Chapter 24
Climate Change and Food Security in India: Adaptation Strategies and Major Challenges

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Abstract India has made rapid strides in improving food production and the country has become not only self-sufficient in food production, but now exports to several other countries as well. However, climate change has emerged as a major threat to India's hard-earned success. Much of India's population depends on climate-sensitive sectors such as agriculture, forestry, and fishing, and thus the livelihoods of hundreds of millions of people are at risk. In fact, the country has already witnessed adverse impacts of climate change on food production, transportation, storage, and distribution. Rising temperatures, erratic rainfall, extreme weather conditions (such as prolonged droughts and floods), changing soil fertility, and new pest infestations are major factors contributing to stagnant agricultural growth. "Climate-smart agriculture" is considered a pragmatic approach to ensuring food security in a changing climate. Adaptation strategies based on the principles of climate-smart agriculture can counter the impacts of climate change, such as the promotion of conservation agriculture, the sustainable management of natural resources and the promotion of climate-smart crops. However, the existing problems of transboundary water conflict, universal insurance of crops, the significant reduction in food wastage needed and the improvement of food distribution are essential to achieving the goals for adaptation. It is also important to note that ready acceptance of "climate-smart agriculture" by farmers cannot be expected, even if the necessary technologies are made accessible to them. Rather, more community-based participatory research is needed to explore socioeconomic and location-specific variables that are influencing farmers' preferences towards the approach.

Keywords Climate change · Food security · India · Conservation agriculture · Climate-smart crops · Food wastage · Public distribution of food · Crop insurance

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24.1 Climate Change: Indian Scenarios

For the Indian subcontinent, the Intergovernmental Panel on Climate Change (IPCC) projected a rise in temperature from 2 to 4.7 °C, with the most probable level being around 3.3 °C by the year 2100 (Solomon et al. 2007). Indian Scientists have indicated that across the region temperatures will increase by 3–4 °C towards the end of the twenty-first century (Kumar et al. 2006; Lal and Harasawa 2001). Although this warming has been projected to be widespread across the country, comparatively more changes will be pronounced over northern parts of the country (Kumar et al. 2006). While precipitation has been projected to rise, there will be spatial variations, with some pockets showing an increase and others experiencing a decline in rainfall (Sulochana 2003). Most models have projected an increase in precipitation between 10% and 40% from the baseline period (1961–1990) to the end of the twenty-first century, with the maximum expected increase in rainfall over the north western and central parts of India (Kumar et al. 2006). A trend analysis of India's precipitation from 1901 to 2012 shows a gradual decrease in intensity. During the same period, drought occurrences have increased considerably with an unequal distribution along with a rise in torrential rains (Mishra 2014). The effects of possible changes in the intensity of the monsoons will be significant since a large part of the country receives varying intensities of precipitation during the summer monsoon season (Lal and Harasawa 2001). Almost three-fourths of India's precipitation is concentrated over 4 months of the monsoon season (June–September) (Mishra 2014). Therefore, adequate summer monsoons are essential to the annual precipitation of the entire Indian subcontinent (Solomon et al. 2007). The northeastern states, which are known for moist weather, are also facing a significant rise in temperature, leading to short-duration torrential rains and promoting stormier and drier seasons. In fact, storm occurrences in India have increased significantly during the past century and rising temperatures may lead to more frequent and stronger storms in the near future. Torrential rains have increased the frequency and intensity of landslide disasters, particularly in the mountainous regions of the Himalayas (Mishra 2014).

India has traditionally been highly vulnerable to natural disasters due to its unique geo-climatic conditions. According to the Annual Disaster Statistical Review (2016), over the last decade, India was one of the top five countries that is most frequently hit by natural disasters (Guha-Sapir et al. 2016). The 2016 report also shows that the total number of people affected by various disasters was the highest (569 million) since 2006, far above the 2006–2015 annual average (224 million). This unprecedented rise was mainly due to the human impact of drought in India, which affected 330 million people in both 2015 and 2016, the highest number of people affected by a natural disaster ever reported (Guha-Sapir et al. 2016). Unsurprisingly, almost 2% of annual GDP is lost due to natural disasters (Mani et al. 2012). Out of 35 total states and union territories, 27 are known to be disaster-prone (Mishra 2014). Around 40 million hectares of agricultural land (almost three times the size of New York State) are prone to floods with 8 million hectares being affected every year (GoI 2002). Flood disasters are the largest cause of economic damage and losses of human lives and livestock (Kumar et al., 2006). The changing volume, timing and pattern of precipitation, and the melting of snow influence streamflow patterns and further intensify the severity of floods (Gosain et al. 2006). India's 8000-km-long coastline that stretches from Gujarat to West Bengal is extremely vulnerable to cyclones (GoI 2006). Lying in the path of tropical hurricanes from the Bay of Bengal, the eastern coast of India is particularly at risk of being damaged by storms and floods (Emanuel 2005; IPCC 2007). The National Institute of Oceanography assessed the impacts of climate change on sea levels and determined that the occurrence of extreme events may change with a projected increase in the occurrence and strength of cyclones in the Bay of Bengal (DEFRA 2005).

Indeed, other non-climatic factors, such as the blocking of natural drainage systems by human encroachment, widespread soil erosion due to deforestation and declining water carrying capacity due to siltation in river beds and other water bodies have further exacerbated the flood risks. The receding of Himalayan glaciers reduces river flows and affects their catchment areas. The increasing frequency of droughts and declining water availability in the channels have resulted in the over-extraction of groundwater and depletion of the water table (Mishra 2014).

Under the circumstances, the present chapter makes a modest attempt to examine the effects of climate change on the food security situation in India and analyze the existing adaptive strategies and their critical overviews.

24.2 Impacts on Food Security

Climate change is a major concern for India because the majority of India's population depends on climate-sensitive sectors such as agriculture, forestry, and fishing for livelihood (Dev and Sharma 2010). The agriculture sector alone represents 23% of India's Gross National Product (GNP) and thus plays a crucial role in the country's development and shall continue to occupy an important place in the national economy. It sustains the livelihood of nearly 70% of the population (Khan et al. 2009). The existing problem of food security in India, if not addressed in time, will become more precarious due to changes in climate, since more than one-third of the population is estimated to be absolutely poor and one half of all children are malnourished in one way or another (Dev and Sharma 2010).

