# Managing Climatic Risks in Agriculture

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## 1 Introduction

The contribution of agriculture in India's national gross value added (GVA) is only about 17%. However, its role in human wellbeing is vital considering its critical contribution in food, employment and livelihood security for 1350 million people.

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Agricultural production of India has been continuously rising and has reached almost 290 million tonnes in 2019; but India continues to have an undernourished population of approximately 14% (von Grebmer et al., 2020). Absolute quantity of food grains demand will continue to increase with rising population and income. The pace of food production must be accelerated to achieve food and nutritional security, which is imperative for India to achieve the zero-hunger goal by 2030. A systemic approach is necessary for increasing food production, and improving its distribution and service delivery mechanisms in view of the rapidly changing climatic conditions, continued population growth, urbanisation, changes in diets and depletion of natural resources that are exerting unprecedented pressure on food systems (FAO, 2018). Broader context of managing risk in Indian agriculture needs to be the basic need for securing human well-being.

The immense influence of climatic stressors, particularly the spatial and temporal rainfall variability, continues to keep the seasonal and annual yield from Indian agriculture uncertain. Climate change is projected to cause significant adverse impacts on the agriculture of tropical regions including India. Combined with increased competition for land, water and labour from non-food sectors, climate change and associated increase in climatic variability will exacerbate seasonal/annual fluctuations in food production. As all agricultural commodities are climate-sensitive, hence, even the current climate and weather patterns—the droughts, floods, tropical cyclones, heavy precipitation events, hot extremes, heat waves, cold waves, frost events and hailstorms– are impacting agricultural production and farmers' livelihoods. For instance, loss of farm revenue due to extreme temperatures and rainfall shocks is estimated to be ~12% for monsoon (*kharif*) and ~6% for winter (*rabi*) crops with more impacts on unirrigated systems. Similarly, extreme temperatures caused a farm revenue loss of 4% during *kharif* and 5% during *rabi* (The Economic Survey, 2018). Negative anomalies of monsoon seasonal precipitation and number of rainy days during 1966–2010 are highly correlated with negative anomalies of *kharif* and *rabi* food grain yield (Prasanna, 2014).

Climate change is causing significant shifts in weather patterns throughout the world, and climate change is expected to alter the agricultural production systems across the world, posing major challenges to the livelihoods and food security of millions of people (IPCC, 2014). South Asia, along with Africa, is likely to be the most impacted in future. Increased temperatures, changed rainfall patterns and more frequent and intense floods and droughts will impact the food production (Lobell et al., 2012; Rosenzweig et al., 2014). The impacts of climate change on crop yields indicate that yield losses may be up to 60% by the end of the century depending on crop, location and future climate scenario (Rosenzweig et al., 2014; Challinor et al., 2014). Increasing climatic variability may further complicate agricultural production and food security as almost one-third of yield variability is related to climatic variability (Ray and Chowdhury, 2015).

Risk management in agriculture sector is getting complicated due to rising market uncertainty. As mentioned above it is becoming clear that production, distribution and delivery mechanisms need to be managed systematically in Indian context. Production uncertainty leads to income uncertainty and price volatility. Attention, therefore, needs to be given for both commercial and home gardens and minimising pest attacks and livestock related diseases. This also impacts accessibility and affordability and market opportunity for various social groups in different ways leading to indebtedness to meet basic and decent living standards. There are many options to mitigate the negative impacts of climate change, to minimise risks to agricultural systems and make the latter resilient to climate change and help reduce emissions (Some et al., 2019). Options range from change in crop management, such as sowing time, stress resistance varieties, change in cropping systems and land use, to adjust to new climates (Porter et al., 2014). This chapter will provide a summary of the probable impacts of climate change and the options available to India for managing its negative impacts.

## 2 Climate Change in India

Climate change projections, derived from the bias corrected probabilistic ensemble of 33 global climate models, indicated that rise in minimum temperature is likely to be more than the rise in maximum temperature in India. It will be more during *rabi* (October–April) than that during *kharif* (June–September). An increase in minimum temperature by 0.946–4.067 °C in 2020–2080 over baseline (1976–2005 period) in *kharif*; and by 1.096–4.652 °*C* in *rabi*, is projected. Similarly, an increase in maximum temperature by 0.741–3.533 °*C* (2020–2080) during *kharif* and by 0.882–4.01 °*C* is projected for *rabi*. Rise in temperatures is projected to be more in northern parts of India than that in southern parts. Variability in minimum and maximum temperatures is projected to be significantly more during *rabi* than that during *kharif*. Increase in rainfall by 2.3–3.3% (2020), 4.9–10.1% (2050) during *kharif*, and by 12% (2020), 12–17% (2050) *rabi* with increased variability as compared to baseline period (1976–2005) are projected (Naresh Kumar et al., 2019).

These changes will increase occurrence of extreme events including unseasonal rainfall, droughts and floods throughout the country. The sea-surface temperature has already risen by almost 1 degree over the last century and is expected to rise in the coming years (Krishnan et al., 2020). This will lead to a projected sea-level rise of 300 mm in the Indian ocean by the end of the century relative to 1986–2005 values. There has been an increase in both the spatial and temporal frequency of droughts since 1950s. Some of these droughts showed an increased severity over the last few decades and are projected to increase in frequency and magnitude. Increase in severe tropical cyclones along the coastline of India is also anticipated.

