Bhartiya Krishi Anusandhan Patrika, Volume 41 Issue 2: 158-166 (June 2026)

Climate Change and Agriculture Sector of India- Risks and Responses: A Review

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10.18805/BKAP809

ABSTRACT

The ever-growing impact of global climatic change on agriculture is becoming more evident each day, with a continual rise in earth's temperatures altering precipitation patterns, particularly affecting the monsoon season. These changing conditions pose significant threats to agricultural production, impacting fisheries, livestock farms and agribusiness infrastructure, thereby contributing to food insecurity and malnutrition. Due to climate change, India, a major producer of key crops such as wheat, rice, cotton, sugarcane and maize, is witnessing adverse effects on its agriculture. Despite the formidable challenges posed by climate change, agriculture holds significant promise as a key solution. This potential can be realized through concerted efforts aimed at reducing emissions and implementing widespread strategies for both mitigation and adaptation. Adopting optimal management practices, encompassing techniques like organic farming, agroforestry, irrigation planning, efficient manure management and rainwater harvesting, is pivotal in this endeavor. This paper endeavors to conduct a thorough review encompassing pertinent literature, articles, documents and reports and assess the impacts of climate change on agriculture. With a specific focus on elucidating the ramifications of climate change on agricultural production in India, the study seeks to highlight prevailing risks while delving into avenues for mitigation. Ultimately, the aim is to underscore the critical importance of embracing resilient agricultural methods to safeguard household food security amidst the challenges posed by climate change.

Key words: Adaptation, Agriculture, Climate change, Food security, Mitigation.

India exhibits diverse climatic conditions due to geographical features such as the Himalayas and the Thar desert. While the southern regions experience warmth, the northern parts of the Himalayas receive continuous winter snowfall. The country is divided into seven climatic zones, characterized by four primary climatic groups based on either precipitation or temperature (Senapati *et al*., 2013). The most pressing environmental issue worldwide is global warming, carrying significant implications for natural ecosystems, agriculture and human health (Jadaun and Khan, 2023). As reported by the Intergovernmental Panel on Climate Change (IPCC) in 2014, the earth has experienced a surface temperature increase ranging from 0.8 to 1.2°C due to global warming. Agriculture-related activities alone account for 50% of global methane emissions and 75% of global N_2O emissions, among other anthropogenic activities (FAO, 2021; Dutta and Begum, 2022). Given that a substantial portion, approximately two-thirds, of India's agricultural land relies on rainfall and even the irrigated systems are contingent on monsoon rain, the sensitivity of Indian agriculture to climate change challenges, particularly drought, is high (Barua *et al*., 2017). India is now the world's fourth greatest producer of GHGs (Green *et al*., 2019); the Indian agriculture sector contributed 17.6% of greenhouse gas (GHG) emissions in 2007. As greenhouse gas concentrations in the atmosphere increase, we can be assured that the impacts of these changes will be seen for centuries to come, well beyond the year 2100, which currently serves as the forecast baseline (Lyon *et al*., 2022). However, combined with the continued population rise (United Nations, 2017). Achieving India's 2030 goal of reducing greenhouse gas (GHG) emissions intensity by 33-35% compared to the 2005 levels may pose a considerable challenge (Government of India, 2017). By altering ecosystem design, climate change is also accelerating biodiversity loss due to shifting ideal temperature ranges (Barman *et al*., 2026). Some food, water and vector-borne infections, including the coronavirus pandemic, are made more likely by climatic changes. It also hastens the development of antimicrobial resistance, which is already occurring as a result of resistant pathogenic diseases (Abbass *et al*., 2022). Floods, food and water shortages and extreme heat from rising temperatures are the primary climatic dangers in South Asia. The impact of climate change could potentially affect as many as 800 million individuals residing in a region that is home to some of the planet's most

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How to cite this article: Ashkra, Jadaun, K.K. and Khan, A.A. (2026). Climate Change and Agriculture Sector of India- Risks and Responses: A Review. *Bhartiya Krishi Anusandhan Patrika.* **41(2):** 158-166. doi: 10.18805/BKAP809.