Climate change has adversely affected India's agriculture sector and is an emerging threat to food security. Agriculture yields in India are very sensitive to climate changes such as unnatural high or low precipitation, erratic temperatures and humidity. There is evidence of a rise in the frequency and intensity of extreme weather conditions (flood, drought, heat waves) severely affecting India's food production and food security. Studies show that for every 1 °C rise in temperature, wheat production is reduced by four to five million metric tons. There is extensive evidence on the impacts climate change has on the yield and quality of food crops, beverage crops (tea, coffee), medicinal plants, dairy, and fish (GoI 2018). The current challenges facing Indian food security involve problems impacting the food-producing sector and production, transportation, storage, and access to food. Amid the climatic changes, the biggest challenge for India is to enhancing the current level of food production and maintaining its equitable access across the country to ensure food security in a sustainable manner.

The concept of food security is very complex and multidimensional. Therefore, the issues of food production, distribution, the quality of food, the capability of purchasing, and the sustainability of the entire process must be included. Climate change affects food security in complex ways, as it has been found that it impacts crops, livestock, forestry, fisheries, and aquaculture, and can cause grave social and economic consequences in the form of reduced incomes, eroded livelihoods, trade disruptions, and adverse health impacts (Chakrabarty 2016). However, it is important to note that the net impact of climate change depends not only on the extent of the climatic shock but also the underlying vulnerabilities. According to the Food and Agriculture Organization, both biophysical and social vulnerabilities determine the net impact of climate change on food security (FAO 2016).

If we compare decadal growth pattern of India's population with the growth of production of food grains, it has been observed that during 1981–1991, the decadal population growth was 24%, which declined to 21% during 1991–2001, whereas the growth rate of production and yield have declined for crop groups/crops during the period 1996–2008 compared to the period 1986–1997 (Dev et al. 2010). The growth rate of food grain production (rice, wheat, pulses, and other cereals) declined from 2.9% to 0.93% during the same period (Dev and Sharma 2010). This is undoubtedly a matter of concern and there is a need for considerable enhancement in the production of food grains to match the growth of the population. If the growth patterns of Indian agriculture are considered, it has been observed that the growth of agriculture decelerated from 3.5% between 1981–1982 and 1996–1997 to around 2% between 1997–1998 and 2004–2005 (Chand et al. 2014). Eventually, the very low growth has adverse effects on the farm economy and the livelihood of the farming community and poses a serious threat to national food security. Some initiatives were taken towards the end of the 10th national plan and during the 11th national plan to revive the agriculture sector. Consequently, the growth rate accelerated to 3.75% during 2004–2005 to 2012–2013 (Chand et al. 2014).

However, the country faces major challenges in increasing its food production to the tune of 300 million tons by 2020 in order to feed its ever-growing population, which is likely to reach 1.30 billion by the year 2020. To meet the demand for food from this increasing population, the country's farmers need to produce 50% more grain by 2020. Although the arable land of India has increased from 178 thousand hectares to 224 thousand hectares (26% rise) from 1950 to 2000, during the same period the population has grown from 360 million to 1 billion (almost three times). So rapid population growth along with burgeoning urbanization and industrialization have reduced the per capita availability of arable land from 0.48 hectares in 1950 to 0.15 hectares in 2000 and are likely to further reduce it to 0.08 hectares by 2020 (Mall et al. 2006). Indian agriculture, and thereby India's food production, is highly vulnerable to climate change largely because the sector continues to be highly sensitive to monsoon variability, as 60% of the cropped area is still in the rain-fed zone. Wheat and rice, two crops central to nutrition in India, have been found to be particularly sensitive to climate change (Chakrabarty 2016). Wheat growth in northern India is highly sensitive to temperatures greater than 34 °C (Lobel et al. 2012). The IPCC report of 2007 echoed similar concerns about wheat yield: a 0.5 °C rise in winter temperature is likely to reduce wheat yield by 0.45 tons per hectare in India. Acute water shortage conditions, together with thermal stress, will affect rice productivity even more severely (Metz et al. 2007).

Rising demand for water in agriculture and dwindling and unpredictable river flow due to climate change are causing conflict within the regions. In India, one can witness several cases of water disputes that are inter-state, intra-state and also international (with the neighboring countries Nepal, Bangladesh; and two nuclear-armed countries, i.e., Pakistan, and China). Unfortunately, the condition is escalating due to a lack of pragmatic policies and political will. Several tribunals addressing individual rivers have failed to resolve the disputes and have affected the farmers of the involved states due to a lack of proper decision making at the right time (SANDRP 2016). In addition to interstate and international riparian concerns, there is increasing evidence of local grassroots-level water disputes. There are growing conflicts between pastoralists and different agricultural as well as domestic users, traditional farmers have to compete with investors (such as tourist resorts or factories) and there are examples of villages competing with each other for the same water resources (Taenzler et al. 2011).

There is also a great concern about the impact of climate change on the decline in soil fertility, soil moisture, changes in the water table, rising salinity, the increasing resistance of pests to many pesticides and the degradation of irrigation water quality in various parts of India (Sinha et al. 1998; Mall et al. 2006). Fluctuations in the production of crops in India due to a high dependency on monsoons also has had adverse impacts on the prices of agricultural commodities. As a result, the agricultural market has become unstable and this has given opportunities to middle men to speculate the prices of agricultural commodities. But the farmers suffer as they do not get the justified price due to a lack of government control over the agricultural market (Dev et al. 2010). Insurance for crop loss due to natural disasters is a very important tool for giving farmers relief and economic support.

