosystem services. These trade-offs and synergies are difficult to predict since they are influenced by several dynamic factors, such as climate change, time and spatial scale, forest types, or specific local conditions. Stakeholders perceive similar trade-offs and synergies between energy wood production and provisioning (e.g., timber production, competition between material and energy use, marketability of wood, employment, and rural development), regulating (e.g., climate, soil and water regulation, wildfire prevention), supporting (e.g. biodiversity and nature conservation, political regulations), and cultural (e.g., recreation) ecosystem services (Peters et al. 2015). It is also important to point out that management of natural resources creates an impact on the ecosystems that must be identified and quantified in order to contribute to sustainable development.

12.3.1.1 Forests Are Sources of Wood and Fiber

UN's SDG 9 is "Industry, Innovation and Infrastructure," whereas SDG 12 is "Sustainable Consumption and Production." Forests have a long history of being important providers of economic material for human society. In the old times, timber production was one of the major goals in forestry. To increase the supplement of industrial wood, European countries and the United States of America started to establish forest plantations since the eighteenth century, while the rest of the world followed after World War II (Pandey and Ball 1998; Woziwoda et al. 2019). In the beginning, industrial forestry focused on monoculture and fast-growing plantations. However, with the awakening of the concept of ecosystem and its services, how to sustainably keep supporting human and other organisms' needs became one of the major issues in forestry (MEA 2005). In addition, with the rising issues regarding climate change and its impacts, forestry is moving from supplying wood and fiber to mitigating climate change by reducing atmospheric CO_2 concentration. In this section, we discuss the differences between monoculture plantations and mixed forest plantations, and how climate change affects the production of these two management strategies.

Monoculture (i.e., one tree species plantation) has the advantage of being easy to manage with less cost. Depending on the species and the final needs, the rotation length can be as short as 7 years to as long as 70 years (Pandey and Ball 1998). However, such intense and short rotations cause soil fertility degradation, higher chance of erosion, higher susceptibility to fire, and wind and insect disturbances, among other issues (Wei et al. 2012; Wei and Blanco 2014). In central Europe, planting pure Scots pine (*Pinus sylvestris*) stands, which started in the eighteenth century, was the first major trend in forestry (Woziwoda et al. 2019), while in the United States several other pine species were chosen for plantations. Later, fast-growing eucalyptus, pine and acacia species, as well as rubber and oil palm were also chosen for industrial tree plantation all over the world (Pandey and Ball 1998). As forestry is trying to increase wood and fiber supply to meet human demands, the extent of the world's forests continues to decline due to growing human populations and increasing demand for cropland. According to FAO's 2015 Global Forest Resources Assessment, world forests have decreased from 4128 million ha in 1990 to 3999 million ha in 2015 (MacDicken et al. 2015). Among these forests, only 3.5% are plantation forests (Brown and Ball 2000).

Even though wood and fiber are still in high demand, with the perception change of other ecosystem function and services (MEA 2005), monoculture plantations have become less favored. For example, in Europe, mixed Scots pine plantations with Norway spruce or with broad-leaf species started to become the management trend since the late twentieth century (Woziwoda et al. 2019; Bielak et al. 2014). In other regions, mixtures of eucalyptus and acacia, or mixtures of conifer species with local native broadleaves, have also been chosen to increase forest productivity or maintain biodiversity (Wei and Blanco 2014). If the focus is on forest productivity, some recent studies show 20–30% overyielding of mixed versus pure stands in stand volume productivity in temperate and boreal forests (Bielak et al. 2014; Pretzsch et al. 2015). Thus, when compared to pure Scots pine stands, pine and beech mixed stands achive higher stand volume, stand density, basal area growth, and stand volume growth, with increases ranging from 8% to 20% depeding on site-specific conditions (Pretzsch et al. 2015).

Although genetic biotechnology, silviculture practices, and different management strategies can be used to improve forest productivity (Karoshi and Nadagoudar 2012), environmental factors play the major role to control forest productivity. Figure 12.3 shows how environmental factors affect forest biomass production. In short, light, CO_2 concentration, and water directly affect photosynthesis rate, and all together with other environment factors such as temperature, precipitation, and soil nutrient plus stand condition (i.e., age or stage of development, stand density, and

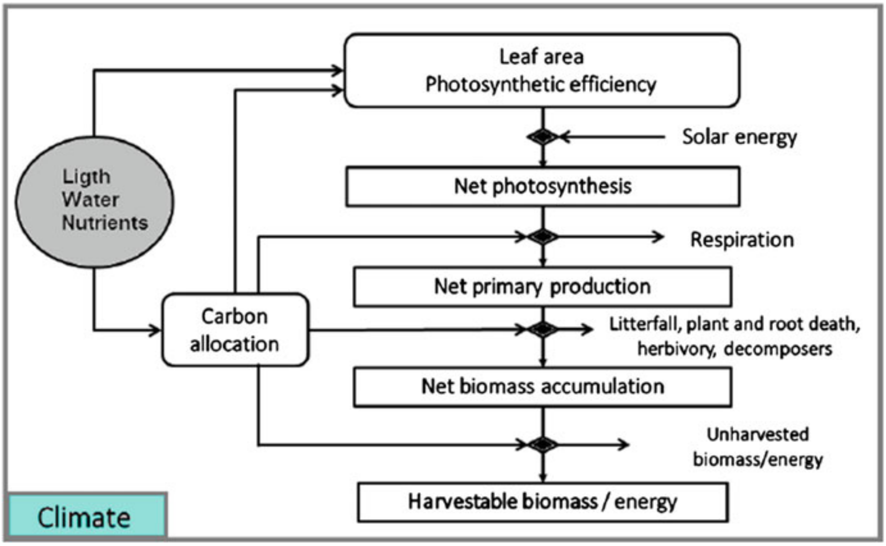

Fig. 12.3 Main limiting factors involved in the transformation of solar radiation into harvestable wood and fiber (own elaboration)

species composition) determine the final amount of forest productivity (Lo et al. 2011; Blanco et al. 2018).

Even though climate change may increase forest productivity with increasing atmospheric CO_2 concentration and increasing mean air temperature (Lemordant et al. 2016), other environmental factors diminish this effect due to the lack of sufficient nutrients or to more severe and frequent disturbances such as drought, flooding, fire, insects and wind damages, etc. (Poulter et al. 2013; Lo et al. 2019). Depending on the location and site condition, how to choose the proper species combination and management strategy become a major challenge in forestry oriented to meet UN's Sustainable Development Goals.

12.3.1.2 Forests Are Sources of Energy

UN's SDG 7 is "Affordable and Clean Energy." Enhanced environmental concerns are encouraging the use of renewable and alternative sources of energy, especially in developed countries (IEA Bioenergy 2002). Expansion of renewable energies is a key measure in climate change mitigation and reducing greenhouse gas emissions (de Jong et al. 2017), but the design of energy policies should identify options that reconcile national and international obligations to address climate change and the loss of biodiversity and ecosystem services (Holland et al. 2016). Besides, the expansion of renewable energy can be considered controversial regarding land use competition and social acceptance, and entails trade-offs with nature and biodiversity conservation (Hastik et al. 2015). Meeting the world's energy demand represents a major challenge for society over the coming century (Holland et al. 2016), and renewable bioenergy can improve the delivery of social, economic, and environmental benefits from forestry (Dale et al. 2017). In this sense, there is increasing recognition of general environmental advantages of bioenergy (IEA Bioenergy 2002). The main drivers for bioenergy are the mitigation of global climate change, the increase in fossil fuel prices, and the concerns about energy security.

Bioenergy refers to the generation of renewable energy via the use of plant- and animal-based matter (Gasparatos et al. 2017). The main sources for providing bioenergy are forestry and agricultural residues or waste from different sectors (e.g., municipal and industrial waste, livestock, and food). Bioenergy use differs notably in different regions: almost approximately 50% of energy supply in Africa comes from renewables as biomass sources, but only a percentage of 10% of the supply in Europe comes from renewable energies (WBA 2018). Increasing the contribution of bioenergy to total energy production can reduce their reliance on finite fossil fuel resources and help mitigate anthropogenic climate change. However, the increased use of bioenergy has potential implications for land management, biodiversity, and ecosystem services (Ranius et al. 2018).

Forest bioenergy is typically a side product of forest harvesting and wood processing. It is generally produced as a complementary co-product of wood and fiber products as sawlogs and pulpwood and during pre-harvesting operations such as thinning (Berndes et al. 2018). It is unusual for forest bioenergy to be the sole product from harvested wood (Matthews et al. 2014). In general, biomass for energy has a lower bulk density and economic value than wood for timber or paper and pulp industry (Abbas et al. 2011), so that bioenergy systems often use biomass that would otherwise be unmarketable (IEA Bioenergy 2002). Forest bioenergy must be considered as an integral part of forestry-industry-energy systems (Berndes et al. 2018). In this context, an integrated production system for wood and bioenergy exhibits an example of synergy as the thinned stand maximizes the value of wood products, and thinnings are used for bioenergy.

Biomass is the most widely used fuel in underdeveloped countries (Mateos et al. 2016). Fuel wood or charcoal are still used for heating and cooking, mainly in developing countries, whereas large quantities of industrial wood and forest wastes are used to generate energy in developed countries (IEA Bioenergy 2002). Characteristics of different regions and countries need to be taken into account to develop long-term and far-reaching political frameworks (Peters et al. 2015).

Interest in the utilization of forest biomass for energy is growing due to environmental reasons, such as concerns about climate change and energy security, promotion of innovative bio-based industries, and policies to displace non-renewable resources. During the last decades, European energy demand has increased and is expected to further increase in future years due to socio-political changes (Peters et al. 2015). Predictions indicate a significant increase in the use of biomass for transport, indoor heating, electricity generation, and diverse industrial processes (Börjesson et al. 2017). At the same time, renewable energy polices in the European Union (EU) have developed gradually since the 1990s, setting a long-term goal to develop a competitive, resource-efficient, and low carbon economy by 2050 (European Commission 2011). In parallel, European countries have developed and implemented different policies to promote the production and use of bioenergy from forests (Lindstad et al. 2015).

Sustainable forest management focuses on the balance between various economic, ecological, and social functions and is key to maintaining healthy and productive forests (Hastik et al. 2015; IEA Bioenergy 2018). Managed forests are considered strategic areas for the importance of storing carbon and providing a continuous stream of ecosystem services, including wood products, energy, and biodiversity conservation (Nabuurs et al. 2015). Conventional forest industry focuses on producing high-value products, such as saw-wood and wood panels, or pulp and paper, but residues and by-products have typically been used for energy. Consequently, forest managers take advantage of low-value stemwood from short rotation periods, thinnings, and diseased or low-quality trees to generate bioenergy (IEA Bioenergy 2018). The energy valuation of biomass also improves the forest economy and provides ecological benefits and other additional advantages, such as the generation of employment in rural areas or reduction of forest fire risks (Mateos et al. 2016).

Forest biomass for bioenergy is commonly referred as woodfuel (Matthews et al. 2014). Woodfuel can be classified in different types of products used as fuel for different energetic purposes such as cooking, heating, or power production. Forest industry develops different types of forest biomass to be available for energy uses, such as logs, briquettes, wood chips, pellets, or charcoal. These woodfuel products present diverse sizes, shapes, and consistency to meet bioenergetic demands (e.g., domestic or commercial heating, power generation at different scales, generation of steam and electricity in the service industry) or non-fuel uses (e.g., food smoking, animal bedding). Global wood pellet demand has experienced a recent growth that has been driven largely by EU renewable energy targets to reduce greenhouse gas emissions (Dale et al. 2017). Europe is the world leader in pellet production (WBA 2018). The EU and individual countries' bioenergy policies promote biomass sustainability policies that stimulate the pellets' market, such as tax exemptions, mandatory targets, electric power feed-in tariffs, or direct subsidies (Dale et al. 2017). Charcoal is also an important source of renewable energy with great industrial importance in the world. Charcoal is produced via the partial burning of biomass, and it is used as domestic fuel or chemical product, but it can also be used in agriculture (e.g., soil amendment) and industrially (Rodrigues and Braghini Jr. 2019). The charcoal sector is underestimated due to the traditionally informal trade of the product. Charcoal is produced and consumed locally, unlike pellets and liquid biofuels. Moreover, the process of conversion is a highly inefficient process (WBA 2018). However, all these woodfuel products for bioenergy provide a renewable alternative to fossil fuels.

Current industrial processes homogenize and prepare woodfuels for the market and reduce the differences in heat power among different tree species, making almost irrelevant what the composition of the forest is. It is much more important which forest operations are applied, as during those operations (pruning, thinning, partial harvesting, clearcutting, etc.) residual biomass that can be used for bioenergy is generated. Therefore, bioenergy from the forest is easily incorporated into modern near-to-nature and mixed forests management, which can support the contribution of forest management to reach UN's Sustainable Development Goals.

Many and diverse reasons are argued for promoting energy wood, such as its renewable and storable characteristics, the increase in security and diversity of energy supply, or its relatively low and less volatile prices compared to fossil energy sources (Peters et al. 2015). Moreover, the use of wood for bioenergy can also provide multiple environmental benefits (Dale et al. 2017) such as climate change mitigation and employment to local people. On the other hand, impacts caused by the increase of biomass energy production are related to forestry practices, transport activities, and infrastructures. For example, large-scale biomass production can result in site compaction, runoff, soil erosion, or loading of sediments and nutrients to water bodies (Abbas et al. 2011), resulting in unexpected tradeoffs (Peters et al. 2015). Aspects such as conversion efficiency into energy products, cost efficiency, biodiversity issues, soil carbon, and nutrient balances also need to be considered when extracting energy wood (Nabuurs et al. 2015). Therefore, the development of policies and forest management strategies for bioenergy must include potential trade-offs and synergies between biomass production, changes in ecosystem structure and function, and forest ecosystem services.

12.3.1.3 Forests Are Sources of Food

UN's SDG 2 is "Zero Hunger." The elimination of hunger and malnutrition or the increase in food security is one of the sustainable development goals of the United Nations. The World Food Summit held on 13–17 November 1996 in Rome, Italy, defined food security in the "Rome Declaration on World Food Security" as "the right of everyone to have access to safe and nutritious food, consistent with the right to adequate food and the fundamental right of everyone to be free from hunger."[1] Although the major problem of malnutrition in the world is undernutrition with an estimated number of 821 million people in 2017 (FAO et al. 2018), the problems of overnutrition and micronutrient deficiencies are also affecting health, especially in some rich countries. Efforts on food security as such, therefore, mean not just the supply of sufficient food for everyone but also the diverse food resources that give the multiple nutrients and micronutrients needed for a healthy life.

Modern agriculture systems that feed the majority of people rely on intensive use of croplands for producing staple food and vegetables. On the other hand, there are still diverse food sources growing in the forests and about 20% of the world population is partially depending on them, while millions of indigenous people are fully dependent on these foods (Vira et al. 2015). Stadlmayr et al. (2013) reviewed the tree products used by indigenous people in Africa and indicated their high nutrient values. People living in the environment with higher forest coverage have higher access to diverse and nutritious foods (Ickowitz et al. 2014). Therefore, dietary sources from forests may provide those people with important micronutrients

[1]FAO (1996) Declaration on world food security. World Food Summit, FAO, Rome http://www.fao.org/3/w3613e/w3613e00.htm

(Ickowitz et al. 2016). While forest tree species that produce edible parts could be utilized by collecting them during the suitable seasons, some species may potentially be further cultivated and bred to reach higher production rates (Jamnadass et al. 2010).

Forests are important protein sources as well for some tropical inhabitants (Nasi et al. 2011). People living in the rural areas of the Amazon, for example, consume approximately 60 kg bushmeat annually per person (Nasi et al. 2011). For some regions, the bushmeat could be the only animal protein source because meat from husbandry of the typical meat-providing animals is not available. Except bushmeat, forests also provide animal proteins from fishes and insects to those people who have access to these resources.

Besides the direct provisioning of foods by forests, diverse traditional medical resources are used from wild animals (Alves and Alves 2011) and plants (Uprety et al. 2012). Trees and shrubs also provide fodder for livestock (Pimentel et al. 1997). Moreover, for many people living in developing countries, fuelwoods could be collected from forests for cooking. Without sufficient fuelwoods, some raw food materials are just not feasible for consumption and therefore the potential provisioning service of food will not be reached (Makungwa et al. 2013). In agricultural landscapes, the woodland/forest patches could help maintaining vigorous populations of crop pollinators (Winfree et al. 2008; Koh et al. 2016). In a recent synthesis work, Reed et al. (2017) recognized that forests can maintain or enhance yields compared to a monoculture system in the tropics, although research in larger spatial and temporal scales are still needed.

In climate change scenarios with increasing temperature and changing precipitation regimes, together with increases in deforestation, forest fragmentation, the loss of biodiversity, and the spread of invasive species, the food availability from forests is expected to be changed (Vira et al. 2015). For people relying on the food from forests for their daily life, the impact of global environmental changes will be drastic (Paumgarten et al. 2018). However, for those who feed on agricultural products and live in the rural areas where original forests are accessible, the climate change–induced reduction of crop yield might be partially compensated by the foods from forests. Woody tree species in the forests usually are more resistant to changing weather conditions between years than the annual crops because of their nutrient storage in the tissues. The high diversity of tree species in a natural forest usually implies a high diversity of fruit types, different timing of fruiting (phenology), and different water use efficiency, which may potentially safeguard the food provision through the year under adverse weather conditions (Vira et al. 2015).

12.3.1.4 Forests Are Sources of Water While Stabilizing Soil

UN's SDG 6 is "Clean Water and Sanitation." Thousands of millions of people suffer the effects of inadequate access to water (Mekonnen and Hoekstra 2016). In many regions of the world, excessive exploitation of hydrological resources, inadequate water use, and pollution are increasing threats for water availability and quality for agricultural, industrial, or urban uses (FAO 2009). Climate change can exacerbate water scarcity and threaten food security, becoming a main driver for massive migrations and increased social and political conflicts (Kelley et al. 2015). Forests play an integral role in water quality and availability for different uses, as well as in stabilizing and protecting soils from erosion. Most drinkable water in the world originates in forest-covered watersheds, and forests protect many reservoirs from being silted. In addition, forests also protect underground waters from pollutants due to the forest soil's filtering capabilities (FAO 2009). Both soil and water are essential elements for tree growth and health, as well as for the rest of the organisms that inhabit forests. However, due to an increasing water demand for urban, agricultural, and industrial uses, as well as land for urban development caused by increasing human population and consumption, forests are usually under strong pressures. Such pressures will be exacerbated in many regions of the world due to climate change (Blanco 2017).

At global scale, forests play an important role in regulating both atmospheric water flows and precipitation patterns on landmasses (Ellison et al. 2017). On land surfaces, passive water evaporation by heat is joined by active water transpiration by plants, which take water from the soil to release it to the atmosphere as a way of moving their own internal fluids. Such evapotranspiration usually accounts for at least 40% of precipitation on landmasses, reaching up to 70% in some tropical humid forests (Van der Ent et al. 2010; Jasechko et al. 2013). The resulting atmospheric moisture circulates around the globe with the winds, redistributing water among different continents (Ellison et al. 2017). Although traditionally the relationships between forests and water have been understood in the framework of the hydrological cycle at watershed level, such a view fails to recognize the connections among watersheds due to precipitation recycling. For example, it has been proven than in tropical regions, the same moist air over forested watersheds can produce twice as much precipitation than over sparse vegetation (Spracklen et al. 2012). On the other hand, forests can promote precipitation by generating particles and aerosols (bacteria, pollen, spores, canopy fragments), which can work as condensation nuclei for water vapor (Sheil 2014). Due to these teleconnections among watersheds, with increasing deforestations, sites further away from coastal winds would be the first ones exhibiting changes in predictability, extension, and amount of precipitation. Such changes can even produce a switch from humid to dry climates in ecosystems in the ecotone between such climatic zones (Sheil and Murdiyarso 2009). In fact, the new theory of the "biological pump" suggests that normal wind circulation from ocean to continents is mostly due to low pressures created by forests over landmasses as a consequence of their evapotranspiration (Makarieva et al. 2013). If this is true, severely modifying forest cover could change wind patterns at regional or even continental scales, and therefore affect spatial precipitation distribution (Sheil and Murdiyarso 2009).

In any case, the connections between forests and water are much more evident at local scales. Rainfall intercepted by canopy and evaporated from leaves and branches reduces the direct conversion of precipitation into runoff and underground water, and transpiration by plant leaves increases this reduction. Although such reductions in "blue" water flows could be considered as losses for water production in forested watershed, it must be taken into account that trees produce "green" water contained in timber, fiber, flowers, fruits, and seeds (Calder 2007). Hence, although there is no doubt that forests use water, they also produce many goods and services needed by human societies (FAO 2009).

On the other hand, forests can actively intercept water vapor, fog, and clouds, creating the so-called "water towers" (Vivorili and Weingartner 2004). These towers consist of forest areas at high altitudes that catch water and fog when they condense on plant surfaces (Bruijinzeel 2004). In fact, fog forests can generate more water for the root zone than other forest types with similar precipitation levels (Caballero et al. 2013). Hence, such "water tower forests" can become important water sources for downstream regions (Muñoz-Villers et al. 2015). For example, the Andean Yungas are the main water source for 40.000 ha of irrigated farmland and two million people (Malizia et al. 2012). Fog forests are also highly efficient capturing water as they are composed by a high variety of plant forms (Valencia-Leguizamón and Tobón 2017), and therefore the conservation of their biodiversity should be a priority (Ochoa-Ochoa et al. 2017). In addition, water provision by fog forests is important not only in amount but also in temporality, and it can reach up to 75% of total available water during the dry season in some areas (Bruijinzeel et al. 2011). For example, in dry regions in southern China, up to 80% of precipitation during the dry season appears as fog (Liu et al. 2004). Such temporal regulation of water flows by forests will be even more important under climate change, as rainfall unpredictability and extension of the dry season will be the norm in many forest regions around the world.

Forest also have important roles in arid regions. In many parts of the world, especially in climates with dry seasons, water flow regimes are more important than total water available annually to sustain both aquatic and terrestrial ecosystems and agricultural and industrial activities (Bruijinzeel 1990). Water flow in streams during the dry season is vital for navigation, wildlife, rural communities, cattle, fisheries, and particularly for irrigation systems without technology to pump underground water (Aylward 2005). Therefore, flow-regulating services by forests in arid regions can be more important than total water yield downstream (Sandström 1998). Many arid and semi-arid regions suffer also from overexploitation of their plant and soil covers, generating erosion and desertification issues. Therefore, restoring forest cover with a diverse plant and tree community is vital to recover hydro-ecological services or at least to avoid worsening water availability issues (Bargues Tobella 2016).

The relationship between forest management and water availability downstream is not clear. Traditionally it has been assumed that removing forest cover increases water yield downstream as the evapotranspiration is drastically reduced. There are strong evidences supporting this assumption, as the works by Bosch and Hewlett (1982) and Grip et al. (2005) have shown. However, this assumption may not be true for tropical fog forests or boreal conifer forests, which can store and intercept important amounts of water as snow or fog (Buttle et al. 2000). Hence, the actual balance among the different components of the hydrological cycle in forested regions depends on precipitation, evapotranspiration, and runoff (Balvanera 2012). However, this traditional paradigm that states that the less forest cover the more water downstream is being challenged, as it does not take the particularities of recharge, seasonality, and recycling of water flows (Ellison et al. 2017). In any case, gains in water yields downstream after harvesting can be temporal, as the ecosystem always transforms a ecological succession (or active landscape management) takes place.

Forest species composition is also an important tool to actively manage water use by forests. Different tree species vary in their use of water as they reach different soil depths or are most active at different times of the year (Jones et al. 2018). Forest stands of mixed species may display complementary water resource use and they can reach higher use efficiency both in temperate and tropical climates (González de Andrés et al. 2018; Forrester 2015). Therefore, mixed-species forests may be more resilient to drought than monoculture plantations.

In any case, how forests affect the hydrological cycle would also be altered by global change. The main determinants of change in the forest–water relationship related to climate would be firstly precipitation, as it is the most robust single determinant of stream flow (Sun et al. 2011). Changes in both the amount and seasonality and storminess of precipitation can alter water yields downstream of forested regions (McNulty et al. 2018). Other factors that will alter the hydrological cycle under global change are air temperature modifications, as tree water demand increases with increased temperature (Zhang et al. 2015). Wind speed is another factor that can influence forest evapotranspiration. A recent slowing down of wind speed in the northern hemisphere has been attributed to increased roughness of forest canopy as a consequence of changes in forest cover (expansion, reforestation) and forest composition (species, age cohorts) (Vautard et al. 2010). Also, atmospheric pollution can first reduce water yield as nitrogen deposition stimulates tree growth and therefore evapotranspiration (Quinn et al. 2010). However, such effect quickly reaches its peak as soils become N-saturated, causing among other effects tree mortality which in turn increases streamflow (McNulty et al. 2014). In addition, water quality drops when leachable nitrate reaches streamflow (Aber et al. 1989). Other pollutants such as nitrogen oxides and volatile organic compounds are precursors of ozone formation, which in turn damage stomata, making trees less efficient using water (McLaughlin et al. 2007). All these changes can be modulated in mixed forests, as different tree species differ in their sensitivity to changes in temperature, wind speed, or pollution. This effect makes mixed forests more resilient to climate–change induced alterations of the hydrological cycle than monospecific forests, and particularly even-aged tree plantations.

12.3.2 Relationships Between Ecosystem Function, Species Traits, and Ecosystem Services

Essentially, functional traits are attributes of organisms that influence their fitness. They can be of different nature: morphological, physiological, phenological, or even behavioral when concerning animals, but must be well defined and measurable (Blaum et al. 2011; McGill et al. 2006; Violle et al. 2007). Moreover, functional traits are often easily measurable; some typical examples in plant research include seed size, lifespan, maximum height, age at maturity, leaf mass per area, nutrient concentrations and stoichiometries, wood density, or specific root length (fine root length per mass). Functional traits show intra- and interspecific variability depending on external factors such as the environment or the interaction with other organisms, and through this plasticity, we can measure responses to biotic and abiotic conditions.

The key benefit of using the functional trait approach is that it helps us to establish general rules in community ecology, including forest research (McGill et al. 2006). For example, to conclude that *Populus alba* grows faster than *Quercus robur* is less useful than saying that, in general, tree species with higher wood density have a lower growth rate (e.g., Kunstler et al. 2015). In addition, functional traits influence ecosystem processes (Violle et al. 2007; Westoby and Wright 2006), which allow us to use them to evaluate ecosystem services. It is being increasingly recognized that a functional approach, based on functional diversity or traits, explains better the ecosystem functioning and properties than focusing on species diversity (e.g., Gagic et al. 2015; Nadrowski et al. 2010).

In forest research, seed mass, leaf mass per area, wood density, and maximum height are considered key traits. Especially wood density stands out as a highly informative attribute when trying to explain demographic rates (Poorter et al. 2008; Wright et al. 2010). Other traits can be linked to forest resilience as they are related to plants hazard tolerance. For example, germination phenology, growth form, or shoot height are response traits to fire (Lavorel and Garnier 2002), while stature and architecture are related with grazing tolerance (Díaz et al. 2007).

Assessment of ecosystem services can also be done using this approach. The set of functional traits related with carbon cycling can be used to evaluate forest carbon sequestration. Key traits in this regard are growth rate, lifespan, or litter C/N ratio (De Deyn et al. 2008). Water cycling is influenced by canopy architecture and litter production by means of regulating infiltration, runoff, or rainfall interception (Westoby and Wright 2006). Canopy traits are also often linked to climate regulation while the root size and architecture affect soil stability (de Bello et al. 2010).

Research on the assessment of ecosystem services by means of evaluating functional traits has found this methodology as promising, and that the models created this way are usually more useful than those using only species diversity or abiotic variables (de Bello et al. 2010; Gagic et al. 2015; Lavorel et al. 2011). However, there still exist some knowledge gaps where further research could focus. Mainly, current studies are biased toward particular trophic levels and services (especially plant communities and pollinators). However, the relationship between traits and services are often complex, with one trait affecting several services and vice-versa, creating possible trade-offs and interactions (de Bello et al. 2010; Lavorel et al. 2011). In this context, the evaluation of one trait will often not be enough: ecosystem complexity prompts us to use a bigger set of traits in order to improve our models (Wright et al. 2010).

Complexity in forests due to multiple species interactions is also a field where the functional approach has proven to be useful. Species coexistence, and biodiversity, can be promoted by strategy specialization through trait differentiation (Kraft et al.

2008, 2015). Functional traits play a key role in community assembly, for example, regulating how different organisms interact to create the biological community (Kunstler et al. 2015). The way in which functional traits synthesize ecosystem functioning makes them an essential tool for managing forests, especially at a time when complex, mixed species forests are increasingly being favored over monospecific ones.

12.3.3 Climate Change Impacts on Ecosystem Services

Climate change represents an important threat for forests (Lindner et al. 2010). In many regions, climate change will reduce water availability by increasing evapotranspiration (Blanco 2017). In addition, forest fires will increase in severity as consequence of reduced relative humidity, increased temperatures, and increased wind speeds. Also, torrential rainfall will be more common, causing erosion and flooding events. As wind speeds will be increased in an atmosphere with more energy, windthrow events will be more common, causing more episodes or wind-related mortality. Pest and pathogens, whose life cycles are usually linked to dead or sick trees (weaker and with less defenses) and to climate conditions as a number of generations per year depend on degree-days accumulated during the growth season, will become more frequent and reach higher population peaks. Similarly, the phenology of most plants (including trees) is tightly linked to temperature and water availability, and therefore it will be modified as climate change advances (Chmielewski and Rötzer 2001).

These six effects combined will be translated into losses of stability in forest stands, regeneration being altered, and biomass being lost. In other words, climate change will modify local environmental conditions, affecting trees ecophysiology (Saxe et al. 2002; Morin et al. 2010), demography (Hansen et al. 2001; Benavides et al. 2013), and in the long term their geographic distribution (Peñuelas et al. 2007; Lenoir et al. 2008; Urli et al. 2013). Changing tree species distributions may be caused as some species will be able to "escape" climate change's worst effects by moving into regions with environmental conditions more favorable. However, in trees such possibility is reduced due to their long life cycles and their limited dispersion capacity (Jump and Peñuelas 2005; Jump et al. 2006). Hence, it is expected that climate change will produce changes in forest communities' composition, altering forest function (Kumar 2010).

As ecosystem services provided by forests are a reflection of how forest ecosystems work, any modification caused by climate change will impact on how such ecosystem services are provided. For example, reduction of forest biomass will have a direct impact in the provisioning of wood, fiber, and bioenergy. However, effects on other ecosystem services will not be necessarily linear. For example, a reduction in tree biomass could translate into a more vigorous growth of the understory, producing more fruits or habitat for some game species, which then could increase food provisioning. On the other hand, if tree fruits are a main food source in the region (i.e., chestnuts), such food source would be diminished. Other changes could be even more difficult to predict, or they could not be constant. For example, many edible mushroom species in the forests depend on coarse woody debris and litter to grow. If tree mortality were increased by climate change, dead wood would increase and cause a temporal increase in mushroom yields, but as mushrooms and mostly symbiotic entities that also depend on alive trees, such increase would be temporal. Similarly, water provisioning may be increased or decreased (or not being impacted) by changes in the forests, depending on tree species, topography, soil, etc. (Jones et al. 2018). Such difficulty in predicting impacts of climate change is mainly caused by the site-specific nature of many of these ecosystems services, and particularly cultural, recreational, and spiritual services that depend not only on the forests but also on the people living in the region or with access to those forests.

12.4 Scaling up from Ecosystem Function to Human Well-Being

UN's Sustainable Development Goal 3 is "Good Health and Well-Being." Three case studies are presented as examples of representative ecosystems of boreal, temperate, and tropical ecosystems. In all of them, emphasis is placed on synergies between climate change and other direct drivers, biodiversity, ecosystem function and services, indirect drivers of change, and human well-being in forests. They illustrate how the relationships of humans with forests, which are dynamic and complex, are strongly influenced by the ecological-socioeconomic background and the drivers of change. Despite this, common patterns and processes emerge which are the base, as many studies are showing, to improve human well-being.

12.4.1 Case Study: Boreal Forests in China

Boreal forests, or taiga, are distributed across the high latitudes of the northern hemisphere. The north-south width of the boreal forests ranges from above 500 to 2300 km in Eurasia to above 1000 km in North America (Archbold 1995 in Hendrick 2001). The northern edge of the boreal forest corresponds roughly to a July isotherm of 13 °C. The southern border generally follows an 18 °C July isotherm (Hendrick 2001). Common genera include the conifers *Picea*, *Abies*, and *Pinus*, and the hardwoods *Populus*, *Betula*, *Sorbus*, and *Alnus*.

The Greater Khingan Mountains are situated in northeastern China in the only cold temperate zone in the country. The forests on the Greater Khingan Mountains form the southern boundary of the boreal forests in NW Asia and are dominated by *Larix gmelinii* (Editorial Committee for Vegetation of China 1980) (Fig. 12.4). The mean annual temperature is about −3 °C and the mean monthly maximum and minimum temperatures are 17 to 20 °C and −20 to −30 °C in July and January, respectively. Between 330 and 1750 m.a.s.l., the annual precipitation ranges from 350 to 500 mm, most of which falls from May to October. Snow pack averages 300–500 mm and lasts for 5 months. The frost-free period is less than 100 days.