Submitted: 25-10-2024 **Accepted:** 13-05-2026 **Online:** 16-06-2026

impoverished and vulnerable populations. Climate-related disasters impacted 750 million South Asians in eight countries during the preceding two decades: Maldives, Afghanistan, Bhutan, Nepal, India, Pakistan, Bangladesh and Sri Lanka (Asian Development Bank, 2020). Climate change might cost Bhutan 18% of its GDP per capita by 2100, Nepal 13%, India 10% and Pakistan 10% (Asian Development Bank, 2014).

This study's main objective is to assess the risks posed by climate change across different agricultural sectors and analyze its repercussions on food security in India. Additionally, it proposes strategies for responding to climate change. The review seeks to emphasize the impact of climate change on various sectors, including health, agriculture, tourism, biodiversity, economy, forestry and food security, identifying critical threats. Moreover, this study aims to provide insights into existing research on the subject while proposing avenues for future research in the same domain.

Risk of climate change

Climate change affects a range of sectors (Akhtar and Masud, 2022). Including the tourist sector, increasing trade costs, exposing tiny or landlocked nations to transportation infrastructure damage and the elderly, who are the most susceptible to heat-related diseases and mortality (Abbass *et al*., 2022). Fig 1 indicates the most significant climate change risks to India's economy and population manifest in the severity, frequency and geographical extent of droughts. Droughts may become more frequent as temperatures rise, evapotranspiration increases and winter precipitation decreases. Winter droughts will become more likely in certain areas. Due to the impact of climate change, the Godavari and Mahanadi river basins along the eastern coast of India are anticipated to experience more frequent and severe flooding events, leading to potentially devastating consequences (Gosain *et al*., 2006). The third most notable threat encompasses storm surges, coastal flooding and cyclonic storms. Projections indicate that the anticipated increase in sea surface temperature within the Indian Ocean, expected to range from 2 to 4°C over the next century, is likely to result in a 10-20% intensification in cyclone strength, as highlighted by the National Disaster Management Authority of the Government of India. The devastating impact of the 1999 Odisha super cyclone, which claimed over 10,000 lives and caused extensive damage to structures in ten coastal and six inland districts, resulted from a combination of cyclonic winds, coastal flooding and storm surge. The cyclone, striking the Odisha shoreline and penetrating up to 20 km inland, brought about a record storm surge of 26 feet (8 meters). The aftermath included heavy rainfall across southeast India, leading to unprecedented flooding in low-lying areas. In addition to the human toll, the disaster wreaked havoc on the agricultural sector, with a total of 6,600 m^2 of crops damaged and an additional 90 million trees uprooted or broken. Stern's predictions further indicate that the repercussions of rising sea levels could necessitate significant relocations of people from coastal areas. However, it is the agricultural industry that has borne the brunt of these challenges (Akhtar and Masud, 2022). Climate change might turn rural India's agrarian crisis into a migratory route owing to increased monsoon unpredictability, chronic drought, floods and resource conflict (Senapati *et al*., 2013). Significant challenges in food production and climate-induced human migration are anticipated to arise well before the year 2100, raising growing apprehensions about the viability of specific Earth regions beyond the turn of the century (Lyon *et al*., 2022). According to a study by the Universal Ecological Fund, rising temperatures will harm the world's food supply, with India suffering the most.