Climate change is affecting the population's nutritional intake (micronutrients such as vitamins, minerals, and antioxidants), due to negative impacts on fruits and vegetables. One of the most threatening biological responses to terminal heat stress and deprived soil water availability is the loss of production of horticulture crops (Malhotra 2017). The productivities of thermo-sensitive crops such as tea, coffee, cardamom, cocoa, cashew, and black pepper will be directly affected by the rise in temperature (2–3 °C). The increase in night temperatures is going to affect the flowering of mangos and cashews. Floods and summer droughts are likely to affect crop coconut productivity (Rao et al. 2013). Due to poverty and also for cultural reasons, plants are the principal sources of protein in India. However, studies show that rising atmospheric CO_2 can lower the protein content of rice, wheat, barley, and potato. Considering Indian dietary patterns, the study estimated that the average Indian may lose more than 5% of their dietary protein and an additional 53 million people may become at risk. Thus, elevated atmospheric CO_2 may widen the disparity in protein intake within the country, with the people living on plant-based diets being the most vulnerable (Medek et al. 2017).

In India, climate change has brought new patterns of pests and diseases that are affecting all plants and animals and posing new risks for food security, food safety, and human health. Climate change has triggered major changes in geographical distribution and the population dynamics of insect pests, insect-host plant interactions, the activity and abundance of natural enemies, and the efficacy of crop protection technologies, which eventually affect both crop production and food security. Various insect pests currently limited to tropical/subtropical regions will move to temperate regions along with a shift in the areas of cultivation of their host plants. On the other hand, the population of native insect species (some are natural predators of pests) vulnerable to high temperatures in the temperate regions may decrease as a result of global warming. It has also been found that the relative efficacy of pest control measures such as host-plant resistance, natural enemies, bio-pesticides, and synthetic chemicals is likely to change as a result of global warming and climate change (Sharma 2016; Karuppaiah and Sujayanad 2012).

The wastage of food in the stages of production, handling, transportation, storage, and consumption put enormous stress on the economy, environment, and food security. Wasting a kilogram of wheat and rice would mean wasting the 1500 L and 3500 L of water, respectively, that go into their production. According to FAO, every year, almost one-third of food produced globally for human consumption is either lost or wasted. The associated economic, environmental, and social costs of this loss are around $1 trillion, $700 billion, and $900 billion per year, respectively. In India, the cost of food wastage (harvest and post-harvest losses of major agricultural produce) is estimated at around $14 billion per annum at 2014 wholesale prices (Bordoloi 2016; Athar 2018). Poor production of food is not the only reason for food insecurity in India. Farm output has been setting new records in recent years, with increased output from 208 million tons in 2005–2006 to 263 million tons in 2013–2014. India needs 225–230 million tons of food per year, so even when accounting for recent population growth, food production is clearly not the main issue. The most significant but long-ignored factor is that a high proportion of the food that India produces never reaches consumers. $8.3 billion worth of food, or nearly 40% of the total value of annual production, gets wasted and thus India is regarded as the world's biggest waster of food. Apart from perishable food, an estimated 21 million tons of wheat rots or is eaten by insects and rodents as a result of inadequate storage and poor management by government.

Increasing temperatures and unstable, moist weather conditions could result in grain being harvested with more moisture required for stable storage. The lack of drying facilities in these regions creates hazards for food safety and even causes complete crop loses. The absence of modern food distribution chains, too few cold-storage centers and refrigerated trucks, poor transportation facilities, an erratic electricity supply, and a lack of incentives to invest in the sector are believed to be the major reasons for the massive wastage of food (Biswas 2014). About 30–40% of the fruit and vegetables grown in India (40 million tons, amounting to US$13 billion) get wasted annually due to gaps in the cold chain such as poor infrastructure, insufficient cold storage capacity, the unavailability of cold storage in close proximity to farms, and poor transportation infrastructure. This has resulted in instability in prices and farmers cannot get remunerative prices in addition to rural impoverishment and farmers' frustrations (Ali 2004). Even with modern storage technologies, foods get wasted due to poor storage management and a lack of monitoring. The study shows there are 10%, 20%, and 25% post-harvest losses in durables (cereals, pulses, and oilseeds), semi-perishables (potato, onion, sweet potato, tapioca), and products like milk, meat, fish, and eggs, respectively, in modern storage (Maheshwar and Chanakwa 2006). Grain storage is a component of the grain marketing supply chain that evens out fluctuations in the supply of grain from one season, usually the harvest season, to other seasons, and from one year of abundant supply and releasing to lean years. So any losses in storage are bound to disturb the supply chain and, in turn, also affect market prices.

Climate change mostly affects small and marginal farmers, as they depend mostly on rain-fed mono cropping. Their food stocks begin to run out 3 or 4 months after harvest and farm jobs also remain mostly unavailable and by the next monsoon/sowing season, food shortages peak to hunger (Ramachandran 2014). Climate change will also have an adverse impact on the livelihoods of fishers and forest-dependent people, who are already vulnerable and food insecure. The increasing number of weather-related hazards will restrict fishermen from venturing into the sea, which may result in declines in fish catch. In addition, the rise in sea surface temperature will also disturb the marine ecosystem and have negative impacts on fish and other marine resource availability. Forest-dependent people, mainly the tribal population, will face a difficult situation as the yield of forest products will also be affected due to climate change (Chakrabarty 2016). Landless agricultural labourers wholly dependent on agricultural wages are at the highest risk of losing their access to food (Dev 2012). Besides climate change, poverty and unemployment are also an important factor in India, which reduces purchasing power as well as the capacity to access food and other basic necessities of life. Reducing poverty and generating employment among the population are among the biggest challenges facing India, particularly in relation to ensuring food security for the population living below the poverty line.

Climate changes will also have adverse effects on urban food security, especially for those who belong to a low-income group and are living in slums and informal settlements, as they are often exposed to hazards such as floods and landslides. For example, the city of Kolkata (erstwhile Calcutta) is particularly vulnerable to natural disasters, as climate change is likely to intensify the frequent flooding in the Hooghly River during monsoons. The poor inhabitants of Kolkata are most vulnerable as their homes are located in low-lying areas or wetlands that are particularly prone to tidal and storm surges (Dasgupta et al. 2012). Given that food is the single largest expenditure for poor urban households, displacement, loss of livelihood or damage to productive assets due to any extreme weather event will have a direct impact on household food security. The urban poor have also been identified as the group most vulnerable to increases in food prices following production shocks and declines that are projected under future climate change.