Agriculture also contributes about 16% to total greenhouse gas (GHG) emissions in India. The Indian agriculture emits 417.2 Mt $CO_2$e of total GHG emissions that comes from—enteric fermentation, 54%; agricultural soils, 19%; rice cultivation, 18%; manure management, 7%; and field burning and agricultural residue, 2% (MoEFCC, 2018).

# 3 Projected Impacts of Climate Change on Indian Agriculture

## 3.1 Crops

Studies indicated different values of impact on crop yields depending upon the method and climate change scenario used for impact assessment. Most studies indicated a decrease in yield with time. Studies conducted at the Indian Agricultural Research Institute and elsewhere indicated a yield loss in wheat up to ~9%, irrigated rice ~12%, maize ~18%, mustard ~12% and potato ~13% by 2040 under RCP 4.5 scenarios without adaptation as compared to the mean yield between 2000–2007 despite $CO_2$ fertilisation effects (Naresh Kumar et al., 2013, 2014a, b, 2015, 2019). In addition, negative impacts of ~2.5% on rainfed sorghum yield by 2040 are projected as compared to the mean yield of 2000–2007 (Srivastava et al., 2010; Naresh Kumar et al., 2012) even with rise in atmospheric $CO_2$ concentration in future climates. Increase in minimum temperatures is affecting maize yields in the Telangana region (Guntukula and Goyari, 2020). *Rabi* maize is projected to have increased yield in the range of 8.4–18.2% in 2020 scenario in Bihar (Haris et al., 2013). Pearl millet yields are projected to reduce in parts of Maharashtra while they may improve in Haryana in future scenarios of 2030 and 2050 (Piara Singh et al., 2017). On an all-India basis, yields of groundnut, soybean (Naresh Kumar et al., 2012) and cotton are projected to improve due to climate change. Similarly, chickpea yield is projected to improve (by 17–25%) in Haryana and central Madhya Pradesh but is projected to decrease (by 7–16%) in southern Andhra Pradesh in 2050 scenario (Piara Singh et al., 2014). However, regression analysis indicated a plausible decrease in pigeon pea yield by ~ −3.2 to −10.1% in 2035 scenario, without considering $CO_2$ fertilisation effects. The decrease in yield may be even up to ~18% in 2065 scenario (Birthal et al., 2014). Coconut plantations are projected to gain in western coast while significant yield loss is projected for eastern regions of the country (Naresh Kumar & Aggarwal, 2013). Shift in apple belt to higher elevations from 1250 to 2500 mamsl is reported from Himachal Pradesh and Kashmir. Changes in rainfall pattern and shift in seasons are significantly affecting Assam tea yields (Nowogrodzki, 2019). Arabica coffee plantations in India are projected to lose yield and may shift to higher altitudes (Merga & Alemayehu, 2019). The Indo-Gangetic plains of Uttar Pradesh, Bihar and West Bengal exhibited high sensitivity of crop yields to climatic variables (Rao et al., 2016). Severity of droughts and intensity of floods in various parts of India are likely to increase (Pathak et al., 2014).

Climate change is projected to affect grain quality as well. Grain protein is projected to reduce by about 1.1% in high $CO_2$ and low N input conditions in wheat. In addition to protein, the concentration of minerals such as Zn and Fe is also likely to reduce in many crops (Porter et al., 2014). Similarly, the quality of horticultural crops is reported to be affected due to temperature stress, heavy rainfall events and high $CO_2$ (Table 1; Naresh Kumar, 2009).

**Table 1** Effect of elevated $CO_2$ (550 ppm), temperature and rainfall on the quality of produce of some horticultural crops

| Crop | Parameter |
|---|---|
| Apple | Exposure to direct sunlight and high temperatures causes accumulation of sugars; high temperatures increase tartaric acid in fruits, affects fruit firmness; causes sunburn, loss of texture and development of water core in fruits. In ripening apples, anthocyanins are synthesised at temperatures <10 °C. High temperatures affect biosynthesis of anthocyanin pigment and cause poor red peel |
| Strawberry | Warmer day (25 °C) and night (18–22 °C) increase antioxidant components such as flavonoids. Fruits develop darker red colour |
| Vine grape | High variation (15–20 °C) in day/night temperature promotes anthocyanin development |
| Sweet potato | Elevated $CO_2$ increases starch, carotene and glucose |
| Coconut | Increase in storage temperature reduces keeping quality of oil |
| Arecanut | Storage temperature >28 °C reduces myristic acid |
| Cashew | High rainfall coinciding nut development causes nut germination, blackening of nuts |
| Black pepper | Increased temperatures may increase b-caryophyllene and lower limonene, sabinene and myrcene |
| Onion | High $CO_2$—decreases flavonoids, temperature above 40 °C reduces the bulb size in onion |
| Tomato | High $CO_2$ increases lycopene and carotenoid content; increases vitamin C, sugars and acids |
| Capsicum | Temperature >27 °C inhibits red colour development |

(*Source* Naresh Kumar, 2019)

## 3.2 *Pests and Diseases*

Climate variability and change impact the interactions between crops, insect pests and their natural predators. Pests are projected to cause more damage to crop owing to excessive feeding on foliage that has high C:N ratio. In addition, alterations in synchrony of crops and pest phenological events, reproductive behaviour of pests, etc., affect the pest load on crops and alter pest species dominance. In the last 20 years, several insect pests such as Asian fruit fly, American tomato moth, blackfly, desert locust, fall armyworm and mango fruit borer have been reported as invasive species along with others across various regions in India (Chakravarthy et al., 2013; Vennila et al., 2018).