Agriculture risk

Agriculture is affected both directly and indirectly by climate change (Ashkra *et al*., 2023). Temperature and rainfall fluctuations have direct effects on many agricultural production systems. Pollinators, pests, disease vectors and invasive species may all have an indirect influence on production. The indirect effects might be severe. They are complicated to study because of the multiple relationships, various of which are unidentified. The most serious concern in agriculture is pollution from fossil fuels, farm animals, tillage and fertilized soils (Praveen and Sharma, 2019) and the most significant anthropogenic gas (CO_2), with a growth rate of 1.9 ppm per year during the last ten years. The IPCC forecasts a consistent and unfavorable impact on agricultural production in low-latitude nations, whereas northern countries might see either a positive or negative effect. In high-latitude places where the climate is becoming

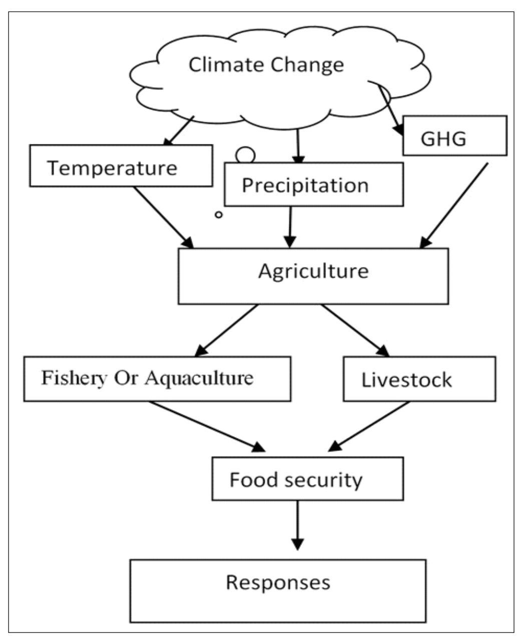

Fig 1: Climate change and food security.

more favorable for crop production, advances in agricultural output may be constrained by soil quality and water availability (IPCC, 2014). Only in situations where moisture is not a problem may increase CO_2 concentrations increase crop production. Some plants may increase their photosynthesis by 30% to 100% in response to higher CO_2 levels (IPCC, 2007). The Indian subtropical Trans and Upper Gangetic plains (TUGP) between latitudes 25 and 28°N have become more exposed to negative climate change, notably a rise in maximum summer/monsoon and lowest winter temperatures (Choudhary and Sirohi, 2022). Climate change is impacting the central Himalayan water supplies and agriculture. The coolest period, January, has gotten colder, while the hottest months, April and May, have become hotter. More frequent temperature extremes are more likely. In general, the period that preceded the preceding one had a much higher trend of warming (Swain *et al*., 2022). Rising seasonal temperatures are linked to losses in the majority of locations. Climate change is predicted to affect cold climate places as well. Agricultural output will suffer significant costs in both the immediate and distant future (Nguyen and Scrimgeour, 2022). The data presented in Table 1 reveal significant fluctuations in grain and mustard crop yields in northern India. Across the majority of the country, the total number of days with precipitation will be reduced, ranging from 5 to 15 days on average (Indian Institute of Tropical Meteorology, 2019). Conversely, there is an anticipated increase in the occurrence of bulky precipitation days during the monsoon season. It is anticipated that these developments will make Indian agriculture more vulnerable. The fluctuations in temperature and precipitation patterns can substantially impact the livelihoods of over 350 million individuals dependent on rain-fed agriculture. Farmers are dealing with increasingly extreme weather occurrences, such as torrential rains, floods, landslides and drought. These problems, in turn, severely affect agricultural productivity and profitability, especially for low-income farmers (Shrestha *et al*., 2022). India, ranked as the world's second-largest producer of rice and wheat, confronts the possibility of a