24.3 Current Adaptation Strategies and Challenges

Reducing risks to food security from climate change is one of the major challenges of India and adaptation actions to reduce risks are necessary. However, the extreme complexities of India's food insecurity due to existing factors and further exacerbation of the situation by climate change have made developing adaptation strategies very challenging. Poor people in India are more at risk of food insecurity, as they face more severe resource and economic constraints due to the high population growth rate and limited arable land (Kumar 2003). Food insecurity among the poor farming communities due to climate change has been further complicated by the decreasing per capita availability of arable land and is compounded by the challenge of meeting rising food demand due to high population growth (Roul et al. 2015). One of the most important widespread issues is linking food security in India to poverty and sustainability. Low food intake, poor health, low agricultural productivity and low income are perennial forces in the vicious poverty cycle in India. So, the issue is not only the availability of food but the affordability of food for vulnerable populations in adequate quantity and quality. So the question is whether increased food production can meet the needs of the rising population in a sustainable manner. A long-term strategy is needed to reduce the vulnerability of the farming community and sustainably intensify agricultural productivity with minimum degradation of land and natural resources being used (Varadharajan et al. 2013).

The following section will address risk factor-specific adaptation strategies based on the impacts of climate change. It is worth mentioning that several adaptation strategies have already been put in place by various stakeholders. The Indian Council for Agricultural Research (ICAR), the focal organization for India's agriculture research, technology development and transfer of technology, has accorded high priority to understanding the impacts of climate change and developing adaptation and mitigation strategies to meet the challenges posed by climate change to the agricultural system (Srinivasa et al. 2016). In 2011, the ICAR launched a network project called National Innovations in Climate Resilient Agriculture (NICRA, http://www.nicra-icar.in/nicrarevised/) to enhance the resilience of Indian agriculture to climate change and climate vulnerability through strategic research and technology demonstrations. The research on adaptation and mitigation covers crops, livestock, fisheries, and natural resource management. The project consists of four components: (a) enhancing the resilience of Indian agriculture to climatic variability and climate change through strategic research on adaptation and mitigation; (b) validating and demonstrating climate-resilient technologies on farmers' fields; (c) strengthening the capacity of scientists and other stakeholders in climate-resilient agriculture; and (d) drawing policy guidelines for wider-scale adoption of resilience-enhancing technologies and options. The expected outputs are (a) the selection of promising crop genotypes and livestock breeds with greater tolerance to climatic stress; (b) existing best bet practices for climate resilience demonstrated in 150 vulnerable districts; (c) the strengthening of infrastructure at key institutes for climatic change research; and (d) adequately trained scientific manpower to take up climate change research in the country and empower farmers to cope with climate variability (ICAR 2018).

The country adopted the National Agroforestry Policy in 2014 to encourage and expand tree plantation in an integrated manner with crops and livestock to improve productivity, and the employment, income, and livelihoods of rural households; to protect and stabilize ecosystems; and to promote resilient cropping and farming systems to minimize risks during extreme climatic events (Srinivasa et al. 2016). The policy also envisages meeting the raw material requirements of wood-based industries, of small timber for the rural and tribal populations, and for reducing the pressure on forests.

As the part of the adaptation to climate change, the Government of India (National Action Plan on Climate Change) emphasized dryland agriculture, risk management, access to information and the use of biotechnology (GoI 2018).

1. Adaptation for dryland agriculture: Sixty percent of India's agricultural land falls under the dryland/rain-fed zone. Thus, the impacts of climate change will significantly affect the nation's food security. To overcome the adverse impacts of climate stress on yield, the current policies have focused on (a) developing drought- and pest-resistant crop varieties; (b) improving the methods of conservation of soil and water; (c) stakeholder consultation and training for farming communities on agroclimatic information and dissemination; and (d) financial support to enable farmers to invest in and adapt relevant climate-smart technologies.
2. Managing risks due to extreme climatic events: The priority areas are: (a) strengthening agriculture and insurance; (b) better GIS-based, web-enabled natural resource mapping and utilization; (c) risk and vulnerability assessment and prediction; and (d) effective risk communication and management based on vulnerability and risk assessment.
3. Knowledge dissemination and translation: The strategies are: (a) developing micro-level databases of natural resources (soil, water), land-use patterns, plant genotypes, and weather patterns; (b) regular, accurate monitoring of natural resources, their degradation and impacts on agricultural production; and (c) the collation and dissemination of customized information to farming communities.
4. The development and utilization of climate-smart biotechnology: The targeted technological solutions are: (a) drought-, flood-, and pest-resistant crops; and (b) genetic engineering to develop more carbon-responsive C-4 crops for increased productivity, the high utilization of CO_2 and sustaining thermal stresses (GoI 2018).

Climate-Smart Agriculture or CSA is considered a pragmatic approach that helps to guide actions needed to transform and reorient agricultural systems to effectively support development and ensure food security in a changing climate. According to FAO, the CSA has three main objectives: (a) sustainably achieving agricultural productivity and incomes; (b) adapting and building resilience to climate change; and (c) reducing and/or removing greenhouse gas emissions, where possible. CSA is not a monolithic approach; rather, it considers the existing diversity of social, economic and environmental contexts including agro-ecological zones and farming systems accordingly. CSA, therefore, identifies and integrates a package of climate-resilient technologies and practices for the management of natural resources at the farm level while considering the linkage between agricultural production and ecosystems services at the landscape level (Likhi 2017). Thus, CSA provides a broad enabling framework to help all stakeholders to identify sustainable agricultural strategies suitable to the local conditions. The following section will address adaptation strategies based on the principles of CSA applicable to Indian conditions (FAO 2015; Shelat 2014).

24.3.1 Conservation Agriculture

Conservation agriculture embodies three main principles: reduced or zero soil disturbance, permanent organic soil cover to reduce soil loss, and crop diversification. According to the FAO, crop diversification with intercropping and rotation improve the nutritional security of farm households and reduce the risk of total crop failure in unfavorable or erratic weather. There is also the potential for gender equity in conservation agriculture; for example, male-driven soil tillage work can be replaced by female-driven weeding work. This is extremely important in the current situation due to a rising feminization of the agriculture workforce due to the outmigration of the male workforce to cities for better opportunities (FAO 2013).