The recent 2020 desert locust attack on crops in north-western India is reported to be highly damaging vis-à-vis earlier attacks since 1993. The locust swarm came from Africa and Middle East triggered by climatic risks in the region. The 2020 outbreak affected cumin, rapeseed and mustard, particularly in Rajasthan and Gujarat. According to the Locust Warning Organization, Jodhpur, so far 19 events of locust plagues have occurred between 1964 and 2020. Before the recent event, the last major outbreak was in 2010. The prolonged monsoon is suggested to have helped its outbreak. In India, fall armyworm affected maize crop in about 170 thousand ha mainly in Karnataka, spreading to western Maharashtra and Gujarat and eastern states in 2018 and 2019. While advancing fast, it also damaged paddy, sugarcane and sweet corn. Yield loss due to fall armyworm is estimated to be 33% in an isolated study from a single district of Telangana (Balla et al., 2019). Long dry spells coupled with overcast sky made maize susceptible to attacks of pest. Adverse impact on biodiversity in home gardens owing to climate change through changing pests is becoming common in South Asia (Marambe et al., 2018) and in dry zones of West Bengal (Jana et al., 2014, Jana & Roy, 2019), where home gardens are substantial supplementary nutrition security providers.

Simulation studies indicated additional generations drive higher incidence of *Spodoptera litura* and *Aphis craccivora* on groundnut (Rao et al., 2014); *Bactrocera dorsalis* on mango (Choudary et al., 2017) and *Tuta absoluta* on tomato (Kanle Satishchandra et al., 2018) in climate change scenarios. Similarly, diseases such as powdery mildew of wheat, are likely to be restricted to the western zone only, except a slight change in the eastern plains. A marginal increase in leaf blast pattern in boro rice grown during December to March in the eastern part of the India is projected (Viswanath et al., 2017).

The devastating effect of plant pests impacts mainly the food-insecure populations. In India, estimated crop loss due to insect pests increased from about 7.2% in 1960s to 16.8% in 2010s (Dhaliwal et al., 2015). Hence, these pest and disease incidences and outbreaks should be effectively controlled by starting online plant clinics like online human health clinics in COVID-19 pandemic.

### *3.3 Livestock*

The livestock sector is also projected to be significantly affected by climate change. Risks to plants and animals in home gardens in dry districts of West Bengal are becoming more visible (Jana & Roy, 2020). The thermal stress affects the quantity and quality of milk and reduces body weight of goats (Pragna et al., 2018). It is estimated that this will reduce milk yield by 1.6 million tonnes in 2020 and >15 million tonnes in 2050 (Naresh Kumar et al., 2012). Crossbreeds are more affected than that of local breeds. In addition, heat and cold waves cause short- and long-term cumulative effects on health and milk production in cattle and buffaloes. Climatic stress related loss of milk yield in Trans and Upper Gangetic plains of India is projected to cause a loss of INR 12 billion per year in this decade (up to 2029), which may double in the next decade (Choudhary, 2017). Poultry is also projected to face heat stress causing a reduction in yield of meat and egg; temperatures beyond 42 °C cause bird mortality. Increase in temperature from 31.6 to 37.9 °C decreases feed consumption by 36% and egg production by 7.5% in broiler breeds. In commercial layers decline in egg production was 6.4% (Naresh Kumar et al., 2012).

### 3.4 Fisheries

Climate change is projected to impact fisheries by altering abundance and distribution of marine fish species and their breeding and migration patterns. Extension of abundance of oil sardine species from southern latitudes to northern latitudes along the Indian coast is linked to increasing sea surface temperatures (Vivekanandan and Jeyabaskaran, 2010). The freshwater fish species are also affected due to increased breeding cycles and higher growth rates. The climatic change is projected to exacerbate more negative impacts than earlier thought owing to changes in zoo- and phytoplankton, sea surface temperatures, precipitation changes, sea water acidification, sea surface salinity and oxygen deficiency.

Despite the climatic challenges, marine fish landings increased from about 0.53 million tonnes/year in 1950–51 to ~3.81 million tonnes/year in 2017. The assessments project a production potential of ~5 million tonnes/year in Indian exclusive economic zone (EEZ). Further, marine culture options including open sea cage farming, seaweed farming, integrated multi-tropic farming, mussel and oyster culture, ornamental fish production, pearl culture, seaweed farming along Indian coasts can augment marine food and other marine production (Gopalakrishnan et al., 2017).