substantial decline, potentially up to 30%, in its agricultural output by the decade's end (FAO, 2016). The expected rise in monsoon precipitation of 10-15% in some locations is offset by a 5-25% loss in drought-prone central India and a significant decrease in winter rainfall in the country's north (Ministry of Earth Sciences, Government of India, 2020). The Intergovernmental Panel on Climate Change, a joint effort comprising over 3000 experts, emphasizes the immediate threat to India's rice and wheat output as a result of climate change. Projections show that a 1.5°C temperature increase and a 2 mm increase in precipitation might result in a 3-15% drop in rice yield. Consequently, the ramifications of diminished food grain output are poised to increase India's dependency on food imports, requiring substantial financial resources (Bhuyan *et al*., 2023). The effect of climate change on crops varies depending on the crop, with cotton being one of the most impacted (Davidson, 2018). Crop output decreases when the temperature rises in various locations of India, according to simulations utilizing dynamic crop models. An increase of 20°C in average air temperature has been observed to correlate with a reduction of around 0.75 tons per hectare in rice yields in high-yield regions. At the same time, low-yield coastal areas experience a decrease of approximately 0.06 tons per hectare. Additionally, an anticipated 0.5°C increase in winter temperature is expected to result in a decline of 0.45 tonnes per hectare in rainfed wheat production in India (Dharbale, 2019). Despite the impact of carbon fertilization, studies undertaken by the Indian Agricultural Research Institute (IARI) suggest that every 10 degrees Celsius increase in temperature might result in a loss of 4-5 million tons in annual wheat output (Aggarwal, 2008). Researchers anticipate a 5-30% yield drop between 2080 and 2100 (Fischer *et al*., 2002). India holds the position of the world's largest producer of pulses, contributing to 25% of the global output (Food and Agriculture Organization, 2022). The IPCC predicted that temperatures will increase by 3-4 degrees above present levels by 2050, significantly affecting rainfed crops (IPCC, 2014). Since pulses make up a significant portion of rainfed agriculture, production reductions due to climate change are expected to be more acute for these crops, particularly in indo-gangetic plains, under conditions of inadequate water availability since there is no means of compensating for rainfall variations (Dharbale, 2019). The resulting impact on farm-level net income would be a 9-25% loss for a temperature increase of 2-3.5°C. Farm income in Karnataka fell by 17-21% for every one-degree rise in average maximum temperature (Kalli and Jena, 2022). A survey from the Deloitte Economic Institute predicts that by 2070, India's GDP would have decreased by roughly 12.7% and its economic potential will have decreased by about 5.5% annually (Deloitte Economic Institute, 2021). By the year 2100, the cost of climate change in India has estimated a 3-10% GDP loss (Ewert *et al*., 2005). It is crucial to highlight that India faces substantial vulnerability to the effects of environmental changes, primarily attributed to its heavy dependence on agriculture, constrained natural