In South Asia, conservation agriculture has emerged as a new paradigm to achieve sustainable agriculture goals. Conservation agriculture is an approach developed to manage farmland for sustainable crop production, while simultaneously preserving soil and water resources. Conservation agriculture largely depends on three major principles: (a) the maintenance of a permanent vegetative cover or mulch on the soil surface; (b) minimal soil disturbance (no/reduced tillage); and (c) a diversified crop rotation. Given the effects of conservation agriculture on soil, water, and economic viability, this management has been widely recommended and adopted with mixed success (Jat et al. 2014).

The Green Revolution, which improved food security in India, ignored a vast swath of rain-fed agro-ecosystems. Unpredictable patterns of rainfall, biotic and abiotic stresses and adherence to traditional farm practices have resulted in poor cropping intensities and low yields (Pradhan et al. 2018). However, for India's rain-fed areas, further local-level adjustments are needed before implementing any broad policy on conservation agriculture (Jat et al. 2014). The tribal population, the most vulnerable sector of India's society, lives in the rain-fed areas located in the central region of the country (also known as the Poverty Belt). Since more than 90% of the nation's tribal people are totally dependent on agriculture for their livelihood and food consumption, poor food production has led them to suffer from chronic malnutrition (Pradhan et al. 2018). Excessive and inappropriate tillage increases soil degradation and erosion, reducing soil productivity and soil organic carbon. Agricultural intensification is needed in the rain-fed regions without further degrading of the natural resource base. It is paramount that the implementation of a new agricultural production system to improve household food and nutritional security as a part of adaptation to climate change be viewed in the context of enhancing farm productivity, environmental quality, and profitability of agriculture (Pradhan et al. 2015).

Reduced and no tillage for planting wheat is gaining increasing acceptance with farmers in South Asia because of reduced land preparation costs. More than 13,500 on-farm trials have been conducted in South Asia to evaluate different resource conservation technologies for rice and wheat. These trials showed that reduced and zero tillage with residue mulch performed better than the conventional till broadcast (Jat et al. 2014). However, the experience in China shows that despite some benefits in crop production, conservation agriculture can also reduce crop production through undesirable effects on soil's physiochemical and biological conditions. According to the researchers, the key limiting factor in the application of conservation agriculture in China is the uncertainty of the long-term effects on soil and crop yields. The effects of conservation agriculture on crop yield increased and decreased with decreasing and increasing annual precipitation, respectively (Zhang et al. 2015). A study in India showed that reduced tillage combined with planned intercropping had higher system productivity and net benefits. The results demonstrated that conservation agriculture could concurrently increase crop yield, diversify crop production and improve soil quality, which eventually would move towards the sustainable intensification of crop production, improving household income and ensuring food security (Pradhan et al. 2018).

24.3.2 Natural Resources Management

Irrigation plays very significant roles in reducing the negative effects of climate change on agricultural productivity, with the biggest reduction being in rain-fed farming systems (Birthal et al. 2014). However, it is important to note that irrigated lands are not insulated from climate change. Changing precipitation has already affected the river systems. Poor rainfall and receding glaciers are major threats to normal water flow. In addition, unsustainable groundwater extraction has made the situation more precarious.

India has 20 river basins and 12 of them are considered major, covering a total catchment area of 2.53 million km^2. Large irrigation potential has been the foundation of India's agricultural growth and past food security. However, the large river irrigations have been significantly affected by climate change by impacting their hydrological cycle. Eventually, these changes have affected the supply of water from inflow from rivers, reservoirs, tanks, ponds and groundwater resources and impacted their ability to replenish water. The projected increase in precipitation variability, which implies longer drought periods, would lead to an increase in irrigation requirements, even if total precipitation during the growing season remains the same. In addition, the irrigation demands could become even greater if rain-fed areas are not able to meet expected food needs. It has been projected that a significant increase in runoff may be witnessed in India. Predictably, as the increased runoff will be mostly in the wet season, the extra water will remain unavailable in the dry season. On the other hand, the extra water in the wet season may increase the frequency and duration of floods. A detailed simulation study on the impact of climate change on water resources in the river systems established that in the near future, while some river systems may have decreased water flow, other rivers may have a high intensity of floods (Kaur et al. 2003). Therefore, adequate water storage infrastructure is needed as a part of adaptation measures. The increased melting and recession of Himalayan glaciers associated with climate change could further alter the run-off (GoI 2013).

Groundwater resources are being rapidly depleted because of unsustainable extraction levels that exceed natural recharge rates. While the global average of the contribution of groundwater in irrigation is about 40%, in India it is expected to be over 50%. Some Indian states have a very high dependency on groundwater for irrigation (60–80%) (Dhawan 2017). Groundwater is crucial, even where crops are irrigated by surface water, particularly when prolonged droughts affect the supply of water. Thus, climate change is likely to increase the demand for groundwater to facilitate irrigation management (Palanisami et al. 2013). Despite the growing scarcity, groundwater irrigation in India remains highly inefficient from a technical point of view. For example, only 3% of India's 8.5 million irrigation well owners used drip or sprinkler irrigation and 88% delivered water to their crops by flooding through open channels. Now, almost 40% of the wells are showing a decline in groundwater level (Dhawan 2017). Groundwater irrigation often encounters competition from urban and industrial demand for water, resulting in conflict in many places. The rapid depletion of groundwater results in an increase in the energy required to pump water, making irrigation more expensive and in turn adding more stress to agriculture (Palanisami et al. 2013).

Studies on watershed development and joint forest management programs in India show that direct human pressure on forests has been considerably high and climate change is making the situation worse. It is important to have integrated knowledge management and effective coordination in the management of the water shed and forest sector and social vulnerability assessment. The research should focus on long-term and multi-sector planning, implementing and interventions for climate change adaptation. Internalization of the valuation of environmental services in the mainstream economy, information sharing, and improvement of governance can ensure sustainability (CCA RAI 2014).

As part of adaptation strategies to climate change, the following steps should be implemented:

(a) Integration of the uses of surface and groundwater needs to be developed.
(b) Reducing wastage, better water-harvesting capacity, and increasing the rate of storage recharge (particularly by community-based micro-storage facilities and aquifer recharge).
(c) Ensuring natural recharge rates are closer to groundwater extraction rates so these reservoirs become more sustainable.
(d) Lining of water transport systems to reduce seepage losses.
(e) Developing the ability to carry over water from one season to the next by proper storage such as in the vadose zone (between the soil surface and water table) above aquifers.