### 3.5 Food Supply and Prices

In India, a lot of spatial and social variations exist with respect to exposure to climatic stresses. Demand-supply inequalities and availability, accessibility and affordability due to market price volatility of food are markedly high in areas prone to climatic stresses such as droughts and floods (Ghosh and Roy, 2006; Roy et al., 2005). Livelihoods and annual income reduced by 60% in drought affected villages of Jalna district, Maharashtra (Vedeld et al., 2014). Long-term malnutrition in children was observed to be associated with frequent floods in Jagatsinghpur district of Odisha (Rodriguez-Llanes et al., 2011). Moreover, migration of many landless and marginal farmers to cope with climate variability is commonly seen in India and elsewhere (Bhatta et al., 2015), and is considered as an adaptation strategy to cope with climate change (Jahn et al., 2018).

Field level socio-economic studies across India showed that increasing frequency of extreme climatic events are leading to growing uncertainty in farmers' income and price volatility in agricultural product markets affecting access, affordability and nutrition at the household level. Nelson et al., (2009) projected an increase in the prices of wheat, rice and maize in the range of 121–194% by 2050 because of climatic change. Thus, the multi-factorial effects on food production and supply systems will significantly impact the food and nutritional security of vulnerable populations. With increasing risks in production and markets because of climate change, there exists a high volatility of operating cash flow and profit from agricultural activities. As a result, farmers face constraints in scaling up agricultural activities, and volatile profits further restrain them from reinvesting in farm related activities. And some farmers leave the agricultural sector, which was evident from reports from states Punjab, Madhya Pradesh and Tamil Nadu (ADB, 2011). Some farmers resort to borrowing from formal or informal sources with constraints of repayment (Kumar et al., 2017).

# 4 Technological Options

Several existing technologies can be suitably used to manage climatic risks. Certain such potential technologies are discussed here and assessed in terms of adaptation benefits, mitigation co-benefits, productivity and income, their ease of implementation, no-regret options and friendliness to small-holding farmers (Table 2). In addition, farmers' decision to adopt a technology is influenced by several other factors such as their socio-economic characteristics, age, gender and land-holding size (Khatri-Chhetri et al., 2017). Therefore, a suitable policy response is required for finding an optimal balance between preference and prioritisation by different stakeholders for promoting a technology.

## *4.1 Field and Horticultural Crops*

### 4.1.1 Multiple Stress Tolerant Varieties

Developing varieties tolerant to multiple abiotic and biotic stresses using stress-tolerant QTLs, genes and alleles in elite cultivars, is an efficient way of achieving climate resilience with easy access to farmers. ICAR developed crop varieties such as CR Dhan 801 and CR Dhan 802 for rice and several others for different crops, which are tolerant to multiple stresses i.e. submergence, salinity, drought, heat, pests and diseases (Pathak et al., 2018).

### 4.1.2 Inter-Specific Grafting of Crops

This strategy was successful for flood-tolerance in tomato, where grafting of tomato plants was done onto brinjal rootstocks. Grafted tomato plants exhibited better survival and improved fruit yield over self-grafted and un-grafted plants under flooding (Bahadur et al., 2015).

**Table 2** Technological options with their potential benefits for climate-smart agriculture

| Strategy | Technology | Adaptation benefit | Mitigation benefit | Productivity gain | Income gain | Ease of implementation | No regret character | Small farmer friendly | Average |
|---|---|---|---|---|---|---|---|---|---|
| 1. Food and horticultural crops | 1. Multiple stress tolerant varieties | 5 | 1 | 4 | 4 | 5 | 4 | 5 | 4.0 |
| | 2. Inter-specific grafting of vegetable crops | 5 | 1 | 4 | 4 | 2 | 3 | 5 | 3.4 |
| | 3. Diversification to stress-tolerant and new crops | 5 | 2 | 4 | 4 | 2 | 2 | 2 | 3.0 |
| 2. Livestock and poultry | 4. Stress-tolerant breeds | 4 | 1 | 4 | 4 | 3 | 3 | 2 | 3.0 |
| | 5. Feed and housing management | 4 | 4 | 4 | 3 | 3 | 4 | 2 | 3.4 |
| | 6. Livestock health care for emerging diseases | 3 | 1 | 4 | 3 | 3 | 4 | 3 | 3.0 |
| | 7. Small ruminants in drought-prone areas | 4 | 3 | 2 | 2 | 3 | 2 | 4 | 2.9 |
| 3. Fisheries | 8. Composite and drought-escaping fish culture | 4 | 1 | 4 | 4 | 4 | 3 | 3 | 3.3 |
| | 9 Diversification of fish species | 4 | 1 | 4 | 4 | 3 | 2 | 3 | 3.0 |

(continued)

**Table 2** (continued)

| Strategy | Technology | Adaptation benefit | Mitigation benefit | Productivity gain | Income gain | Ease of implementation | No regret character | Small farmer friendly | Average |
|---|---|---|---|---|---|---|---|---|---|
| | 10 Pen/cage culture of fish | 5 | 1 | 5 | 4 | 2 | 2 | 1 | 2.9 |
| | 11 Wastewater aquaculture | 3 | 2 | 3 | 4 | 2 | 2 | 2 | 2.6 |
| 4. Water management | 12 Dry direct-seeded rice | 4 | 4 | 3 | 4 | 3 | 2 | 4 | 3.4 |
| | 13 Micro-irrigation (drip, sprinkler) | 5 | 5 | 4 | 3 | 3 | 2 | 2 | 3.4 |
| | 14 Rainwater harvesting and drainage | 5 | 3 | 4 | 3 | 2 | 3 | 2 | 3.1 |
| 5. Energy management | 15 Solar energy-based machineries | 2 | 5 | 2 | 4 | 3 | 3 | 2 | 3.0 |
| | 16 Zero/minimum tillage | 2 | 3 | 2 | 4 | 3 | 3 | 2 | 2.7 |
| | 17 Energy plantation | 2 | 4 | 2 | 3 | 2 | 2 | 2 | 2.4 |
| | 18 Protected cultivation and vertical farming | 5 | 1 | 5 | 5 | 2 | 2 | 1 | 3.0 |