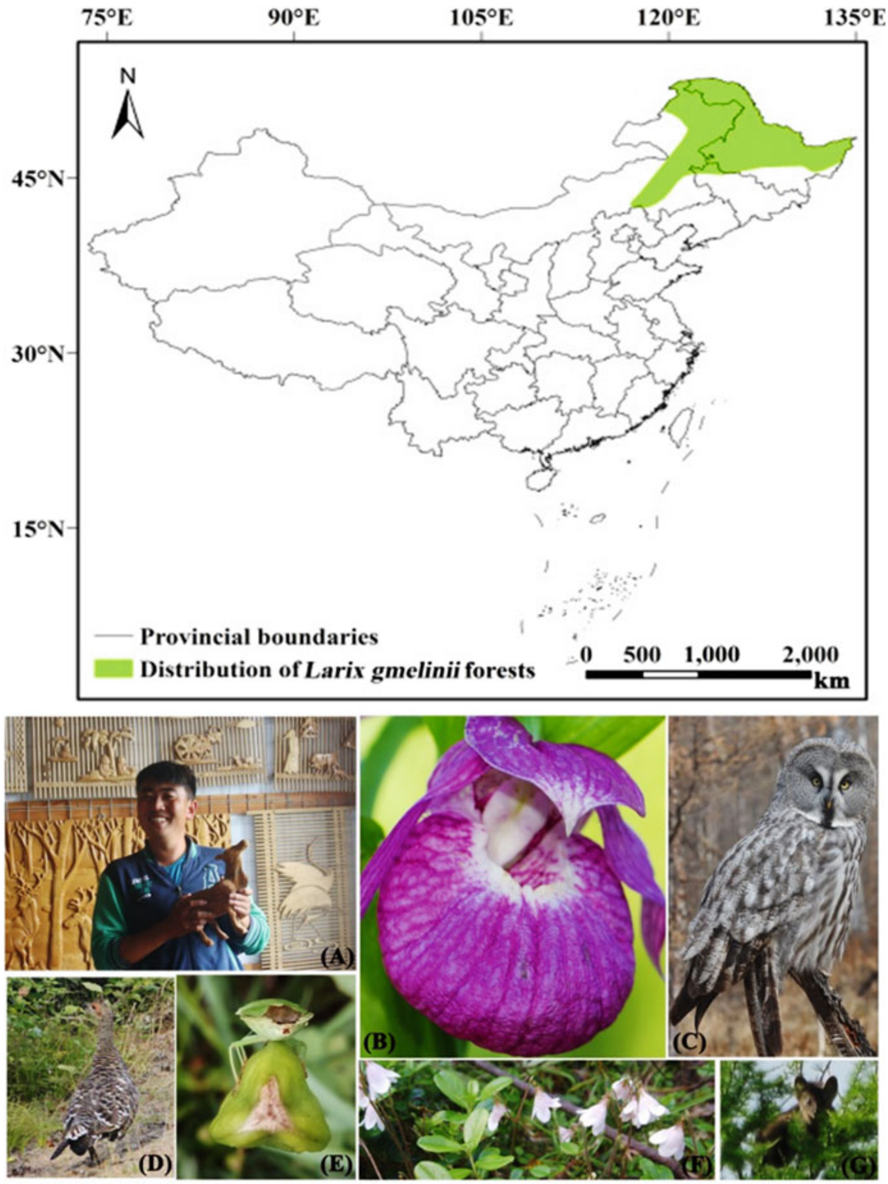

Fig. 12.4 Location of natural *Larix gmelinii* in the Greater Khingan Mountains, Northeastern China. Art wares (A) produced by *Larix gmelinii*; Boreal forests biodiversity: (B) *Cypripedium macranthum* Swartz; (C) *Strix nebulosa*; (D) *Bonasa bonasia*; (E) *Pantatomidae*; (F) *Linnaea borealis* L.; (G) *Martes zibellina princeps*. (Photos reproduced, with permission, from Y. Liu (A), J. Zhou (B), Y. Zhang (C and G), and R. Gao (D, E and F))

Slopes in the region are moderate, being the average slope 10°. Permafrost commonly occurs at about 5–40 m, and the maximum depth can reach 120 m. The soil type is predominantly a dark brown forest soil. Other tree species include white birch (*Betula platyphylla* Suk.), aspen (*Populus davidiana* Dole), Scots pine (*Pinus sylvestris* L. var. *mongolica* Litv.), and Korean spruce (*Picea koriensis* Nakai) (Xu 1998). There are about 180 species of common plants under the *Larix gmelinii* forests. Based on the understory, ground vegetation composition, edaphic and topographic conditions, eight main ecosystems are recognized in *L. gmelinii* forests on the Greater Khingan Mountains:

- *L. gmelinii–Ledum palustre* forests that grow on mesic toe-slopes
- *L. gmelinii*–grass forests that grow on the fertile mid-slopes
- *L. gmelinii–Rhododendron dahurica* forests that grow on the dry infertile steep slopes
- *L. gmelinii–Pinus pumila* forests that grow in sites with harsh conditions
- *L. gmelinii–Quercus mongolica* forests that grow on the fertile lower-slopes
- *L. gmelinii–Sphagnum–Ledum palustre* forests that grow in the wet, cool, and infertile sites
- *L. gmelinii* riparian forests that grow on the banks of rivers and streams under mesic and fertile conditions
- *L. gmelinii–Bryum argenteum–Sphagnum magellanicum* forests that grow in waterlogged soils

The ecosystems of the Greater Khingan Mountains provide a range of goods and services for people. These include: (1) building materials: *Larix gmelinii* trees can reach up to 30 m in height and 60–80 cm in diameter at breast height, providing an excellent building material; (2) abundant medicinal plants such as *Schisandra chinensis*, *Sanguisorba officinalis*, *Bupleurum sibiricum*, *Trollius ledebouri*, and *Pyrola incarnata*, and endangered, precious, and rare plants such as *Glycine soja*, *Astragalus propinquus* Schischkin, and *Phellodendron amurense*; (3) industrial crops for oil and fabrics: given its geographical location, soil, and climate conditions, the region of the Greater Khingan Mountains is especially suitable for large-scale planting of *Linum usitatissimum* L. and the *L. usitatissimum* plants grown here show vigorous growth, high yield, and good quality for textile and fiber industries.

Three river systems (the Heilongjiang, Nenjiang, and Argun Rivers) and more than 30 tributaries with a stream length > 50 km originate in the Greater Khingan Mountains. *L. gmelinii* forests in these mountains play a significant protective role in water conservation and the maintenance of ecological water balance. *L. gmelinii* forests are the most important water conservation forests on the Songnen Plain and the Hulunbuir Grassland, Inner Mongolia (Li 2014).

Forests in this region also influence nutrient flows. The leaves of understory shrubs and herbs in *L. gmelinii* forests are usually evergreen, which is an adaptation to the snowy conditions and short growing season. Because the region is in a cold temperate zone and is covered with thick snow in winter, the snow protects the understory plants on the ground in an evergreen state over winter. Plants that overwinter in such a state can start photosynthesis and growth rapidly when the spring comes. These plants cover the land exposed by snowmelt, effectively reducing runoff and allowing the soil and its nutrients – such as nitrogen (N) and phosphorus (P) – to be preserved. The commercial harvesting of natural forests was halted in the Greater Khingan Mountains on April 1, 2015. This measure has protected the biodiversity and reduced the melting of the permafrost layer in the region. The canopy interception of precipitation has increased and the proportion of precipitation entering rivers via surface and underground runoff has decreased. Soil nutrients are retained longer. The supply of soil nutrients not only promotes the growth of the forests and the understory shrubs and herbs but also facilitates the regeneration and restoration of vegetation, thus effectively conserving biodiversity.

Finally, the forests in this region also have an important cultural and recreational function. Inspired by the cultural resources from "green ecology" in the Greater Khingan Mountains, the local government has built a sociocultural system around forest medicine and green food. For example, edible fungi, edible wild herbs, and red beans are produced on a large scale. People advocate a lifestyle that is closer to nature. Forests serve as an oxygen source, and natural areas including the Moerdaoga Forest Park and the Alihe Forest Park are preferred choices for vacations. Here, people can fully experience the beauty of the landscape provided by forests and trees.

However, these forests are also facing indirect drivers for change. From the socioeconomic point of view, the forests of the Greater Khingan Mountains also produce wood for local residents. The wood delivers an ecosystem service to humans in the form of building materials and furniture. Wood provides important economic benefits and plays a crucial role in China's socialist system, producing an important pressure to increase timber yields to maximize benefits. However, as the forests of the Greater Khingan Mountains offer other ecological benefits, and these forests form an irreplaceable natural ecological barrier in northern China, maximization of their ecological benefits is dependent on their biodiversity.

In this region, the most practical strategy for implementing biodiversity conservation is to establish nature reserves (Li 1993). The aim of establishing such reserves in the Greater Khingan Mountains is to protect and improve wildlife habitats, and creating a habitat protection network based on nature reserves. However, nature reserves have changed the traditional lifestyle of farmers in the surrounding areas. The establishment of these reserves has negatively affected the local society and economy of the Greater Khingan Mountains by reducing their access to the forest, thus influencing the well-being of the farmers. The Chinese government has proposed two measures to address this: (1) local farmers are allowed to collect non-wood forest products such as wild Chinese herbal medicines, pine nuts, agarics, mushrooms, and blueberries but must not damage the nature reserves. This measure can increase the economic income of farmers and simultaneously protect biodiversity. (2) Farmers who depend mainly on the forest for their livelihood are given some economic compensation to increase their income. Ecotourism can be carried out in nature reserves to increase employment opportunities, farmers' income, and local government revenue (SFAPRC 2016).

In addition, because of the unique advantages of the forests in the Greater Khingan Mountains, the cultural value of this region can be promoted and publicized in the following ways: establishing a forest cultural and specimen museum to display forest products and trees in physical and picture forms; initiating activities with the theme of forest biodiversity conservation – such as forest photography, forest exploration, and forest health – to give everyone an opportunity of walking into the forest, feeling its beauty, and stimulating a desire and enthusiasm for nature. Additionally, people can produce distinctive agricultural by-products and decorations such as blueberry drinks and cultural artwork made of birch bark.

The services provided by these forests have direct links with the UN's Sustainable Development Goals. In this region, forests play an important role in air purification, noise reduction, greenhouse gas absorbance, climate regulation, soil and water loss control, and flood disaster reduction, thus greatly improving people's living standards (Zhang 2007). Forests are an important foundation for developing the economy and improving people's lives. As in any other region around the world, forests can provide the wood, food, medicine, fuel, and industrial raw materials that people need. In fact, with the continuous improvement of people's living standards in China, the greater demand for forest tourism has increased people's enjoyment of the mental and physical pleasures of being in the forest, and this is the other source of well-being that the forest brings to humans. Such desire to share these benefits has been translated into plans to create urban forests, including urban forest parks and avenues, providing spaces for people to rest after meals or on holidays. Such spaces play a positive role in people's physical and mental health, and thus can improve their happiness.

In addition, forests in this region have a direct link with poverty reduction strategies. The forests in the Greater Khingan Mountains are mostly distributed in the remote mountainous countryside, where farmers are highly dependent on forest products. The products from forests can provide nutrient-rich foods for farmers to secure their well-being. Firewood is the main source of household energy for farmers, especially impoverished farmers, and the construction of farmers' houses is largely dependent on forest products. Farmers who live on forest products can obtain household income through selling forest products such as fruits and herbal medicine. This compensates for the loss of food and income caused by a reduction in crop yields, which in turn reduces poverty. Industrial value chains with the theme of forest service functions such as forest tourism, agricultural product processing, and construction material processing can be developed to increase employment and thereby reduce poverty.

12.4.2 Case Study: Mediterranean Forests in Southern Spain

Temperate forests occur between the subtropical zone (about 28–30° N) and the boreal zone (46–47° N), although the temperate coniferous rain forests of the Pacific coast of Canada and Alaska grow a little north of 56 °C (Hendrick 2001). The temperate domain occupies the regions where average temperatures over 10 °C occur from 4 to 8 months of the year. It covers a vast territory at mid-latitudes, mainly on the northern hemisphere across North America and Eurasia. The domain experiment changes in the vegetation determined by continentality and altitude. Regions influenced by the mild oceanic climate are dominated by deciduous broadleaved species, *Fagus sylvatica* being the main example in Western Europe (San-Miguel-Ayanz et al. 2016). Mixed forests are common, even intermingling with conifers, which can become dominant as in the case of *Pseudotsuga menziesii* and *Thuja plicata* in the western part of North America. Although there are changes in the identity of the dominant species, mixed broadleaved and conifer species keep their importance while increasing the region continentality. Finally, in colder climates broadleaved species concede importance to conifers and, for example, species from the genus *Pinus*, *Abies*, *Tsuga*, or *Picea* tend to dominate in the temperate mountains. To the interior of the continents, the forest transforms first into a steppe and then into a desert as in the case of the Gobi desert (Simons et al. 2001).

Mediterranean forests are a special case of temperate forests, characterized by having a dry and hot summer and a mild and wet winter, which translates into plants being adapted more to resist drought and fire than to resist frost (Grebner et al. 2013). The Spanish southern region of Andalusia encompasses a typical Mediterranean region (Fig. 12.5). With a great variety in orography, climate, soil types, and the history of human management, added to Andalusia’s position at the southwestern end of Europe and only a few dozens of kilometers from Africa, Andalusia has a rich and biodiverse forest composition, which translates into many areas of special natural interest. Oak species are dominant, mainly holm oak (*Quercus ilex*) and cork oak (*Q. suber*), counting for 22% of forest areas. However, more than half (57%) of the non-agricultural lands are tree-less shrublands. As in the rest of the temperate zone, present forest distribution is strongly dependent of the historical human activity, which in the case of temperate woodlands usually meant alternating periods of deforestation and regeneration depending on economic needs (Verheyen et al. 1999). Forest area have been often altered by the conversion into cropland or pastures, while timber extraction has been the main ecosystem service associated to temperate forests. However, they are being increasingly valued not only for the wood production but also for the broad range of ecosystem services they can offer. In fact, the higher demand in forest products and services is considered the cause behind the recent rise in temperate forest area, and sustainable management that allows forest exploitation without compromising those ecosystem services is being recognized as a key in the future of forests (FAO 2016). For example, in the case of Andalusia, foresters have extensively planted several species of pine and eucalyptus during the last century. In addition, Andalusia has a typical human-made savanna-like formation called “dehesa,” in which the herbaceous layer that separates trees is grazed by different livestock species (Anaya-Romero et al. 2016). The Andalusian forests provide at least 22 ecosystem services (Table 12.1). Among the set of ecosystem services, some are fundamental in the face of global change.

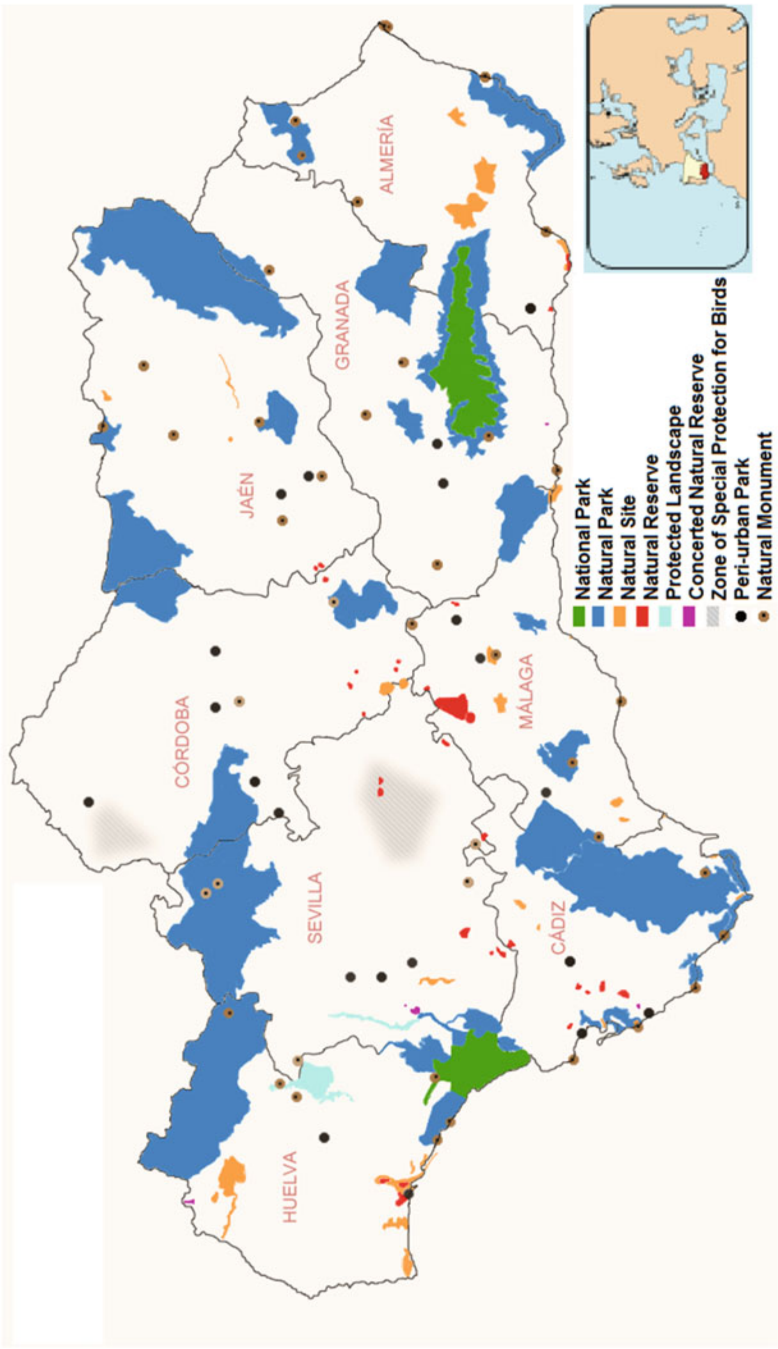

Fig. 12.5 Location of natural reserves in Andalusia (southern Spain), mostly encompassing forested areas in mountains, except in coastal areas (own elaboration)

Table 12.1 Ecosystem services (ES) provided by Andalusian forests. Indicating their relative importance and the trend over the last decades (adapted from Marañón et al. 2012a)

Type of ES	Ecosystem service	Importance	Trend
Provisioning	Foods (traditional)	High	Mixed
	Fresh water	High	Increasing
	Raw materials (biological)	High	Increasing
	Raw materials (mineral)	Low	Mixed
	Renewable energy	Medium-high	Increasing
	Genetic diversity	High	Decreasing
	Medicinal resources	Medium-low	Decreasing
Regulating	Climatic	High	Highly increasing
	Air quality	Medium-high	Increasing
	Water regulation	High	Mixed
	Sedimentary regulation	High	Mixed
	Soil formation and fertility	High	Increasing
	Regulation of natural disturbances	Medium-high	Mixed
	Biological control	Medium-low	Mixed
	Pollination	Medium-low	Decreasing
Cultural	Scientific knowledge	Medium-high	Highly increasing
	Local ecological knowledge	Medium-high	Decreasing
	Cultural identity and sense of belonging	Medium-low	Decreasing
	Cultural and spiritual enjoyment	Medium-low	Increasing
	Landscape and aesthetic appreciation	High	Mixed
	Recreation and ecotourism	High	Highly increasing
	Environmental education	High	Increasing

Temperate forests are involved in important functions maintaining ecological cycles such as water and carbon. Slowing superficial water flow and thus favoring infiltration, these ecosystems improve water conservation and they can act as sinks for global carbon mitigating the impact of global warming. At a global scale, as the temperate forest area increased, its sink capacity also rose contributing up to a third of the global C sinks between 2000 and 2007 (Pan et al. 2011). In Andalusia, C pools in trees have greatly increased over the last half century through a process of afforestation (changing from agricultural and semi-natural areas to forests), which has consisted in planting mostly Mediterranean pine species (*Pinus halepensis*, *P. pinaster*, *P. nigra*, *P. pinea*) (Fig. 12.6).

Other important services are soil protection from erosion, conservation of natural resources such as biodiversity or non-wood forest products, and cultural and recreational values. Timber extraction shows trade-offs with these other services, as it often implies loss of forest area and complexity (Galicia and Zarco-Arista 2014), thus the need of monitoring different ecosystem services and not only logging capacity or cork production in order to achieve a sustainable management.

Direct drivers of change are mainly two: land use change processes and climate change. Although forests in general have faced overexploitation and their area has

Fig. 12.6 Typical forest landscape in Andalusia, a mixture of natural, afforested, and managed forests. (Reproduced with permission)

decreased, in the case of temperate forests, the trend has been inverted and their area has expanded in the last decades (Keenan et al. 2015). For example, during the last half century forests in Andalusia have been able to maintain a relative degree of conservation, still occupying 88% of the forested areas they covered in the 1950s. As in all European temperate areas, and more prominently in Mediterranean areas, land use change over the last half century has consisted mostly in abandonment of mountain pastures and crops, and to a lesser degree in the creation of infrastructures (i.e., water reservoirs, highways, train tracks), as well as urban expansion.

Other direct drivers for change increasingly important in Andalusia and other Mediterranean regions are habitat fragmentation and fires, both interacting negatively with climate change (Valladares et al. 2014). Thus, the ability of biological populations to adapt to changing conditions is diminished in fragmented patches because of reduced genetic variation and dispersal capacity, making species more vulnerable to warming.

Another direct driver for change is the presence of invasive species, which are becoming a hazard of increasing importance as human trade facilitates their displacement (Leung et al. 2012). In the long term, invasive species cause a reduction of biodiversity, as several local species are displaced by a few invasive species. Invasive species have usually more impact on monocultures and even-aged stands than on mixed uneven-aged stands (Guyot et al. 2015). Mixing tree species also increase the potential of the forest as biodiversity reservoir due to the different biota associated with each species (Cavard et al. 2011) and, in this manner, ecosystem services are also influenced by tree diversity. Total forest productivity can also be improved by mixing species, for example, by means of increasing structural heterogeneity (Pretzsch 2014) or improving the system resilience against hazards (Griess and Knoke 2011, Griess et al. 2012). For these reasons, there is a trend in European temperate forests to increase the importance of mixed stands and reduce the presence of monocultures, usually by not removing anymore naturally-regenerated broadleaves in coniferous-dominated stands (Felton et al. 2016).

Climate change is creating stressors that weaken trees. While independent stressors usually cause minor cases of tree mortality, defoliation, or declines in growth, concern is being raised over extreme droughts and heat waves as they are expected to occur more often in the future. Indeed, extensive forest mortality has been found in the last years when drought and heat waves combine with additional disturbance drivers (Millar and Stephenson 2015). In Andalusia, there are already reports of diebacks, reduced growth, and high potential for range distribution of the main tree species (Navarro-Cerrillo et al. 2018).

Country policies can also be indirect drivers of change, for example, creating new biodiversity conservation areas where logging activities or forest conversion are limited (Fig. 12.5). Another case is the promotion of renewable energies. Woodland biomass utilization for energy is often not profitable when competing with modern fuel prices, but new policies promoting renewable energies could favor its use where the wood industry is well developed, as could be the case of California (Nicholls et al. 2018), which also has a Mediterranean climate. Repopulation of rural areas in North America or Europe could potentially increase the use of firewood. As wood is very voluminous in relation to the heat produced, the transport is considerably more expensive than for other fuel options, so reducing the distance between the forest and the population would change the balance between fuel prices in favor of wood biomass. This could be the case of Andalusia, for which great potential but also great barriers to act as an energy source have been identified (Ovando 2017).

In Andalusia, trends of cork prices can influence the extension and management of cork oak (Marañón et al. 2012b). As natural cork is being substituted in some countries by plastic bottle stoppers, cork use can be reduced and therefore management abandoned, or the opposite of natural cork is used by brands as "quality touch" to improve wine bottle visual quality. Therefore, forested rural areas are benefited by forest industry given its importance as an income source relative to other activities. Therefore, promoting cork could be a way of creating new employment opportunities, especially in areas affected by rural depopulation (Pašakarnis et al. 2013, Pinilla et al. 2008). However, over the last decades, employment in the global temperate forest has decreased sharply, from almost 3 million employees in 1990 to less than 2 million in 2010, which could be related to the improvement of logging techniques (FAO 2016). Such lack of employment opportunities drive the rural dwellers to move to urban areas, causing land use change by reduction of agricultural and forestry activities.

12.4.3 Case Study: Tropical Forest of the Ecuadorian Amazon Basin

Tropical forests occur between the Tropic of Cancer (23.5°) and the Tropic of Capricorn (23.5°S). They are located in three geographical formations: American, African, and Indo-Malesian. The tropics generally correspond to frost-free areas where the mean annual temperature is 18 °C or above or where the mean monthly temperature difference between the three warmest and three coldest months is 5 °C or less (Hendrick 2001). There are five primary forest types (Hendrick 2001): tropical evergreen, (sub) tropical seasonal, (sub) tropical semi-deciduous, sub (tropical) evergreen, and mangrove.

The Amazon rainforest covers an area of 7 million km^2 and is the largest rainforest on Earth, stretching over nine countries: Brazil, Colombia, Peru, Venezuela, Ecuador, Bolivia, Guyana, Suriname, and French Guyana (Saatchi et al. 2007). The Amazon rainforest has multiple ecosystems and types of forests in each country according to the physiognomy, phenology, general flooding, geological form, bioclimate, bioclimatic floor, substratum, and biogeography (Ministry of Environment of Ecuador 2012).

In Ecuador, the Amazon basin covers areas under 1300 m.a.s.l. in the eastern foothills of the Andes, including all mountain ranges and lowlands to the east of this limit (De la Torre et al. 2008). The Amazon basin also covers almost 50% of the Ecuadorian territory (Palacios et al. 1999) and contains 22 ecosystems, which include several types of forests, such as lowland evergreen rainforests, flooding forests, evergreen piedmont forests, evergreen low-montane forests, shrubs, and grasslands (Ministry of Environment of Ecuador 2012).

The Ecuadorian Amazon region contains two National Parks, four Biological Reserves, two Ecological Reserves, one Municipal Ecological Conservation Area, one Wildlife Reserve, and one Faunistic Production Reserve. The Protected Area of our interest has recently been declared as a Biological Reserve in 2014 and it is called Colonso Chalupas (MAE-GIZ-IKIAM 2017).

The Colonso Chalupas Biological Reserve (CCBR) is located on the east slope of the Andes, in the Napo province between the Antisana Ecological Reserve in the northeast and the Llanganates National Park in the south (Fig. 12.7). Its surface area is 93,246 ha; the altitudinal range goes from 720 to 4432 m.a.s.l (van der Hoek et al. 2018); the temperature fluctuates from 6.8 to 24.4 °C; it receives an annual precipitation of about 1700 mm in the highest part and 4300 mm in the lowest part (Alvarez-Solas et al. 2016). The reserve is also inhabited by 23 indigenous Kichwa communities (Yaguache et al. 2016). The reserve presents six different types of ecosystems:

- Northern evergreen high montane forest of the eastern Andes Cordillera (9287.30 ha)
- Northern evergreen low montane forest of the eastern Andes Cordillera (37,960.45 ha)
- Northern evergreen montane forest of the eastern Andes Cordillera (28,747.74 ha)

Fig. 12.7 Biological Reserve Colonso Chalupas. (Credit: Byron Maza)

- Northern evergreen piedmont forest of the eastern Andes Cordillera (5753.28 ha)
- Paramo wild herbs (11,357.36 ha)
- Paramo wild herbs ultra-wet subnival (46.62 ha) (MAE-GIZ-IKIAM 2017) (Fig. 12.8)

The reserve harbors 167 species of birds (15 of them are migratory and 8 endemic), 10 species of amphibians, 4 species of reptiles, and 18 species of mammals. There is no data about the number of insects and other arthropods. There are 171 families of plants with 649 genera and 1841 species (MAE-GIZ-IKIAM 2017). The levels of biodiversity and endemism are thought to be high, very similar to hotspots (van der Hoek et al. 2018). More research is needed to know the real number of animal and plant species to recognize how many ecosystem services the CCBR can provide.

In the reserve, forests provide some ecosystem services that deliver direct or indirect benefits for human well-being (Fig. 12.9). These ecosystem services are:

1. *Provisioning services:* material and tangibles services such as food, fibers, fuel, genetic, pharmaceutical, ornamental, food aquatic, and mineral resources. The people use "*chakras*" as an agroforestry system in which they plant their own food, timber, and non-timber species. Some investigations have shown that the communities use 95 species of plants for food, commercial, medicinal, and cultural uses (Peñuela-Mora et al. 2016).
2. *Regulating services*: Every benefit generated as a product of ecological processes essential for the support of the agroecosystem such as: protection against natural disasters (floods being the most typical and potentially damaging in this region), stabilization of climate and air, fertility and control of soil erosion, biological control of diseases and species, pollination, purification and stability of water sources, and nutrient cycle (MAE-GIZ-IKIAM 2017).

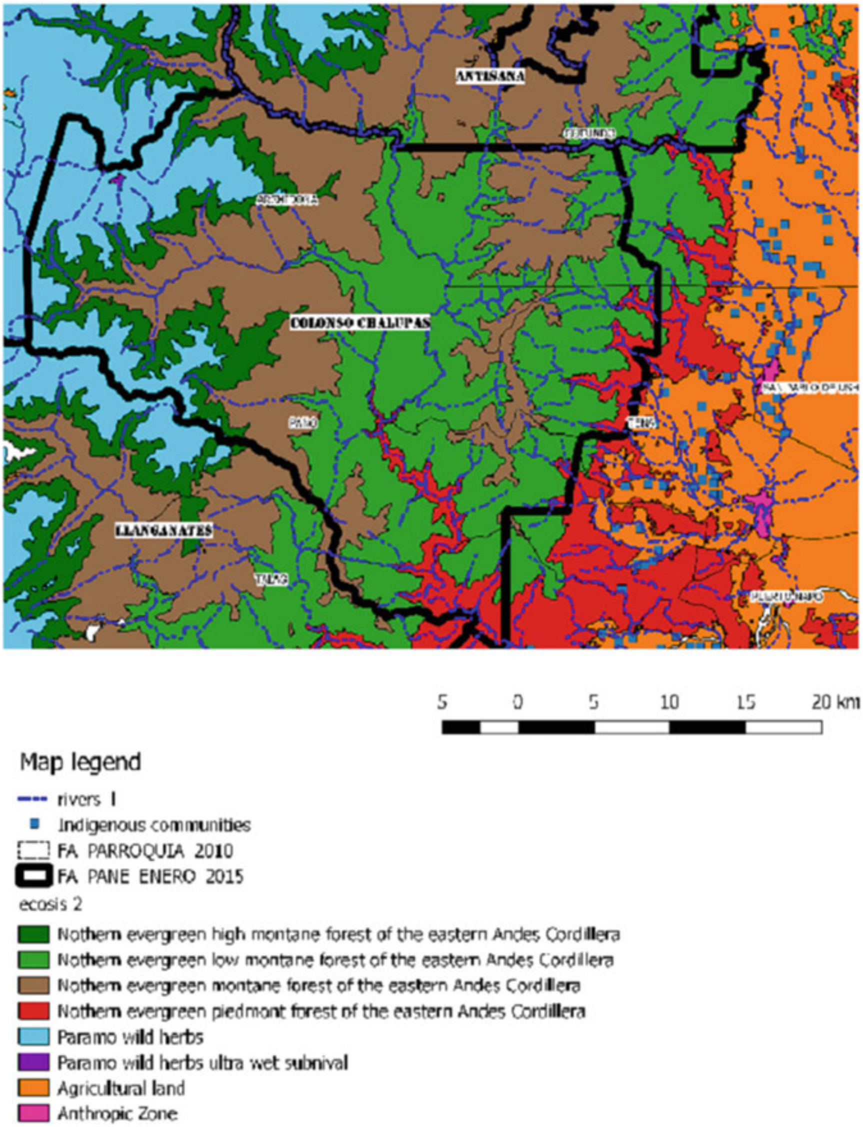

Fig. 12.8 Colonso Chalupas Biological Reserve with their ecosystem types (own elaboration)

3. *Cultural services:* It is common that kichwa communities use nature as inspiration for legends, and myths, so too they use their dreams to predict their future (Mendoza Orellana 2012). In addition, there are different cultural events around nature such as *Jandia warmi* and *Guayusa warmi* that highlight women in the community. They are strongly linked to values and human behavior, and

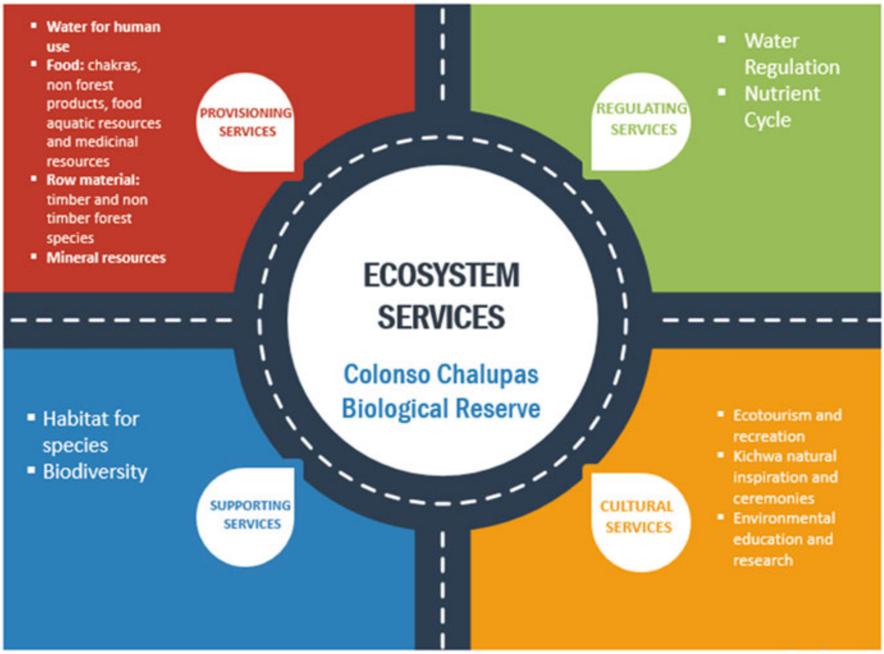

Fig. 12.9 Ecosystem services of Colonso Chalupas Biological Reserve (own elaboration)

determine the behavioral patterns, social institutions and organizations, and political and economic society (Molina 2018).