(f) Improved storage structures with sluice modification, sluice management, canal lining, and rotational irrigation with bore well supplementation.
(g) Starting the vigorous evaluation of industrial and sewage wastewater usage to reduce dependence on freshwater supplies.
(h) Better governance through inter-departmental coordination with a proper framework of sustainable water management and optimized water recycling.
(i) Better coordination with the meteorological department for better planning in selecting crops, selecting dates for planting, spacing, and input management.
(j) Promotion of rice intensification, machine transplantation, alternate wetting and drying.

(Pathak et al. 2003; Naresh et al. 2013, 2014).

Before developing macro-level national policy on rain-fed areas, it is important to generate evidence at the micro level, at least at the block (*taluka*, similar to a county) level. Local agriculture institutions and their affiliated extension centres (also known as *Krishi Vigyan Kendra*) can play pivotal roles in generating evidence by (a) analyzing biophysical and socioeconomic impacts and risks of climatic variations on local watershed development programmes; (b) assessing the sensitivity and vulnerability of the watersheds based on the projected climate scenarios; (c) studying the existing maladaptation practices in the watersheds that can exacerbate the effects of climate change; (d) addressing the risks and opportunities (such as the convergence of watershed development with other ongoing development activities) arising due to climate change; and (e) building and strengthening climate change adaptive capacities of communities within a watershed, without foregoing development for the poor. Therefore, research on assessment of the impacts of climate change should encompass soil, water, forests, pastureland, livestock, agriculture practices and the livelihood of the communities.

24.3.3 Climate–Smart Crops

Adaptation strategies for dealing with the impacts of climate change depend not only on climate parameters but also on the existing system's ability to adapt to change. The potential depends on how well the crops adapt to the concomitant environmental stresses due to climate change. Climate-smart horticulture can be a practical solution, but any single specific agricultural technology or practice cannot be universally applied. Rather, it is an approach that requires site-specific (agro-ecological region) assessments to identify appropriate production technologies. In the event of working out adaptation and mitigation strategies, it will be appropriate to utilize modelling tools for impact analysis for various horticultural crops. As of now, except for potato and coconut, there are no good simulation models for horticultural crops in India. Innovative methods are essential in developing simulation models for important horticultural crops such as mango, grape, apple, orange, citrus, litchi, and guava. The existing climate-smart crops (which are able to cope with high temperature, frost, and excess moisture stress conditions) should be integrated to the specific agro-ecological region. The production systems for each crop should address improved water-use efficiency and adapting to hot and dry conditions. For example, for sowing or planting dates, fertilizer application can be determined by forecasting weather and measuring soil nutrients. Providing irrigation during critical stages of crop growth and the conservation of soil moisture reserves are the most important interventions. Other crop management practices such as mulching with crop residues and plastic mulches to conserve soil moisture, and growing crops on raised beds to protect them from excessive soil moisture due to heavy rain are the most important adaptation strategies (Malhotra 2017).

Rice and wheat are important crops for a large portion of India, being the main sources of food and the agriculture of which is a main source of income. Genome editing, which has been a focal point of research in recent times, is now rightly being targeted towards improving the quality of crops. Research using CRISPR genome editing tools has increased the ability to target and modify crop genes for the development of improved varieties in terms of yield and ability to withstand climate-related stress such as drought, flood, diseases (fungal and pest), high temperature and low humidity. Genome editing is a successful and feasible venture and the latest developments and improvements of CRIPSR tools could further enable researchers to modify more genes in rice and wheat with increased efficiency. Indian scientists have made significant progress in CRISPR technology and it should be used as a part of the development and promotion of climate-smart crops across the country (Mazumdar et al. 2016; Rani et al. 2016; Srivastava et al. 2017). The Philippines-based International Rice Research Institute, which is supported by the Bill and Melinda Gates Foundation, is actively involved in collaborative research on such crops (Temple 2017). CRISPR genome editing tools are also used in fisheries and horticulture. Studies in India showed the recent advances in gene editing techniques in farmed fish (*Labeo rohita* also known as *rohu*) and bananas (*rasthali*) (Chakrapani et al. 2016; Kaur et al. 2018).

24.3.4 Farmers' Prioritization of CSA Technologies

Despite the known benefits of CSA technologies, the current rate of overall adoption by Indian farmers is fairly low. A community-based participatory study in India assessed farmers' preferences and willingness to pay for some selected climate-smart technological options, such as water-smart (rainwater harvesting, drip irrigation, laser land levelling, drainage management, cover crops), energy-smart (zero/energy tillage), nutrient-smart (site-specific integrated nutrient management, green manure, intercropping with legumes), carbon-smart (agro-forestry, fodder management, integrated, pest management, concentrate feeding for livestock), weather-smart (housing for livestock, crop insurance), and knowledge-smart (contingent crop planning, climate-smart crops, seed and fodder banks). The study showed that many socioeconomic and location-specific variables have a significant effect on farmers' preferences towards a particular CSA technology. For example, farmers from areas with low rainfall and high coefficients of variations in annual rainfall preferred risk mitigation technologies such as crop insurance, weather-based crop agro-advisories, and rainwater harvesting. On the other hand, farmers from high rainfall zones had a low preference for rainwater harvesting and crop insurance. Despite the demonstrable benefits of many CSA technologies, the concerned farmers may not be willing to invest in them. Therefore, adaptation policies should highlight the crucial role of providing information about available CSA technologies and making financial resources available to the farmers to adopt various locally relevant CSA technologies. More experienced farmers were more confident about choosing CSA technologies, except certain ones such as rainwater-harvesting technologies. Female farmers usually preferred integrated pest management, weather-based crop agro-advisories, and contingent crop planning compared to male farmers. Preferences for rainwater harvesting and climate-smart housing for climate change adaptation were significantly negative for female farmers. The results also indicated that low-income farmers were more likely to prefer site-specific integrated nutrient management, integrated pest management, and laser land levelling compared to rainwater harvesting, contingent crop planning, and crop insurance (Khatri-Chhetri et al. 2017).