(continued)

**Table 2** (continued)

| Strategy | Technology | Adaptation benefit | Mitigation benefit | Productivity gain | Income gain | Ease of implementation | No regret character | Small farmer friendly | Average |
|---|---|---|---|---|---|---|---|---|---|
| 6. Nutrient management | 19 Site-specific nutrient management | 2 | 3 | 4 | 4 | 4 | 4 | 4 | 3.6 |
| | 20. Microbial technologies and bio-fertiliser | 2 | 4 | 3 | 4 | 3 | 4 | 4 | 3.4 |
| | 21. Integrated nutrient management | 3 | 3 | 3 | 4 | 4 | 4 | 4 | 3.6 |
| | 22. Nitrification and urease inhibitor | 2 | 4 | 4 | 4 | 3 | 4 | 4 | 3.6 |
| 7. Management of soil carbon | 23. Conservation agriculture | 3 | 4 | 3 | 4 | 3 | 3 | 3 | 3.3 |
| | 24. Agro-forestry | 3 | 5 | 2 | 3 | 2 | 2 | 2 | 2.7 |
| | 25. Residue management | 2 | 3 | 2 | 3 | 2 | 3 | 3 | 2.6 |
| 8. Weather forecasting and services | 26. Weather forecasting and early warning | 4 | 1 | 3 | 3 | 3 | 3 | 3 | 2.9 |
| | 27. Contingency plan for abiotic stresses | 4 | 1 | 3 | 3 | 2 | 4 | 3 | 2.9 |
| | 28. Insurance | 5 | 1 | 4 | 5 | 3 | 4 | 3 | 3.6 |

(continued)

**Table 2** (continued)

| Strategy | Technology | Adaptation benefit | Mitigation benefit | Productivity gain | Income gain | Ease of implementation | No regret character | Small farmer friendly | Average |
|---|---|---|---|---|---|---|---|---|---|
| 9. Institutional arrangement | 29. Custom-hiring centres | 3 | 1 | 3 | 4 | 2 | 3 | 5 | 3.0 |
| | 30. Seed and fodder bank | 4 | 1 | 3 | 3 | 2 | 3 | 5 | 3.0 |
| | 31. Community nursery | 4 | 2 | 4 | 4 | 3 | 3 | 5 | 3.6 |

*Note* The parameters have been evaluated using rapid expert judgement on a scale of 1–5—where the lowest gain is 1, and the highest 5. Suitable climate-smart technologies were short-listed from a list of reported technologies and prioritised using multi-criteria decision analysis

#### 4.1.3 Diversification to Stress-Tolerant and New Crops

Crop diversification should focus in promoting climate-smart, hardy crops like millets; and more remunerative fruit crops such as dragon fruit and pomegranate in drought prone areas. Dragon fruit, a new crop, has high potential for increasing farmers' income, particularly in climate stressed areas. Diversification, however, should be based on the climate resilience of the crops, availability of water and other resources of the region and market demand. These factors will in turn decide the risks and returns from the diversified system and their adoption by the farmers.

### *4.2 Livestock*

#### 4.2.1 Stress-Tolerant Breeds

Selection and promotion of stress tolerant breeds is paramount for climate resilience. In high stressful environments and for less resourceful farmers, indigenous breeds will be more suitable compared to exotic breeds (TIFAC, 2019). Indigenous breeds however have limitations of low productivity. Therefore, a decision at local level has to be made between stress-tolerance and maintenance cost in one hand and the productivity on the other to decide the profitability and adoption of the breeds.

#### 4.2.2 Feed and Housing Management

To ensure climate resilient livestock production, providing heat-stress-resilient housing, sufficient good quality feed with supplements such as vitamin C for poultry, improving feeding strategy and extending financial and risk mitigation services will be of immense use. Establishment of cattle camps to ensure feeding and housing in adverse years was adopted as a successful strategy for climate resilience in Maharashtra, India.

#### 4.2.3 Small Ruminants in Drought-Prone Areas

Small ruminants, generally not requiring costly housing and feed, make husbandry easier; adjustment to hardy climatic conditions should be promoted in drought-prone areas. This effort can help millions of farmers with minimal incentives from the government (TIFAC, 2019).

#### 4.2.4 Livestock Healthcare for Emerging Pests and Diseases

Climate change is causing the emergence and spread of new pest and diseases. To address this, awareness and number of diagnostic centres should be increased, and their infrastructure and services strengthened for early and better diagnosis (TIFAC, 2019).

