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REVIEW ARTICLE

Impact of extreme climatic events on crop production and need for adaptations -A review

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ABSTRACT
The primary threat to India's agricultural sustainability and ability to provide for its people's needs is increasingly thought to be climate change. Over the past few centuries, the burning of fossil fuels and widespread deforestation have increased atmospheric Greenhouse Gas (GHG) concentrations, and these GHG increases have led to significant global climate changes. Since the beginning of the industrial era (1850–1900), climate change has already warmed the earth. As a result of the rise in global temperature, there have been changes in the frequency and severity of extreme weather events including drought and precipitation events at a highly regional scale, as well as an increase in the number of hot days and nights and a decrease in the number of cold days and nights. Global population growth and continuing deforestation are two factors that have contributed to rising land demand and elevated GHG emissions. Numerous variables, such as the temperature, crop and land management techniques, pathogens and pests, and the frequency of extreme weather occurrences, all have an impact on agricultural productivity. Significant variations in productivity can result from shorter fluctuations in temperature and rainfall. Global cereal production has decreased as a result of extreme heat and drought. Adaptation methods, which seek to lessen the adverse consequences of and take advantage of advantageous opportunities resulting from climate change, must be linked with mitigation efforts to minimise GHG emissions. Temperature fluctuation and a rise in extreme weather events are expected to have the biggest effects on developing countries, which will also have the least resources to adjust to these changes in agriculture. The transformation of agriculture and food systems must be achieved through broad-based, multi-sectoral strategies that lower emissions, sequester carbon, and improve capacity for climate adaptation and resilience. A few adaptation options include altering farming and land use methods, creating better crop types, and modifying food consumption and waste. Recent developments in agronomy and genomics may be able to mitigate some of the effects of climate change on food production. The adaption solutions are anticipated to boost farmers' incomes without sacrificing the sustainability of agricultural output. Planning for mitigation and adaptation is rather difficult due to the significant degree of uncertainty around the future of climate change and its effects. This calls for the development of climate-resilient technology using a regionally-specific transdisciplinary approach. To make the adoption of various climate-smart technologies easier for farmers, they must be made aware of them and given training.
Key worlds : Adaptation, agriculture, climate change, extreme events

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INTRODUCTION

Worldwide, climate change is manifested in the form of rising surface temperatures, increase in frequency and intensity of heatwaves, prolonged drought spells, variation in precipitation etc. [1]. Global agriculture production has been significantly affected by climate change [2, 3]. Due to high dependence on various weather parameters, agriculture is highly vulnerable to changing climate [4]. The climate is sensitive to agricultural productivity in India, and changes in temperature and precipitation patterns have a negative impact on the productivity of food grain yields, which may endanger the country's ability to provide for its people. According to Osborne and Wheeler [58], one of the most significant elements affecting crop production is climate variability, which accounts for over 60% of yield variability. By the middle of the 21st century, crop production in India may decrease by 30% due to projected surface warming and precipitation changes, and as a result, there may be a fall in arable area, placing strain on crop production [5]. Extreme weather occurrences have been more frequent recently, and this trend is expected to continue. Due to their increased reliance on agriculture, tiny landholdings, and lack of financial resources, technologies, infrastructure, and institutions to deal with such shocks, emerging nations like India are more susceptible to extreme event shocks. Depending on the future development scenario, the IPCC has predicted that the Indian region's temperature will rise by 0.5 to 1.2 °C by 2020, 0.88 to 3.16 °C by 2050, and 1.56 to 5.44 °C by 2080 [10]. According to recent studies [6-9], the number of heat waves and extreme precipitation events has significantly increased in the nation. The frequency of severe climatic extremes has grown in recent years, resulting in greater risks and significant losses in agricultural production. An increase in temperature can shorten crop life, increase crop respiration rates, change the way photosynthetic energy is converted into food, affect the survival and distribution of pest populations, leading to the development of new pest-crop equilibriums, hasten the mineralization of nutrients in soils, reduce fertiliser use efficiency, and increase evapo-transpiration. Due to the availability of irrigation water, the frequency and severity of inter- and intra-seasonal droughts and floods, the transformation of soil organic matter, soil erosion, changes in pest profiles, the loss of arable land due to coastal land flooding, and the availability of energy, climate change also has a significant indirect impact on the use of agricultural land in India. Farmers will be the first to experience the harshest effects of the changing climate and agricultural production systems, which will have an impact on food security. Because more than 80% of Indian farmers have cultivable land that is less than one hectare in size or are small farmers with cultivable land that is between one and two hectares in size and have weak coping mechanisms. The average annual agricultural losses caused by extreme weather events are currently. There is a need to identify appropriate adaptation and mitigation methods, capacity building, development activities, and bringing essential adjustments to policies in order to address the long-term negative implications of climate change and the short- and medium-term impacts of climatic variability on agriculture. In order to enhance strategic knowledge systems in important impact areas like water, agriculture, and energy, among others, these activities must be complemented by long-term sustained efforts that create institutional and human capacity.