4. *Supporting services*: Support services refer to the ecological processes that ensure the proper functioning of natural systems, such as biodiversity and habitat (Villamagna and Giesecke 2014). CCBR is habitat for many threat species such as cougar (*Puma concolor*), chorongo monkey (*Lagothrix lagothricha poeppigii*), peccary (*Pecari tajacu*), chuncho tree (*Cedrelinga Cateniformes*), canelo tree (*Ocotea javitensis*), copal tree (*Dacryodes cupularis*), and Ungurahua palm (*Oenocarpus bataua*), a keystone species as a food source for a great diversity of birds and mammals (MAE-GIZ-IKIAM 2017).

The forests at the CCBR are under different drivers of change. Drivers, natural or anthropogenic, directly and indirectly affect the ecosystem services. Natural drivers include disasters such as earthquakes and volcanic eruptions linked to the geological and tectonic activity in the Andean cordillera. In addition, extreme weather-related events such as prolonged drought are usually directly related to the El Niño/La Niña (ENSO) phenomenon (Bustamente et al. 2018). The direct anthropogenic drivers, which are modulated by indirect drivers (e.g., natural resources demand), are the outcome of human activities and governance decisions (Bustamente et al. 2018) that influence the ecosystem processes.

It is well known that climate change is affecting the Amazon rainforest and is one of the anthropogenic drivers of ecosystem change. In particular, drought events in association with forest fragmentation and anthropogenic ignition sources are already causing widespread fire-induced tree mortality and forest degradation across the southeastern Amazon (Brando et al. 2014). Climate model scenarios indicate a constant warming in the twenty-first century for the tropical troposphere, with a temperature increase of 4.5–5 °C in the tropical Andes and with stronger wet and dry seasons (Vuille et al. 2008). During the last years, anomalies in the beginning and the end of rainy seasons, increasing the precipitation intensity and the maximum temperatures of the day have been already reported in the Napo province (Provincial Decentralized Autonomous Government of Napo- GADPN 2015).

As consequence of these climate change scenarios for the Colonso Chalupas Biological Reserve, the main direct drivers of change are droughts that will alter the water sources and vegetation in paramo, forest fires in the highlands of the reserve as consequence of drought and human activities, and floodings in the lowlands of the reserve in rainy seasons by the increase of river flow. In turn, these floodings could generate mass soil movements such as landslides that could affect locally but massively the vegetation and fauna of the reserve (MAE-GIZ-IKIAM 2017).

Over-exploitation of the Amazon basin in the twentieth century has generated population decreases of iconic vertebrate species (both predators and game species). The ecological consequences of such defaunation already threaten the food security of local communities because bushmeat has a fundamental role as protein source for the local dwellers (Campos-Silva et al. 2017). In addition to over-exploitation of timber and palms by logging (illegal or legal), mineral resources exploration and extraction, cropping intensification of Amazon species (guayusa *Ilex guayusa* Loes., cocoa *Theobroma cacao* L.), energy production, and aquatic resources are some examples of drivers of change that have experienced the Ecuadorian Amazon (MAE-GIZ-IKIAM 2017).

The over-exploitation in the last few years of timber species such as chuncho (*Cedrelinga cateniformis*), Canelo (*Ocotea javitensis*), and Copal (*Dacryodes cupularis*) and non-timber forest species such as the ungurahua palm (*Oenocarpus bataua*) have decreased the population of these species in the reserve and in the buffer zone. The decrease of these populations has already produced ecological outcomes (MAE-GIZ-IKIAM, 2017) (Figs. 12.10, 12.11, 12.12, and 12.13).

Habitat change in these tropical forests is evident by agriculture, land use change, and road building activity. These drivers are threatening all ecosystem services and biodiversity. The main driver of habitat change in the buffer zone of Colonso Chalupas Biological Reserve is agriculture, because most of the local communities use the traditional agroforestry system (*chakras*) for self-consumption or for selling their crops in local markets. However, crop intensification is a current phenomenon in Napo province because there are international companies buying cocoa and guayusa tea from local communities for chocolate and tea exportation. In addition, this agroforestry system is used as a focus for agro-tourism activities (MAE-GIZ-IKIAM 2017).

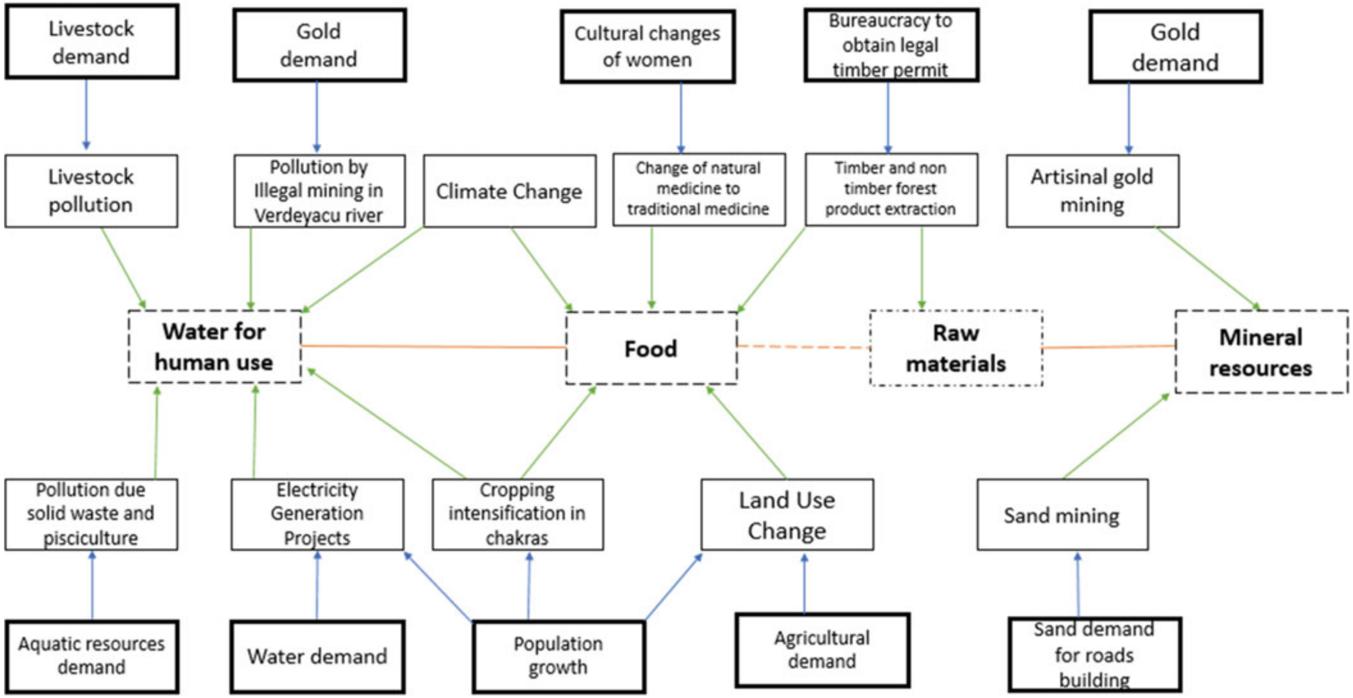

Fig. 12.10 Direct and indirect drivers of change for *Provisioning Ecosystem Service* in Colonso Chalupas Biological Reserve (MAE-GIZ-IKIAM, 2017). Indirect drivers in bold (own elaboration)

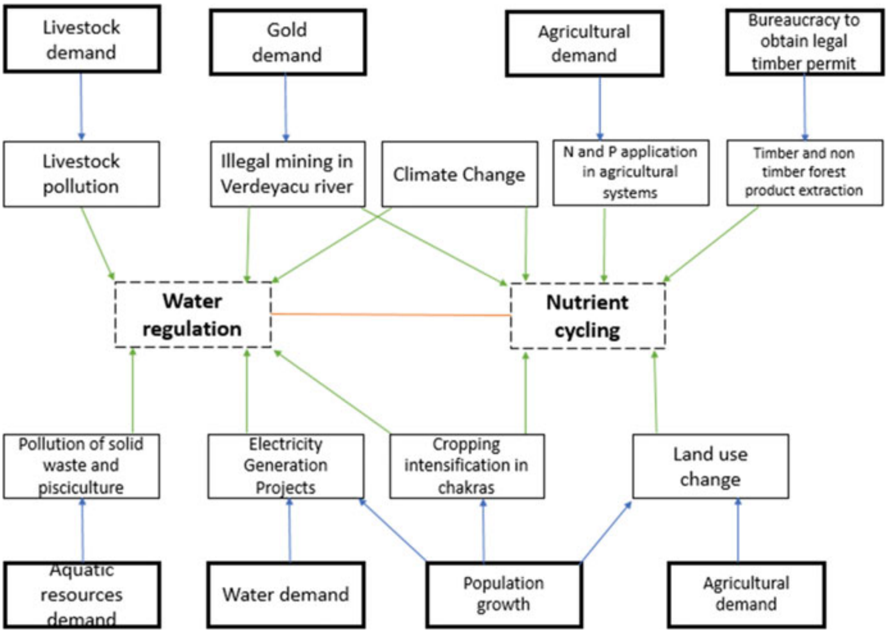

Fig. 12.11 Direct and indirect drivers of change for *Regulating Ecosystem Service* in Colonso Chalupas Biological Reserve (MAE-GIZ-IKIAM, 2017). Indirect drivers in bold (own elaboration)

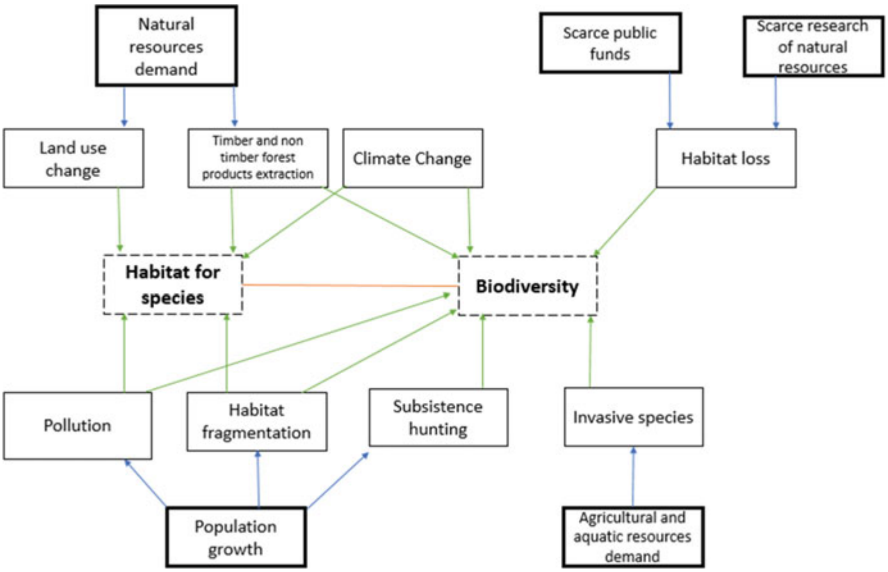

Fig. 12.12 Direct and indirect drivers of change for *Supporting Ecosystem Service* in Colonso Chalupas Biological Reserve (MAE-GIZ-IKIAM, 2017). Indirect drivers in bold (own elaboration)

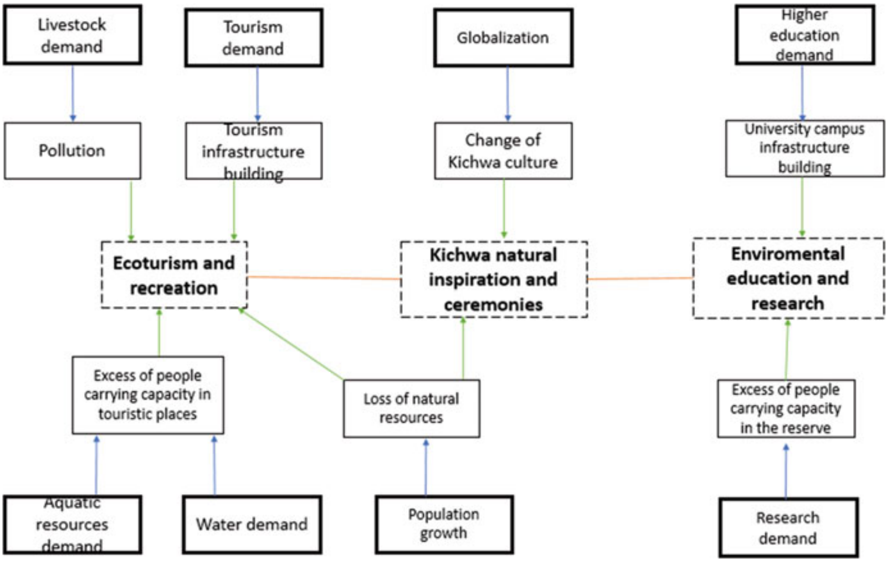

Fig. 12.13 Direct and indirect drivers of change for *Cultural Ecosystem Service* in Colonso Chalupas Biological Reserve (MAE-GIZ-IKIAM, 2017). Indirect drivers in bold (own elaboration)

The main introduced species in the Ecuadorian Amazon are the foreign plants used in agroforestry systems, unfortunately some of them are naturalized (e.g., banana – *Musa sp.*). Although in the Colonso Chalupas Biological Reserve there are no invasive species registered yet, in the buffer zone of the reserve small tilapia fish (*Oreochromis* sp.) pools are already affecting the habitat, and native and endemic fishes of rivers (MAE-GIZ-IKIAM 2017).

Pollution is one of the main direct drivers that affect all ecosystem services through different activities. Although in the protected area, activities that generate pollution are not allowed, it is known that there is pollution due to illegal mining in the Verdeyacu River located inside the reserve. In the highlands, there is also pollution due to livestock activity. In addition, the infrastructure and buildings for touristic and research/academic activities are a threat to the piedmont forest located in the buffer zone (Figs. 12.8, 12.9, 12.10, and 12.11) (MAE-GIZ-IKIAM 2017). In addition, in the buffer zone of the reserve, the river is polluted by fish farming of tilapia (a potentially invasive fish) and cachama (a local Amazonian fish, *Colossoma macropomum*) (Yaguache et al. 2016).

Most of the direct drivers are affected by indirect drivers. The main indirect drivers for the Colonso Chalupas Biological Reserve are the changes in natural resources demand by local populations, which in the buffer zone include the agriculture and forest products (timber and non-timber) extraction, tourism and research demand, sand demand for road building, and aquatic resources demand (tilapia and cachama fishes) (Figs. 12.10, 12.11, 12.12, and 12.13). Inside the reserve, the main indirect drivers are human demand for water, energy, minerals, and livestock. All of these indirect drivers are the result of population growth: from 1962 to 2001 the urban and rural population has increased in the Napo province by 7.5% and 32.5%, respectively (National Institute of Statistics and Censuses 2002). In addition, 78.6% of the people in the Napo province are considered as living under the poverty threshold due to the lack of unsatisfied basic needs (National Institute of Statistics and Censuses 2010). Most of the communities located in the buffer zone of the Colonso Chalupas Reserve are indigenous (from the Kichwa ethnic group), whose youngest generation, through the globalization process, are modifying their language and historical traditions on natural resource uses and demands (MAE-GIZ-IKIAM 2017).

Some national policies are also indirect drivers that affect all ecosystem services in the reserve. On the other hand, the scarce public funds for maintaining and overseeing the reserve do not allow a full real-time surveillance, and in addition, the sometimes cumbersome bureaucracy to access timber permits promotes illegal timber extraction (MAE-GIZ-IKIAM 2017).

In this context, all the ecosystem services of Colonso Chalupas Biological Reserve and the ecosystem services from the Amazon basin support one or several of the UN's Sustainable Development Goals for 2030. Although direct and indirect drivers affect these ecosystem services, the communities located in the buffer zone benefit and depend on these natural resources. Finally as the buffer zone of the reserve has different pressures like direct and indirect drivers, there are national initiatives such as "ProAmazonía" that pretend to reduce these drivers with bio-enterprises using local products and initiatives such as "SocioBosque" that pretends to conserve long-term native forest through the use of economic incentives.

12.5 Conclusions

- Forest ecosystems are key actors to reach many of UN's Sustainable Development Goals, given the number and importance of ecosystem services they provide.
- Relative to other terrestrial ecosystems, forests have low surface albedo, high carbon storage capacity, high CO_2 uptake, and high evapotranspiration rates, which allow them to modulate climate (i.e., regulating services). In addition, they can also provide characteristic provisioning, supporting, and cultural services.
- The importance of these services varies between boreal, temperate, and tropical forests. For instance, climate control and biodiversity are highest in tropical forests and lowest in boreal forests.
- All these forest biomes are threatened by logging, fire, fragmentation, inadequate management, pest and disease outbreaks, and air pollution. These disturbances are interacting with climate and land use changes, resulting in synergies that are generating "a new normal" based on complexity and dynamic stability, which makes difficult predicting ecosystem attributes and services.
- Global trends attributable to climate change include latitudinal and altitudinal range shifts, phenological advances and delays in growth or reproduction, and

changes in disturbance patterns (i.e., tree pest and diseases, fire and drought), resulting in alterations in community structure and function.

- Climate change is also influencing productivity, species interactions, and nutrient cycling of forest ecosystems, all of which interact among them in a complex way. These interactions appear to be different in boreal, temperate, and tropical forests. Therefore, more research is needed to understand how climate factors affect different aspects of forest functioning and structure in order to predict forest responses on ecosystem services provided by forests.
- Evidence is mounting about the existence of a positive relationship between biodiversity and forest function (i.e., regulating services) in boreal, temperate, and tropical forests. However, climate change through changes in water availability appears to modulate the strength of the relationship at least in boreal and Mediterranean forests.
- Knowledge of synergies between different ecosystem services is needed to assure sustainable forest management. For instance, transforming monocultures into mixed forests appears to be a good compromise to increase productivity (i.e., timber, pulp) and mitigate climate change through increases in CO_2 absorption. In this context, an integrated production system for wood and bioenergy exhibits an example of synergy as thinned stands maximize the value of wood products, while thinnings are used for bioenergy.
- Understanding synergies among non-timber forest products, climate, and land use changes and other drivers appears to be crucial in tropical forests, where millions of people live below the thresholds of poverty and depend on forests for food provisioning.
- Forests play a major role in regulating water flows (quantity, quality, and seasonality) in areas where climate change exacerbates water scarcity and threatens food security.
- Assessment of ecosystem services by means of theoretical models taking into account species' functional traits rather than only ecosystem processes seems promising.
- Difficulty in predicting impacts of climate change on ecosystem function and consequently on ecosystem services is mainly caused by the site-specific nature of many of these ecosystems services, and particularly cultural, recreational, and spiritual services that depend not only on the forests but also on the people living in the region or with access to those forests.
- The case studies presented as representative examples of good health and well-being in boreal, temperate, and tropical forests illustrate how the relationships of humans with forests, which are dynamic and complex, are strongly influenced by the ecological-socioeconomic background and the drivers of change. Despite this, common patterns and processes emerge that are the base, as many studies are showing, to improve human well-being.
- Indirect drivers such as social, economic, and political trends can have important influences on forest ecosystems, and therefore sustainable forest planning to support UN's SDGs must be linked to other planning activities at local, regional, national, and international levels.

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Climate Change Projections of Current and Future Distributions of the Endemic *Loris lydekkerianus* (Lorinae) in Peninsular India

13

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Abstract

Loris lydekkerianus (*L. lydekkerianus*) are endemic primates of peninsular India. The current and future potential distribution and range shift of *L. lydekkerianus* were studied using a maximum entropy (maxent) machine learning algorithm. Four scenarios of the Intergovernmental Panel on Climate Change (IPCC)'s fifth assessment, that is, representative concentration pathway (RCP) 4.5 and RCP 8.5 for the years 2050 and 2070, were examined using observed ecological variables and known data of species occurrence, obtained from both published literature and field surveys. This supplied 200 species occurrence points. Spatial thinning was applied to reduce dataset biases. The preliminary extraction of species occurrence data using quantum geographic information system (QGIS 2.14) generated a residual value of <0.001 reflecting reliable extraction. This ecological model suggests an expansion of potentially suitable habitat of *Loris lydekkerianus malabaricus* in the central Western Ghats (WG) and shrinking of the habitat of *Loris lydekkerianus lydekkerianus* in the Eastern Ghats (EG). A third unnamed, undescribed subspecies of *Loris lydekkerianus* found during this investigation was more vulnerable to climate change. Field-collected datasets confirm that *Loris lydekkerianus malabaricus* prefer wetter habitats of the WG, whereas *Loris lydekkerianus lydekkerianus* were more common in the dry, rain-shadow areas of the WG and the Deccan plateau, extending into the EG and coastal areas of Tamil Nadu. The unnamed subspecies of *L. lydekkerianus*

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(hereafter *L. lydekkerianus*, ssp. *A*) prefers an intermediate climatic area, that is, neither the wet parts of the WG nor the dry parts. Ecological models on the future potential distribution of *Loris lydekkerianus lydekkerianus* predict positive expansion of the habitat for RCP 4.5 for 2050 and 2070, whereas the RCP 8.5 (2050) and RCP 8.5 (2070) scenarios predict high impacts on the habitat due to climate change. Range shift models predict a considerable shift in the present habitat range and expansion for *Loris lydekkerianus malabaricus* and *Loris lydekkerianus lydekkerianus*, respectively, and no expansion for the *L. lydekkerianus* ssp. *A* for 2050 and 2070. We also predict that suitable habitat areas of *L. lydekkerianus* ssp. *A* will shrink by 99%. Therefore, *L. lydekkerianus* ssp. *A* stands highly vulnerable to the changing climate of peninsular India.

Keywords

Climate change · Ecological modelling · *Loris lydekkerianus* · *Loris malabaricus* · Western Ghats · Conservation biology

Abbreviation

AP	Andhra Pradesh
AR4	Fourth Assessment Report
AR5	Fifth Assessment Report [Upgraded version of AR4 provides an overview of knowledge concerning climate science]
asl	above sea level
ASPECT	derived continuous layer from DEM. Calculated as compass direction of the downslope direction using spatial analyst extension of ArcGIS 10.4
AUC	area under curve [Receiver operating characteristics also called area under curve provides collective measure of model performance].
BIOCLIM	Bioclimatic Prediction and Modeling System—the first species distribution modeling tool
BAM	biotic-abiotic-mobility model
CC	climate change
CO_2	carbon dioxide
CCASF	Climate Change, Agriculture and Food Security
CGIAR	Consultative Group on International Agricultural Research program
DEM	digital elevation model [DEM is a three-dimensional (3D) computer graphics model generated by satellite elevation data of earth, moon or asteroids (https://databasin.org/datasets/)
DP	Deccan Plateau
ENM	ecological niche modelling (ENM also known as environmental [or ecological] niche modelling or habitat modelling or predictive habitat modelling or species distribution modelling [SDM] or range shift modelling. It uses computational

	algorithm to predict the distribution of a species across geographical space and time using environmental data.)
EG	Eastern Ghats
GARP	Genetic Algorithm for Rule Set Prediction [GARP is a computer-based program based on genetic algorithm that is used for ENM (ecological niche modelling).
GLM	generalized linear model
GAM	generalized additive model
GCM	general circulation model (Numerical model, representing physical process in ocean, atmosphere, cryosphere and land surface. It is currently the most advanced tool available for simulating the response of global climate change.)
GHG	greenhouse gas [Gas that is responsible for absorbing infrared radiation results in the greenhouse effect, e.g., carbon dioxide and chlorofluorocarbons.)
GIS	Geographical Information System (GIS is a computer process for capturing, storing, checking and displaying data related to positions on globe. GIS can help understand spatial patterns and relationships.)
GPS	Global Positioning System (GPS is a global navigation satellite system [GNSS] that provide geolocation and time information anywhere on the earth surface.)
IPCC	Intergovernmental Panel on Climate Change [IPCC is the intergovernmental panel of UN (United nations) dedicated to providing the multidimensional perspective including scientific, economic, political aspects of Climate Change to the World community
IUCN	International Union for Conservation of Nature
KL	Kerala
KR	Karnataka
Maxent	Maximum-entropy-based tool for modelling species niches and distributions
Maximum entropy	Maximum entropy is fundamentally 'a measure of how much "choice" is involved in the selection of an event'. Therefore, in layman's language 'higher the entropy, greater will be the choice with lesser constraints'.
NP	National Park
NND	nearest neighbour distance
QGIS	Quantum GIS (QGIS is free and open source GIS [geographical information system] application desktop-based platform that is used for editing and analysing geospatial data.)
r	Correlation coefficient
RCP	Representation Concentration Pathways (RCP is a greenhouse gas trajectory adopted by IPCC AR5.)
RF	Reserve forest

ROC	receiver operating characteristic
LC	Least Concern
SDM	species distribution modelling
SLOPE	Derived continuous layer from DEM. Calculated as degrees using spatial analyst extension of ArcGIS 10.4
TN	Tamil Nadu
TSS	True skill statistics
WG	Western Ghats
WLS	Wild life sanctuary
HadGEM 2ES	Hadley Global Environment Model 2 – Earth System. (HadGEM2-ES was the first unified model developed by Met Office Hadley Centre. This model included Earth system components as standard. This model is used for operational weather forecasting and for climate research [Griffies et al. 2011].)
GFDL CM3	Geophysical Fluid Dynamics Laboratory – Climate Model 3. (The GFDL Climate Model version 3 (CM3) is developed by incorporating ocean and sea ice components. Aerosol-cloud interactions have also been taken into account in the GFDL CM3 modelling process. Compared to its previous version [CM2.1], CM3 more realistically captures the trends of stratospheric ozone and ozone hole depletion over Antarctica in late twentieth century [Donner et al. 2011].)
NorESM 1M	Norwegian Earth System Model. (NorESM1-M is the core version of the Norwegian Climate Centre's Earth System Model. It is community based climate System model version 4 (CCSM4) co-developed by University Corporation for Atmospheric Research. Advanced chemistry–aerosol–cloud–radiation interaction and isopycnic coordinate ocean is the core of this model [Bentsen et al. 2013].)

13.1 Introduction

Climate change (CC) is one major driver of biodiversity loss that impacts the habitats of all occupants (Cordellier et al. 2012). Intergovernmental Panel on Climate Change (IPCC) Fifth Assessment Report (AR5) predicts minimum rise in temperature from 0.9 to 5.4 °C globally by the end of the twenty-first century (Pachauri et al. 2014). Such significant – and potentially catastrophic – changes in temperature at a global level will scale up local and microclimatic conditions, resulting in local range shifts and in the shrinkage of range size of endemic and climate-sensitive species (Malcolm et al. 2006; Sony et al. 2018).

Loris lydekkerianus lydekkerainus (the grey slender loris) is a small, sensitive, often solitary, shy, nocturnal and insectivorous primate (Singh et al. 1999; Kumara et al. 2006). In India, two genera of lorises are known – *Loris* and *Nycticebus* (slow loris). Species of *Nycticebus* are common in the north-east of India (Arunachal Pradesh, Assam, Meghalaya, Nagaland, Manipur, Mizoram and Tripura) and in adjacent Southeast Asia, whereas two subspecies of *Loris* are known to be occurring commonly in the peninsular India and Sri Lanka (Kumara et al. 2009). Table 13.1 presents the geographical distribution of loris species and their conservation status.

The first distribution map of *Loris lydekkerianus* generated using analogue data is largely unhelpful when projected digitally (Osman Hill 1933; Kumara et al. 2006). Early distribution maps generated between 1889 and 1929 were based on field data and museum specimens (Blandford 1888; Ponder et al 2001; Ramaswami and Anand Kumar 1962; Rao 1994). The exact geographical coordinates were not recorded in the past, and therefore, the locations recorded were approximations (e.g. 2.5 km south-west of Anamudi). However, recent surveys conducted (2006–2016) show significant differences between the analogue data of the past and the digitized Global Positioning System (GPS) data of recent decades (Kumara et al. 2016; Radhakrishna et al. 2011; Sasi and Kumara 2014). Precise data (e.g. asl [above sea level]) are necessary for ecological niche modelling (ENM) (de Souza Muñoz et al. 2011).

Loris lydekkerianus is a species considered under the Least-Concern (LC) category (IUCN 2010; Nekaris et al. 2008). Nevertheless, the current heavy decline of habitat for this taxon predicts high chances of it soon shifting to the 'threatened' category within the next decade, if no effective conservation measures are launched. The Wildlife Protection Act of India, 1972 grants the 'highest protection' status to *Loris lydekkerianus* (Kumara and Singh 2004). Anthropogenic pressures, such as deforestation, habitat fragmentation, urban encroachment and mining, have contributed to the loss of habitat for this taxon, threatening their existence (Kinnaird et al. 2003; Linkie et al. 2006). These primates are also hunted for oil and some random folklore medicine in Brahmagiri-Makut in the Western Ghats (WG) (Kumara et al. 2006). Usually, hunters do not kill this taxon for its meat; however, during hunting times, a practice prevails among these hunters seeing them as a bad omen (Lewis 1917; Nekaris and Jayewardene 2004). In the Kolar region (Karnataka, KR), several native people follow a hunting event when they hunt a variety of wild animals including the slender loris (Kumara et al. 2006). Road kills of *L. lydekkerianus* are common in human settlements in the WG (Molur et al. 2003).

Many (e.g., Schulze and Meier (1995); Schulze et al. 2005; Kumara and Singh 2004) have discussed the anthropogenic pressures in the context of *L. lydekkerianus* population decline. However, no comprehensive study on the impact of climate change on the species distribution, shift in habitat ranges and population dynamics exists presently. Therefore, to evaluate the impact of climate change on populations of *L. lydekkerianus*, we have modelled their present distribution and future range shift.