### *4.3 Fisheries*

#### 4.3.1 Composite and Drought-Escaping Fish Culture

In composite fish culture, more than one type of compatible fish such as grass carp, common carp, big head carp and amur carp are cultured together. Amur carp (modified variety of common carp) has more growth and tolerance to varying temperature regimes compared to common carp (Medhi et al., 2018).

#### 4.3.2 Drought-Escaping Fish Culture

In this, fishes are grown in smaller ponds that retain water for 2–4 months, and fish species such as *Pangasius* sp., *Puntius javanicus*, *Pygocentrus nattereri* and *Oreochromis niloticus* are cultured.

#### 4.3.3 Diversification of Fish Species

Culturing brackishwater fish in freshwater and low salinity tolerant freshwater fish in brackishwater is a reality (Trivedi et al., 2015). Several stress-tolerant species such as *Pangasianodon hypophthalmus*, *Anabas testudineus* and *Channa stiatus* were identified for stress conditions to provide flexibility and resilience in fish culture.

### *4.4 Natural Resource Management*

#### 4.4.1 Water Management

To conserve, store and enhance water use efficiency, pressurised, low cost and demand-driven irrigation methods are being promoted. Technologies such as alternate wetting and drying in rice, dry direct-seeded rice (Pathak et al., 2018), rainwater harvesting and groundwater recharge have substantial adaptation benefits. A successful technology for drought-prone and low rainfall areas is Jalkund i.e., low-cost rainwater harvesting structures, for harvesting rainwater during the rainy season and its subsequent use during the dry periods (Prasad et al., 2014).

### 4.4.2 Nutrient Management

Efficient management of nutrients can help in climate change adaptation by enhancing root growth and early vigour of plant and improving soil microbial activities that lead to adequate supply of plant nutrients under climate-stress conditions. Soil test-based, balanced fertiliser application, use of efficient fertilisers, site-specific real time N application and integrated nutrient management are some options of efficient nutrient management practices. Use of neem-coated urea, soil health card and leaf colour chart for enhancing fertiliser use efficiency were successfully utilised in India. Integrating all these options will further improve the efficiency of applied fertilisers (Pathak et al., 2019). Microbe-based technologies for nitrogen fixation, nutrient recycling, bio-residue management and alleviation of abiotic and biotic stress will be very useful in the changing climate scenario.

### 4.4.3 Conservation Agriculture

Conservation agriculture helps (i) reduce the carbon footprint of the production system, (ii) improve productivity and (iii) enhance adaptability, by modulating soil moisture and temperature regimes (Somasundaram et al., 2020). Such practices are followed by farmers on a large scale in the Indo-Gangetic Plains. However, refinement and promotion are required to extend the technology in climatic stressed, dry land areas.

### 4.4.4 Mechanisation in Agriculture with Renewable Energy Sources

Solar-powered machineries such as water pumps, sprayers and weeders are better alternatives to diesel-powered machines in India. Such machines are economical, help in timely field operation at low cost, affordable to small farmers and do not release greenhouse gases. Individual farmers, panchayats, cooperatives, farmer producer organisations can install solar power plants for which government is providing incentives.

### 4.4.5 Protected Cultivation and Vertical Farming

Protected cultivation and vertical farming practices such as plastic low tunnel, hydroponics, trench underground greenhouse, fogponics, aeroponics, vertically stacked layers, vertically inclined surfaces and/or integrated in other structures have advantages of flexibility of location and are well-adopted in adverse climatic conditions (TIFAC, 2019).

# 5 Institutional and Policy Options for Adapting to Climate Risks

Climate resilient technologies undoubtedly play an important role in climate change adaptation in agriculture. However, strong institutional support is necessary to apply and scale up these technologies for successful adoption and societal embedding. This support may include correcting market distortions, strengthening implementation machinery at different levels, better linkages and prudent financial allocation.

## *5.1 Mainstreaming Climate Adaptation in Development Planning*

Climate change has largely remained a subject dealt by the national government under eight Missions of the National Action Plan on Climate Change (NAPCC). However, agriculture being a state subject, more active involvement of states is needed so that state specific problems can be addressed effectively. Most state governments have prepared State Action Plans (SAPs) covering different sectors including agriculture but are weakly formulated around CSA without adequate financial allocations and provisions for adequately trained climate service providers. Agriculture being a state subject greater attention and better coordination are required among concerned departments at the state level. Singh et al., (2019) found that many schemes of the Government of India have strong implications for climate change adaptation. A systemic comprehensive effort might help in accelerating strategic actions. Multiple experimental or small-scale uncoordinated actions in project mode are happening through NABARD and other agencies but review and strengthening of efforts towards scale up need specific attention. These require institutional mechanism for multi-level collaboration and governance. Vertical integration of national-subnational-local scales and horizontal integration among various private sector players, framers and financial institutions would be very useful.