24.3.5 Addressing Fundamental Issues: Conflict Resolution, Crop Insurance, Food Wastage, and the Public Distribution of Food

For conflict resolution with regard to water disputes, it is paramount to pay special attention to conflict components in each context. To avert future climate change-induced conflicts over scarce water resources, different available options should be availed of for peaceful crisis management and conflict resolution. There is a need to enact a new national water policy to combat, mitigate, and adapt to water scarcity situations which may arise out of climate change. If the uncertainties arising out of climate change are to be integrated into water management planning, there is an urgent need for enhancing water storage capacity, and effective technological and financial planning to stop overconsumption and to apply the more sensible use of ground and surface water. The successful operation of a national water policy that is responsive to climate challenges requires strong research-based knowledge and appropriate institutional support at all levels of governance. Since the Indian Constitution reserves the power of the federal government in establishing legislation on the use of interstate rivers and on the adjudication of interstate disputes over water, it is important to use this precious natural resource amicably and to accept shared benefits. To reduce future water stress, all the stakeholders should be part of monitoring and planning on climate change impacts on water resources, improving management capacities, building water management institutions to serve local purposes and reliance on dialogue and confidence building (Taenzler et al. 2011).

Though the Government of India has initiated efforts for providing crop insurance to farmers since independence, a major boost was given in the form of the Comprehensive Crop Insurance Scheme (CCIS) in 1985 during the Seventh Five Year Plan period, which covered the risk in the cultivation of major crops against natural calamities and pests and diseases (Raju and Chand 2009). The National Agricultural Insurance Scheme (NAIS) which is also known as the *Rashtriya Krishi Bima Yojana*, replaced the CCIS in 1999–2000. NAIS operates in all States and Union Territories of India. The percentage of farmers covered under NAIS increased from 9.08% in 2000 to 15.95% in 2007 (Brahmanand et al. 2013). Still, a substantial percentage of farmers remain without crop insurance coverage and, not surprisingly, regular crop failures due to climate change result in the suicides of thousands of Indian farmers. A study in India demonstrates that fluctuations in temperature, particularly during India's agricultural growing season, when heat also lowers crop yields, significantly influence suicide rates. The study concludes by estimating that around 60,000 additional suicides in 30 years (since 1980) can be attributed to warming and the author could not find any evidence of adaptation to reduce the number of suicides (Carleton 2017). Therefore, crop insurance being made available to all the vulnerable farmers is essential to prevent such unfortunate consequences of climate change-driven crop failure.

If the current rate of food wastage continues, no adaptation strategy will be able to achieve the desired food security. Therefore, the adaptation strategy should consider the prevention of food wastage at all stages. The proposed solutions are (a) improved access to low-cost handling and storage technologies (evaporative coolers, metal silos); (b) real-time wireless/mobile-enabled sensors to monitor the storage conditions of perishable food during transportation and data transfer to the clients; (c) the establishment of mega food parks to increase the processing of perishables; (d) the development of innovative and intelligent packaging for perishables; (e) the identification/creation of businesses that buy unwanted food/produce directly from distributors/manufacturers for discounted retail sale; (f) the development and expansion of secondary markets for items with cosmetic damage; (g) the expansion (in number and capacity) of large food grain storage facilities, which are essentially managed by government (Food Corporation of India). Evidence shows that technology is central to addressing food waste, but the ultimate success requires the readiness to change attitudes of the stakeholders along the value chain (Bordoloi 2016; Athar 2018).

The Public Distribution System (PDS) plays a very important role in developing countries to ensure the fair distribution of subsidized food grains (especially rice and wheat) and other essential commodities such as sugar and kerosene to the poor population through a network of fair price shops. In India, this scheme was launched in 1947 and it is still the biggest social scheme for the poor, especially for people living under the poverty line. Although millions of poor citizens of India receive benefits from this scheme, which acts as a food security system, there are still several problems that have prevented this scheme from producing the desired effect on the availability, accessibility and optimum utilization of food grains. The major problem faced by the PDS in India is widespread corruption. A large number of poor and deserving households are left out and a lot of fake cards (which are required for receiving food) are also issued. People often do not get the sanctioned amount of food grains from the fair price shops due to the corruption of the shop owners or ignorance of the beneficiaries. The shop owners are notorious for stealing and overcharging, supplying poor-quality food grains, trading cards for money, and complicated bureaucratic procedures prevent many poor Indians from obtaining such cards. The study shows that more than half of the PDS food grain does not reach the intended people (Kumar et al. 2014). The PDS is the only available system for access to food for the vulnerable population across the country. The benefits of CSA can be achieved by ensuring equity only after revamping the PDS. Better governance, such as effective grassroots monitoring, empowering the local regulatory authority, addressing public grievances, and developing a decentralized functioning system are the keys to the effective functioning of PDS.

24.4 Use of Drama Theory: A Behavioral Decision Model in Food Security, Adaptive Strategies for Public Policy Perspectives

This section gives a view about the application of a behavior model to change people's and government's perspective in terms of adoption and food security. We proposed the potential use of drama theory, a behavioral decision model, to find a win-win situation for the multiple players involved in their dynamic responses. Rationally, any choice is determined in terms of costs and benefits and what maximizes their net benefits. But drama theory captures the "non-rational" aspects of the decision-making process such as crisis, emotion, and self-realization. This approach addresses how players apply rational emotional-pressure on each other to redefine the game prior to it being played (Stubbs et al. 1999).

Drama theory is further developed by Howard et al. (1993), Bennett and Howard (1996) and Howard (1999, 2007). This approach addresses how players (characters) apply rational emotional-pressure on each other to redefine the game prior to it being played (Stubbs et al. 1999). The fundamental difference between game theory and drama theory is that a drama allows for the possibility of the game itself changing even though the environment remains informationally closed; that is, it considers the possibility of endogenous changes arising from interactions within the game itself (Howard 1994). The elements of a frame which corresponds to the game theoretic concept of a game include a set of characters that have options in which characters interact through a series of episodes. A dramatic episode is an interaction between parties in which a set of issues is at stake. It ends when some of the issues are decided so that there is now a new set of issues (Howard 2007). Characters' choices influence the outcome of each particular episode, and also what episodes happen next. Within each episode, the phases are referred to as scene setting, buildup, climax, and denouement, a structure repeated on a large-scale for the drama as a whole. In the buildup stage, characters communicate, with each pressing for a particular position, a scenario they wish to have created and in the climax of the episode, the frames themselves come under pressure. The "moment of truth" occurs in a drama-theoretic model at the end of the buildup and they move on to the climax. It is a point in an interaction where each party has communicated a position and stated intentions it regards as "final."