This chapter attempts to assess and analyse the current distribution and predict the future distribution of the populations of *Loris lydekkerianus lydekkerianus* (Fig. 13.1), *Loris lydekkerianus malabaricus* (*L. l. malabaricus*) (Fig. 13.2) and *L. lydekkerianus* ssp. A in peninsular India using Maxent, an open source machine-

Table 13.1 Geographical distribution of *Loris* and *Nycticebus* species and their conservation status

Biological name	Common name	Conservation status	Occurrence	References (s)
Nycticebus sp.	Slow loris	Vulnerable	North eastern states of India (such as Arunachal Pradesh, Assam, Meghalaya, Nagaland, Manipur, Mizoram and Tripura) and parts of southeast Asia	Roos et al. (2014)
Nycticebus bengalensis	Bengal slow loris	Vulnerable	Eastern Bangladesh, North-eastern India (Assam, Arunachal Pradesh, Nagaland, Manipur, Mizoram and Meghalaya), South China, Myanmar, Laos, Cambodia and Thailand	Roos et al. (2014)
Nycticebus coucang	Sunda slow loris	Vulnerable	Southern Thailand, peninsular Malaysia, Singapore, Sumatra, Malacca Strait Island, and Riau Archipelago	Roos et al. (2014)
Nycticebus javanicus	Javan slow loris	Endangered	West and central Java, and some isolated patches in east Java	Roos et al. (2014)
Nycticebus menagensis	East Bornean slow loris	Vulnerable	North and east Borneo and southern Philippines	Roos et al. (2014)
Nycticebus bancanus	Bangka slow loris	Not evaluated	South-western Borneo and Bangka island of Sumatra	Roos et al. (2014)
Nycticebus borneanus	Schwaner mountains slow loris	Not evaluated	South-central Borneo	Roos et al. (2014)
Nycticebus kayan	Kayan River slow loris	Not evaluated	Central and northern Borneo	Roos et al. (2014)
Nycticebus pygmaeus	Pygmy slow Loris	Vulnerable	Vietnam, Laos and eastern Cambodia	Roos et al. (2014)
Loris tardigrandis	Sri Lanka red slender loris	Endangered	Western, southern provinces and central province highlands of Sri Lanka	Roos et al. (2014)
Loris lydekkerianus grandis	Highland Ceylon slender loris	Endangered	Hill country especially sub montane zone of central Sri Lanka	Groves (1998)
Loris lydekkerianus nordicus	Northern Ceylon slender loris	Endangered	Dry zone of Sri Lanka lowlands	Groves (1998)
Loris tardigradus nycticeboides	Ceylon mountain slender loris	Endangered	Upper montane cloud forests of central high plains of Sri Lanka	Groves (1998)

(continued)

Table 13.1 (continued)

Biological name	Common name	Conservation status	Occurrence	References (s)
Loris tardigradus tardigradus	Western Ceylon slender loris	Endangered	Southwestern wet zone of Sri Lanka	Groves (1998)
Loris lydekkerianus ssp.	Grey slender loris	Least Concern	Eastern foothill of southern WG	Kumara et al. (2009)
Loris lydekkerianus lydekkerianus	Mysore slender loris	Near threatened	Mysore plateau, the Eastern Ghats, and eastern side of the Western Ghats especially dry forest of southern Indian states such as Andhra Pradesh, Karnataka and Tamil Nadu	Groves (1998) and Kumara et al. (2009)
Loris lydekkerianus malabaricus	Malabar slender loris	Near threatened	Wetter tropical evergreen forest patches of Western Ghats	Groves (1998) and Kumara et al. (2009)

Fig. 13.1 Mysore slender loris (*Loris lydekkerianus lydekkerianus*) (Courtesy: Honnavalli N. Kumara)

learning algorithm. This chapter reports the information combining species occurrence reported so far and the newly generated datasets on the distribution and range shifts based on IPCC AR5 representative concentration pathway (RCP) 4.5 (year 2050), RCP 4.5(year 2070), RCP 8.5 (year 2050) and RCP 8.5 (year 2070) scenarios. Distribution modelling and analysis of shifts in species range aid in the understanding of the current and future distribution and help in the understanding of possible

Fig. 13.2 Malabar slender loris (*Loris lydekkerianus malabaricus*). (Courtesy: Honnavalli N. Kumara)

expansion or shrinkage of habitat under different climatic scenarios. We believe that this study would aid the scientific community, policy-makers and stakeholders to: (a) extend or design new reserves and identify areas for protection and (b) synthesize effective climate change mitigation strategies, further incorporating them into state or national policies (Subrahmanyam 2015; Sony et al. 2018).

13.2 Materials and Methods

13.2.1 Study Area

Loris lydekkerianus is widely distributed in peninsular India, an area that covers the southern Indian states of Andhra Pradesh (AP), Telangana (TE), Karnataka (KR), Kerala (KL) and Tamil Nadu (TN) (8°5'–14°30'N, 74°30'–80°20'E). The study area included the biodiversity-rich mountain chain of central and southern WG, the Deccan plateau and parts of the Eastern Ghats (EG). Figure 13.3 refers to the study area including the occurrence patterns of *Loris lydekkerianus lydekkerianus*, *Loris lydekkerianus malabaricus* and *L. lydekkerianus* ssp. *A* in the WG, Deccan Plateau and the EG.

The Western Ghats, a part of Malabar coastal biogeographic region in the peninsular India, is a continuous mountain chain that runs for c. 1600 km along

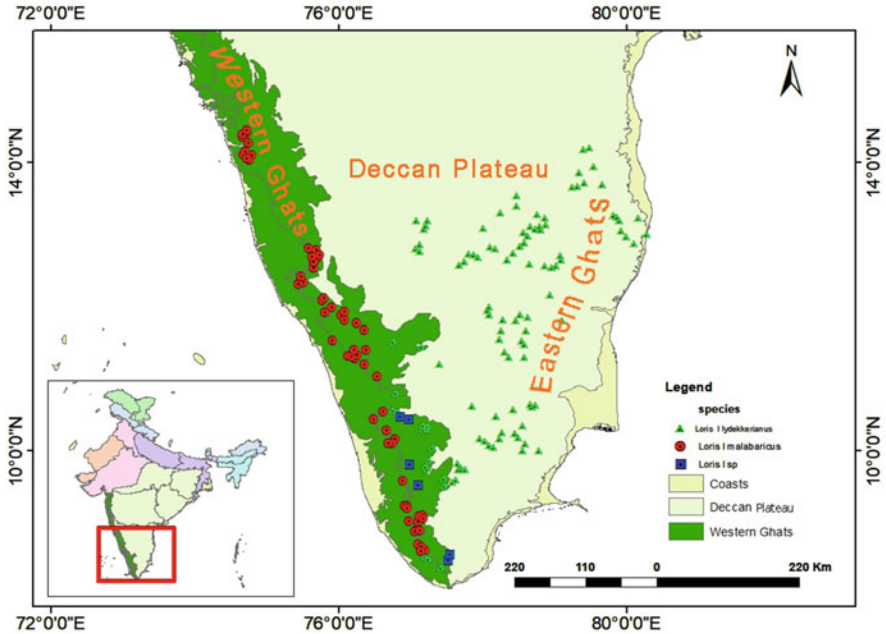

Fig. 13.3 Study area map showing occurrence of *Loris lydekkerianus lydekkerianus*, *Loris lydekkerianus malabaricus and Loris lydekkerianus* ssp. *A* in Western Ghats, Deccan Plateau and Eastern Ghats of India

the west coast (8–21°N, 73–89°E) interrupted by the Shencottah–Achankovil gap (8–9°N, 77–78°E) and the Goa gap (14–15°N, 74–75°E) and one major 30–40-km-wide Palghat gap (10–11°N, 76–77°E) (Ganesh et al. 2013). Narrow strips of 30–60 km separate the WG from the Arabian Sea (8–20°N, 73–78°E). Elevations of the WGs range between 600 and 2000 m, with a few peaks >2000 m in the Nilgiris (11.37°N, 76.76°E), Palani (10.2°N, 77.5°E) and Anamalais (10.3°N, 77°E) (Daniels 1992). The WG is latitudinally subdivided further into (a) the Northern WG between 16–20°N and 73–75°E, in the political boundaries of Gujarat and Maharashtra, (b) the Central WG (Goa and Karnataka 12–16°N and 74–76°E and (c) the Southern WG (Tamil Nadu and Kerala), which lies between 8 and 12°N and 76–78°E longitude (Sony et al. 2018). The central and southern parts of the WGs include large habitats for *Loris lydekkerianus malabaricus* (Fig. 13.3).

The Deccan plateau (DP), between the WG and the EG, forms another significant biome, and it is India’s largest biogeographic area defined by specific geology and climate pattern (Fig. 13.3) (Rawat 1997). The DP is further subdivided into central highland, Chota Nagpur, eastern highland, central plateau and the southern Deccan (Rodgers and Panwar 1988). The EG lie along the eastern edge of the Deccan plateau. The EG originate from the Mahanadi in southern Odisha, which run through AP further extending up to the northern region of TN 11°30’–21°0’ N to 79°–

85°20'E. Southern Deccan is a notable habitat for *Loris lydekkerianus lydekkerianus*, since they prefer dry and deciduous forests of the southern EG (Kumara et al. 2009), which receive a relatively scanty average rainfall of 60–90 cm/annum, compared with the cooler and wetter northern regions that experience a higher average rainfall of 120–160 cm/annum (Subrahmanyam 1982).

13.2.2 Species Occurrence and Field Data Collection

For climate modelling, 114 geo-referenced occurrence points of *Loris lydekkerianus lydekkerianus*, 62 of *Loris lydekkerianus malabaricus* and 6 of *L. lydekkerianus* ssp. *A* were determined from previous publications for processing (Kumara et al. 2016; Sasi and Kumara 2014). After applying spatial thinning to minimize sampling biases, the final datasets used in computational modelling were: (a) populations of *Loris lydekkerianus lydekkerianus* in 81 occurrence points, (b) populations of *Loris lydekkerianus malabaricus* in 38 occurrence points and (c) *L. lydekkerianus* ssp. *A* in six occurrence points. Table 13.2 presents field data of occurrence points and status of endemism for *Loris lydekkerianus lydekkerianus*, *Loris lydekkerianus malabaricus* and *L. lydekkerianus* ssp. *A*.

The occurrence points were determined using ArcMap 10.3 following Bloom et al. (2018). It was ensured that the resolution of the species occurrence points (1 km^2) was greater than the bioclimatic variables and further that the occurrence points were equally distributed to obtain meaningful outputs (Wiens et al. 2009). Only species occurrence points which showed <0.001 georeferencing residual values were chosen for further processing because lower residual values are strong indicators of high accuracy (Oniga et al. 2017).

Table 13.2 Occurrence points and endemicity of *Loris lydekkerianus lydekkerianus*, *Loris lydekkerianus malabaricus and Loris lydekkerianus* ssp. *A, collected from the field, and subsequently used for computational modeling after removal of sample biases* [Between 8° 5' N – 14° 30' N and 74° 30' E – 80° 20' E]

Species name	Endemic/non-Endemic	Region	Occurrence localities	Localities used after spatial thinning
Loris lydekkerianus lydekkerianus	Endemic	DP	114	81
Loris lydekkerianus malabaricus	Endemic	WG	62	38
Loris lydekkerianus ssp. *A*	Endemic	SWG	6	6

Deccan Plateau = DP
Western Ghats= WG
Southern Ghats= SWG

13.2.3 Elimination of Sampling Biases Using 'Spatial Thinning' Technique

Spatial thinning was used to address sampling biases. Spatial thinning is both efficient and viable, and therefore, is frequently used in niche modelling, resulting in better performance (Zadrozny 2004; Aiello-Lammens et al. 2015). Spatial thinning was achieved using a spThin package (https://cran.r-project.org/package=spThin) in R Studio (https://www.rstudio.com/products/rpackages/). Spatial thinning is a special package where 'thin' function randomly deletes the unwanted data clusters based on nearest neighbour distance (NND) and keeps equally spaced data points (Pearson et al. 2002, 2007). In this study, the linear distance (x = 10 km) was used in the data cluster to overcome sample biases. The 'linear distance (x = 10 km)' here means that each data point could be placed greater than or equal to 10 km apart in any direction, resulting in retention of largest possible number of records (Anderson and Raza 2010).

13.2.4 Environmental Variables and Covariates

Biotic and abiotic factors have a huge influence on the species dispersal, which are all crucial factors for geographic expression of the niche of a species (Soberon and Peterson 2005). Since the biotic interactions and dispersal layers are not easy to simulate in the current as well as future scenarios, these factors were kept as constants in the model-building process. Essentially, an assumption was made that in the next 80 years, no substantial differences would occur both in the biotic interactions and in dispersal layers, conceding an element of uncertainty, mathematically referred to as arbitrary constant. Such decisions are inevitable when we model the potential distribution of species (Pearson et al. 2002, 2007).

Representative concentration pathways (RCP) 4.5 and 8.5 for 2050 and 2070, respectively, were considered for future projection of range shift and potential distribution of species. The maxent model incorporates 19 bioclimatic and 3 biophysical variables included for modelling of *Loris lydekkerianus lydekkerianus*, *Loris lydekkerianus malabaricus* and *L. lydekkerianus* ssp. A (Table 13.3). These variables (which climate modellers address as 'bioclimatic predictors') capture annual climatic trends, such as annual mean temperature, annual range of temperature, annual precipitation as well as seasonal mean climate conditions, such as maximum temperature of the warmest month, precipitation of the wettest month, and intra-year seasonality such as precipitation of the driest quarters and coldest quarters (Phillips 2017; O'Donnell and Ignizio 2012).

Fine-scale resolution of 30 arcsec or 1 km^2 was used for modelling bioclimatic predictors. These spatially downscaled climate datasets were available from the open-source portal (http://www.ccafs-climate.org/data_spatial_downscaling/.) Topographical layers such as slope and aspect variables were derived using ArcMap 10.3 from the DEM (Digital Elevation Model) dataset, available in the public-domain portal (https://databasin.org/datasets/.)

Table 13.3 Environmental and topographical layers included for modelling of *Loris lydekkerianus lydekkerianus*, *Loris lydekkerianus malabaricus and Loris lydekkerianus* ssp. A

Abbreviation	Variables	Units
BIO1	Annual mean temperature	°C
BIO2	Mean diurnal range (Mean of monthly [maximum temperature – minimum temperature])	°C
BIO3	Isothermality (BIO2/BIO7) (* 100)	–
BIO4	Temperature seasonality (standard deviation *100)	°C
BIO5	Maximum temperature of warmest month	°C
BIO6	Minimum temperature of coldest month	°C
BIO7	Temperature annual range (BIO5-BIO6)	°C
BIO8	Mean temperature of wettest quarter	°C
BIO9	Mean temperature of driest quarter	°C
BIO10	Mean temperature of warmest quarter	°C
BIO11	Mean temperature of coldest quarter	°C
BIO12	Annual precipitation	mm
BIO13	Precipitation of wettest month	mm
BIO14	Precipitation of driest month	mm
BIO15	Precipitation seasonality (Coefficient of variation)	–
BIO16	Precipitation of wettest quarter	mm
BIO17	Precipitation of driest quarter	mm
BIO18	Precipitation of warmest quarter	mm
BIO19	Precipitation of coldest quarter	mm
Slp	Slope	–
Alt	Altitude	m
Asp	Aspect	–

13.2.5 Multicolinearity Among Variables

High correlation among environmental variables (aka multicolinearity) can potentially suppress the functions of critical variables in data processing, resulting in errors (Graham 2003). Therefore, highly correlating variables with $r \geq 80$ were eliminated using Pearson correlation coefficient (r) following Yang et al. (2013). A point sampling tool in quantum geographic information system (QGIS) 2.14 was utilized to extract the pixel value of each of the stacked environmental layers. The values were arranged in MS Excel 2010 and a Pearson correlation coefficient(r) was derived from the 19 bioclimatic and 3 biophysical variables. The highly correlated variables $r \geq 80$ were then eliminated (highlighted in Tables 13.4a, 13.4b, and 13.4c) and the remainder were used for modelling (Tables 13.4a, 13.4b, and 13.4c).

Table 13.4a Correlation coefficients of variables using multicollinearity test (r ≥ 80) for *Loris lydekkerianus lydekkerianus*. The highlighted ecological variables were used for modelling

r>=.80	***bio_1***	***bio_2***	***bio_3***	***bio_4***	*bio_5*	*bio_6*	*bio_7*	*bio_8*	*bio_9*	*bio_10*	*bio_11*	***bio_12***	*bio_13*	***bio_14***	***bio_15***	*bio_16*	*bio_17*	*bio_18*	***bio_19***	***alt***	***slope_indi***	***india_aspe***
bio_1	1.000																					
bio_2	-0.266																					
bio_3	-0.209	-0.440																				
bio_4	0.328	0.514	-0.943																			
bio_5	0.835	0.232	-0.639	0.728																		
bio_6	0.873	-0.636	0.224	-0.145	0.478																	
bio_7	-0.047	0.851	-0.842	0.851	0.503	-0.518																
bio_8	0.951	-0.226	-0.180	0.323	0.784	0.821	-0.044															
bio_9	0.933	-0.342	-0.006	0.076	0.709	0.913	-0.208	0.861														
bio_10	0.962	-0.064	-0.454	0.563	0.946	0.715	0.217	0.912	0.847													
bio_11	0.928	-0.473	0.124	-0.038	0.614	0.976	-0.363	0.870	0.969	0.802												
bio_12	-0.045	-0.656	0.328	-0.419	-0.329	0.259	-0.575	-0.089	0.045	-0.164	0.138											
bio_13	0.125	-0.515	0.200	-0.284	-0.083	0.348	-0.423	0.032	0.248	0.036	0.286	0.890										
bio_14	-0.049	-0.761	0.749	-0.713	-0.546	0.360	-0.886	-0.031	0.017	-0.277	0.190	0.610	0.360									
r	0.090	0.621	-0.584	0.530	0.495	-0.230	0.708	0.020	0.107	0.265	-0.065	-0.528	-0.180	-0.872								
bio_16	0.066	-0.478	0.134	-0.225	-0.100	0.267	-0.360	-0.013	0.162	-0.001	0.201	0.911	0.974	0.336	-0.180							
bio_17	0.059	-0.829	0.712	-0.692	-0.455	0.468	-0.904	0.055	0.136	-0.173	0.304	0.680	0.452	0.972	-0.838	0.423						
bio_18	-0.239	-0.555	0.480	-0.542	-0.533	0.083	-0.601	-0.244	-0.124	-0.373	-0.037	0.819	0.622	0.701	-0.661	0.625	0.718					
bio_19	0.421	-0.586	0.109	-0.124	0.168	0.586	-0.413	0.316	0.470	0.325	0.508	0.626	0.654	0.385	-0.305	0.634	0.471	0.399				
alt	-0.981	0.404	0.165	-0.240	-0.768	-0.914	0.152	-0.919	-0.947	-0.923	-0.949	-0.081	-0.232	-0.028	-0.040	-0.172	-0.152	0.122	-0.496			
slope_indi	-0.525	0.032	0.301	-0.325	-0.538	-0.385	-0.145	-0.489	-0.507	-0.551	-0.446	0.048	-0.082	0.241	-0.288	-0.096	0.162	0.197	-0.218	0.521		
india_aspe	-0.201	0.028	0.315	-0.335	-0.246	-0.078	-0.163	-0.204	-0.074	-0.252	-0.069	0.030	0.066	0.073	0.027	0.039	0.020	0.094	-0.109	0.177	0.166	1.000

Table 13.4b Correlation coefficients of variables using multicollinearity test (r ≥ 80) for *Loris lydekkerianus malabaricus*. The highlighted ecological variables were used for modelling

	bio_1	***bio_2***	***bio_3***	*bio_4*	*bio_5*	*bio_6*	*bio_7*	*bio_8*	*bio_9*	*bio_10*	*bio_11*	***bio_12***	*bio_13*	*bio_14*	*bio_15*	*bio_16*	*bio_17*	***bio_18***	*bio_19*	***alt***	***slope_indi***	***india_aspe***
bio_1	1.000																					
bio_2	-0.439																					
bio_3	0.730	-0.772																				
bio_4	-0.502	0.816	-0.932																			
bio_5	0.860	0.011	0.324	-0.025																		
bio_6	0.963	-0.632	0.818	-0.618	0.754																	
bio_7	-0.596	0.964	-0.911	0.906	-0.142	-0.757																
bio_8	0.966	-0.567	0.842	-0.655	0.727	0.957	-0.719															
bio_9	0.973	-0.360	0.650	-0.396	0.885	0.928	-0.518	0.914														
bio_10	0.991	-0.340	0.637	-0.386	0.914	0.933	-0.496	0.930	0.981													
bio_11	0.997	-0.436	0.740	-0.526	0.848	0.957	-0.599	0.962	0.970	0.986												
bio_12	-0.358	0.472	-0.553	0.444	-0.183	-0.474	0.531	-0.469	-0.310	-0.302	-0.332											
bio_13	-0.508	0.624	-0.714	0.599	-0.276	-0.646	0.699	-0.610	-0.452	-0.441	-0.488	0.956										
bio_14	0.468	-0.811	0.860	-0.864	0.054	0.611	-0.866	0.648	0.362	0.360	0.463	-0.678	-0.777									
bio_15	-0.601	0.806	-0.860	0.776	-0.268	-0.757	0.875	-0.722	-0.529	-0.515	-0.587	0.814	0.932	-0.909								
bio_16	-0.451	0.592	-0.665	0.554	-0.232	-0.589	0.657	-0.560	-0.399	-0.386	-0.429	0.978	0.995	-0.755	0.905							
bio_17	0.518	-0.808	0.889	-0.870	0.128	0.667	-0.879	0.677	0.409	0.413	0.514	-0.682	-0.812	0.973	-0.939	-0.782						
bio_18	0.462	-0.695	0.638	-0.591	0.232	0.633	-0.723	0.476	0.435	0.407	0.470	-0.322	-0.561	0.537	-0.692	-0.503	0.668					
bio_19	-0.163	0.467	-0.539	0.530	0.061	-0.309	0.527	-0.285	-0.141	-0.088	-0.162	0.837	0.841	-0.599	0.730	0.852	-0.640	-0.445				
alt	-0.992	0.461	-0.725	0.519	-0.829	-0.950	0.608	-0.960	-0.960	-0.981	-0.992	0.286	0.441	-0.448	0.557	0.382	-0.490	-0.436	0.096			
slope_indi	0.185	-0.146	0.060	-0.039	0.159	0.191	-0.130	0.166	0.149	0.186	0.173	0.044	-0.030	0.096	-0.120	-0.005	0.085	0.134	0.136	-0.187		
india_aspe	-0.055	-0.263	0.102	-0.136	-0.214	0.003	-0.216	0.000	-0.048	-0.079	-0.061	0.061	0.029	0.160	-0.109	0.024	0.111	0.096	0.106	0.036	0.262	1.000

Table 13.4c Correlation coefficients of variables using multicollinearity test (r ≥ 80) for *Loris lydekkerianus* ssp. *A*. The highlighted ecological variables were used for modelling

	bio_1	***bio_2***	***bio_3***	***bio_4***	*bio_5*	*bio_6*	*bio_7*	*bio_8*	*bio_9*	*bio_10*	*bio_11*	***bio_12***	*bio_13*	***bio_14***	***bio_15***	*bio_16*	***bio_17***	*bio_18*	*bio_19*	***alt***	***slope_indi***	*india_aspe*
bio_1	1.000																					
bio_2	-0.647																					
bio_3	-0.029	-0.601																				
bio_4	0.659	-0.106	-0.670																			
bio_5	0.966	-0.431	-0.228	0.725																		
bio_6	0.993	-0.714	0.080	0.572	0.938																	
bio_7	-0.556	0.986	-0.723	0.055	-0.331	-0.638																
bio_8	0.997	-0.644	0.013	0.629	0.963	0.992	-0.562															
bio_9	0.991	-0.579	-0.052	0.624	0.982	0.984	-0.496	0.991														
bio_10	0.997	-0.583	-0.090	0.684	0.984	0.983	-0.490	0.993	0.996													
bio_11	0.994	-0.632	0.011	0.591	0.967	0.993	-0.554	0.994	0.998	0.993												
bio_12	-0.871	0.496	0.371	-0.895	-0.855	-0.826	0.350	-0.838	-0.829	-0.871	-0.818											
bio_13	-0.815	0.574	0.291	-0.847	-0.760	-0.779	0.431	-0.779	-0.752	-0.800	-0.750	0.980										
bio_14	0.473	-0.886	0.453	0.248	0.247	0.511	-0.844	0.463	0.361	0.405	0.411	-0.502	-0.619									
bio_15	0.032	0.542	-0.235	-0.002	0.225	-0.002	0.507	0.074	0.137	0.099	0.099	0.210	0.392	-0.696								
bio_16	-0.815	0.507	0.369	-0.880	-0.784	-0.771	0.358	-0.777	-0.761	-0.808	-0.753	0.990	0.996	-0.544	0.332							
bio_17	0.017	-0.728	0.900	-0.428	-0.229	0.107	-0.802	0.043	-0.061	-0.059	0.006	0.153	0.018	0.748	-0.551	0.111						
bio_18	-0.704	0.059	0.705	-0.979	-0.800	-0.618	-0.096	-0.675	-0.694	-0.738	-0.655	0.891	0.817	-0.117	-0.113	0.862	0.538					
bio_19	0.617	-0.939	0.451	0.300	0.403	0.657	-0.893	0.610	0.519	0.554	0.567	-0.588	-0.679	0.983	-0.601	-0.611	0.702	-0.197				
alt	-0.999	0.647	0.017	-0.642	-0.966	-0.995	0.560	-0.997	-0.993	-0.997	-0.996	0.859	0.799	-0.463	-0.048	0.800	-0.018	0.690	-0.609			
slope_indi	0.276	0.211	-0.896	0.826	0.386	0.181	0.366	0.215	0.256	0.309	0.210	-0.668	-0.637	-0.050	-0.131	-0.692	-0.668	-0.825	-0.047	-0.259		
india_aspe	0.840	-0.308	-0.137	0.679	0.878	0.802	-0.231	0.868	0.846	0.860	0.833	-0.687	-0.593	0.234	0.397	-0.606	-0.126	-0.710	0.363	-0.836	0.191	1.000

Table 13.5 Percentage contribution of environmental variables for *Loris lydekkerianus lydekkerianus*, *Loris lydekkerianus malabaricus and Loris lydekkerianus* ssp. A

Variable	*L. l. lydekkerianus*	*L. l. malabaricus*	*L. l. ssp.*
BIO–1 (Annual mean temperature)	0.5	-	-
BIO–2 (Mean diurnal range)	1.2	3.6	0.2
BIO–3 (Isothermality)	22.8	51.4	41.6
BIO–4 (Temperature seasonality)	8.9		18.2
BIO–12 (Annual precipitation)	1.5	32.4	–
BIO–14 (Precipitation of driest month)	3.1	–	38.7
BIO–15 (Precipitation seasonality)	12.7	–	0.5
BIO–18 (Precipitation of warmest quarter)	–	3.2	–
BIO–19 (Precipitation of coldest quarter)	44	–	–
Slope	3.3	3.2	–
Altitude	1.7	6	0.8
Aspect	0.3	0.1	–

13.2.6 Maxent Modelling and Validation

13.2.6.1 Maxent Modelling

Maxent algorithm (3.4.1) was preferred over other similar algorithms (e.g. generalized linear models (GLMs), generalized additive models (GAMs) or machine learning techniques such as neural networks) because it is possible to 'run' the maxent model with a small number of training data (Phillips et al. 2004, 2006), which eliminates the need for 'species absence' or 'pseudo absence' data (Phillips et al. 2006).

Maxent is comparatively less sensitive to small sample size and offers high resolution among the available niche modelling tools (Wisz et al. 2008). In comparison with mathematical tools such as Genetic Algorithm for Rule Set Predication (GARP), maxent is efficient in niche modelling because it can render the output data with merely 3 occurrence points (van Proosdij et al. 2016), whereas GARP requires a minimum of 10 occurrence points to produce results of 90% accuracy (Pearson et al. 2007, 2018).

To calibrate the model, data were partitioned into random test percentage (30%) and training data (70%) following a successful method demonstrated by Araújo et al. (2005). An iteration value of 5000 and 11 replicates were set before running the model. Usually, the default iteration value of 500 is set. The high value is because higher iteration values allow the model to have sufficient time for convergence. The model may *under-predict* or *over-predict* if adequate time to converge is not provided (Young et al. 2011).

Data validation of ecological variables within the model was performed by two methods. The first method calculated the average percentage contribution of the variables used in the model. Table 13.5 presents the percentage contributions of environmental variables for *Loris lydekkerianus lydekkerianus*, *Loris lydekkerianus malabaricus* and *L. lydekkerianus* ssp. A. The second method (Jackknife analysis)

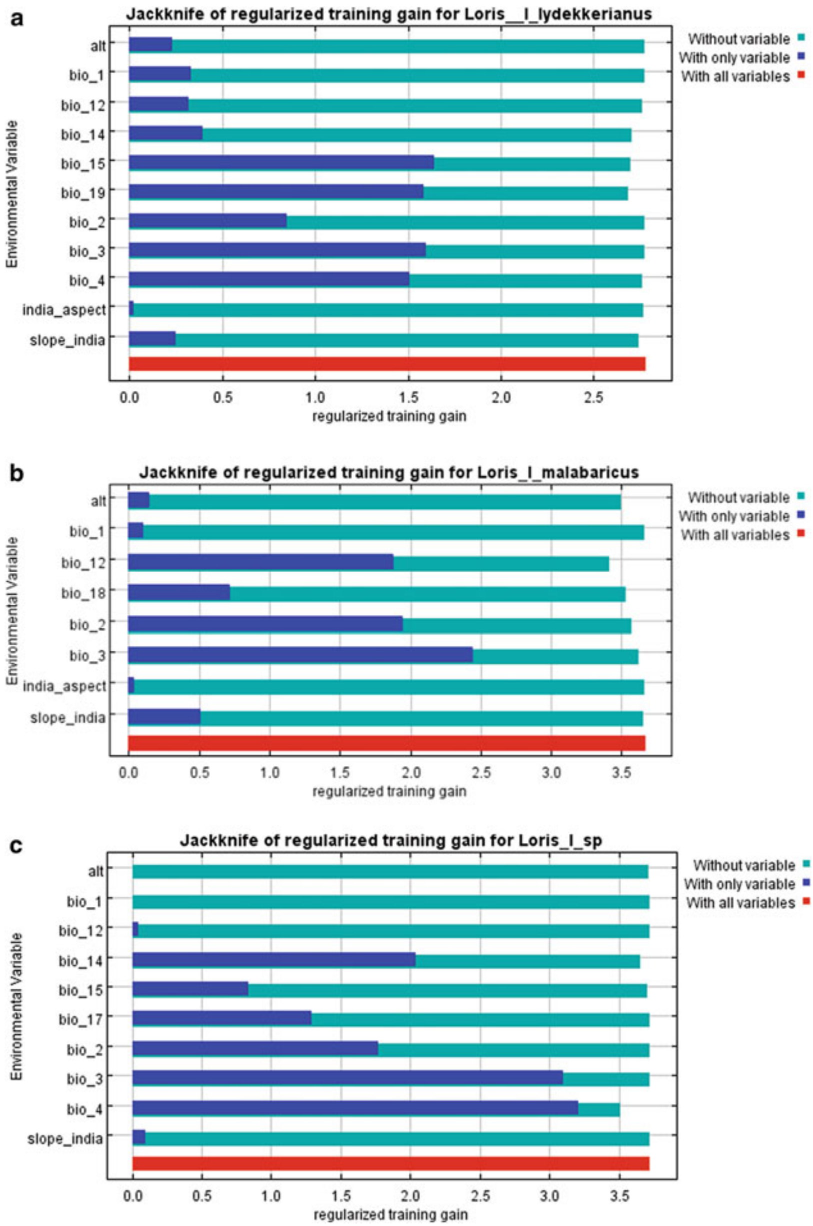

Fig. 13.4 (**a**, **b**, **c**) Jackknife analysis to calculate importance of input variable for *Loris lydekkerianus lydekkerianus*, *Loris lydekkerianus malabaricus and Loris lydekkerianus* ssp. *A*, respectively

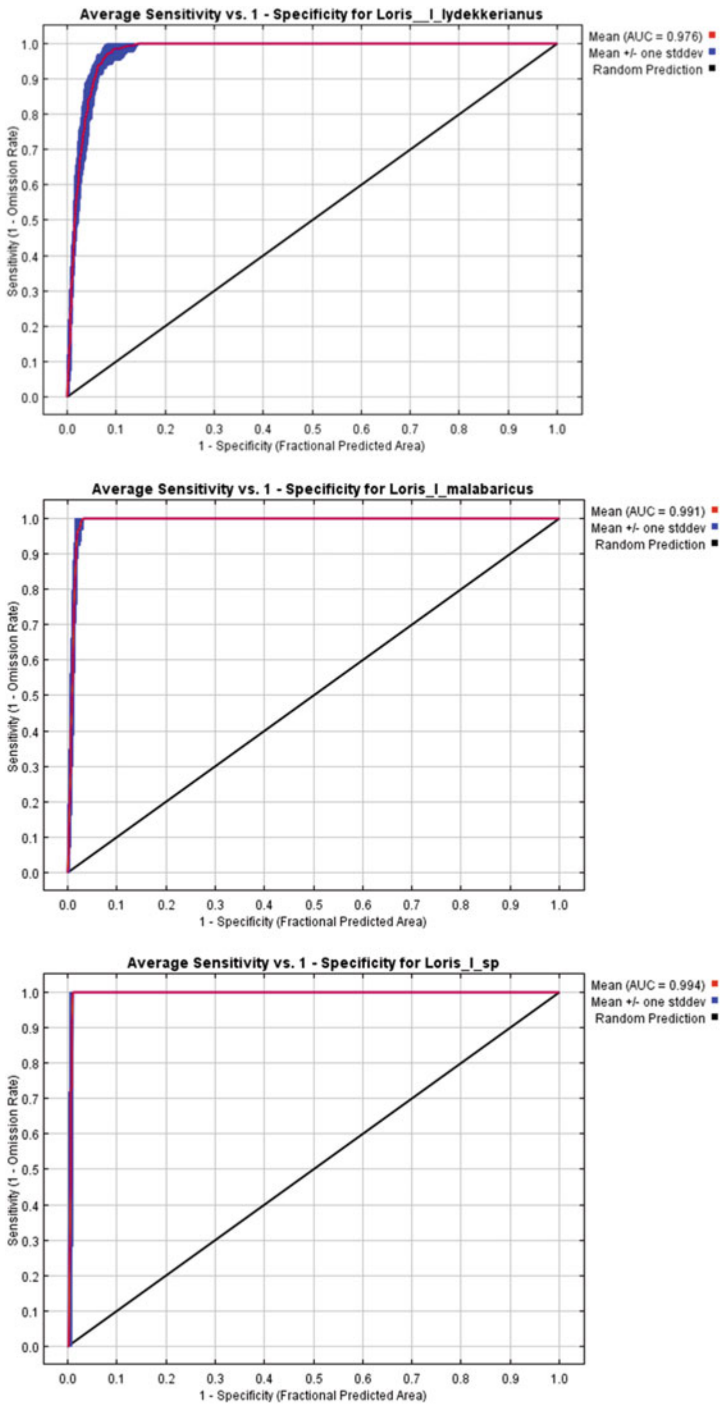

Fig. 13.5 (**a**, **b**, **c**) The AUC curves for *Loris lydekkerianus lydekkerianus*, *Loris lydekkerianus malabaricus and Loris lydekkerianus* ssp. *A*, respectively

employed a procedure to identify the most influential variables (those with greatest regularized gain) for inclusion in the final model, following earlier authors (Wang et al. 2014; Young et al. 2011) (Fig. 13.4a–c).