Table 1: Variations in crop yields in India due to climate change by 2040 under the RCP 4.5 scenario.

Crop	Change in yield (%)
Wheat	-9
Irrigated rice	-12
Maize (*Kharif*)	-18
Mustard	-12
Potato	-13
Sorghum	-3
Maize (*Rabi*)	13

Source: Derived *via* Kumar *et al*. (2019) and Aggarwal *et al*. (2021).

resources, a notable surge in both human and livestock populations, evolving land use patterns and socio-economic factors. These elements collectively pose a significant risk to the country's ability to meet its needs for food, fiber, fuel and fodder (Dharbale, 2019).

Impact on fishery or aquaculture

Over time, the Indian fishing industry grew and became a significant socioeconomic asset for the country. Seafood is an economical and high-quality source of animal protein, thus providing a good alternative for combating poverty and malnutrition across the country. India is the globe's third-biggest fishery and aquaculture producer, responsible for around 16% of all inland and 5% of overall aquatic fish output (Food and Agriculture Organization, 2022). In fiscal year 2021-22, India produced 162.48 lakh tonnes of fish, with 121.21 million tons coming from domestic sources and 41.27 million tons coming from the marine sector. The fishing industry holds immense significance in the national economy, substantially contributing to foreign currency earnings. Notably, India's fish production has grown substantially, escalating from 56.56 million tonnes in 2000-01 to 162.48 million tonnes. Top fish-producing states in 2021-22 include West Bengal, Karnataka, Andhra Pradesh, Odisha and Gujarat. States such as Uttar Pradesh, Odisha, Bihar, Kerala and Tamil Nadu exhibit the highest per capita fish consumption, while Kerala and Lakshadweep lead in per capita prawn consumption (Ministry of Fisheries, Animal Husbandry and Dairying, 2022). Tripura stands out with the highest number of families, both rural and urban, engaged in fish consumption. On the global front, India ranks third among the top fish-exporting nations, following China and Indonesia. Fisheries contribute approximately 1.1% to the Indian GDP, whereas agriculture contributes about 6.72%. In the fiscal year 2021-22, India set a record by exporting 1.36 million metric tonnes of seafood valued at US $7.76 billion, with exports reaching 123 countries (Marine Products Export Development Authority, 2022). Notably, the United States and China emerged as the primary importers of Indian seafood. The range of exported marine products encompasses frozen prawns, fish, cuttlefish, squids, dried goods and live and chilled products. Frozen prawns stand out as the key marine product, constituting over 53.18% of the total quantity and 75.11% of the overall export value. The value of marine exports in 2022 witnessed a remarkable 30% increase compared to the previous year, reaching $7.76 billion (Handbook Stats, 2023). However, sea temperature variations have an influence on aquatic creatures' physiological, biochemical and physical processes, including a drop in fish population (Abowei, 2010). Climate change has had various effects, including the loss of natural habitat, the pollution of seas and other bodies of water and the dominance of foreign breeds, which promotes an imbalance in marine ecosystems (Brander, 2010). By the end of the century, ocean levels are anticipated to increase by 9-90 cm (Church *et al*., 2001). Since the rising water level has submerged marsh and other natural habitats, it has disrupted the usual rhythm of reproduction for several fish species that depend on such ecosystems for regeneration, affecting the reproduction and fecundity of many fish species (Hlohowskyj *et al*., 1996). Aquatic ecosystems have become more acidic as CO_2 concentrations have increased, causing carbonic acid to dissolve in water and reduce pH. The impact of climate change on water bodies has also resulted in a change in the salinity of ocean or seawater. An imbalance in the salt content of water bodies causes intolerance in aquatic plants and creatures. Various impacts on phytoplankton and fish populations have been examined as a result of the salt concentration imbalance that eventually changes the food chain, including marine flora and fauna (Schallenberg *et al*., 2003). Global warming has also altered the distribution of marine species throughout the world, affecting fish migratory behavior and there would be a 30% loss in tropical marine fish owing to transfer to higher latitudes (Cheung *et al*., 2009). Many fisheries are already stressed due to causes like overfishing and water pollution. Climate change has the potential to intensify these stresses. Temperature variations, in particular, might have a significant impact. The distribution of various fish and shellfish species is contingent upon specific temperature ranges, as many marine organisms have temperature limitations for optimal growth. For instance, cod in the North Atlantic thrives in water temperatures below 12.2°C Exceeding temperatures of 8.3°C at the seabed poses a threat to their reproductive capabilities and the survival of their offspring. Projections for this century anticipate the region experiencing temperatures that approach both ends of this spectrum, impacting these marine species' habitat and reproductive success (Barua *et al*., 2017).