## 5.2 Leveraging Watershed Programmes and MGNREGA

India has long experience of implementing watershed development programme in rainfed areas and command area development in irrigated regions. Several institutions like Water Users Associations (WUA), Watershed Committees (WC), Watershed Development Teams (WDT), Project Implementing Agencies (PIA), etc., are functioning at the village/watershed level for many years. The National Rainfed Area Authority (NRAA) is currently revising common guidelines of the Watershed Development Programme. It provides an opportunity to integrate climate change adaptation objectives as many NRM interventions in watersheds also help in climate resilient agriculture. MGNREGA (Mahatma Gandhi National Rural Employment Guarantee Act) provides legal status to right to work and social security through enhanced livelihood security in rural areas. It provides at least 100 days of wage employment in a financial year to every household for adult members ready to volunteer for unskilled manual work. The list of work covers – water conservation and water harvesting; drought proofing including afforestation; irrigation works; restoration of traditional water bodies; land development; flood control; rural connectivity and works notified by the government. All these activities are closely linked to adaptation options for climate change. It is already operating with an institutional structure, on digital platform and financial allocations. Though it is primarily designed as a rural job creation programme to provide income security, yet it provides a vehicle to achieve climate change response objectives as well. Women are the most vulnerable section to climate change, yet they contribute significantly to adaptation actions in Agriculture. India has a very strong institutional setup of women Self Help Groups (SHGs) at village level and their federations at block level. These are playing a stellar role in natural resource management, crop and livestock production and fisheries. It is pertinent to make effective use of this institutional mechanism for achieving the goals of CSA.

## 5.3 Contingency Crop Planning and Agro Advisory Services

While climate change will have long term impacts on the farm sector, inter-annual climate variability triggers no lesser risks. ICAR prepared district-wise contingency crop plans for all rural districts in India for coping with monsoon aberrations (www.agricoop.nic.in). However, owing to lack of a systemic approach, no institutional mechanism exists to implement these plans at the subnational level. The key challenges are—production, storage and supply of seeds of short duration contingent crops and varieties at a short notice. It is recommended that states develop a special seed production programme of contingent crops and varieties, build infrastructure and logistics for storage and supply of such seeds at short notice. One or two such hubs can be built in each state and operated under private-public-partnership mode or through new innovative business model solutions. If the monsoon is normal, the seed can be disposed as grain and the cost difference can be absorbed by participating parties.

Over time, India's established institutional structure of AGROMET advisory services of IMD have expanded and now each district has a District Agro Met Unit (DAMUs) involving IMD, Krishi Vigyan Kendras (KVK) and State Agricultural Universities for dissemination of short and medium range forecasts and crop advisories under the Grameen Krishi Mausam Seva (GKMS). However, considering large spatial and temporal climatic variability, weather information with higher spatial resolution of a block or panchayat is required. This needs better high-resolution forecasting models, international collaboration, investments in infrastructure and large number of appropriately trained manpower (Mehajan et al., 2019). Considering the importance of this function, serious consideration needs to be given to whether a separate dedicated organisation can be created through new legislation in parliament or an existing organisation can be re-mandated. At the ground level under global adaptation projects in India climate service providers are emerging, but all these experiments need an institutional mechanism to get mainstreamed in agricultural extension service or agricultural enterprise level. New enabling conditions will help in enhancing social acceptance of new practices and technologies and better management of natural capital like soil quality, water quality and quantity and watershed. Many of these come under new public service categories. Additional services to reduce information asymmetry and market access and provision of security at various subsystem levels in agricultural sector can be categorised under broader public service categories.

## 5.4 Insurance, Credit and Risk Management

Insurance can be one of the key instruments for managing short-term climatic risks in Indian agriculture. India has one of the largest agricultural insurance programmes in the world covering more than 30 million farmers. It is a comprehensive scheme covering many crops, hazard types and low premium contribution by farmers but bottlenecks in implementation and delay in claim settlements remain. Another major criticism of the scheme is the time-consuming nature of Crop Cutting Experiment (CCE), which is often contested both by the farmers and insurance companies. Use of new technologies and tools like remote sensing and drones, simulation modelling, blockchain technology and artificial intelligence could possibly make the scheme more efficient and transparent (Aggarwal et al., 2016). Considering that almost the entire premium is paid by the central and state governments, it will be useful to examine if the scheme could be modified to run as a social welfare scheme with insurance principles for management; various possibilities need to be scientifically weighed. The additional budget could be made available by merging a few disaster management schemes into this scheme. Moreover, insurance cannot be a stand-alone solution to climate change. In the farm sector, it shall form part of a comprehensive risk mitigation strategy, illustrated in Fig. 1, encompassing investments in infrastruc-

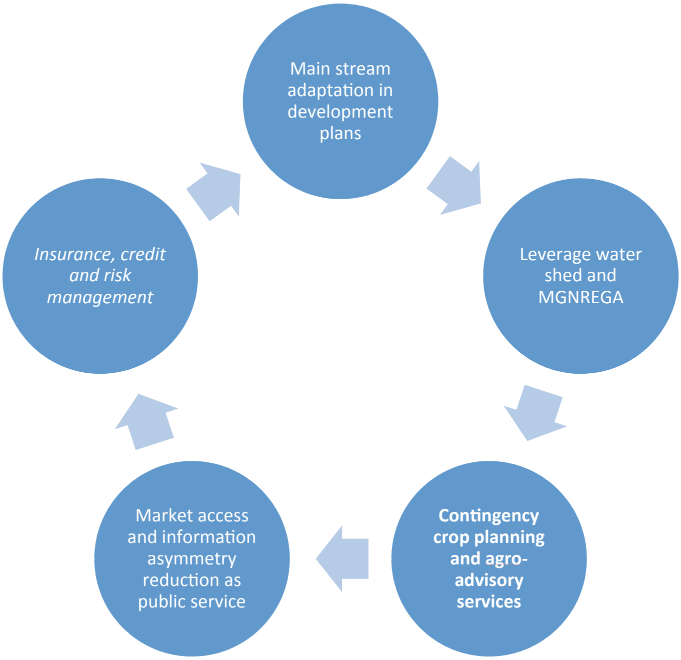


**Fig. 1** Illustrating the various components required for building a comprehensive climatic risk management strategy in agriculture

ture and adoption of climate smart practices at the farm level (Koerner and Loboguerrero, 2019) to reduce likely loss and damage related to climate change and disasters by enhancing resilience through climate proofing of production, distribution and access.