13.2.6.2 Maxent Model Validation

Receiver operator characteristics (ROC) also known as area under curve (AUC) was used to evaluate the model performance based on the quality of ranking (Pepe 2000; Fielding and Bell 1997). The ranking was based on the probability of choosing 'species presence record' over 'species absence record'. The perfect ranking has an AUC value of 1.0 and the poor ranking has an AUC value of 0.5. The intermediate value >0.75 indicates that the model is valid (Phillips and Dudík 2008). AUC is widely used in maxent modelling to estimate predictive capacity, aiding in evaluating the performance of multiple maxent models (Peterson et al. 2008). Finally, to plot the maxent output, the modelling outcomes were categorized as follows: (1) unsuitable habitat (whose probability of distribution [p] lies between 0.0–0.2), (2) barely suitable habitat (0.2–0.4), (3) suitable habitat (0.4–0.6), (4) highly suitable habitat (0.6–0.8) and (5) very highly suitable habitat (0.8–1.0). Figures 13.5a–c present AUC curves for *Loris lydekkerianus lydekkerianus*, *Loris lydekkerianus malabaricus* and *L. lydekkerianus* ssp. A, respectively.

13.2.7 Ecological Forecasting of Habitat Changes in Response to Climate Change

Potential habitat and range shift forecasting were performed using climate data downloaded from the General Circulation Model (GCM) data portal (http://www.ccafs-climate.org/data_spatial_downscaling/) maintained by Consultative Group on International Agricultural Research program on Climate Change, Agriculture and Food Security (CGIAR–CCASF).

13.2.8 Representative Concentration Pathways

The representative concentration pathways (RCPs) are those synthesized for climate research based on long- and short-term modelling experiments. The climate change scenarios based on the IPCC Fifth Assessment Report (AR5) are assigned based on earth's net radiative forcing values, which is the difference between sunlight absorbed by the earth (insolation) and the energy radiated back to space (ranging from 2.6 to 8.5 W/m^2). The pathways are generated after intense deliberations between a variety of stakeholders such as assessment experts, climate modellers, emission inventory experts and terrestrial ecosystem modellers. The input components such as socio-economic factors, land-use patterns, greenhouses gas (GHG) concentrations and other atmospheric emission data were harmonized with RCPs to ensure consistency with historical climate trend.

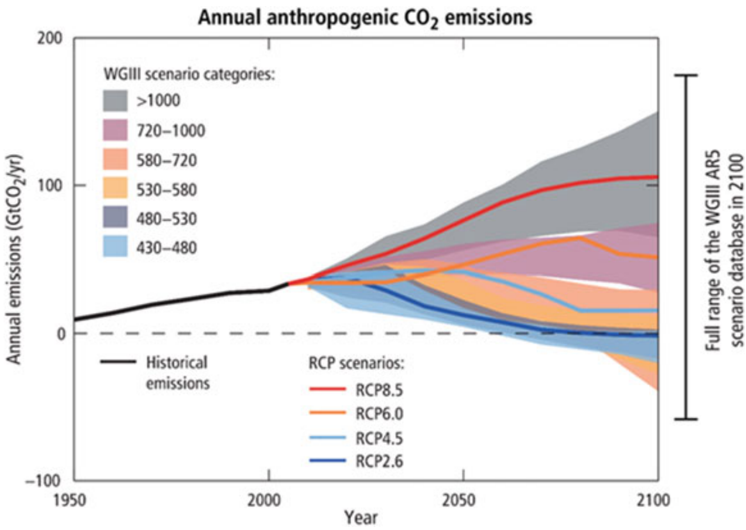

Fig. 13.6 **Four different scenarios projected in IPCC AR5.** (Presented here for academic purposes without the explicit written permission from, Pachauri et al. 2014). RCP 8.5 represents the most damaging scenario, with RCP 2.6 representing the 'least damaging' scenario, and RCP 4.5 and RCP 6.0 representing intermediate scenarios

A median stabilizing scenario (RCP 4.5) and a high-emission baseline scenario (RCP 8.5) for 2050 and 2070 were considered, respectively, in the maxent modelling to cover both possible consequences of infinite rising and stabilization of greenhouses gases (GHG). RCP 4.5 stabilizes at 4.5 W/m^2 (equivalent to ~650 ppm CO_2) by the end of twenty-first century; however, RCP 8.5 is a rising radiative forcing pathway, which leads to 8.5 W/m^2 (equivalent to 1370 ppm CO_2) concentrations in atmosphere (Clarke et al. 2007). RCP 8.5 incorporates factors such as corporate demographics, short-lived aerosols and other chemical species impacting the environment, land use and socio-economic factors that simulate future radiative forcing of 8.5 W/m^2 (Moss et al. 2010; Riahi et al. 2011). Figure 13.6 presents the global rise in median temperature yearly over the twentieth and twenty-first centuries. The figure represents four different scenarios stipulated by IPCC AR5 team (Pachauri et al. 2014). RCP 8.5 is the most damaging scenario, with RCP 2.6 being the 'least damaging' scenario and RCP 4.5 and RCP 6.0 being intermediate scenarios.

The Global Circulation Model (GCM) processed incomplete data of the WG because of inadequate field stations (Sony et al. 2018). Therefore, we used the 'mean data' of climate models from three sources: (1) GFDL (Geophysical Fluid Dynamics Laboratory), (2) NorESM – 1M (Norwegian Earth System Model), and (3) HadGEM – 2ES (Hadley Global Environment). GFDL and NorESM perform best on data pertaining to precipitation and temperature, most suited for Indian climatic setting (Chaturvedi et al. 2012; Menon et al. 2013).

13.3 Results

13.3.1 Model Building and Validation

The best-fit model employed the following bioclimatic variables: annual mean temperature, mean diurnal range, isothermality, temperature seasonality, annual precipitation, precipitation of the driest month, precipitation seasonality, precipitation of the warmest quarter and precipitation of the coldest quarter, as well as the topographic layers: slope, altitude and aspect for *Loris lydekkerianus lydekkerianus*, *Loris lydekkerianus malabaricus and L. lydekkerianus* ssp. *A*. Temperature-derived (Bio5–Bio11) and precipitation-derived variables (Bio 13, Bio16, and Bio17) were removed due to multicolinearity for the reasons described in Sect. 13.2.5.

Table 13.5 presents the percentage contributions of the environmental variables in the model. The variables with higher values represent greater validity in the model because of the impact they have on species distribution. 'Isothermality', 'precipitation of the coldest quarter', 'annual precipitation' and 'precipitation of the driest month' are the four most strongly impacting factors that influence species distribution (Table 13.5). In particular, 'precipitation of the coldest quarter' impacts *Loris lydekkerianus lydekkerianus* more than *Loris lydekkerianus malabaricus and L. lydekkerianus* ssp. A.

The percentage contributions of the ecological variables used in the computational model and the Jackknife plots are comparable, confirming that the four variables used in Sect. 13.3 of this chapter are the most critical in developing the model.

In *Loris lydekkerianus lydekkerianus*, precipitation of the coldest quarter (Bio19) and isothermality (Bio3) contribute to >65% of the total predictor variables. Similarly, the annual precipitation and isothermality contribute to > 82% of the total predictor variables for *Loris lydekkerianus malabaricus* and the precipitation of the driest month along with isothermality contributes to > 79% of the total predictor variables for the *L. lydekkerianus* ssp. A. Therefore, isothermality turns out to be a key variable, playing a crucial role in model building and in the subsequent distribution of the involved taxon in relation to climate change.

The AUC values for all the three taxa denote greater accuracy with the highest average AUC score of 0.994 for *L. l* ssp. A, followed by 0.991 for *L. l. malabaricus* and 0.976 for *L. l. lydekkerianus*, respectively (Fig. 13.5a–c), far higher than the mean AUC of 0.75 or greater, which is generally considered a characteristic of a good fit model (Phillips et al. 2017).

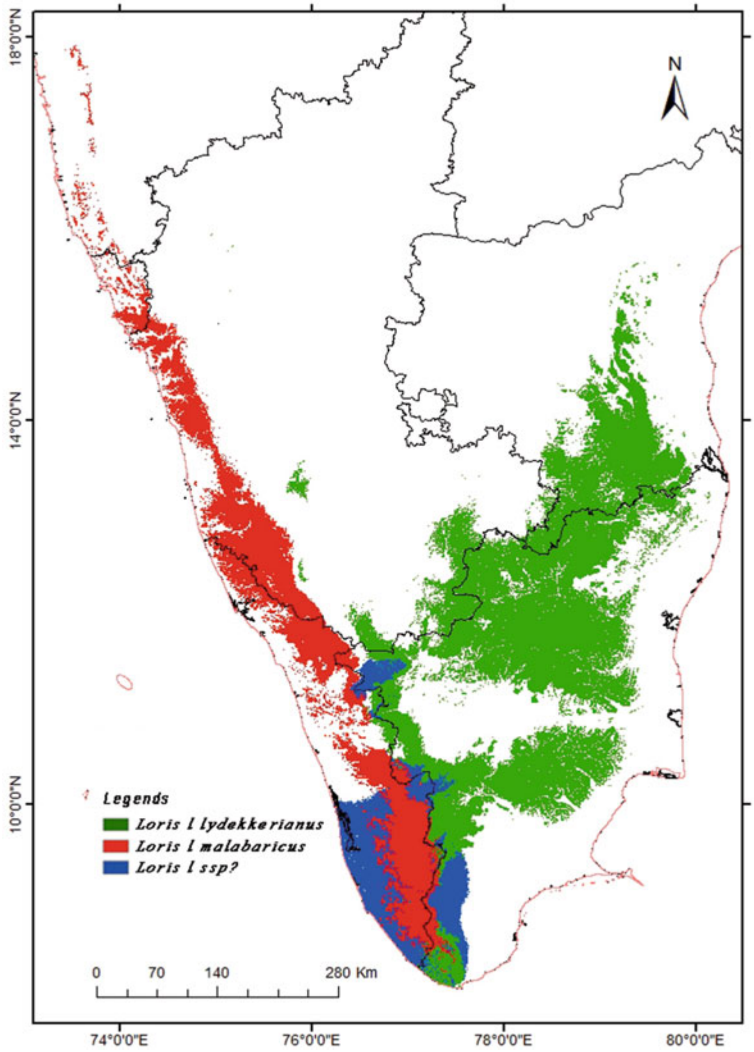

Fig. 13.7a Distribution map showing distinct niches of three subspecies of *Loris lydekkerianus lydekkerianus*, *Loris lydekkerianus malabaricus and Loris lydekkerianus* ssp. *A*. ($p \geq 50$) in peninsular India

13.3.2 Characterization of the Niches of *Loris lydekkerianus lydekkerianus, Loris lydekkerianus malabaricus* and *L. lydekkerianus* ssp. *A*

Figure 13.7a presents the details of the niche for *Loris lydekkerianus lydekkerianus*, *Loris lydekkerianus malabaricus* and *L. lydekkerianus* ssp. *A*.

Loris lydekkerianus malabaricus is more common in the Malabar and western parts of the WG, whereas *Loris lydekkerianus lydekkerianus* are more common in the eastern parts of the WG. *Loris lydekkerianus* ssp. *A* are more common in the southern parts of the WG. Furthermore, *Loris lydekkerianus lydekkerianus* prefer dry forest patches, human-dominated areas and are more common across the rain-shadow areas of the WG. To be precise, their populations prosper in shrub and deciduous forests along the plains, which are interspersed with agricultural and horticultural efforts.

The potential distribution of all three taxa when plotted indicates specific habitats. *Loris lydekkerianus malabaricus* widely establishes its habitat in a transition area dominated by moist evergreen and semi-evergreen forest.

This area is moist because it receives two monsoons – southwest monsoon in June (*Eḍavappathi* in Malayalam, because it arrives in the middle of the Malayalam month *Eḍavam*) and the northeast monsoon, arriving in middle of October (*Thulāvar□am*, because it arrives in the Malayalam month *Thulām*). *Loris lydekkerianus malabaricus* appears to establish its habitat on the rainier and the wetter areas of the WG, whereas *Loris lydekkerianus lydekkerianus* prefers dry areas of the WG, extending into the south of the Deccan plateau and the southern EG (Fig. 13.7a). *Loris lydekkerianus* ssp. *A* prefers an intermediate climate (neither too dry nor too moist), establishing itself in the summit of the southern WG. This intermediate area receives plenty of rain gaining both from southwest and northeast monsoons (Gunnell 1997; McGinley 2007; Kumara et al. 2009). Comparable results on the habitat of these taxa were reported earlier by Kumara et al. (2009) using Genetic Algorithm for Rule Set Prediction (GARP) modelling of *Loris lydekkerianus* ssp. *A*.

Table 13.6 The current habitat suitability of *Loris lydekkerianus lydekkerianus*, *Loris lydekkerianus malabaricus and Loris lydekkerianus* ssp. A in India

Habitat type	*p value*	*Loris lydekkerianus lydekkerianus* (%)	*Loris lydekkerianus malabaricus* (%)	*Loris lydekkerianus* ssp. *A* (%)
Unsuitable habitat	0.0–0.2	95.04	96.05	98.80
Barely suitable habitat	0.2–0.4	1.87	1.85	0.29
Suitable habitat	0.4–0.6	1.33	1.06	0.16
Highly suitable habitat	0.6–0.8	1.16	0.61	0.24
Very highly suitable habitat	0.8–1.0	0.60	0.43	0.51
Percentage sum whose $p \geq 0.40$		3.09	2.10	0.91

Table 13.7 Gain or loss in the habitat suitability (km^2) of *Loris lydekkerianus lydekkerianus*, *Loris lydekkerianus malabaricus and Loris lydekkerianus* ssp. *A* under the four IPCC climate scenarios

			2050		2070	
	Habitat suitability class	Current	RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5
Loris lydekkerianus lydekkerianus	Unsuitable habitat	3962855	35409	49256	17418	42183
	Barely suitable habitat	77973	−4075	−11805	−1099	−680
	Suitable habitat	55479	−12198	−9900	−4948	−11310
	Highly suitable habitat	48311	−20950	−22020	−13049	−23058
	Very highly suitable habitat	25082	1814	−5531	1678	−7135
Loris lydekkerianus malabaricus	Unsuitable habitat	4005038	88261	80540	63663	59326
	Barely suitable habitat	77293	−48619	−45454	−38791	−33154
	Suitable habitat	44169	−26626	−24997	−18647	−22603
	Highly suitable habitat	25253	−8991	−8698	−7080	−5601
	Very highly suitable habitat	17947	−4025	−1391	855	2032
Loris lydekkerianus ssp. *A*	Unsuitable habitat	4119575	12145	12638	8996	9699
	Barely suitable habitat	12064	1604	1004	−1758	4800
	Suitable habitat	6646	9984	8262	5097	10961
	Highly suitable habitat	10021	−2677	−1465	5616	−4395
	Very highly suitable habitat	21394	−21056	−20439	−17951	−21065

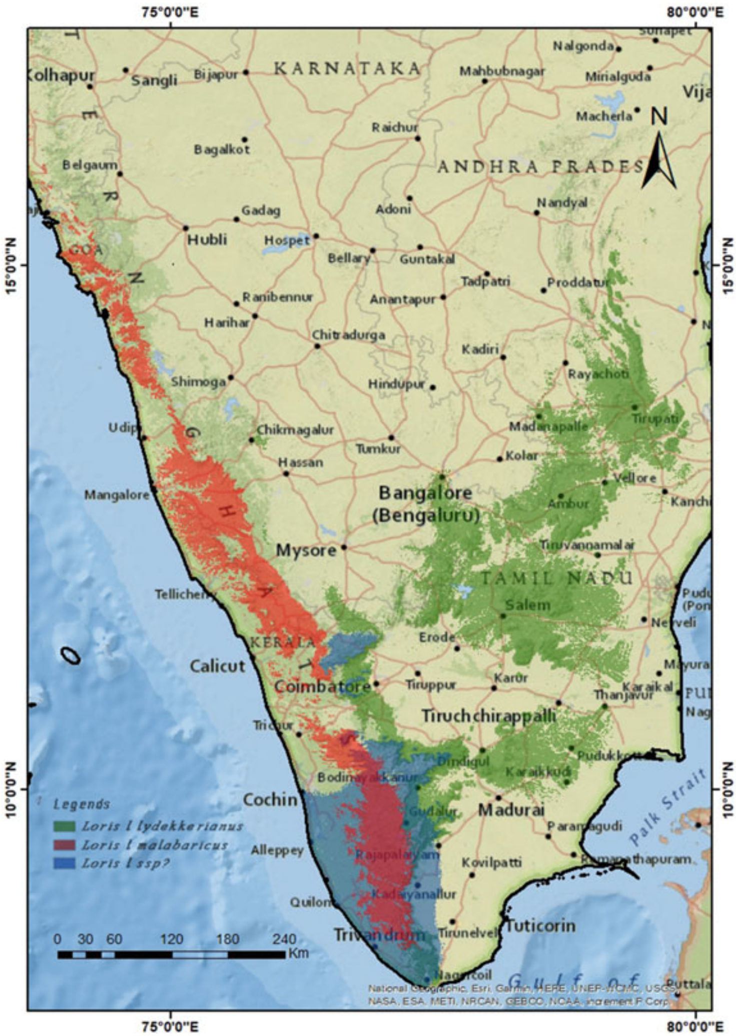

Fig. 13.7b Distribution map showing distinct niches of *Loris lydekkerianus lydekkerianus*, *Loris lydekkerianus malabaricus and Loris lydekkerianus* ssp. *A* superimposed on a base map of peninsular India

13.3.3 Potential Habitat Suitability of *Loris lydekkerianus lydekkerianus, Loris lydekkerianus malabaricus and L. lydekkerianus* ssp. *A* in India Under Current, RCP 4.5 and RCP 8.5, Scenarios

13.3.3.1 Habitat Suitability Under Current Scenario

Suitable habitats (in percentage) for *Loris lydekkerianus lydekkerianus*, *Loris lydekkerianus malabaricus and Loris lydekkerianus* ssp. *A* in India are presented in Table 13.6. It is inferred from the results that only 3.09% for *Loris lydekkerianus lydekkerianus*, 2.1% for *Loris lydekkerianus malabaricus and* 0.91% *Loris lydekkerianus* ssp. *A* of India, respectively, serve as habitats for these species, which is roughly 38,000 km^2 of the total 3.9 million km^2 of India's land area.

Loris lydekkerianus lydekkerianus is restricted within three geographically administrative states of India, which are Andhra Pradesh (AP), Karnataka (KR) and Tamil Nadu (TN). Currently, the species has a habitat of 25,000 km^2, classified as 'very high suitability category' ($p > 0.80$) and ~50,000 km^2 of habitat, classified as 'high suitability category' ($p > 0.60$–0.80). Table 13.7 presents the net gain or loss of habitat presented for each of the 'habitat suitability categories' and climate change scenarios. Positive gains in habitats of 1814 and 1678 km^2 were observed only in RCP 4.5 scenario for the years 2050 and 2070, respectively, for *Loris lydekkerianus lydekkerianus* under very 'high suitability category'. Habitat gains of just 855 and 2032 km^2 were also recorded for RCP 4.5 (2070) and RCP 8.5 (2070) scenarios, respectively, under 'highest suitability category' for *Loris lydekkerianus malabaricus*.

In TN and AP, the current potential distribution is largely restricted to the eastern parts of the EG, specifically within the Cumbum forest range, Lankamalla reserve forest, Turupukonda reserve forest (TRF) and the human-dominated landscape of Tirupati (Fig. 13.7b). The known areas of species occurrence are around the Koundinya Wildlife Sanctuary (WS) and its proximity, areas of which both AP and TN share administrative responsibilities. The model indicates highly suitable habitat for *Loris lydekkerianus lydekkerianus* in the Alankayam and Jawadhu Hills, particularly in Jawadhu Polur RF southwest of Vellore, TN.

Koundinya WS and Jawadhu Hills are discontinuous and the original populations are restricted in Yelagiri and Jawadhu Polur Reserve Forest (RF) in Jawadhu Hills, agricultural areas close to Jawadhu Hills, areas west and northwest of Koundinya WS dominated by humans. Figure 13.7b displays the niches of *Loris lydekkerianus lydekkerianus*, *Loris lydekkerianus malabaricus and Loris lydekkerianus* ssp. *A* superimposed on a base map of peninsular India.

Further in TN, Kalrayan Hill Forest, Jarugumalai RF, Nayinarmalai Forest, Gangavalli RF and Nagoor RF of the EG, predominantly around the southwest of Salem are known habitats, harbouring large numbers of known populations of *Loris lydekkerianus lydekkerianus* (Fig. 13.7b). The maxent model indicates continuous and 'highly suitable habitat' class in the entire hill ranges of the EG around Salem. In Madurai region, the level of fragmentation of the EG is so high that the population have adapted themselves in the human-dominated and agricultural landscape, east and northeast of Madurai (see Fig. 13.7b). The model outcomes show continuous habitat suitability of Sirumalai RF, which is prevalent in the south of Dindigul and Alagar Kovil RF north of Madurai. Unconventional known presence of *Loris lydekkerianus lydekkerianus* was reported in Chennai (Kumara et al. 2016) and rural parts of Bangalore (Kumara et al. 2006; Das et al. 2011). The high ranges of the WG in Tamil Nadu, particularly in Nilgiris, Annamalai Tiger Reserve, eastern edges of Cardamom Hills and Palani Hills serve as habitats for *Loris lydekkerianus lydekkerianus* (Kumara et al. 2016). Srivilliputhur Grizzled Squirrel Wildlife

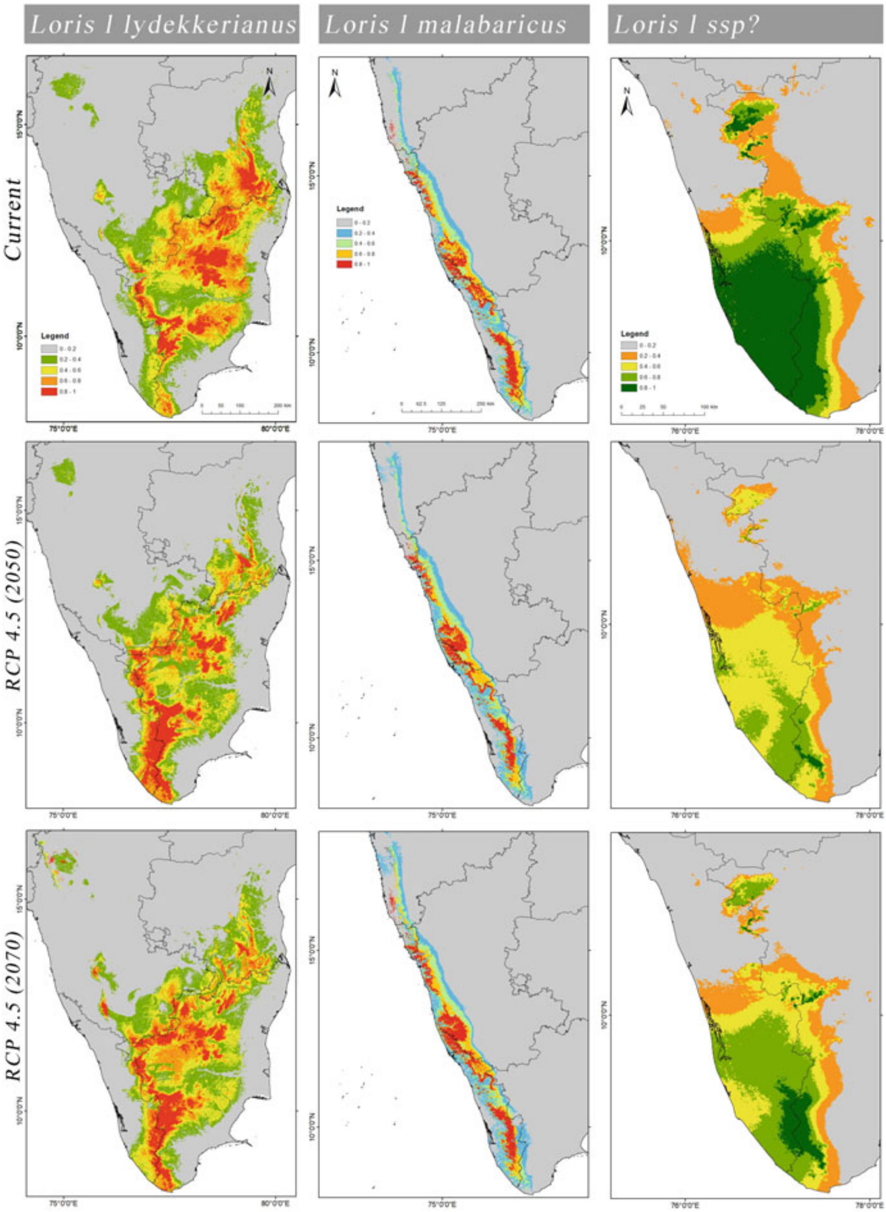

Fig. 13.8a Current and future habitat prediction for *Loris lydekkerianus lydekkerianus*, *Loris lydekkerianus malabaricus and Loris lydekkerianus* ssp. *A* under current, RCP 4.5 (2050) and RCP 4.5 (2070) climate scenario

Loris lydekkerianus lydekkerianus is labelled in green to red colour gradient. Green colour denotes least suitable habitat and red colour denotes highly suitable habitat

Loris lydekkerianus malabaricus is labelled in blue to red colour gradient, with blue colour denoting least suitable habitat and red colour denoting highly suitable habitat

Loris lydekkerianus ssp. *A* is labelled in orange to green gradient, with orange colour denoting least suitable habitat and deep green colour indicating highly suitable habitat

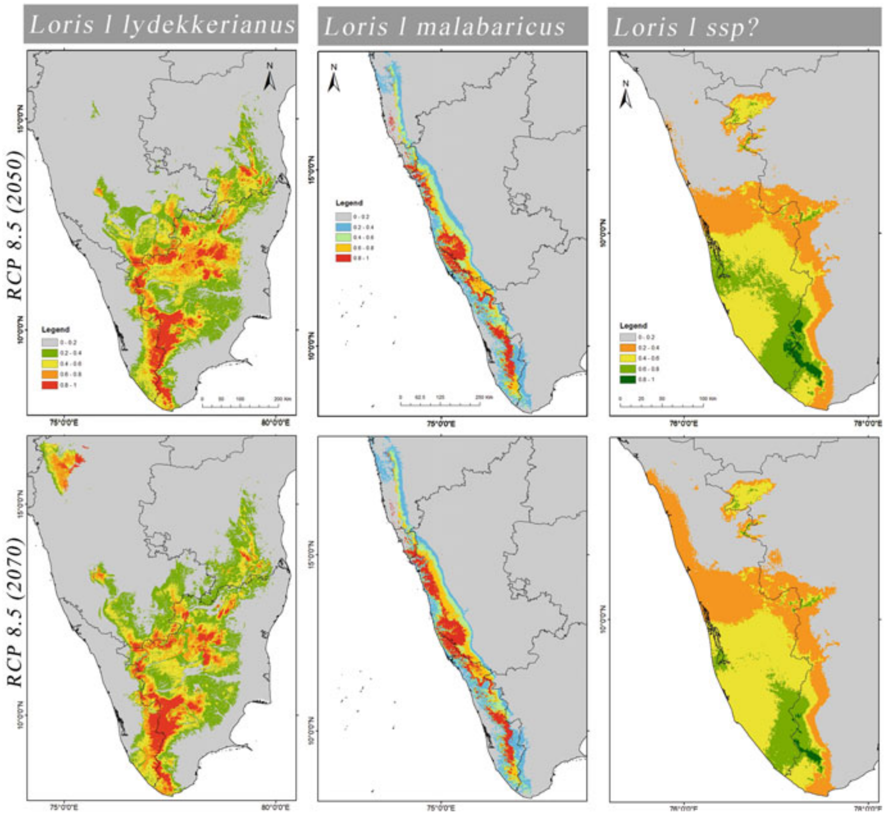

Fig. 13.8b Current and future habitat prediction for *Loris lydekkerianus lydekkerianus*, *Loris lydekkerianus malabaricus and Loris lydekkerianus* ssp. *A* under current, RCP 8.5 (2050) and RCP 8.5 (2070) climate scenarios
Loris lydekkerianus lydekkerianus is labelled in green to red colour gradient. Green colour denotes least suitable habitat and red colour denotes highly suitable habitat
Loris lydekkerianus malabaricus is labelled in blue to red colour gradient, with blue colour denoting least suitable habitat and red colour denoting highly suitable habitat
Loris lydekkerianus ssp. *A* is labelled in orange to green gradient, with orange colour denoting least suitable habitat and deep green colour indicating highly suitable habitat

Sanctuary, Agasthyamalai (TN) and the proximity of Kanyakumari are also potential habitats. In Kerala, *Loris lydekkerianus lydekkerianus* have restricted distribution, with their presence being reported within the narrow gaps of Palghat (Palakkad) and Chinar WS, areas to the south of Anamalai Tiger Reserve, Neyyar WS and southern edges of Agasthyamalai, which receive scanty rainfall and remain dry throughout the year, forming suitable habitats for *Loris lydekkerianus lydekkerianus*.

Loris lydekkerianus malabaricus is prevalent across the western side of the WG, running through Kerala and Karnataka, marginally touching Ooty and Anamalai, extending up to Goa and Maharashtra. Currently, it has 17000 $km^2$of habitats that are classified under 'extremely high suitability' ($p > 0.80$) and 25000 km^2 are classified under 'high suitability' ($p = 0.60$) (Table 13.7). Specifically, in Kerala, the habitat suitability of *Loris lydekkerianus malabaricus* begins from the southern tip of the WG, particularly west of Agasthyamalai Biosphere Reserve, Thenmala RF, Periyar NP, Idamalayar RF, Sholayar RF, Attapadi RF, Pidri RF, Kottiyoor RF and the human-dominated areas west of New Amarambalam WS (Fig. 13.7b). In Karnataka, two major national parks bordering Kerala report no presence nor does the model suggest potential suitable habitat in the future. However, the western rain-fed edges support few populations. A large number of occurrences were reported in Talacauvery National Park and Bisle State Forest, west and northwest of Medikeri (Fig. 13.7b).

Loris lydekkerianus ssp. *A* establishes itself in the intermediate climatic zone, particularly, in the eastern slopes of southern WG. Its suitable habitat lies in the patchy areas of Anamalai Tiger reserve, Idukki WS, Periyar NP and the intermediate forest areas of Tirunelveli and Nagercoil districts of TN (Fig. 13.7b). The maxent model predicts potential habitat in the Nilgiri Region, while similar outcomes were also reported by Kumara et al. (2009).

13.3.3.2 Potential Habitat Suitability for Future Scenarios

Two future scenarios (RCP 4.5 and RCP 8.5) for the two years 2050 and 2070 were modelled for *Loris lydekkerianus lydekkerianus*. A gradual shift in the species distribution range towards the southwestern part of peninsular India and a considerable shrinking of its current habitat are evident. Figures 13.8a and 13.8b present current and future potential habitats for current RCP 4.5 and RCP 8.5 scenarios, for 2050 and 2070.

The two highly probable categories (suitable habitat [0.40–0.60] and highly suitable habitats [0.60–0.80]) are projected to shrink in the following order (current>RCP 4.5[2050]>RCP 4.5[2070]>RCP 8.5[2050]>RCP 8.5(2070)), except for the RCP 4.5 scenario, which predicts an increase in the habitat (~1800 and ~1600 km^2) under 'very highly suitable class' for years 2050 and 2070, respectively (Table 13.7).

It is projected that there would be a potential shift in the habitat for RCP 8.5 scenario from Tirupati, Vellore, Salem and Madurai to the southwest of their current habitat, particularly areas closer to Kodaikanal, Anamalai Tiger Reserve and Periyar NP.

The model predicts that *Loris lydekkerianus malabaricus* on the other hand has better prospects particularly for year 2070, with an increase of its habitat by ~850 km^2 (RCP 4.5) and ~2000 km^2 (RCP 8.5) for the 'very highly suitable habitat' category. However, the other habitat categories would witness a minor shrinking in the southern WGs and shifting in the central WG. The model also predicts that *Loris lydekkerianus* ssp. *A* will lose ~17000 km^2 (RCP 4.5; 2070) and ~21000 km^2 (RCP 4.5; 2050), which totals to nearly 99% of their 'very highly suitable' habitat (Table 13.7). Therefore, *Loris lydekkerianus* ssp. *A* is more vulnerable to climate change than the other two species studied.