Impact on livestock

As per the 20th Livestock Census, India boasts one of the highest animal populations globally, with 303.76 million comprising bovines, 148.88 million goats, 74.26 million sheep, 9.06 million pigs and a substantial poultry count of about 851.81 million (Annual Report, 2023). India is first in the world for the number of buffaloes, second for the number of cattle and goats, third for the number of sheep, sixth for the number of poultry and ducks and tenth for the number of camels. Animal farming alone is responsible for around 14.5% of total emissions of greenhouse gases (Gerber *et al*., 2013). Climate change and animal husbandry are inextricably linked since livestock raising is very sensitive to the impacts of climate change and livestock rearing is a significant source of greenhouse gas emissions. Animal agriculture alone accounts for about 14.5% of total greenhouse gas emissions (Gerber *et al*., 2013). According to a Food and Agriculture Organization estimate, around 43 crore people are directly or indirectly involved in cattle raising. Climate change has a multifaceted influence on animals, forages and grain. Erratic rainfall increases the likelihood of bacterial and viral infection, resulting in a decrease in fodder supply. Temperature variations can cause stress in livestock's physical and physiological processes, such as animal growth and development, milk production capacity, illnesses and the availability of fodder, feed and water, among other things. The most serious detrimental consequence of climate change is the increased prevalence of different illnesses in cattle populations. Some vectors need high temperatures to multiply quickly and infect animals. Mosquitoes, flies and ticks also cause discomfort in cattle and Rhiticephalus microplus (tick) infection causes an 18-20% weight loss in animals (Wittmann *et al*., 2001). The word "acclimation" is used to describe the stressed state that cattle experience as a result of a rise in body temperature. Such circumstances caused animals to lose their appetite, which reduced their intake of fluids and other feeds and impaired their ability to reproduce and engage in other growth processes (Nardone *et al*., 2010). Temperatures exceeding 30°C are very harmful to the poultry population. Climate change has caused many internal organs, such as the liver, heart and salivary gland, to malfunction and several metabolic pathways, such as glucose, protein and lipid metabolism (Bernabucci *et al*., 2006). There is an increase in death and morbidity rates in the cattle population with temperature increases of 1 to 5°C. The primary effects on other animals may also be observed in illness and fertilization. Climate change makes several vector-borne diseases more likely. Higher animal mortality and morbidity result from the minor pest becoming a significant pest (Dutta and Begum, 2022). The persistent effect of global warming on the nation's cattle becomes evident each year, marked by a distressing toll on animal existence. Instances such as the 1999 tropical storm in Orissa, which claimed the lives of 4.45 million livestock and the 2013 floods in Uttarakhand, responsible for the loss of 9470 animals and the destruction of 649 cow sheds, underscore the urgent need for a response to address the escalating losses in livestock due to climate change. Poor farmers are compelled to sell their animals for pennies after a catastrophe because of the severe feed scarcity and other challenges. In 2014, when catastrophic floods in the area killed 10,050 dairy animals as well as 33,000 sheep and goats, the people of Kashmir faced a similar quandary. According to research, the biggest zoonotic disease loads are observed in Ethiopia, Nigeria and Tanzania in Africa and India in Asia. Research shows that 2020 heat stress is projected to have a notable impact on India's total milk production, resulting in a decrease of 1.6 million tonnes, equivalent to approximately Rs 23.65 billion at current prices (National Dairy Development Board, 2019). The greatest significant decrease in milk yield is projected among crossbreds (0.63%), followed by buffalo (0.5%) and indigenous cattle (0.4%).

Risk of food security

Food instability and malnutrition will have a detrimental influence on the general health of millions of individuals, with significant consequences for newborn mortality (IPCC, 2014). In 2022, about 783 lakh people will be hungry worldwide. In 2030, it is predicted that 600 million individuals will have chronic undernourishment. This emphasizes the enormous difficulty in reaching the SDG goal of ending hunger. In 2021, 42 per cent of the world's population, or over 3.1 billion people, could not afford decent food. While this suggests an increase of 134 million individuals from before the pandemic to 2019, the proportion of those unable to afford a healthy meal actually fell by 52 million between 2020 and 2021 (FAO, 2023). India is ranked 107th on the 2022 Global Hunger Index, having a very high level of hunger, with a score of 29.1. According to the state of food insecurity investigation, India, having 224.3 million malnourished individuals, or 16.3% of the overall population, is responsible for about one-quarter of the world's hunger issues (FAO, 2022). This is the highest proportion of any nation. Insufficient food supply predominantly impacts women and those living in rural regions (Gurusamy, 2025). Climate change continues to endanger food and nutritional security, an essential component of the sustainable development agenda (Akhtar and Masud, 2022). Food security in India may be jeopardized in the future as a result of climate change, which would increase the frequency and severity of droughts and floods, hurting productivity on small and marginal farms. With greater magnitude temperature rises, western India may see some adverse effects on production owing to shorter crop durations (Dharbale, 2019). The ramifications of climate change have the capacity to reverse the strides made in combating hunger and malnutrition. Its effects include the decline of rural employment and earnings, ocean and shoreline habitats and terrestrial and inland water ecosystems, resulting in the breakdown of food chains and direct challenges to food security. Climate change has far-reaching repercussions beyond the environment, affecting commerce, markets for food and price stability, posing new challenges to human health. Urgent and significant upgrades in climate change response efforts are required to protect the potential of food systems in maintaining global food security (Food and Agriculture Organization, 2016).