Howard (1999) developed a technique to analyze conflict and cooperation to solve real-world problems, which is called Confrontation Analysis. This is also called Dilemma Analysis. This is derived from drama theory. This technique uses a card table model to analyze the conflict. A card table model of the moment of truth consists of:

1. A set of characters, each holding a number of cards, for each of the characters has a position. This is a specification of each card (belongs to all the characters) and whether it should be played or not played.
2. Fallback positions/threatened future. (A character's fallback consists of the cards it is threatening to play if its position is not accepted. The character may not intend to carry out its threat; that is, it may be bluffing. In any case, threatened future is a scenario that would result from the implementation of everyone's declared fallback).

Howard (1994) mentioned that there are only six dilemmas the character faces during the confrontation phase. Later, he again modified it as three dilemmas (Drama Theory 2). In Drama Theory 2 (Levy et al. 2009) states that all dilemmas are defined in terms of doubts. It is simpler and also more insightful. Instead of asking "Is this whole future preferred to this one?" it asks "Which option choices in this future are preferred to those in this one?" The metaphor of drama describes the interaction of different characters and how they change their preferences, develop and perceive the new outcomes. When none of the dilemmas exist, then the characters have an agreement that they fully trust each other to carry out the action. To solve the food security problem, close cooperation is needed among government and citizens. The government also needs to change their policy based on public opinion. The effectiveness of ongoing traditional approaches may be limited without the addition of measures to understand how to engage citizens in cooperative behavioral change (Hefny 2012).

A simplified government and farmers interaction is modeled using Drama Theory II to analyze how parties can find mutual ground to collaborate. Figure 24.1 shows a dilemma for adaptation strategies related to giving subsidies to farmers by the government. In this figure, a frame of confrontation has been depicted where farmers and government both are in a rejection dilemma as both the parties are in a situation where there is a possibility of little change of their respective positions. This situation must be avoided as this case would be a lose-lose situation for both parties and not taking adaptive strategies would lead to a bigger cost to the society.

To eliminate the rejection dilemma, parties can choose a new fallback position (Fig. 24.2). Here, communication between both parties plays a big role. Both parties' cooperation has added value. After communicating with each other, the gov-

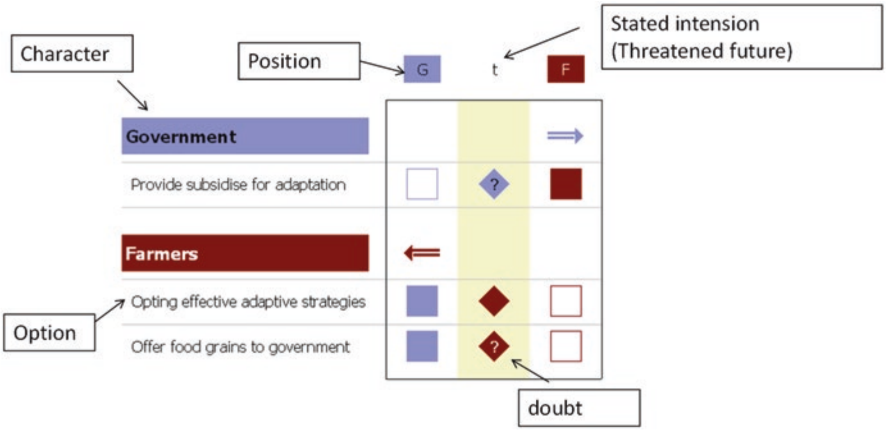

Fig. 24.1 Confrontation card table: government and farmers

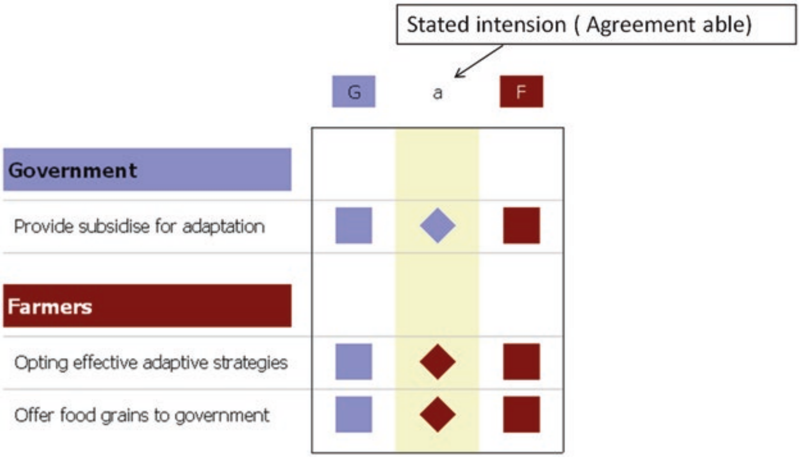

Fig. 24.2 Possible collaboration

ernment comes up with a subsidies option and thus the farmers are able to take adaptive strategies and agree to sell their food grains to the government, which turns the confrontation, and eventually leads to the adopting of different options and preferences by the parties, to a win-win situation. Now, in this new phase of the episode, both parties' positions are compatible with each other's; thus, no dilemma exists. Thus, drama theory leverages how to redefine the parties' options and preferences through continuous communication to find their acceptable positions.

24.5 Conclusion

"Climate-smart agriculture" seems to be a pragmatic approach to counter the impacts of climate change on food security. However, extensive community-based research is required to develop more realistic strategies. Regular dialogues between all the stakeholders are key to the acceptance and successful implementation of the approaches. Lastly, the core issues such as transboundary water conflicts, crop insurance, food wastage and food distribution are essential components to achieve the goals for adaptation.

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