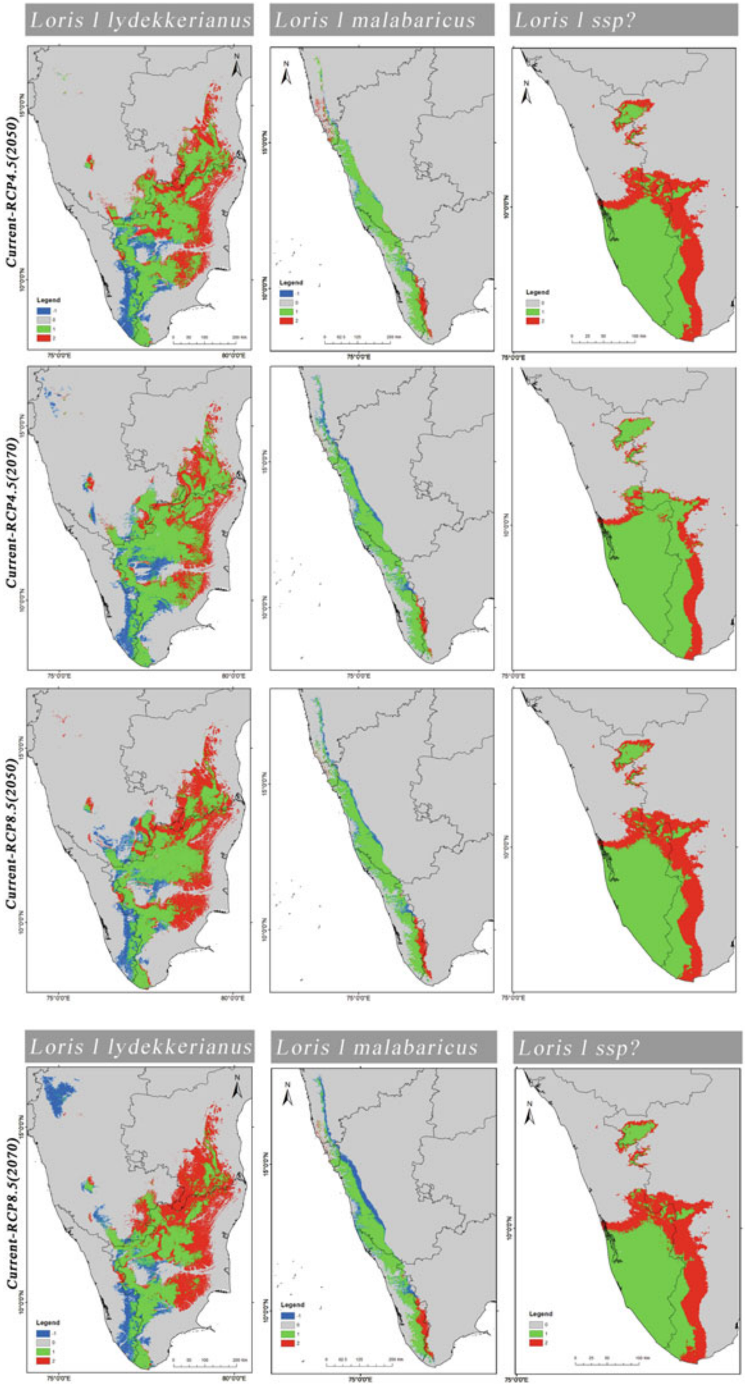

Fig. 13.9 Current and future scenario range shift for *Loris lydekkerianus lydekkerianus*, *Loris lydekkerianus malabaricus and Loris lydekkerianus* ssp. *A*. under current, RCP 4.5 and RCP 8.5 for the years (2050) and 2070. The threshold 'p' was set at 0.4

13.3.3.3 Range Shift of Potential Habitat in Future Scenarios

There are clear indications of a shift in the habitat ranges for *Loris lydekkerianus lydekkerianus*, *Loris lydekkerianus malabaricus and Loris lydekkerianus* ssp. *A* in southern India. The colours red, blue and green in Fig. 13.9 denote 'contraction', 'occupancy' and 'no changes in the habitat range', respectively.

Table 13.6 presents the results of range shift analysis for 2050 and 2070 under the climate scenarios RCP 4.5 and RCP 8.5. It is predicted that the habitats of *Loris lydekkerianus lydekkerianus* would contract by ~40,000 km^2 in the RCP 4.5 (2070) scenario and contract by ~66,000 km^2 in the RCP 8.5 (2070) scenario. It is further predicted that *Loris lydekkerianus* ssp. *A*. would see no expansion of its range for any of the scenarios, *while Loris lydekkerianus malabaricus and Loris lydekkerianus lydekkerianus* would expand their ranges for the RCP 8.5 (2050) RCP 8.5 (2070) scenarios, respectively. The model also predicts that in the year 2070 (for RCP 8.5), the suitable habitat that caters to considerable population of *Loris lydekkerianus lydekkerianus* would be completely lost. Areas around Tirupati, Vellore, Pudukkotai and east of Madurai would also witness contraction in the same period (Fig. 13.9).

The model predicts further that *Loris lydekkerianus malabaricus* would experience range contraction for the RCP 4.5 (2070) and RCP 8.5 (2070) scenarios, which is almost twice the amount of suitable area that would get lost in Periyar NP and the Cardamom hills. However, there would also be an expansion of ~3500 km^2 (RCP 4.5, 2050) and ~17,000 km^2 (RCP 8.5, 2070) into new territory near the Palghat Gap (Fig. 13.9).

There would be no range expansion for *Loris lydekkerianus* ssp. *A* for any of the scenarios studied; however, there would be range contraction in the RCP 8.5 and RCP 4.5 scenarios for the year 2070.

13.4 Discussion

The predictor variables, most relevant in predicting model performance, are presented in Table 13.3. Isothermality is an influential variable that impacts the habitats of *Loris lydekkerianus lydekkerianus, Loris lydekkerianus malabaricus and Loris lydekkerianus* ssp. *A*. This could be due to the innate capacity of the species to respond to small or large fluctuations in temperature. Furthermore, loris are highly sensitive to temperature fluctuations between day and night, relative to oscillation between summer and winter (O'Donnell and Ignizio 2012). The wider the gap in day to night temperatures versus oscillations between winter and summer temperatures, the lower is the species' ability to cope with changes in climate.

The next influential variable is the annual precipitation. As presented in Sect. 13.3.2, *Loris lydekkerianus malabaricus* prefers moist habitats, and therefore, annual precipitation is crucial. However, in comparison, *Loris lydekkerianus lydekkerianus* prefers the rain-shadow areas of peninsular India and habitats that are cold and dry, indicating that 'precipitation of the coldest quarter' and 'precipitation seasonality' are the major ecological variables that determine the habitat of *Loris lydekkerianus lydekkerianus*, *Loris lydekkerianus malabaricus*.

Table 13.8 Range shift analysis of the years 2050 and 2070 for two climate scenarios (RCP 4.5 and RCP 8.5) presenting area change in different climate change scenarios

Value	Area Change(km^2)		2050		2070	
		Current	RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5
Loris lydekkerianus lydekkerianus						
−1	Range expansion		18497	17460	21207	24412
0	No occupancy	4040828	4022331	4023368	4019621	4016416
1	No change	128873	79042	73961	91347	62957
2	Range contraction		49831	54912	37526	65916
Loris lydekkerianus malabaricus						
−1	Range expansion		3467	7860	15789	17107
0	No occupancy	4120237	4116770	4112377	4104448	4103130
1	No change	49464	44260	44423	46708	44090
2	Range contraction		5204	5041	2756	5374
Loris lydekkerianus ssp. *A*						
−1	Range expansion		0	0	0	0
0	No occupancy	4131639	4131639	4131639	4131639	4131639
1	No change	38062	24312	24419	30823	23562
2	Range contraction		13750	13643	7239	14500

The other three key variables, namely (a) variation in the monthly precipitation over a period of one year (Biob15), (b) precipitation in the coldest season (Bio19) and (c) temperature fluctuation during day to night relative to summer to winter (Bio3), determine how *Loris lydekkerianus lydekkerianus* responds to the changes in climate as shown in Figure 13.4. Therefore, the above variables collectively form the third most important ecological variable that influences the habitat of *Loris lydekkerianus lydekkerianus*, *Loris lydekkerianus malabaricus and Loris lydekkerianus* ssp. *A*.

The fourth most important ecological variable that influences the choice of the habitat is that of 'Temperature seasonality', which represents change in temperature over a course of 1 year, confirmed by the Jackknife analysis (Fig. 13.4a–c).

The computer models identify distinct habitats for *Loris lydekkerianus lydekkerianus*, *Loris lydekkerianus malabaricus and Loris lydekkerianus* ssp. *A* (Fig. 13.7a). Furthermore, the model indicates the distinct habitat for *Loris lydekkerianus* ssp. *A* (distributed to only between one and three percentage of the Indian landmass), qualifying them the endemic IUCN status. A similar work by Kumara et al. (2009) using genetic algorithms predicted distinct habitats for *Loris lydekkerianus* ssp. *A*., validating our predictions.

The investigation also confirms the habitat suitability of *Loris lydekkerianus lydekkerianus*, demonstrating a negative trend for almost every habitat suitability class, except for RCP 4.5, which is favourable for both 2050 and 2070 (Table 13.7). This may be because RCP 4.5 is a scenario that signifies stability where the GHG after optimal rise in concentrations will reverse (or stabilize) to present-day concentrations by the end of the twenty-first century (Clarke et al. 2007)

(Fig. 13.6). Thus, the 'stabilizing scenario' may provide a window of opportunity for positive outcomes. Similarly, since *Loris lydekkerianus malabaricus* prefers cool and moist conditions, with the rise in human-induced global warming, there is likelihood of a rise in extreme precipitation in many areas, which may favour expansion of habitat for *Loris lydekkerianus malabaricus*, which is precisely what the model suggests. The model also predicts that *Loris lydekkerianus* ssp. *A* would lose 99% of its habitat by 2050, classified as the 'highly suitable class', which is approximately 25000 km^2 in both RCP 4.5 and RCP 8.5 scenarios, respectively (Table 13.7).

Table 13.6 provides the numerical estimation of change in habitat range and possible direction of the shift in the ranges, which are important for future conservation measures. The study indicates expansion of the ranges for both *Loris lydekkerianus lydekkerianus, and Loris lydekkerianus malabaricus*. Furthermore, it is clear from Figs. 13.7a and 13.7b that *Loris lydekkerianus lydekkerianus* would move southwest towards southern India and in future; it would likely compete for a niche that *Loris lydekkerianus* ssp. *A* currently holds (Table 13.8).

Loris lydekkerianus lydekkerianus is vulnerable in the southern parts of the WG, mainly due to encroachment and expansion of human settlements in eastern part of TN. The model further suggests that RCP 8.5 (2070) climate scenario would likely favour *Loris lydekkerianus malabaricus*, where there is a minor contraction in the habitat range in the southern WG, but a huge expansion in the central and northern WG. Therefore, the suitable habitat of *Loris lydekkerianus lydekkerianus* in the Travancore region is predicted to expand, and the suitable habitat limit of *Loris lydekkerianus malabaricus* is shifting towards the foothills of the WG (Figs. 13.7a and 13.7b).

13.5 Conclusion

Apart from the long-term threat to their existence due to climate change, loss of habitat, loss of forest cover due to human-influenced pressures, hunting of the species for use as a medicinal resource, hunting of the species for black magic practice common in some parts of the WG, death due to road accidents and electrocution are some of the major reasons for their dwindling numbers (Nekaris and Jayewardene 2004; Kumara et al. 2009).

The following conservation strategies are recommended: (1) Maintain continuous vegetation in and around the current distribution area, as has been suggested in the past (Singh et al. 1999). (2) Promote the growth of tall trees such as tamarind and native species along the roads and highways to ensure safe and continuous corridor for the species to assist in nocturnal foraging. It has been identified in the past that loris species do not leap branches, and therefore, trees such as tamarind and mango offer greater density of insects for these insectivorous species. (Singh et al. 2000). (3) Educate the public and the native people on ecological importance of these species, which will help prevent hunting and killing. (4) Educate the public about the mating calls of *Loris sp*. This is because, along with the mating calls, their large reflective eyes and mournful cry are perceived to bring misfortune, resulting in these species often being killed (Lewis 1917). (5) Due to their small size, this species are often not visible, especially during night, when they are run over by automobiles (Singh et al. 2000), and therefore, putting cautionary sign boards along roads, particularly in their habitat, could help maintain their population. (6) Plantation of trees around cultivable land to maintain forest continuity and gene flow (Singh et al. 1999). Isolation of populations into smaller breeding units may result in genetic drift, leading to population exclusion. Maintaining gene flow is an important conservation strategy to ensure habitat suitability, especially in response to climate change. (7) These species does not feed on cultivable products (Singh et al. 1999); therefore, there is less scope of human-species conflict; however, domesticated dogs and cats are a threat (Nekaris and Jayewardene 2004). (8) Overhead live wiring has been one of the major reasons for their death, and there are frequent reports of electrocution (Nekaris and Jayewardene 2004). If the distance between two live wires is kept greater than the maximum body size of these species, mishaps could potentially be greatly reduced. (9) Contrary to the general understanding, there is at least one report that argues that protected areas, reserve planning or expansion of current reserve do not offer much protection to these species (Voskamp et al. 2014). However, since the majority of the sighted specimens are located outside the protected areas, we believe all efforts must be taken to create protected areas and plan for new reserves because along with the extended 'protected areas', the combined effects of ecological benefits of better niche, larger area, reduced conflicts, cleaner environment, conserved gene flow and enhanced habitat suitability will all help these species to better survive the threats of climate change and human development.

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Climate Change, Air Pollution, and Sustainable Development Goal 3: An Indian Perspective

14

Urvashi Prasad and Shashvat Singh

Abstract

Climate change and air pollution are caused by a range of natural phenomena. The situation is further compounded by human beings who are leading increasingly resource-intensive lifestyles. Climate change is a major threat to public health. Our health systems are already under pressure, and they are being further crippled by a rise in the incidence of heat waves, floods, droughts, and other vagaries of nature. It is the poor and developing countries that are bearing the highest brunt of climate change. According to some estimates, 22 of the 30 most polluted cities in the world are in India. The health consequences of this are already proving to be lethal, with the State of Global Air Report, 2019 highlighting that over 1.2 million deaths took place in India in 2017 due to air pollution on account of conditions such as stroke, heart disease, and lung cancer. In fact, the Global Burden of Disease Study, 2017, shows that "India accounts for a higher proportion of global health loss owing to air pollution as compared to the country's proportion of the worldwide population."

In the recent past, the severity of the situation and therefore the need for urgent measures have gained traction within the political and policy spheres in the country. In this chapter, we review the global best practices along with their applicability to the Indian context, as well as initiatives that have been taken in India with respect to mitigating climate change and air pollution. Based on this, we also make recommendations for tackling this growing public health emergency and protecting the well-being of the current and future generations. Of

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course, government alone cannot achieve this; hence, we also suggest steps that need to be taken by the private sector and citizens.

Keywords

Climate change · Air pollution · Clean energy · Sustainable environment · Global warming · Public health

14.1 Introduction

Climate change and air pollution are caused by a range of natural phenomena, including, but not limited to, volcanic eruptions and dust storms. The situation is further compounded by human beings who are leading increasingly resource-intensive lifestyles. This means that we are producing and consuming more, thereby generating more greenhouses gases, particulate matter, and chemicals that pollute the air. A report published by 90 scientists from across 40 countries warns that lack of urgent and concerted action could result in climate change with catastrophic consequences over the next 20 years (Schlanger 2019).

Climate change is a major threat to public health. Our health systems are already under pressure, and they are being further crippled by a rise in the incidence of heat waves, floods, droughts, and other vagaries of nature. It is the poor and developing countries that are bearing the highest brunt of climate change. Within these countries, the poor, whose number far exceeds the prosperous class, are the worst affected. Thus, the externalities arising from the actions of rich and industrialized countries are being borne by their poorer counterparts. For instance, while the carbon footprint of the poorest billion people in the world is only 3%, the consequences of climate change are borne disproportionately by them. In the year 2000, 75% of the 5.5 million disability-adjusted life years lost were in Africa and Southeast Asia.

Climate change has the potential to raise the temperature of oceans as well as the air. A rising sea level can result in coastal flooding, ultimately causing severe loss of life and money, besides triggering large-scale migration to other areas. Rising temperatures and changing rainfall patterns could lead to a decline in crop yields (Venkatramanan et al. 2020a, b). This may cause severe shortage of resources vital for survival, further denting population health.

Climate change–induced health impact can be classified as extreme weather-related health effects, air pollution–related health effects, water- and food-borne diseases, vector-borne diseases, effect of food and water shortages, psychosocial impact on displaced populations, as well as the health impact of conflicts that take place over access to vital resources.

One of the areas which can be adversely impacted by climate change is mental health. Obradovich et al. (2018) reported that climate change can cause a serious and large-scale deterioration of mental health. Further, it was stated that for every 1 °C increase in temperature over a 5-year period, mental health issues increased by 2%. In places where the average temperature already ranges between 25 °C and 30 °C, a shift in the temperature to just over 30 °C can add 0.5% to the population's mental health burden.

Further, climate change is bound to have a serious impact on labor productivity with the inequality between low- and high-income countries deepening and those who are most vulnerable experiencing worsening working conditions. Informal workers, who constitute 90% of all workers in India, Bangladesh, Cambodia, and Nepal, are likely to be especially badly impacted. Moreover, those in older age groups, who represent an increasing share of workers in India, will also be hit hard, owing to lower physiological resistance to high levels of heat. In fact, studies have estimated that substantial national-level gross domestic product (GDP) losses can occur in 2030 due to heat stress, with Thailand, Cambodia, India, and Pakistan experiencing reductions in GDP of more than 5% each.

According to the World Health Organisation (WHO), nine out of ten people worldwide today breathe air, which is unsafe. While there are many pollutants which degrade air quality, the most common indicator for air pollution is PM2.5 (tiny particulates smaller than 2.5 microns which penetrate the lungs), which is generally used as an overall measure of air quality (Makkar and Singh 2019).

Household air pollution[1] results largely from the ignition of domestic solid fuels for cooking and to a lesser extent due to heating of wood, dung, agricultural remains, coal, and charcoal. When volatile organic compounds emitted from vehicles, power plants, and factories react with nitrogen oxides in the presence of sunlight, ground-level ambient ozone is produced (Balakrishnan et al. 2019). Solid wastes are another significant contributor to air pollution through incineration because plastics tend to produce toxic substances, such as dioxins, when they are burned. It is estimated that 11.2 billion tons of solid waste is collected worldwide every year. The decay of the organic portion of solid waste contributes roughly about 5% of global greenhouse gas (GHG) emissions.

An estimated one-third of deaths globally from stroke, lung cancer, and heart disease are caused by air pollution. Toxic air has now also been linked to dementia, Alzheimer's disease, and declining mental health.[2] Every year, globally, more people die from air pollution–related diseases as compared to road traffic injuries or malaria. This adds up to seven million deaths annually with welfare losses to the tune of INR 5.11 trillion. Household air pollution is responsible for 3.8 million deaths annually, accounting for nearly 8% of deaths worldwide. Nearly all of these deaths occur in low- and middle-income countries (LMICs), with non-communicable diseases being the leading cause of death. It is believed that phasing out the use of fossil fuels could prevent more than three million premature deaths annually worldwide.

[1]Household air pollution—the world's leading environmental health risk. (2020). In: World Health Organization. Retrieved from https://www.who.int/airpollution/household/about/en/. Accessed 1 Jan 2020.

[2]Air pollution. (2020) In: Who.int. Retrieved from https://www.who.int/airpollution/en/. Accessed 1 Jan 2020.

To mitigate the impact of climate change on human health, it is important to create a strong health system, as well as robust service delivery mechanism through timely disease surveillance and control. The health insurance system also needs to be strengthened, in addition to increasing investment in research and development, health risk assessment, and vulnerability mapping studies.

14.2 Indian Scenario

Over the last century, India has contributed only 2% to the total fossil fuel carbon emissions; however, the country is grappling disproportionately with the consequences of extreme weather conditions arising due to such emissions.

Rapidly developing countries, like India, are faced with the dual challenge of being exposed to both ambient and household air pollution. India, unfortunately, has one of the highest exposure levels to air pollution, which comprises primarily of polluted ambient particulate matter and indoor air.[3] Most places in the country exceed the WHO-defined safe air quality standards multiple times over. Nearly half of the 50 worst polluted cities in the world, and 22 of the top 30, are in India (Griffiths 2019). In fact, the Global Burden of Disease Study, 2017, shows that that India accounts for a higher proportion of global health loss, owing to air pollution as compared to the country's proportion of the worldwide population (Balakrishnan et al. 2019). The major originators of ambient particulate matter pollution in India are emissions from coal-fired thermal power plants, industry, brick kilns, vehicles, diesel generators, as well as burning of biomass, waste, and agricultural stubble, along with construction activity and road dust.

As per the India State-level Disease Burden Initiative Report,[4] air pollution was at the second position among all risk factors that contributed to the country's disease burden in 2016. The Study also indicated that exposure to ambient particulate matter pollution is on the rise, while household pollution is declining. Of course, there is considerable interstate variability in India, with respect to exposure to ambient particulate matter and household air pollution. This emphasizes the need to take heterogeneity into consideration while designing policies and interventions for controlling air pollution in the country.

It has been reported that exposure to outdoor and indoor air pollution contributed to over 1.2 million deaths in India in 2017.[5] In fact, India accounts for 25% of global mortality on account of air pollution, with more than two million premature deaths.

[3]Ministry of Finance (2019) Economic Survey 2018–19 (Volume 2). Government of India, New Delhi.

[4]The India State-Level Disease Burden Initiative. (2017). Public Health Foundation of India. In: Phfi.org. Retrieved from https://phfi.org/the-work/research/the-india-state-level-disease-burden-initiative/. Accessed 1 Jan 2020.

[5]Air pollution kills 1.2 million Indians in a year, third biggest cause of death. (2019. April 3). In: Business-standard.com. Retrieved from https://www.business-standard.com/article/current-affairs/

Cardiovascular ailments and diabetes constitute around 40% of diseases caused by air pollution, in addition to lung cancer and chronic obstructive pulmonary disease. In fact, health gains made as a result of lower tobacco usage among the population can be significantly dented if air pollution and other negative environmental conditions are not checked.

An analysis by Brookings Institute also highlighted the deleterious impact of air pollution on children's health (Singh et al. 2019). It showed that exposure to air pollution during the first trimester of pregnancy contributes adversely to both underweight and stunting for children under 5 years of age, especially those belonging to poorer households and living in north India.

Global warming is another key challenge. An International Labour Organization Study,[6] projects that India is set to lose 5.8% of working hours in 2030, owing to global warming. Heat stress generally occurs in places with high humidity, coupled with temperatures over 35 °C. Those working outside are its worst victims and are highly prone to fatal heat strokes.

It is also estimated that heat stress could amount to a productivity loss[7] equivalent to 34 million full-time jobs in the country. Agricultural and construction sectors are likely to be especially impacted, affecting both male and female workers.

Every year, there is news of heat waves engulfing one or the other part of the country. As a consequence, deaths take place by the hundreds, hospitals get stretched beyond their capacity, educational institutions remain closed, construction activities halt, and people start migrating.

Estimates suggest that more than 6000 people have died since 2010 due to heat waves (Williams and Viswanath 2019). The situation is only going to worsen in the times to come, owing to a rise in global temperatures on account of human-induced changes in climatic conditions. Experts have predicted that by the end of this century, parts of South Asia could be so hot and humid that people may not be able to remain outdoor for more than 6 h.

In India, researchers have found that the number of suicides increases when crops are damaged during the growing season due to heat. In fact, beyond 20 °C, every degree rise in temperature per day correlates with around 70 more people killing themselves.[8] Such a trend could lead to an estimated 59,300 suicides in India over a period of 30 years.

air-pollution-kills-1-2-mn-indians-in-a-year-third-biggest-cause-of-death-119040300300_1.html. Accessed 1 Jan 2020.

[6]International Labour Organization (2019) Working on a warmer planet: The impact of heat stress on labour productivity and decent work. International Labour Organization, Geneva.

[7]India could lose the equivalent of 34 million jobs in 2030 due to global warming, says ILO. (2019, July 02). Retrieved from https://www.thehindubusinessline.com/news/india-could-lose-the-equivalent-of-34-million-jobs-in-2030-due-to-global-warming-says-ilo/article28259436.ece. Accessed 1 Jan 2020.

[8]Suicide data. (2020). In: World Health Organization. Retrieved from https://www.who.int/mental_health/prevention/suicide/suicideprevent/en/. Accessed 1 Jan 2020.

Further, coastal flooding due to rising sea levels is expected to impact tens of millions of Indians. Farmer incomes may be hit to the tune of 15–18%, owing to the changing agricultural productivity patterns. Acute water scarcity is also knocking at India's doors, with the demand for water expected to exceed supply by 2020. India's poor, who already face disproportionate barriers in accessing these critical resources, will be worst affected by such shortages.

Climate change is a crisis for public health, as it impacts just about everything, right from the nutritional content of our food to the strength of our immune system. Unfortunately, the world's richest nations are the biggest contributors to this problem, while their poorer counterparts are the most vulnerable.

India has witnessed several positive developments on the public health front over the previous decade, including a steady decline in mortality rate as well as improvements in the sex ratio, food security, nutritional status of the population, and average life expectancy. While climate change poses a formidable challenge and has the potential to halt this upward trajectory, it also presents an opportunity to mitigate and prevent the negative consequences by taking action in a timely manner. In fact, the WHO has highlighted that India could gain health benefits to the tune of INR 3.28–8.4 trillion if it can contain global warming and limit increase in temperature to 1.5 °C by the end of the century.

14.3 Global Cooperation Is a Must

The Sustainable Development Goals (SDGs) encompass a broad range of interconnected issues, including economic growth, social challenges, and global public goods. In order to realize such an ambitious vision, an equally robust financing plan is required. Globally, United Nations Conference on Trade and Development (UNCTAD) estimates suggest that investment to the tune of USD 5–7 trillion per annum will be required for achieving the SDGs (Kituyi 2015). The total investment requirements for developing countries are estimated to be approximately USD 3.9 trillion every year, primarily in the areas of health, education, food security, basic services, and mitigation of climate change impact.

For India, some estimates[9] suggest that there is a shortfall of USD 8.5 trillion over the 15-year period for accomplishing the SDGs. On an annual basis, this works out to approximately USD 565 billion, which is equivalent to nearly 25% of India's GDP in 2014–2015.

While domestic budget resources will assume greater importance[10] as compared to international public finance, Official Development Assistance (ODA) will also

[9]International Solar Energy Alliance Launched at COP21. (2015, Nov. 30) UNFCCC. Retrieved from https://unfccc.int/news/international-solar-energy-alliance-launched-at-cop21. Accessed 2 Jan 2020.

[10]United Nations Environment Programme (2016) Delivering a Sustainable Financial System in India. United Nations Environment Programme.

play an important role. High-income nations that are a part of the Development Assistance Committee (DAC) need to honor their commitments of providing 0.7% of Gross National Income as ODA.[11] ODA assumes special significance for financing of global public goods like mitigation of climate change. At the 21st Conference of the Parties of the United Nations (UN) Framework Convention on Climate Change, developed nations made a commitment to mobilizing additional resources in the range of USD 100 billion annually by 2020 through the Green Climate Fund for addressing the needs of developing countries (Brittlebank 2016).

However, countries often fall short of the 0.7% ODA target. Thus, it is imperative to ensure greater transparency and explicitly define what constitutes aid. In the absence of this, a substantive part of ODA is often double counted as climate finance, thereby contradicting the spirit of the Cancun agreement. Robust mechanisms for monitoring the aid commitments of donor countries are critical.

Signed by 32 nations in the pan-European region, the United Nations Economic Commission for Europe (UNECE) Convention on Long-Range Transboundary Air Pollution[12] was the first international treaty to address the issue of air pollution at a broad regional level. The Convention which came into effect in 1983 established the general principles for international cooperation to reduce air pollution and put in place an institutional framework, which has subsequently laid emphasis on policy and research. Over time, the scope of the Convention and its protocols has been expanded to also include organic pollutants, heavy metals, ozone at the ground level, and particulate matter. The Convention's activities are supported by a number of intergovernmental bodies, scientific centers, and research groups. One of the major achievements has been its contribution to the establishment of a general framework for international environmental law. Emission of harmful substances has been reduced by 40–80% since 1990 in Europe. Similarly, sulfur emissions in the region are close to 20% of their 1990 levels. Nitrogen emissions too have been reduced, albeit to a lesser extent as compared to sulfur emissions.

More recently, over 190 countries came together in 2015 to approve the Paris Agreement at the 21st session of the Conference of the Parties (COP21) to the United Nations Framework Convention on Climate Change (UNFCCC) for addressing the challenge of climate change (Rastogi 2019). As part of this Agreement, all countries committed to working toward limiting global temperature rise to below 2 °C. In fact, it states that best efforts should be made by all to ensure that global temperature does not increase beyond 1.5 °C to enable the accomplishment of the Sustainable Development Goals. If the goals of the Paris Agreement are met, at least a million lives

[11]ODA is defined as government aid designed to promote the economic development and welfare of developing countries. Aid may be provided bilaterally, from donor to recipient, or channeled through a multilateral development agency. Aid includes grants, "soft" loans (where the grant element is at least 25% of the total) and provision of technical assistance.

[12]The Convention and its achievements. A common framework for transboundary cooperation on air pollution. (2020). Retrieved from https://www.unece.org/environmental-policy/conventions/envlrtapwelcome/the-air-convention-and-its-protocols/the-convention-and-its-achievements.html. Accessed 2 Jan 2020.

could be saved across the world on account of the consequent reduction in air pollution.

The WHO also launched an initiative in 2017 on Climate Change and Health in Small Island Developing States. Though these countries make a minimal contribution to the problem, they are among the most vulnerable to the consequences of climate change.

India too has pledged for global cooperation on climate change through the Paris Agreement. It is worrying that carbon emissions, which are a key contributor to global warming, are increasing at a faster pace in India compared to other countries. Recognizing the seriousness of the situation, the government has put in place ambitious targets such as installing 175 GW of renewable energy by 2022. By 2030, the country is committed to cutting its emission intensity of GDP by 33–35% of the 2005 levels. The country is also committed to securing 40% of its total electricity capacity from nonfossil fuel-based energy sources. Further, India intends to create an additional sink of 2.5–3 billion tonnes of carbon dioxide through additional forests by 2030.

14.4 Promoting Clean Energy and a Sustainable Environment in India: Current Initiatives and Way Forward

At the highest political level, India's prime minister has stated that failing to act in a concerted manner on curbing climate change would amount to no less than an "immoral and criminal act." The Indian government recognizes that multi-sectoral efforts pertaining to power production, industry, transport, city planning, construction, and agriculture need to be made for mitigating the impact of climate change. In the "Strategy for New India @ 75[13]" released by National Institution for Transforming India (NITI) Aayog in 2018, several suggestions have been included for tackling the issue of pollution comprehensively. Some of the key recommendations include expeditious implementation of the recommendations of the Task Force on Biomass Management, constituted by NITI Aayog under the "Cleaner Air, Better Life" initiative; creation of a "Clean Air Impact Fund" to provide viability gap funding for projects with long gestation periods and low returns on investment such as bio-power or bioethanol projects; effective implementation of the Solid Waste Management Rules, 2016, which have significantly expanded the scope of efficient solid waste management in the country; continued efforts to switch households from the use of solid biomass to cleaner modes of cooking through the provision of liquified petroleum gas (LPG) connections under the *Pradhan Mantri Ujjwala Yojana*; expedited use of biodigester toilets, a technology licensed by the Defence Research and Development Organization for nationwide implementation;

[13]National Institution for Transforming India (NITI) Aayog (2018) Strategy for New India @ 75. Government of India, New Delhi.

as well as prioritization of large-scale and sustained behavior change campaigns for citizens.

To tackle the challenge of air pollution across the country in a comprehensive manner, the government has launched a number of initiatives. The National Air Quality Monitoring Programme (NAMP), for instance, covers 312 cities/towns in 29 states and 6 union territories across the country. Four major types of air pollutants, that is. sulfur dioxide (SO_2), oxides of nitrogen as NO_2, suspended particulate matter (PM10), and fine particulate matter (PM2.5) are being monitored regularly under the NAMP. Smaller PM2.5 is particularly deadly, as it can penetrate deeper into the lungs.

National Ambient Air Quality Standards (NAAQS) have been developed for ambient air quality with reference to various identified pollutants, notified by the Central Pollution Control Board (CPCB) under the Air (Prevention and Control of Pollution) Act, 1981. A key objective of NAAQS is (a) "to indicate the necessary air quality level as well as the appropriate margins required for ensuring the protection of vegetation, health and property" and (b) to provide a uniform yardstick for assessment of air quality at the national level. The Air Quality Index (AQI) is a mechanism for effectively communicating information about air quality to citizens in an easily understandable manner. This is possible because the index converts complicated air quality metrics pertaining to numerous pollutants into a single number (the index value).