Extreme Climatic events and crop production

According to data from the Food and Agriculture Organisation (FAO) and as depicted in Figure 1, the frequency of extreme climatic occurrences such drought, flood, high temperatures, and storms has significantly increased. In particular, the resource-poor who would be most affected, such as small and marginal farmers are those who would be most in need of crop productivity improvement (Figure 2). Nearly 60% of India's total arable land is dependent on rainfall; hence natural disasters are likely to pose a threat to the nation's overall economy. These pressures have a negative economic impact on Indian agriculture because they cause a fall in production and crop yields, which has a significant negative influence on farmer income.

Heatwave

Since the middle of the 20th century, variations in the frequency and intensity of daily temperature extremes have been recorded on a global basis. It is now very likely that human impact has contributed to these changes. In India, the majority of studies on temperature trends have concentrated on the examination of mean maximum and lowest temperatures e.g., [11-19]. They have generally observed rising trends in both the maximum and lowest temperatures over India. The occurrence of heat waves may be exacerbated by changes in the mean value or variance of temperature (Trenberth *et al.*, 2007). According to the IPCC's 2014 predictions, the temperature will rise in the Indian region by 0.7–2.0 °C by 2030 and 3.3–4.8 °C by 2080.During the rabi season (November to March), the rise may be greater in north India. A negative impact on food production will result from a rise in temperature of 0.5-1.56 °C by 2080-2100, which will result in a loss of 10-40% in food grain production in India [20, 21]. Recent research suggests that heat wave episodes are becoming more frequent, longer, and more intense over land regions all over the world [17, 24]. Due to their significant effects on agriculture and the national economy, climatic extremes like heat waves are of great interest on a global and regional scale [22, 23, 24]. Extreme temperatures frequently affect a plant's physiological processes, including transpiration rate, stomata opening and closing mechanisms, photosynthesis, respiration rate, and, if they occur during the reproductive phase, severe damage to reproductive organs like pollen grains [25], a disruption of grain setting and filling [26], and an early onset of senescence [27]. India is experiencing a trend of shorter winters and an earlier start to much higher temperatures than usual. Early starts of noticeably higher temperatures coincide with the period of wheat grain filling, particularly in the Indo-Gangetic plains, which causes terminal heat stress and a decrease in yield. The maturation phase of wheat, rapeseed, and vegetables in March 2004 coincided with heat wave conditions in many regions of North India. For many days straight, the lowest temperature was also higher than usual in a number of locations in Jammu and Kashmir, Himachal Pradesh, Punjab, and Uttar Pradesh. As a result, around 4.6 Mt of wheat output were lost [28]. High temperature (>35 °C) during blooming and pod development reduces grain yield [29]. Heat waves caused a loss in wheat yield of 11 to

21% in Baghpat and Kushinagar, 9 to 21% in Gorakhpur, 15 to 20% in Gonda, and 32 to 34% in Jhansi in the year 2022 in Uttar Pradesh. Uttar Pradesh's Kushinagar and Gorakhpur districts saw yield reductions of 9 to 11 percent and 14 to 18 percent for cow pea and mustard, respectively. The heat wave also hit several regions in Haryana, causing the grains of wheat and chickpea to wilt and shrivel. Due to the heat wave, wheat yield was reduced by 10 to 15%, especially in late-sown wheat, and chickpea yield was reduced by up to 19%. Extreme temperatures caused wheat and chickpea to mature earlier and have smaller grain weights in the Madhya Pradesh districts of Datia, Morena, and Tikamgarh. High temperatures in Brassica species promoted plant growth while also resulting in flower abortion, poor grain filling, and a sizable reduction in seed output. Canola seed output decreased by 430 kg/ha as a result of a 3^0C increase in the maximum daily temperature (21-24^0C) during flowering and grain filling [30]. When exposed to extremely high temperatures, horticultural crops like vegetables are vulnerable to very large transpiration losses, which also affect citrus fruit setting. On young trees especially, high temperatures have a scorching impact on the flowers. High temperatures can cause fruit trees including apricot, cherry, and apple trees to experience moisture stress, which can result in sunburn and cracking signs. In litchi plantations, the increase in temperature during the ripening period causes fruit to burn and break [31]. Extremely high temperatures in the year 2022 caused the Chamba district in Himachal Pradesh to see vegetable crop reductions of up to 50%. Similar to this, heat waves in several districts of Jammu and Kashmir caused poor vegetative growth, a reduction in plant canopy, severe flower and fruit drop in several vegetable crops, early drying of cucumber and bitter gourd, cracking and scalding in tomato, and a reduction in fruit size and weight loss of 40 to 50% [32].