The eNAM – a pan-India online trading platform for agricultural commodities by the GoI – was opened to improve market access and reduce information asymmetry among farmers (MoA&FW, 2020). The scope of this platform maybe expanded to integrate agricultural financial markets to widen and deepen the scope of agri-financial services. For mainstreaming such innovative mechanisms to weed out information asymmetry, requirement of hard and soft infrastructure, and capacity are necessary pre-conditions. Agricultural extension centres need to be overhauled and enabled to provide services to bridge these gaps.

In the face of climate change, it is imperative to ensure adequate income flow security from agriculture and to introduce a transparent and climate responsive credit policy. While, at present, agricultural credit is a priority sector lending for institutional lenders, approaches for evaluation of credit worthiness must consider climate risks going beyond standard approaches. With risks in production and markets due to climate change, there exists a high volatility of operating cash flow and profit from agricultural activities. As a result, the farmer faces constraint to scale up agricultural activities. Agricultural credit policies are macro level policies. Changes in those macro level policies are impacted by landscape factors and are outside the control of farmers (Pingali et al., 2019).

The formal financial system must accord attention to decreasing reliance of farmers on informal lenders for ease of regulatory management. Further, to ensure better price realisation, infrastructure related to agriculture—both backward and forward linkages in the value chain—are to be developed. The proposed policies of the central government concerning agricultural infrastructure fund are a welcome step in this direction (Express News Service, 2020).

## 6 Conclusions

Risks to food systems with ripple effects on income security of the agricultural sector and nutritional security of the population can originate from climatic factors, and from the malfunctioning of dynamics and interlinkages between components of the subsystems. Risk triggers are both on the supply side and demand side. It may emerge from supply side factors—degradation of land, change in land use patterns, deteriorating biodiversity, pollution, depletion natural resources, pest attacks, epidemics, emerging health risks, socio-political conflicts and climate change and disasters. Supply side disruptions during flood, drought and extreme weather events leading to market price volatility are a major cause of concern. Demand side factors stem from inadequate infrastructure and hence access to markets, market failures, migration and displacements, income fluctuations among consumers together with rapidly evolving tastes, preferences and patterns of consumption, changing trade policies, etc. (Bricas et al., 2019). Further, there may be both spatial and temporal variations in risks with different resultant outcomes. It is clear from the above description that climate change induced impacts will exacerbate the pre-existing broad categories of risks—production, market, institutional, financial and personal in Indian agriculture. The management strategies are inter-related. Consequently, while considering risk mitigation strategies, a systemic and holistic approach is likely to elicit maximum benefits for the system.

On an aggregate level, we harvested less than 50% of the genetic potential of most crops (Aggarwal et al., 2008) This gives an immense opportunity to raise food production in a resilient and profitable manner. Several technological and institutional options (Table 1) are now available to build resilience in Indian agriculture to current as well as future climate. Replacement foods such as plant-based meats and focus on solar energy and circular economy could help transform management of climate change in agricultural systems in future. Most of these options are no-regret options with mitigation co-benefits linked to Sustainable Development Goals (SDGs). However, more targeted detailed research can help in identifying exact strategies going forward. This, however, requires significant financial and institutional investment in scaling up these on a large scale. Intelligent use of climate information services and big data analytics can facilitate efficient use and targeting of increased public and private investment in natural capital through management of water, energy, soil quality and natural resources and climate change literacy. Bottom-up farmer level consultation is no less important, if not more, to indicate an equitable path going forward.

While there are numerous technologies available, systemic enabling conditions for nutrition service delivery mechanisms, avoiding market price volatility and providing basic income security for decent living, need to be strengthened. This has become clear from recent experiences during the pandemic COVID-19. There is a clear need for scientific studies to design incentives, sustainable business models to shift current developmental actions and social practices along sustainable development pathways. More research is needed to understand risk profile, implications of various agricultural service delivery models for various social groups to strengthen resilience and finally to reduce loss and damage by investing in climate proof agricultural system. Risks to climate variability have always been there and incremental responses have been helping to guard against adverse impacts but now risks are exacerbating with climate change. Big opportunities are available in targeting climatic services, advisories, insurance and precision agronomy but to scale we need sound business models. Need for right partnerships, science-based actions, policies, market/nonmarket incentives, investments, institutional changes are becoming more important. Investments in natural capital, physical capital, knowledge and human capital and social and institutional capital and valuing their impact for creating green jobs in these sectors and impact on various dimensions of human wellbeing are becoming imperative in policy planning.

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