The National Clean Air Programme[14] (NCAP) is a 5-year plan with 2019 as its first year. It will be institutionalized by ministries with oversight provided by inter-sectoral groups, comprising Ministry of Petroleum and Natural Gas, Ministry of New and Renewable Energy, Ministry of Road Transport and Highways, Ministry of Health, Ministry of Housing and Urban Affairs, Ministry of Agriculture, Ministry of Heavy Industry, NITI Aayog, CPCB, as well as experts from industry, academia, and civil society. NCAP aims to prevent and control air pollution alongside enhancing the monitoring network for air quality across India. The overall objective of NCAP is prevention, control, and abatement of air pollution, besides augmenting the air quality monitoring network across the country. The tentative national level target of a 20–30% reduction in PM2.5 and PM10 concentration by 2024 is proposed under the NCAP with 2017 as the base year for comparison of concentration. City-specific plans will be formulated for 102 non-attainment cities—where the prescribed National Ambient Air Quality Standards (NAAQS) are violated.

In addition, the Program will focus on channelizing technological support, setting up certification agencies for monitoring equipment, and catalyzing greater awareness among citizens. The number of ambient air quality monitoring stations has been increased across India over the last few years. The National Clean Air Programme proposes to establish monitoring stations in rural areas and increase their presence

[14]Government launches National Clean Air Programme (NCAP). (2019, Jan 10). In: Pib.nic.in. Retrieved from http://pib.nic.in/newsite/PrintRelease.aspx?relid=187400. Accessed 2 Jan 2020.

nationwide for measuring PM2.5 levels. It is also important to create a data system for assessing India's exposure to ozone.

The CPCB has issued a detailed set of directions under section 18 (1) (b) of the Air (Prevention and Control of Pollution) Act, 1986, for implementing 42 measures that can reduce air pollution in key cities, including Delhi and the National Capital Region (NCR). Some of the critical action points include controlling and mitigating vehicular emissions, industrial pollution, biomass/municipal solid waste burning, and construction activities, among other steps.

A Graded Response Action Plan for Delhi and NCR has also been notified by the government for tackling every source of pollution as per the categories of the AQI. The Action Plan also notes the health advisory in broad terms for every level of the AQI adopted by the Indian government.

Ambient particulate matter pollution could be controlled greatly if relevant action is taken across sectors, and the necessary linkages are established. For instance, the Ministry of Power is making efforts to reduce particulate matter emissions by coal power plants and lower energy consumption for industrial purposes. The Ministry of Environment, Forests, and Climate Change has set emission standards for the brick-making industry and is facilitating agricultural residue management to prevent stubble burning. The Ministries of Road Transport and Highways, as well as Petroleum and Natural Gas, have put in place stringent regulations pertaining to vehicle emissions and the requirement for vehicle upgradation to more fuel-efficient standards. The Ministry of Housing and Urban Affairs is taking steps to enhance the availability of public transport.

The government has also accelerated the adoption of Bharat VI emission standards. The deadline for automakers for adoption is April, 2020. With the norms becoming considerably tighter, PM levels in diesel cars can be brought down by up to 80%. By 2030, India plans to shift to selling only electric vehicles.[15]

Further, states and union territories are taking steps to improve the quality of the environment in general, and air in particular. At least 32 states/UTs have also prepared State Action Plans on Climate Change consistent with the objectives of the National Action Plan on Climate Change. The Plan will, however, need to specify targets for different sectors and put in place the necessary mechanisms for enforcing implementation (Abi-Habib and Kumar 2019).

Delhi, for instance, has mandated the use of compressed natural gas in vehicles; Punjab provides subsidies for using alternative technologies that prevent stubble burning and Maharashtra necessitates compulsory usage of fly ash in constructions within a 100-km radius of coal and lignite thermal plants. Other states and union territories can also incorporate such provisions in their policies to effectively control

[15] A total of 2500 government buildings to be fitted with super-efficient ACs for the first time in the country. (2018, Jan 24). In: Business Standard. Retrieved from https://www.business-standard.com/article/government-press-release/2500-government-buildings-to-be-fitted-with-super-efficient-acs-for-118012301313_1.html

particulate matter emissions. Other efforts include electrification of public transportation and upgradation of vehicles to Bharat Stage-VI emission standards.

The Gujarat government has introduced an emissions-trading scheme aimed at reducing particulate air pollution. Emissions have been capped by the government, and industries are allowed to buy and sell permits for staying below the cap. This is a pioneering market-based approach to regulation of emissions in India. It is expected that such an approach can lower air pollution at reduced costs for the government as well as industry. It can also serve as a best practice for replication of trading schemes to other emissions (Sharma 2019).

In Delhi, construction activities were halted for a fixed period of time in November 2018, for checking smog. For reducing vehicular traffic and associated pollution, the Delhi government has implemented the odd-even road-rationing scheme. Under the scheme, cars with license plates ending with an odd or even digit are allowed to ply on the roads on alternate days, with certain exemptions. The aim is to reduce vehicular traffic by half and check emissions. Further, the Delhi government tested an "anti-smog" gun in one part of the city in 2017, which sprays water into the air, in order to bring down pollution levels (Thakur 2017). Such measures, of course, can, at best, be short term, implemented for defined periods of time to bring down prevailing high levels of pollution. Certain longer-term and more sustainable efforts are also underway. For instance, the Badarpur Thermal Power Plant, which was considered a major source of air pollution in Delhi, has been permanently shut down. By the end of 2002, the city had replaced all its diesel buses with those using compressed natural gas (CNG), making it among the cleanest public-transport systems in the world (Jain 2016). Delhi is now in the process of adding electric buses to its fleet.[16] Moreover, following an order of the National Green Tribunal, all petrol vehicles older than 15 years and diesel vehicles older than 10 years have been banned from operating in the NCR area.[17] Similarly, in Pune, vehicles older than 12 years have been banned from plying on the roads (Dharwadkar 2018). Additionally, a subsidy of around INR 12,000 is provided to autorickshaws for switching to CNG. Over 18 projects of bio-methanization have been launched in Pune, and efforts are being made to substitute diesel generators with solar generators.

Alappuzha in Kerala was recognized by the United Nations Environment Programme (UNEP) as one of the five cities in the world, making strides toward reducing pollution through sustainable solid waste management practices. Since November 2012, the city has implemented the *Nirmala Bhavanam Nirmala Nagaram* (Clean Homes Clean City) initiative. It has also adopted the practice of decentralized waste management and is now on the path toward ensuring 100%

[16]Delhi government adds 1000 electric buses to its public transport fleet. (2019, March 2). In: Businesstoday.in. Retrieved from https://www.businesstoday.in/top-story/delhi-government-adds-1000-electric-buses-to-its-public-transport-fleet/story/323911.html. Accessed 8 Jan 2020.

[17]Supreme Court imposes ban on old petrol, diesel vehicles in Delhi. (2018, Oct 30). In: Livemint. Retrieved from https://www.livemint.com/Politics/WyuoVB1IM65ELIKWs2TYBL/Govt-may-stop-private-vehicles-in-Delhi-if-pollution-worsens.html. Accessed 8 Jan 2020.

segregation across all 23 wards in the city. Biodegradable waste is separated at the ward level and treated in small composting plants, providing over 174,000 residents with biogas for cooking purposes. As many as 80% of households in the city now have biogas plants and a decentralized composting system (Agarwal 2017).

Though severe ambient particulate matter pollution in north India during the winter season in particular and its immediate impact on health have attracted considerable attention from the public and media, what is needed now is to raise awareness about the adverse long-term and chronic health impact of high pollution levels throughout the year. There is a shortage of long-term studies that evaluate the ill effects of air pollution on health in the country. Thus, another focus area should be building the evidence base around health loss caused by air pollution. Findings from such a data system will help policymakers, in particular, to ascertain the states where the situation is more alarming, thereby paving the way for state-specific solutions to be devised.

To tackle indoor air pollution, Government of India has launched the *Pradhan Mantri Ujjwala Yojana* in May 2016 with the objective of providing liquefied petroleum gas to low-income households. More than 80 million LPG cylinders have been distributed to poor households under the scheme (Dutta 2019). LPG is a cleaner source of energy compared to solid fuels like wood and dung. The scheme provides financial support of INR 1600 each to eligible below poverty line (BPL) households for LPG connections. The connections are registered in the name of the female head of the household (Mhamia 2016). Use of LPG as household fuel goes a long way in curbing air pollution, besides helping to achieve the WHO-recommended air quality norms for within the home. The focus of the scheme should now shift to ensuring sustained usage of LPG. Targeted and innovative subsidies could help in achieving this objective. Another important scheme is *UJALA* under which more than 300 million LED bulbs have been distributed, and more than 7 million LED streetlights have been installed.[18]

Another important policy initiative is the launch of the Green Highways Policy[19] by the Ministry of Road Transport and Highways in 2015. The objective of the Policy is “to promote the greening of highway corridors with participation from all stakeholders including farmers, private sector, NGOs, and government institutions.” A strong monitoring mechanism is in place through the Indian Space Research Organisation (ISRO’s) Bhuvan and GPS-aided Geo-augmented navigation (GAGAN) satellite systems. It has also ensured that regular auditing of every planted tree is carried out. If successful, the initiative is expected to bridge the gap between the current status and the goal of having at least 33% forest and tree cover as per the National Forest Policy.

[18]PIB (2018, Dec 12). Year End Review 2018- Ministry of Power. In: Pib.nic.in. Retrieved from http://pib.nic.in/PressReleseDetail.aspx?PRID=1555605. Accessed 8 Jan 2020.

[19]Shri Nitin Gadkari launches Green Highways Policy. (2015, Sept 29). In: Pib.nic.in. Retrieved from http://pib.nic.in/newsite/PrintRelease.aspx?relid=128298. Accessed 8 Jan 2020.

The Bureau of Energy Efficiency (BEE)[20] was set up under the Energy Conservation Act, 2001. It coordinates among the government, industries, manufacturers, and consumers to facilitate energy conservation. The Bureau also sets performance standards for appliances and designs labeling schemes for the same. The star rating of various appliances, including air-conditioners, refrigerators, fans, pumps, and water heaters falls within its mandate. Additionally, BEE organizes training sessions for people who implement energy efficiency projects. It also develops certification procedures along with promoting testing facilities, as well as innovative financing of energy efficiency projects.

To deal with the challenge of heat stress, Ahmedabad, in its 2017 Heat Action Plan, incorporated a cool roofs initiative as part of which the city's poor and slum residents were provided cool roofs at affordable rates. The initiative aimed to ensure that at least 500 slum dwellings have cool roofs along with improving the reflectivity of roofs on government buildings and schools. Heightened awareness about the cause and impact of heat waves could go a long way in spurring collective action to tackle the problem. For instance, though heat waves are rising year after year, related deaths have been on a downward spiral in India. While 2015 saw more than 2000 deaths due to heat-related fatalities, in 2016, the death toll was 375, and 2017 saw only 20 deaths. This impressive trend is perhaps a result of the government's well-coordinated efforts to make people aware about the ill effects of extreme heat, as well as the mechanisms for tackling it.

The Indian government is also taking several steps to provide an enabling policy and regulatory framework to offer compelling reasons for businesses to engage. For instance, in the context of increased use of nonfossil fuel sources, a combination of Feed in Tariff and Renewable Energy Certificates has been provided. Enhanced use of renewable sources will also create demand for supporting technologies and supply chains.

In this context, initiatives like the International Solar Alliance, launched by India and France for boosting solar energy in developing countries, are important. A Report[21] launched by the Federation of Indian Chambers of Commerce and Industry and the United Nations Environment Programme also highlights several initiatives that have been taken in India for attracting private funding for green assets. For example, social infrastructure and decentralized renewable energy have been included in the priority sector lending requirements for banks, and the *Pradhan Mantri Fasal Bima Yojana* has been launched for extending crop insurance.

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[20]Bureau of Energy Efficiency (2020). Bureau of Energy Efficiency. A statutory body under Ministry of Power, Government of India. Retrieved from https://www.beeindia.gov.in/. Accessed 8 Jan 2020

[21]New Report Shows How India Can Scale up Sustainable Finance. (2016, April 29). In: UNEP - UN Environment Programme. Retrieved from https://unepinquiry.org/news/new-.report-shows-how-india-can-scale-up-sustainable-finance/. Accessed 9 Jan 2020.

An example of a public-private collaboration in this area is the India Innovation Lab for Green Finance,[22] which brings together diverse stakeholders for developing innovative investment vehicles for promoting green and sustainable growth in India. A recent initiative launched by the Lab is the Rooftop Solar Private Sector Financing Facility,[23] which structures small projects together in a manner such that the collective deal is of a substantive enough size and credit quality for attracting additional investments.

It is critical that businesses design products and services that can better meet the world's ever-growing environmental needs. Multinationals can aid the abatement of air pollution by reporting on emissions and the steps taken to reduce energy use. Businesses can also calculate the life-cycle pollution footprint of their products and identify the process changes, technology improvements, and material substitutions necessary for making their products more environmentally friendly and sustainable.

Capacity-building and employee-awareness programs are other strategies that businesses can adopt. Many employees are not aware of how pollution affects their health and the consequent need for behavioral change. Efforts need to be made to encourage people to switch to alternative, cleaner modes of transport, as well as using cooking fuels in their homes that can protect the environment. Providing training on a regular basis or recruiting already-trained employees such as those with advanced degrees or a specialization in environmental engineering and science could be a helpful step toward creating a more livable environment. Further, companies with superior technology can help address gaps in air quality data. Currently, India has one air-pollution-monitoring station for every two million people, with a larger number of manual stations as compared to those that can generate real-time data (Nandi 2018).

UNEP lists an important role for the financial sector as well in combating pollution (UNEP 2017). Some of the suggestions include internalizing the costs of pollution in financial decisions and seeking to create a positive impact; reorienting finance away from polluting companies and activities toward greener technologies; preventing, reducing, and managing risk through insurance pricing and risk research and analytics, catastrophe risk models, and loss prevention; as well as working with multilateral development banks to ensure compliance with their own pollution management and control standards.

The energy sector too has a key role to play, as it is the biggest emitter among all industries. Royal Dutch Shell has announced that it plans to halve its carbon footprint by 2050, by increasing its output of lower-carbon products, including natural gas, biofuels, electricity, and hydrogen (Bousso 2019). Rival BP has announced that it has established a USD100 million fund for projects that will deliver new GHG emission reductions in its upstream oil and gas operations. BP

[22]The Global Innovation Lab for Climate Finance. (2020). Retrieved from https://www.climatefinancelab.org/the-labs/india/. Accessed 9 Jan 2020.

[23]The India Innovation Lab for Green Finance (2016) Rooftop Solar Private Sector Financing Facility: Lab Instrument Analysis.

has defined short-term specific targets aimed at reducing its emissions and advancing the energy transition, including achieving 3.5 million tonnes of sustainable GHG emission reductions across the BP Group between 2016 and 2025, as well as targeting a methane intensity of 0.2%.[24] Similarly, ExxonMobil has reported that it has spent around USD 8 billion since 2000 to deploy low-emission energy equipment across its operations, and that it is conducting and supporting research on technologies to make further reductions. Estimates suggested that the five largest oil companies have collectively curbed their emissions by an annual 13% between 2010 and 2015.

In the wake of increasing pollution and climate concerns, large corporations need to make such voluntary cuts in emissions, even as renewable and cleaner sources of fuel provide new business opportunities.[25] In India, some companies have started making notable efforts. For instance, KPIT Technologies, an Indian technological firm, won the Promising Innovation in Transport Award in 2016 for developing a modular system for converting new and existing diesel buses to electric buses through retrofitting.[26] Graviky Labs in Bengaluru has developed a device that can be fitted onto the exhaust pipe of a car or portable generator to collect the soot that forms from burning diesel fuel. By mixing the fine black powder with solvents, they produce ink that can go into bottles and markers. Not only is this device recycling the soot from vehicles, it is also replacing the carbon black that otherwise would have been used to make black ink (Nunez 2017).

In addition to the government and private sector, citizens can also make a difference by switching to climate-friendly means of transportation, harvesting rain water, saving electricity, reducing all kinds of waste, and promoting promote green spaces.

Greenhouse gas emissions, for instance, can be reduced considerably through some simple changes in our daily lifestyles (Rastogi 2019). Old gadgets should be replaced with energy-efficient ones. Similarly, turning off lights and appliances that use electricity when not in use not only saves energy but is also good for the climate. If the option exists, solar panels should be installed in homes.

Landfills can be checked if we recycle waste of different kinds, including plastic, paper, and glass. Of course, using refillable water bottles and not using plastic bags when shopping can also cut down on the amount of waste we generate. Composting food scraps is another doable and effective strategy.

[24]BP commits USD 100 million to fund new emission reduction projects. (2019, March 26). In: BP global. Retrieved from https://www.bp.com/en/global/corporate/news-and-insights/press-releases/bp-commits-100-million-to-fund-new-emissions-reductions-projects.html. Accessed 9 Jan 2020.

[25]Big Oil Becomes Greener with Progress in Cutting Pollution. (2017, Sept 18). In: Bloomberg NEF. Retrieved from https://about.bnef.com/blog/big-oil-becomes-greener-with-cuts-to-greenhouse-gas-pollution/. Accessed 9 Jan 2020.

[26]Indian Tech Company wins innovation award for turning diesel buses into electric vehicles. (2016, May 17). In: ERTICO Newsroom. Retrieved from https://erticonetwork.com/indian-tech-company-wins-innovation-award-turning-diesel-buses-evs/. Accessed 9 Jan 2020.

Further, using bikes or public transport whenever possible is also a lifestyle modification that can go a long way in mitigating the impact of climate change. Such measures can not only reduce emissions, control rising global temperatures, and improve air quality but also yield several direct health benefits by preventing diseases like diabetes and cancer. For instance, if people walk or cycle to work instead of using a car, it will allow them to be physically active, thereby addressing one of the key risk factors for chronic diseases, that is, a sedentary lifestyle.

14.5 Notable Global Initiatives That India Can Adopt

An example of an effective legislation is the Clean Air Act in the United States, which was passed with the mandate of controlling air pollution. Under the Clean Air Act, the Environmental Protection Agency (EPA) specifies standards with respect to the maximum permissible levels of air pollutants across the country. The Clean Air Act vests the EPA the authority to limit emissions of air pollutants emanating from sources such as chemical plants, utilities, and steel mills. The Act also addresses issues like acid rain and ozone depletion. While individual states or tribes can put in place stronger air pollution laws, the standards cannot be weaker than those prescribed by the EPA. To reduce pollution, the Act requires manufacturers to build more environmentally friendly engines, refiners to produce cleaner fuels, and areas with high levels of air pollution to adopt and run passenger vehicle inspection and maintenance programs. In fact, the EPA has issued a series of regulations, affecting passenger cars, diesel trucks, and buses.[27]

In Freiburg, Germany, people are forbidden from parking cars near their homes. They are required to pay a fee of approximately €20,000, in order to secure a spot near the boundary of the town (Aravind 2016). In return, they are provided cheap housing and an efficient public transport system with trams and bicycle routes spanning 500 km. As a result, nearly 70% of residents in the town do not own cars. Zurich too has capped the number of parking spaces in the city and allows only a certain number of cars into the city at a given time. Additional more car-free zones, plazas, tram lines, and pedestrianized streets are also being developed in the city. The results have been encouraging in terms of reduced traffic congestion and air pollution.

Mexico City and Beijing have dealt with air pollution in urban centers by switching over to cleaner energy options, increasing the application of technology for controlling emission, promoting public transport, controlling total energy consumption, encouraging environmental education and research, as well as ensuring coordinated air quality management.

The Finnish capital of Helsinki has been at the forefront of introducing innovations in its public-transport system, with the goal of eliminating car

[27]Overview of the Clean Air Act and Air Pollution. (2020). In: US EPA. Retrieved from https://www.epa.gov/clean-air-act-overview. Accessed 9 Jan 2020.

ownership. The city rolled out a minibus service called Kutsuplus, which allows riders to specify their own desired pickup points and destinations through smartphones. The requests are then aggregated, and the application calculates an optimal route to meet the requirements of most riders to the extent possible. While it costs more than a regular bus fare, it is less expensive as compared to a cab ride.

China is actively encouraging households to switch to low-emission heating systems. Nearly 9 million households made the transition from coal to natural gas and electricity during 2017 and 2018. The share of coal in the nation's overall energy mix is now 59%, down from more than 68% in 2012.

Another global good practice is the use of district heating wherein "heating is supplied by a central plant which can use advanced methods to run on many different fuels or recover heat from other sectors, instead of every building having its own boiler. This is beneficial for households, industry and the environment." Besides, district heating can make use of many kinds of renewable energy (biomass, geothermal, solar thermal).[28] A key aspect of district heating is that it comes from combined heat and power CHP (plants), where electricity and heat are produced at the same place.

To tackle the challenge of solid waste, the Swedish government has implemented a legislation stating that recycling centers must be located within 1000 feet of residential areas (Folk 2019). Conveniently located facilities encourage citizens to dispose their waste properly. It is estimated that more than 50% of the waste produced in Sweden is processed in waste-to-energy plants. The energy generated by these facilities, in turn, serves as a source of heat for households across the country during the winter months. Ash and other by-products of the burning process can be used for road construction materials. The Swedish government has shifted the responsibility for managing waste from cities to industries, which produce materials that eventually become waste. Tax incentives are offered to companies for burning waste to generate energy.

Another noteworthy example is from Kamikatsu in Japan, which is on track toward becoming a zero-waste town by 2020. Residents of this region sort their garbage into 34 separate categories such as aluminum cans, steel cans, paper cartons, and paper flyers. The waste-management center has deliberately been morphed into a hub of the local community. For instance, a shop accepts clothing, tableware, and other items that are in a useable condition but no longer wanted by their owners, and it offers them to those who might need them. More than 8000 items of tableware can be borrowed by people every year, thereby eliminating the requirement for single-use cups and plates for special or one-off occasions. They also have an upcycling craft center where old kimonos brought by residents are converted into usable products by women from the community. Today, less than a fifth of the town's

[28]Swedish district heating: Reducing the nation's CO_2 emissions. (2017, May 02). In: Euroheat & Power. Retrieved form https://www.euroheat.org/news/swedish-district-heating-reducing-nations-co2-emissions/. Accessed 9 Jan 2020.

waste needs to be sent to incinerators or landfills as a result of these efforts (Gray 2019).

A deposit-refund scheme for cans and drinking bottles is in place in the United Kingdom and European Union for incentivizing consumers to return the bottle or can for which they are compensated, thereby reducing the pressure on landfills, increasing the life cycle of the product, and ultimately abating waste generation. Consumers pay an up-front deposit between 8–22 pennies when purchasing cans or bottles, which can be redeemed upon the return of the empty drink container. It is hoped that implementation of a deposit-return system will help boost beverage-container recycling from 57% in the United Kingdom to more than 95%. A similar program in Iceland has enabled them to retrieve more than 300,000 bottles in less than a year (Mace 2019). ECOBOT vending machines in Colombia provide shopping discount coupons, movie tickets, or monetary rewards every time a citizen deposits a plastic bottle or bottle caps.[29]

Other techniques include the use of vermiculture in Cajicá, Colombia, for instance, involving the use of worms for making compost from decomposing food waste. The outcome is rich compost with lower levels of contaminants that local residents can use as organic fertilizer for their vegetable beds. Instead of the trash can, leftovers at food stalls in Penang, Malaysia, end up in a machine that turns them into fertilizer for use on farmers' fields. To minimize the amount of trash going into landfills, Bio-Regen food-processing machines are used for composting as much of the Malaysian city's waste as possible. The machines are compact, odorless, and do not attract any vermin. They grind organic waste with microbial solution and water for producing a bio-liquid soil enhancer. Composting also lowers the cost of transporting and disposing of waste and helps prevent pollution of the city's waterways.[30]

China is building Asia's first vertical forests, which are high-rises packed with greenery in the form of trees, shrubs, and plants. While acting as a carbon sink, they are also expected to produce 60 kg of oxygen every day. If placed horizontally, the forests will cover an area of 6000 m^2.[31] In fact, a tower in Xian in Shaanxi province in China has been dubbed as the world's largest air purifier. It has large greenhouses around its base, which absorb polluted air, which, in turn, is heated using solar power, and released after going through multiple layers of cleaning filters. This has contributed to a substantial reduction in average PM2.5 levels around the tower (Chen 2018).

[29]Turning Trash into Cash: Colombian company gives coupons for recycled bottles, cans. (2017, Aug 24). In: News.cgtn.com. Retrieved from https://news.cgtn.com/news/3d3d674d79674464776c6d636a4e6e62684a4856/share_p.html. Accessed 9 Jan 2020.

[30]Solid approach to waste: how 5 cities are beating pollution. (2017, Nov 22). In: UN Environment. Retrieved from https://www.unenvironment.org/news-and-stories/story/solid-approach-waste-how-5-cities-are-beating-pollution. Accessed 9 Jan 2020.

[31]China Is Building Asia's First Vertical Forest to Fight Air Pollution. (2017, Feb 21). In: Interestingengineering.com. Retrieved from https://interestingengineering.com/china-vertical-forest-fight-air-pollution. Accessed 9 Jan 2020.

Copenhagen in Denmark has invested significantly in cycling infrastructure. In fact, there are five times as many bikes in Copenhagen as cars. The enabling infrastructure for encouraging cycling includes innovative bridges and super-cycling highways. It has been estimated that for every kilometer someone rides on their bike in Copenhagen, the city experiences an economic gain of 75 cents (Fleming 2018). Cities like Madrid, New York, and London too are imposing restricted bans on usage of cars. In Paris, the first Sunday of every month is car-free. Many cities around the world plan to phase out diesel cars over the next few years (Bendix 2019).

14.6 Building a Resilient Public and Preventive Health System[32]

The science of public health, which is the primary tool for disease prevention and health protection, does not have concerted institutional mechanisms for its implementation in India. While there are several strategies implemented under the various national health programs that address disease prevention, an area that is largely missed is that of health promotion through targeting behavioral risk factors for disease, as well as determinants of health that often lie outside the purview of health departments, including environmental and social determinants. According to the Global Burden of Disease Study, 2010, the top 15 risk factors contributing to India's disease burden include, among others, dietary factors, household and ambient air pollution, smoking, high blood pressure, occupational risks, alcohol use, physical inactivity, high body mass index, high total cholesterol, and sanitation.[33]

A robust public health system is a must for better preparedness, as well as mitigating the impact of climate change and pollution on human health. Climate change is putting health systems around the world to test (Agarwal and Bass 2019). In India, changing weather patterns such as rising temperatures, extreme rainfall, and flooding are causing sudden and often unpredictable outbreaks of various diseases. For instance, the first major outbreak of dengue occurred in Chhattisgarh in 2018, which was rare for the region based on historical trends. In the same year, Kerala suffered its worst episode of flooding in 100 years. This, in turn, challenged the health system with outbreaks of a range of water-borne and vector-borne ailments.

Much like other low- and middle-income countries, India too, historically, had a health system, which focuses on vertical disease programs such as malaria, tuberculosis, and human immunodeficiency virus (HIV). However, for tackling the widespread effects of climate change on health, which range from malnutrition to waterborne diseases, lung cancer, and mental health, a resilient and adaptive public health system is the need of the hour. Moreover, in a rapidly urbanizing India, there

[32]This section draws on insights from the Health Division Team at NITI Aayog, comprising Mr. Alok Kumar, Adviser; Mr. Sumant Narain, Director; and Dr. Kheya Melo Furtado, Research Assistant.

[33]Global Burden of Disease (GBD). (2020). In: Institute for Health Metrics and Evaluation. Retrieved from http://www.healthdata.org/gbd. Accessed 10 Jan 2020.

is an urgent need for a strong public health system, as the risk of disease outbreaks and spreading of contagion are much higher in densely populated urban areas. It took a significant human cost and sociopolitical crisis after the severe acute respiratory syndrome (SARS) outbreak for China to boost investments in public health and disease monitoring on a priority basis. A strong public health system would exemplify several elements, including an emphasis on ensuring the continuum of care, effective surveillance systems, disaster preparedness plans, and adequately trained health personnel at every level. Without a robust public health system, morbidity and mortality caused by climate change will continue to worsen.

Experiences from nineteenth-century Europe, Japan in the early twentieth century, China, Sri Lanka and closer home from Tamil Nadu provide a compelling case for investing in public and preventive health. This approach is particularly relevant for India as it works well for both communicable and non-communicable diseases. In addition to the cost-effectiveness of public health interventions, the case for government investment in this area is buttressed by the fact that it is a pure public good and will therefore be under-provided in any market mechanism. Thus, in order to optimize limited resources, it is important for the government to assure public and preventive health in a comprehensive manner, while other services can be implemented by the private sector either exclusively or with monitoring from the government.

Unfortunately, the Government in India has inadvertently deemphasized public health programs through a series of policy decisions. For instance, in 1943, the Bhore Committee recommended the amalgamation of the medical and public health services, resulting in career incentives for the latter being done away with. The Madras presidency dissented to this, and the strong performance of Tamil Nadu on various public health indicators is considered to be largely due to this decision. Additionally, disease-specific programs for targeting high-priority conditions were introduced, but they diverted attention from the provision of public and preventive health services. Further, the concept of a multipurpose worker was developed by merging the roles of sanitary workers with disease-specific workers. This, in turn, resulted in lower priority being accorded to environmental health services. Another crucial action was the separation of nutrition, water, and sanitation from the department of health.

While the National Health Mission's (NHM) focus on health system strengthening did make some course corrections, it has perhaps not gone far enough. We believe that the government would be failing in its stewardship role if it does not accord top priority to establishing a strong public health system. This also implies that expenditure on public health should be the first charge on government expenditure on health.

Bringing public health to the center stage would require the creation of a designated focal point within the Union Health Ministry to deal with public health functions. The functions would include disease surveillance and response, monitoring of health status, informing the public, providing evidence for public health action, as well as enforcing public health regulation. A number of these functions are especially relevant for promoting consciousness among citizens about the environment as well as protecting public health from the deleterious effects of climate change.

A counterpart to the focal point in the Union Health Ministry will need to be established in every state. This body should be autonomous and empowered to enforce compliance from other public authorities and citizens. Without this, it will not be effective in its role since action is often required from multiple stakeholders to establish accountability and achieve a measurable impact on population health. For example, control of dengue/chikungunya is highly dependent on proper enforcement of building regulations to prevent clean stagnant water collection. The authority to enforce such regulations does not rest with the Health Department, and mere fogging after breeding sites are established is insufficient to control the spread of the mosquito vector. Similarly, the toxic levels of air pollution experienced in major cities and directly impacting respiratory health require action with respect to regulation of construction site practices, vehicular regulation, etc. Road traffic injuries are a major public health concern in India; however, health departments can do little to put in place the required preventive interventions, since road and traffic legislations do not fall within their ambit.

The specific powers that will need to be vested in this public health focal point include assigning responsibility to different levels of government and agencies with specifications about the source of funding for discharging their duties, as well as taking action for protecting public health, including powers of regulation, oversight, and inspection and use of such powers in situations of "public health nuisances." For instance, health facilities that dispose potentially harmful waste inappropriately should be held accountable as should residential colonies that allow water to stagnate, providing breeding grounds for mosquitoes that spread dengue and malaria. Other necessary powers include setting standards or overseeing bodies that set standards for food, hygiene, water quality, sanitary practices, and the environment.

The success of the state-level focal points for public health would be critically dependent on financing and the availability of motivated and capable human resources. To this end, it would be essential for the central government to partner with state governments for creating a dedicated structure for public health at the state, district, block, and village levels (Fig. 14.1). This may be largely achieved by ensuring that existing personnel have the requisite skill sets with the need for only minimal additional staff. The required skills include the ability to integrate health with the key social determinants, carry out community surveillance, analyze data, and enable public participation. Currently, expertise in the discipline of public health is limited with a majority of posts in the central health service belonging to the teaching, nonteaching, and general duty medical officers sub-cadres and a smaller percentage to the Public Health sub-cadre. In addition, frontline health workers such as accredited social health activists (ASHAs), auxiliary nurse midwives (ANMs), and multi-purpose workers (MPWs) must be trained to deliver effective health promotion information and effect behavioral change.