Responses

A global response to global warming requires an in-depth awareness of long-term goals and consensus on practical solutions (Senapati *et al*., 2013). Raising awareness about the present impact of climate change on the nutritional and food well-being of those who are most endangered individuals is critical. If immediate action is neglected, warming temperatures will progressively undercut the objective of ending hunger. This is a compelling incentive for governments to take decisive measures across all industries to combat climate change. An accurate delineation of the mechanisms through which climate change directly affects people's access to food is essential. Illustrating the necessary measures is vital, with solutions ranging from technical innovations to social protection and enhanced international collaboration. A comprehensive understanding of these channels and potential solutions provides the foundation for the Food and Agriculture Organization (FAO) to eradicate malnutrition and starvation around the globe. This effort also intends to spark continuing discussions about how to successfully implement climate change adaptation strategies. It emphasizes the need to identify food security, nutrition and the supporting agricultural sectors as critical focal topics for action in response to climate change (FAO, 2016). It is time to increase agricultural research and extension investment through targeted and advanced planning on strategic and applied aspects in an integrated approach that can elevate India's agricultural sector to a well-organized planned industry rather than remaining the largest unorganized industry. Climate change significantly impacts agriculture in developing countries because of a lack of adaptation. India's economy is based largely on agriculture, yet most farmers there are smallholders, making them especially susceptible to the effect of climate change (Datta and Behera, 2022; Singh *et al*., 2017). In order to improve India's sustainable agricultural development, India must establish a comprehensive climate strategy to prevent the detrimental impacts of climate change on the agricultural sector and its associated activities (Singh *et al*., 2022). Adaptation techniques differ greatly throughout India owing to a variety of geographical variables. Because India is so varied, each area has its own climatic, physiographic, social, cultural and economic difficulties and possibilities. Because of these disparities, farmers used a number of adaptation techniques to protect their agricultural produce against climate radiation. For example, in drought-affected parts of Maharashtra, where droughts have become more frequent, Panda, (2016) discovered that farmers in Odisha's drought-prone regions choose to adjust their cropping patterns, save water, conserve their soil, diversify their livestock and get crop insurance. Pandey *et al*. (2018) noted that farmers in Uttarakhand decreased animal raising volume to save water. Singh *et al*. (2017) discovered that rich producers expanded their cultivation practices with horticulture industrial crops in some remote areas of Arunachal Pradesh, whereas poor farmers produced drought-tolerant oil seeds and subsistence horticultural crops. Tripathi and Mishra (2016) found that peasants in Uttar Pradesh use a short-duration variety of crops, intercropping and agroforestry as adaptation strategies to enhance their revenue. Furthermore, in drought-prone locations, it is critical to use all available strategies for maximal rainwater gathering, in-situ moisture conservation and optimal utilisation of this stored moisture in timely management of most suited rainfed crops in dryland fields. This strategy will undoubtedly help to stabilise the output of important field crops in the future (Dharbale, 2019). According to the NITI Aayog (2019) study, India is now dealing with a serious water crisis that, if it persists, might pose a serious danger to the nation's food security. Therefore, there is a pressing need to handle the Indian agricultural situation in its whole given the increasing likelihood that climate change-related concerns would materialize. Existing vulnerability and adaptability research has traditionally emphasized a static, location-specific understanding of risk and response (Singh *et al*., 2018). Innovative agricultural methods and technology may help with climate change adaptation and mitigation. At different scales, institutions and policies matter in this situation improved forecasting and advanced detection systems; hazard and vulnerability mapping, enhanced public awareness; community-based forest management and afforestation programs; and improved irrigation are all critical steps toward mitigating the negative consequences of climate change (Senapati *et al*., 2013). Adaptation strategies are essential to enhance the resilience of agricultural systems in the face of climate change impacts. These measures encompass various approaches such as selecting and altering species and varieties, adjusting fieldwork schedules for greater flexibility, modifying cropping procedures, including fertilization, preservation of plants and watering, as well as adopting strategies that elevate soil organic matter content or enhance soil covering, such as manure management and agroforestry (Praveen and Sharma, 2019). Crop variety changes can also help minimize greenhouse gas emissions (Ayal *et al*., 2017). In drought-prone regions within the semiarid climatic zone of Brazil, researchers have documented that farmers are adopting the practice of cultivating multiple varieties of a single crop species in the same land area. This involves integrating diverse varieties of beans, maize, sorghum and other crops to enhance the overall harvest potential and mitigate the impacts of arid climate anxiety. Farmers in the Philippines are preparing for the spring rains by cultivating highland farmland ahead of schedule, resulting in increased agricultural production for the season and higher household income from farming activities. Similarly, in East Gojam (Choke Mountain) and East Hararghe, Ethiopia, altering the planting dates of crops has proven effective for smallholder farmers in adapting to climate change. Moreover, smallholder farmers in the subhumid southwestern region of Cameroon have implemented various soil and water conservation practices to adapt to variations in rainfall. Farmers in Central Africa use a variety of adaptation measures to combat climate change, including breeding locally suited livestock species, diversifying livestock kinds, employing resource management practices and adopting alternative feed production technology. Notably, feed manufacturing requires the utilization of agricultural byproducts as well as domestic and industrial waste items. The practice of agroforestry is gaining significance in the agricultural sector, particularly in Central Africa, where trees are integrated into farms. This technique improves the ability of small or economically challenged farmers to manage climate change risks through crop and income diversification, water and soil conservation and effective nutrient cycle conservation (Aid, 2008). Agroforestry has a vital role in reducing greenhouse emissions and presents a chance to counteract the negative consequences of climate change *via* joint adaptation and mitigation action (Steinfeld *et al*., 2006).