Postgraduate training of in-service officers may be carried out to improve capacities in the management and delivery of public health services. Additionally,

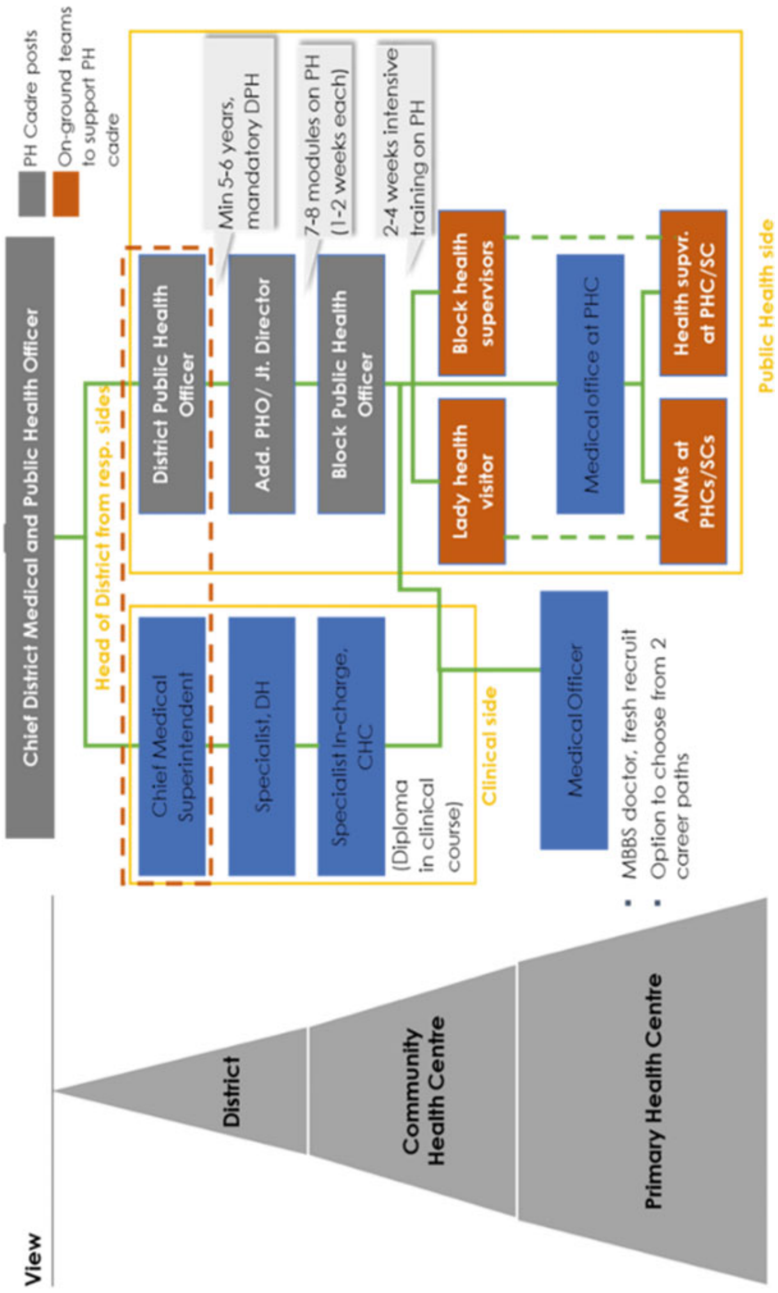

Fig. 14.1 Illustrative design of public health cadre. (Source: NITI Aayog and McKinsey)

while the setting up of public health cadres should be prioritized in the short term, the establishment of an All India Public Health Service should be explored in the longer term.

Making population-level data available at required periodicity is critical. Data on the population prevalence of risk factors, as well as complete disease/health outcome data are not made available regularly to guide public health and health system action. Unless risk factors and disease data are available, we will not know what to budget for or what health resources are needed. Timely use of the data for local-level decision-making, identifying emerging health threats, and for shaping larger health strategies for the country is vital. These data must also be regularly published and publicized so as to make them available to the common man, thereby making health and health issues central to public discourse and creating demand for its provision. For this, institutions at the state level would need to be set up with the capacity to generate the required data, at district levels of disaggregation, on a regular basis. In several states, academic institutions are involved in providing public health education to in-service government officers of the health departments. These institutions could also be engaged in data collection, analysis, and interpretation according to uniform protocols to ensure comparability across states.

Another crucial public health function that needs to be strengthened is disease surveillance and response at the urban ward/rural block level. The ability of the current health system in India to detect disease outbreaks early, especially those that are unforeseen or difficult to anticipate, given changes in climate patterns, and initiate a coordinated response is inadequate. Developing countries such as China paid the human cost of large-scale pandemics such as SARS before efficient surveillance systems were instituted. In India, disease estimates are affected by incomplete surveillance data captured as part of national programs. This is largely since cases recorded in these databases are restricted to those accessing services in public health care facilities, and the larger proportion of cases accessing care in private health care facilities remain largely unreported. With the exception of HIV (sentinel surveillance) and polio surveillance, denominator-based data are unavailable for infectious diseases. Measures to integrate private sector health facilities in disease reporting as part of regular surveillance systems is an impending priority. For this purpose, disease surveillance activities must be coordinated at the district level, with block-level managers being responsible for recruiting the appropriate number of private sector providers into a surveillance network. A 6-month pilot study at each block (or ward level in cities) would provide sufficient information on which private sector health providers are appropriate to include in the surveillance network. Lessons from the polio surveillance program must be utilized to develop an appropriate integrated surveillance system for all diseases. This is linked to the need for strengthening the role of the National Centre for Disease Control to coordinate disease surveillance and control and empower the body sufficiently to perform this function in the context of outbreaks and emergencies. This includes providing dedicated staffing for the implementation of all surveillance and response-related activities to translate into what was achieved for polio surveillance and its ultimate elimination, in an integrated manner.

One of the major challenges, however, is the inability of these systems to interact with each other, leading to the formation of multiple and disassociated clusters of information across programs. This has happened as a consequence of lack of standards for health records and consistent design principles, as well as the absence of a strategic vision for developing a nationwide system. Surveillance data are generated through multiple vertical disease surveillance systems and the Integrated Disease Surveillance Project, which is not adequately integrated with these programs. There are also issues related to the use of data at all levels and the extent to which it informs program planning and implementation. Further, there is incomplete disease reporting from the private sector and urban areas.

14.7 Role of *Ayushman Bharat* in Building a Climate-Resilient Health System

Ayushman Bharat has two key pillars—Health and Wellness Centers (HWCs) and the *Pradhan Mantri Jan Arogya Yojana* (PM-JAY) for providing comprehensive primary health care and health insurance, respectively (Fig. 14.2). Both these initiatives have a key role to play in building a strong health system that is resilient to the adverse effects of climate change.

The existing Primary Health Center (PHC) model in the country is limited in scope. Even where there is a well-functioning public PHC, only services related to pregnancy care, limited child care, and certain services related to national health programs are provided, which represent only 15% of all morbidities for which people seek care. Global evidence points to the fact that a selective model of primary health care cannot respond adequately to the interrelationship between health and socioeconomic development (Magnussen et al. 2004).

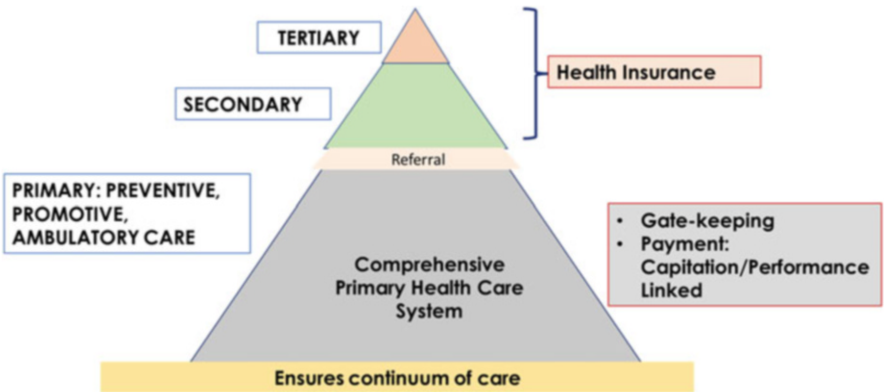

Fig. 14.2 Comprehensive primary health care and financial protection – Pillars of Universal Health Coverage

Fig. 14.3 Design of a model health and wellness center. (Source: School of Planning and Architecture, Delhi)

In this context, by providing a comprehensive package of primary care services, HWCs (Fig. 14.3) will promote healthy lifestyles as well as ensure that chronic diseases are detected early. Tackling non-communicable diseases is all about prevention in the first place. It requires lifestyle and community-level interventions. However, of the total current expenditure on health classified by health care functions, preventive care accounts for a meager 6.7%. The money spent on curing people, on the other hand, is 51% of the expenditure.[34] This approach also makes tremendous sense because we continue to face a high burden of malnutrition, tuberculosis, respiratory infections, and neonatal conditions, all of which are preventable or treatable at a low cost.

Data from the United States shows that emphasizing primary care reaped rich dividends in the form of a 36% reduction in the days spent in hospital, a 42% decline in emergency admissions, as well as a 25% increase in childhood vaccination (Sujatha Rao 2017). Countries like Brazil and Estonia have also improved their health outcomes significantly by focusing on primary health care, in addition to other measures. In fact, comprehensive primary health care is at the core of any universal coverage system, and it is perhaps why developed nations such as the United Kingdom, Australia, Canada, Netherlands, and Sweden spend 80–90% of the federal health care budgets on primary care.

Thus, we can expect that if implemented well, the comprehensive primary health system built on the foundation of 150,000 HWCs will produce outcomes such as a reduced disease burden, lengthened life expectancies, reduction in emergencies and

[34]Ministry of Health and Family Welfare (2017) National Health Accounts: Estimates for India. National Health Systems Resource Centre, Government of India.

hospitalizations, as well as averting of avoidable morbidity. A team led by a mid-level health provider[35] (MLP) along with ANMs, ASHAs, and a male health worker will be responsible for catering to a population size of 5000 each and managing the comprehensive primary health care system. This team can also play an important role in making people aware of the health risks of climate change and identifying the early signs of disease outbreaks that occur in the aftermath of weather changes, leading to extreme heat or flooding, for instance.

Despite all efforts to promote good health and prevent disease, some individuals will inevitably fall sick. PM-JAY will ensure that the most vulnerable and poor families in the country are able to access the requisite secondary and tertiary care services on such occasions by strengthening the public health sector and creating effective demand to trigger private investments in supply deficit areas. India's out-of-pocket expenditure (OOPE) is 62%, which places the country at 182 out of 191 countries. Nearly 80 million people are pushed into poverty due to catastrophic health expenses. Since PM-JAY covers most secondary and tertiary services without any co-payment from poor families, it can play an important role in reducing OOPE. A study of *Askeskin*, Indonesia's largest health insurance scheme that covered about 76.4 million people (34%) in 2007, showed that it had a protective effect on OOPE (Aji et al. 2013). The scheme had a generous benefits package, covering almost all types of care with no cost-sharing policy. While initially focusing on the poorest families, PM-JAY can eventually be expanded to also include families that are "nonpoor" but equally vulnerable to falling into poverty each year due to medical expenses. A strong insurance system is a key pillar of universal health coverage that will allow people to receive treatment for illnesses, including those that might occur unexpectedly due to sudden changes in weather patterns, for instance, without experiencing financial distress and getting pushed into poverty.

14.8 Conclusion

There is no doubt that climate change and air pollution are leading to serious consequences for human health and well-being. In an interconnected world, global cooperation on this issue is a must, especially since the poor in developing countries often bear the brunt of actions taken largely by the developed world. At a national level, there is a growing recognition of the seriousness of this challenge in India, across stakeholders and sectors. Several initiatives have been launched; however, their implementation needs to be ensured across the country in a consistent manner. There is also a lot that we can learn from global good practices and adapt them to the Indian context. Finally, while decisive and strong action by the government and policymakers is key, businesses, civil society, and citizens too must play their part. Only then will we be able to ensure that the deleterious impact of climate change and

[35]With a degree in Nursing, AYUSH or Community Health, and with required training in public health and primary care.

air pollution is prevented or minimized at the very least and good health for all is achieved.

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Empowerment of Fisherwomen Through Marine Farming

15

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Abstract

Marine fisheries sector contributes significantly to the national economy. Marine fisheries production is through capture of fisheries and mariculture farming of marine resources in sea. Mariculture technologies like seaweed farming and marine ornamental fish culture are fisherwomen-friendly technologies. Seaweed farming is being carried out with *Kappaphycus alvarezii*, a red algae, which yields carrageenan, a commercially important polysaccharide, used as a raw material in food, pharmaceuticals, cosmetics, and mining industry. The farming is being carried out as family-based model. Majority of fisherwomen are involved in farming activities such as seeding, tying the seeded rope on the raft, floating, and maintenance of rafts. The culture period is 45 days. A total of 4–5 cycles can be harvested in a year. On an average, a family earns from ₹10,000 to ₹15,000/per month through seaweed farming. The farming is being adopted for more than 10 years in Tamil Nadu. The major positive impact of seaweed farming includes improved economic empowerment and decision-making ability of fisherwomen. Moreover, seaweeds can significantly mitigate the adverse impact of climate change and will earn carbon credits to our country. Similarly, the marine ornamental seed rearing is a less time-consuming and more revenue-generating activity for fisherwomen Around 500 numbers of half-inch-sized clown fishes are supplied from Central Marine Fisheries Research Institute (CMFRI), Mandapam, and the fisherwomen group of 2–3 members grow them up to 1.5 inches in size in 45–60 days and market them. Hence, one cycle is for 45 days. A

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total of five cycles are carried out in a year. On an average, a member earns around ₹10,000/per month. Apart from economic empowerment, the marine ornamental fish seed production paves a way for hatchery-produced ornamental fish trade and reduces the pressure on wild collection and abandoning of destructive collection methods.

Keywords

Marine farming · Sustainable Development Goals · Gender equality · Gender empowerment · Seaweed farming

15.1 Introduction

In India, fisheries sector serves as a significant source of employment and income generation. The male members are recognized well in the fishing family unit, since they go to sea and engage themselves in the actual fishing process. But the role of the female members is often not recognized, though they contribute significantly after the fish is landed. Today's average Indian fishing family often finds it difficult to earn a livelihood throughout the year. Therefore, the vast potential available among the unemployed fisherwomen needs to be tapped, by making them capable of generating additional income for the household for which options available are seaweed farming and small-scale marine ornamental fish seed rearing.

15.2 Seaweed Farming

Kappaphycus belongs to Rhodophyta (red seaweeds) group, which is used as phycocolloids (carrageenan), food, fodder, and bio-fertilizer. The commercial gelatinous products such as agar, algin, and carrageenan (cell-wall polysaccharides) are produced from seaweed or macroalgae and also used as manure, fodder, and bioactive metabolites. The worldwide seaweed production (farming + wild collection) has substantially increased from 4 million tonnes in 1980 to 30.1 million tonnes in 2016 with the first-sale value estimated at USD 11.7 billion (FAO 2018). India contributes less than 1% of global seaweed production. Among the global seaweed production, *Kappaphycus* and *Eucheuma* contributed to 41% of the total production. India has reached more than 7000 tons of dry weight biomass of *Kappaphycus* in a decade between 2005 and 2015.

In India, seaweed farming is being carried out with *Kappaphycus alvarezii*. *Kappaphycus alvarezii* (*K. alvarezii*), a red algae, is known for the production of carrageenan. Hayashi et al. (2007) reported the commercial applications of carrageenan in the industries, including pharmaceuticals, food, and cosmetics (Johnson and Gopakumar 2011). Since 1960, the *K. alvarezii* is commercially cultivated. Nevertheless, its cultivation started in the Philippines (Doty and Alvarez 1975; Johnson and Gopakumar 2011). Subsequently, large-scale cultivation of *K. alvarezii* started in Japan, Indonesia, Tanzania, Fiji, Kiribati, Hawaii, and South Africa

(Subbarao et al. 2008; Johnson and Gopakumar 2011). *K. alvarezii* seaweed cultivation started in India at Mandapam, which is situated on the southeast coast of India (Eswaran et al. 2002; Rameshkumar and Rajaram 2019). It is important to note that the PepsiCo in the year 2002 and, subsequently, "AquAgri Processing Private Limited" in 2008 took active steps and measures to popularize the cultivation of seaweed (Krishnan and Narayanakumar 2010). Further, both PepsiCo and "AquAgri Processing Private Limited" were instrumental to form women self-help groups (SHGs) and their participation in seaweed farming (Narayanakumar and Krishnan 2011; Johnson et al. 2017). Commercial cultivation of *K. alvarezii* was started in 2005 along the Tamil Nadu coast.

In Gulf of Mannar and Palk Bay region of Tamil Nadu, India seaweed farming was found to be economically feasible, and so it is considered as an alternate source of revenue. Seaweed farming is practiced in the districts of Tamil Nadu viz. Ramanathapuram, Pudukottai, Thanjavur, Tuticorin, and Kanyakumari (Johnson and Gopakumar 2011). This type of farming activity is mostly undertaken by fisherwomen. Further, the red algae cultivation has a positive impact as far as climate change mitigation is concerned. The seaweeds augment biodiversity, as they provide protection to diverse group of organisms. The algae too sequester carbon dioxide and play a role in climate change mitigation (Israel et al. 2010). It is also reported that the seaweeds ensure ecological balance, and they also reduce the organic pollution. In effect, seaweed farming has multitude of benefits, including livelihood benefits. Experimental studies were conducted at Munaikadu, Ramanathapuram district, Tamil Nadu, India on "assessment of carbon sequestration potential of seaweed" (*Kappaphycus alvarezii*), and it was observed that carbon di-oxide sequestration rate was about 0.0187 g day^{-1} (CMFRI Annual Report, 2015–2016).

15.3 Seaweed Farming Techniques

Kappaphycus farming is widely practiced in the Tamil Nadu coast of India. The farming techniques adopted in Tamil Nadu include "floating bamboo raft method," "tube net," and "monoline culture" techniques (Johnson et al. 2017). In the coastal waters with calm and shallow conditions, floating raft method is ideal. Bamboo is normally used to make the floating raft with a dimension of 12 $\times$ 12 feet for mainframe and 4 $\times$ 4 feet for diagonals. About 20 "polypropylene-twisted ropes" are used in each floating raft for plantation. Along the length of rope, about 150–200 g of seaweed fragments are tied at a spacing of 15 cm in such a way that about 20 seaweed fragments are tied in a single rope. As regards the total seed requirement, it is about 60–80 kg/raft. In order to avoid grazing, a fish net with a dimension of 4 m $\times$ 4 m size is tied to the bottom of the raft (Johnson and Gopakumar 2011). In normal season, a cluster of 10 rafts are positioned in the near shore area of 1.0–1.5 m depth using a 15-kg anchor, whereas during rough season the same cluster has to be installed using two or three anchors. Most of the seaweed farmers use 25–45 rafts for their cultivation. Further, in most of the villages,


Plates 15.1 and 15.2 Floating raft method in *K. alvarezii* farming


Plates 15.3 and 15.4 Fragments are tied in the rope

due to space constraints, a farmer is restricted to use a maximum of 45 rafts (Johnson et al. 2017).

In regions with moderate wave action, shallow depth and the presence of less herbivorous fishes, monoline method is ideal. Four *Casuarina* sp. poles of 10 feet length and 3–4 inches in diameter is placed at 10×20 feet distance, each in the corner. On two sides, 6 mm rope is tied, on which the seeded rope will be tied. A total of 10 polypropylene-twisted ropes are used for plantation. Similar to the floating raft technique, about 150–200 g of seaweed fragments are tied along the length of rope, at a spacing of 15 cm in such a way that about 40 seaweed fragments are tied in a single rope. In this method, the total seed requirement per raft is about 60–80 kg. High-density polyethylene (HDPE) fishing net is used for fencing to avoid grazing and drifting. Used polyethylene terephthalate (PET) bottles are tied on each rope for floating (Plates 15.1 and 15.2, 15.3 and 15.4, 15.5 and 15.6, 15.7 and 15.8, 15.9 and 15.10).

15.4 Self-Help Group Model in *K. alvarezii* Cultivation

Johnson and Gopakumar (2011) observed the effectiveness of self-help groups (SHGs) in *K. alvarezii* cultivation. The SHG model is actively promoted by District Rural Development Agency (DRDA), Department of Biotechnology (DBT) and


Plates 15.5 and 15.6 Monoline method of seaweed cultivation

Plate 15.7 Raft ready to harvest in 45 days

Plate 15.8 Planting of 150 g grows up to 500–1000 g in 45 days


Plates 15.9 and 15.10 Harvested rope


Plates 15.11 and 15.12 Self-help group model in *K. alvarezii* cultivation in Tamil Nadu coast

Tamil Nadu State Fisheries Department with the assistance of non-governmental organizations (NGOs) was found to be more effective (Johnson and Gopakumar 2011) (Plates 15.11 and 15.12). A Joint Liability Group (JLG) was formed with a group of five members, including men and women. The members of SHG had to actively participate in the training program on seaweed cultivation so that the members were sensitized, from the perspective of farming technologies and economics of seaweed farming. For being part of SHG, the members were to express willingness, possess interest, and fall under the "below poverty line" category. Further, they had to be located near the seashore and be a non-defaulter with respect to banking institutions. The SHGs which met the above mentioned requirements, were eligible to avail loan facility of ₹1,54,000/- for 225 rafts (45 rafts per member). A total of 50% of the loan amount was provided by the promoting agency as subsidy. Bank loan was provided for the remaining amount at a nominal interest rate. The loan repayment period was about 3 years (Johnson and Gopakumar 2011). During 2005–2008, majority of seaweed farmers benefitted through this scheme. Later from 2012–2013, National Fisheries Development Board (NFDB) also started promoting seaweed farming by providing 50% subsidy assistance on unit cost of bamboo raft (₹1,000/−) to women SHGs and entrepreneurs.

Table 15.1 Unit cost for a bamboo raft

S. no	Particulars/description	Quantity required	Cost per Raft (₹)
Fixed cost			
1.	3–4 inches in diameter hollow bamboos of 12 × 12 feet for main frame + 4 × 4 feet for diagonals (without any natural holes, crakes etc.) @ ₹6.00 per feet of bamboo	64′	384.00
2.	Five-toothed iron anchor of 15 kg each (@ ₹64 per kg) – One anchor can hold a cluster of 10 rafts	1.5 kg	96.00
3.	3-mm polypropylene twisted rope for plantation—20 bits of 4.5 m each (@ ₹230 per kg)	420 g	97.00
4.	Cost of high-density polyethylene braider pieces (20 pieces × 20 ropes = 400 pieces of 25 cm each) (@₹330 per kg)	165 g	55.00
5.	Raft framing rope 6 m × 12 ties per raft, that is, 36 m of 4 mm rope (@ ₹230 per kg)	650 g	150.00
6.	Used high-density polyethylene fishing net to protect the raft bottom (4 m × 4 m size) (@ ₹70/kg)	1 kg	70.00
7.	2 mm rope to tie the HDPE net (28 m) (@ ₹230 per kg)	100 g	23.00
8.	Anchoring rope of 10-mm thickness (17 m per cluster of 10 rafts) (@ ₹220 per kg)	100 g	22.00
9.	Raft linking ropes per cluster 10 rafts – 6 mm thick – 2 ties × 3 m × 9 pairs = 54 m length (@ ₹230 per kg)	100 g	23.00
10.	Braider twining charges		80.00
	Total fixed cost		**1000**
Operating cost			
11.	Seed material (150 g × 400 ties = 60 kg) + 10 kg handling loss = 70 kg@ ₹4.00 per kg	70 kg	280.00
12.	Labour (seeding, raft/monoline laying, and maintenance)		200.00
13.	Transportation		100.00
14.	Miscellaneous expenses		20.00
	Total operating cost		**600.00**

Source: Modified from Johnson and Gopakumar (2011) and Johnson et al. (2017)

15.5 Economics of Seaweed Farming

The total cost of production for making one bamboo raft for *K. alvarezii* farming worked out to be around ₹1,600/– (Table 15.1). As the investment was comparatively less and farmers were also supported through the subsidy scheme, the spread of the technology was rapid. The crop duration of seaweed farming was about 45 days. So 4–6 crops or cycles could be harvested per year, provided the climatic conditions are favorable. It is observed that 150 g of seaweed fragments grows into 500–1000 g in about 45 days. The average yield per raft of 12 × 12 feet size is 260 kg. About 60 kg of seaweed is kept as seed material for the next cycle. The remaining seaweed is sold either on fresh-weight or dry-weight basis. On an average,

Table 15.2 Economic feasibility analysis of seaweed farming from 45 rafts per person (Total five cycles in a year; each cycle is 45 days)

1.	Annual seaweed production (260 kg/raft) *(Retaining 60 kg for next crop, total fresh seaweed production from 45 rafts; 5 cycles)*	45,000 kg
2.	Total seaweed production on dry weight basis (10%) *(from 45 rafts; 5 cycles)*	4500 kg
3.	Price of dried seaweed (₹ per kg)	45
	Gross revenue in ₹	2,02,500
	Total cost of production (₹) (₹1600 × 45 rafts)	72,000
	Net income (₹) (Gross revenue − Total cost of production)	130,500

Source: Modified from Johnson et al. (2017)

Plate 15.13 Portion of *K. alvarezii* grazed by herbivores

the dry-weight percentage of the harvested seaweed is 10% (Table 15.2) (Johnson and Gopakumar 2011; Johnson et al. 2017). At present, farmers receive ₹5–10 per kg and ₹40–45 per kg for fresh and dried seaweed, respectively. On an average, a family earns ₹10,000–15,000 per month.

15.6 Constraints in *Kappaphycus alvarezii* Farming

- Grazing is an important problem in the seaweed farming. “The herbivores eaters such as siganid, acanthurid, sea urchin and starfish nibble on the tips of the branches. During the month of May – June, the grazing intensity is more, which affects the yield up to 50–80 per cent” (Plate 15.13) (Johnson and Gopakumar 2011).
- In the tropical environment, the epiphytic growth is construed as an important challenge to the cultivation of seaweed. The examples of epiphytes are *Neosiphonia savatieri*, *N. apiculata*, *Ceramium* sp., *Acanthophora* sp., *Centroceras* sp., etc. (Vairappan 2006). The epiphytic growth is basically an “attachment of undesirable seaweeds to the cultured species” (Plate 15.14). It was

Plate 15.14 Bamboo raft with *K. alvarezii* completely covered by *Lyngbya* sp.

reported that the epiphytic outbreak is influenced by the factors such as "weather fluctuations," "quality of the cultivated strain," and abiotic conditions. Epiphytic attack reduces the marketability of the seaweeds. Further, it increases the vulnerability of seaweed to bacterial attacks. This problem is reported in the Philippines, Malaysia, Tanzania, and India (Ask 2006; Hurtado et al. 2006; Msuya and Kyewalyanga 2006; Muñoz and Sahoo 2007; Vairappan 2006). In Tamil Nadu, seaweed farmers experience this problem during the monsoon months of May and June (Johnson and Gopakumar 2011).

- Ice-ice disease: The changes in salinity and temperature cause ice-ice disease in *K. alvarezii* (Largo et al. 1999). The term "ice-ice" refers to the tissues which lack pigmentation. The branches will show the symptoms of whitening due to stress, which may result in crop loss (Doty 1987). In fact, it is the loss of pigmentation in thallus that results in whitening of tissues. Due to the ice-ice disease, the healthy branches break off. In the infected portion, it is observed that the "carrageenan yield," "gel strength," and "viscosity" are significantly reduced. Even few farmers in Tamil Nadu discontinued the farming due to severe loss during high temperature period (Plate 15.15).
- The natural calamities like cyclone cause complete havoc to the *K. alvarezii* farming.

15.7 Marine Ornamental Fish Seed Rearing

The marine ornamental fish trade is growing rapidly in the national and international markets during the recent years due to high market demand. At present, the marine ornamental fishes for the trade are almost entirely obtained by wild collection from coral reef habitats. The indiscriminate and destructive collection practices from coral reefs lead to irreparable damage to the coral reef habitat (Gopakumar 2004). The

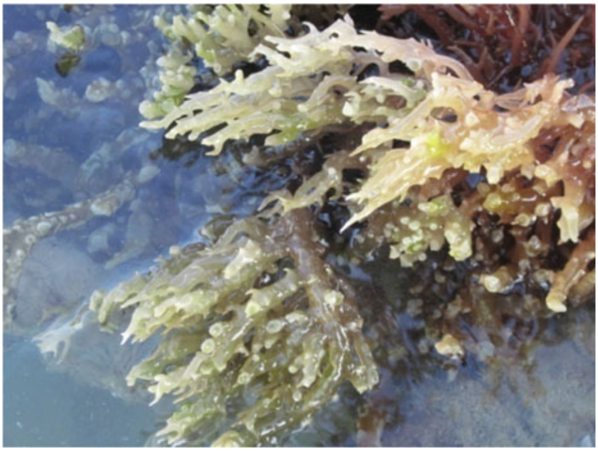

Plate 15.15 Bleached seaweed bunch

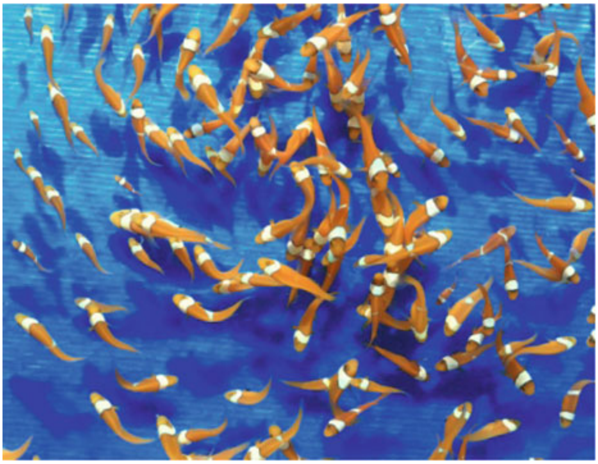

Plate 15.16 Percula clown

establishment of a few small-scale ornamental hatcheries will pave the way for hatchery-produced ornamental fish trade.

The ICAR-Central Marine Fisheries Research Institute (CMFRI) has been pioneering in development of seed production technologies and commercial-level production for more than a dozen species of clown fishes and damselfishes, which are in good demand in marine ornamental fish trade, especially export trade (Plates 15.16 and 15.17). Marine ornamental fish production is a low-volume, high-value enterprise and hence very much lucrative for investment (Pandey and Sagar 2017). The marine ornamental fish production technologies were disseminated to the fishers

Plate 15.17 Designer clown

Plates 15.18 and 15.19 Hands-on training on marine ornamental seed rearing to fisherwomen groups at Mandapam Regional Centre, ICAR-CMFRI

group in Palk Bay and Gulf of Mannar region through different training programs by Indian Council of Agricultural Research (ICAR)-CMFRI, Mandapam (Johnson et al. 2016).

The development of marine ornamental fish brooders is time consuming and involves more technical aspects. Hence, marine ornamental fish seed rearing is being promoted by Mandapam Regional Centre of ICAR-CMFRI. The marine ornamental seed rearing is a less time-consuming and more revenue-generating activity for fisherwomen.

The ICAR-CMFRI, Mandapam, extends technical support for setting up of the seed rearing units as well as its operations. Fisherwomen self-help groups were trained to rear the 0.5-inch-sized juveniles to a marketable size by maintaining adequate water quality, feeding and disease management, etc. (Plates 15.18 and 15.19).

Plates 15.20 and 15.21 Small-scale marine ornamental fish seed rearing unit

Table 15.3 Economics of marine ornamental fish seed rearing unit fixed cost

S. no	Items	Quantity	Cost in ₹
Fixed cost			
1.	Temporary shed	140 ft^2	100,000
2.	Nursery and grow out (Glass tanks)	6	18,000
3.	Water storage tank	2	8000
4.	Sand filter/overhead tank (HDPE)	2	12,000
5.	Submersible pumps	2	10,000
6.	Ozonizer	1	10,000
7.	Air pump	1	10,000
8.	Motor pump	1	10,000
9.	Power installation		15,000
10.	PVC piping, plastic wares (water supply/aeration/drainage)		7000
	Total fixed cost		**200,000**
Operating cost			
11.	Seed (500 numbers/cycle @ Rupees 30 per seed; for 5 cycles)		75,000
12.	Feeds		3000
13.	Electricity		12,000
14.	Maintenance		5000
15.	Miscellaneous expenditures		5000
	Total operating cost		**100,000**

Around 500 numbers of half-inch-sized clown fishes are supplied from CMFRI, Mandapam, and the fisherwomen groups grow them up to 1.5 inches in size in 45–60 days and market them. Hence, one cycle is for 45–60 days. A total of five cycles are carried out in a year. During the rearing period, only pellet feed is required to be given to the fishes apart from routine water quality maintenance. This includes bottom siphoning, water exchange and tank cleaning (Plates 15.20 and 15.21; Tables 15.3 and 15.4).

Table 15.4 Economic performance through marine ornamental fish production

	Amount in ₹
Revenue Sale of clownfish fingerlings @ ₹150/fingerlings (2375 juveniles[a] × 150 = 356,250)	356,250
Total cost	300,000
Profit	**56,250**
From second year onwards, the profit is ₹256,250/−	

[a]95% survival

15.8 Conclusion

Marine fisheries sector in Palk Bay and Gulf of Mannar region is witnessing overexploitation of trawling grounds, declining catches, and consequent reduction in income of fishermen. Under these circumstances, the fisher groups have well understood that seaweed farming and marine ornamental fish seed production activities will serve as best diversified revenue-generating option to them. Since majority of fisherwomen groups are involved in seaweed farming and ornamental fish seed production, one of the outcomes is the economic empowerment of women and the enhancement of their decision-making ability. In the long run, the marine ornamental fish seed production and supply will pave the way for hatchery-produced ornamental fish trade and reduce the pressure on wild collection and abandoning of destructive collection methods. Similarly, seaweed farming has the potential to minimize the climate change impacts in addition to earning carbon credits.

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