CONCLUSION

Adapting agriculture to climate change is a big problem, particularly in emerging nations like India, where the majority of cultivators are marginal and smallholders with lower levels of education and little adaptive ability. Achieving independent adaptability is improbable and even if possible, it may not suffice to offset the losses incurred due to climate change. To effectively tackle these challenges, it is imperative to comprehend the localized effects of climate change and implement resilient technologies, thereby empowering small-scale farmers. Prompt and appropriate measures can enhance the prospects of mitigating the catastrophic impacts of climate change. The precise sectoral impacts of climate change remain unpredictable, underscoring the importance of increased awareness and the integration of climate uncertainty into local and national decision-making processes. The rise in mean seasonal temperatures can potentially curtail the duration of numerous crops, resulting in diminished final yields. Concurrently, the growing population, coupled with escalating challenges of water and land scarcity, exacerbated by the imminent impacts of climate change, poses significant threats to food security, nutrition security and sustainable livelihoods. Agricultural systems are notably vulnerable to climate variations, including changes in temperature and precipitation, which can contribute to pest and disease outbreaks, ultimately jeopardizing the country's food security. Effectively addressing the impact of climate change on agriculture necessitates the development of new crop varieties resilient to climate challenges, coupled with judicious resource management of soil, water and biodiversity. Embracing sustainable agriculture through an integrated, holistic and partnership-based approach, employing cutting-edge scientific tools to empower farmers, is crucial. Simultaneously, urgent measures are required to ensure the provision of essential urban facilities, such as healthcare, education, power, sanitation, *etc*., in rural areas, aiming to deter migration to urban centers.

ACKNOWLEDGEMENT

The authors acknowledge the respondents' cooperation in the study.

Conflict of interest

There is no conflict of interest.

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