Cold wave and frost

In recent years, cold waves have become one of the biggest meteorological threats affecting various regions of the nation (Fig. 3). With the exception of southern India, cold waves are a confined seasonal occurrence that are common throughout the nation [58]. The core cold wave zone is located in northern India, notably in the mountainous parts and nearby plain areas. The frequency, durability, and geographic coverage of cold wave events significantly increased in the decade 1991–2000 compared to the two decades before it, according to Pai *et al*. [59], who analysed cold wave events for the meteorological sub-divisions of India from 1971 to 2000. According to the frequency of events throughout various time frames, Jammu & Kashmir has been seeing less cold waves lately than Rajasthan has [33]. A cold wave's potential for harm is influenced by factors like temperature, exposure time, humidity, and wind speed at freezing temperatures. In the north and northeastern parts of the country, frost and cold waves caused damage to a number of crops and orchards. All plants are susceptible to low temperature injury, however the process and forms of harm differ greatly (Table 1). Low temperatures (decreases to 8–12°C) have been shown to inhibit tomato seed germination, pollen tube growth, and fruit set percentage [60]. The minimum temperatures in Doon Valley were abnormally low between December 2002 and January 2003 due to major cold wave conditions. In contrast to a 30-year average of 3.7-3.9°C, the minimum temperature in the final week of December 2002 ranged between 1.2°C and 1.5°C. Similarly, between January 10 and 14, 2003, a temperature of 1.0°C was noted compared to the 4.3°C average for the previous 30 years. This cold snap persisted until January 26, 2003. A substantial drop in temperature was also recorded in Doon Valley in December 2007, January 2008, and February 2008, which caused chilling damage in various forms in mango, litchi, guava, aonla, and papaya (Table 1). The occurrence of frost in regions next to the Himalayas at lower elevations as well as in places distant from the mountains has increased, resulting in a significant loss of harvests, fruits, and vegetables. Many times, the winters are dry and warm, but in the spring, the weather is unfavourable, temperatures drop, and spring frosts occur, causing frost damage to the flowers, poor fruit set, low fruit retention, and poor yields [1]. Legume crops are significantly impacted by frost and cold waves during the flowering and pod-forming phases.

Drought

In agriculture, a drought is a period of excessive dryness that affects soil moisture levels and slows plant growth. Drought happens when the total amount of moisture present in the soil is less than the amount of water required for transpiration and evaporation. It happens as a result of crop development-related soil and plant moisture stress. Drought-related disaster threats are a common occurrence in India. According to Samra [78], 28% of India's total land area is susceptible to drought. According to meteorology, a rainfall variation from the long-term mean of 19% is regarded as 'normal' in India. According to Samra [78], a deficiency between 20 and 59% indicates a "moderate" drought, while one over 60% indicates a "severe" drought. In India, it happens frequently that the S-W monsoon does not arrive at all or arrives in insufficient amounts, which frequently causes drought and hardship. Based on the moisture index, drought-prone zones are identified and displayed in Table 2. In order to calculate the moisture index, Thornthwaite and Mather [93] used information on annual precipitation and annual water needs. There have been 22 significant droughts in the nation, five of which were very severe [3]. There are just a few pockets of drought-prone land in the central, eastern, northern, and southern regions of the country, which are mostly located in the peninsular and western regions. According to Nagarajan [52], the cumulative consequences of altered precipitation patterns, excessive water use, and agricultural practices that are not ecologically sound are the main causes of the drought in these regions. In years of drought, the result is a reduction in agricultural output. There were 11 significant drought years with widespread rainfall failure over the previous five decades (Table 3), which resulted in the formation of scarcity circumstances. Due to the complete lack of monsoon rains (64 mm total) till August 2002, the drought of 2002 is regarded as the worst in the last 100 years and was called the most intense drought. In contrast to the 650 mm average rainfall in the northwestern area of India, only 102 mm of rain fell during the kharif of 1987. Its effects on people, livestock, and natural resources, especially in the year 2002, have been documented in states like Haryana, Rajasthan, Punjab, Uttar Pradesh, Odisha, Madhya Pradesh, Gujarat, Tamil Nadu, Karnataka, and Kerala [74]. There were indications of reservoir drying, rivers drying, surface water depletion, and soil moisture loss as a result of inadequate rainfall. In such cases, groundwater could not sustainably supply water to humans, animals, and crops [33]. As a result, less space was planted. Agriculture drought frequently causes a drop in sown area, a reduction in productivity, a decline in purchasing power, an increase in unemployment, a shortage of water, inflation, widespread starvation, and the development of illnesses [34]. Murthy and Sesha Sai (2010) stated that approximately 285 million people were affected by the 1987 drought in India, which ruined 58.6 million hectares of cropland. The 2002 drought caused a decrease in food grain production from 212 million tonnes to 174 million tonnes and a reduction in the sown area from 124 million hectares to 112 million hectares, resulting in a 3.2% decrease in agricultural GDP. Any decrease in rainfall has a detrimental effect on crop output because only 45.0% of the total planted land was irrigated in 2009–2010 [35]. The fact that the agricultural sector is dependent on the Indian summer monsoons is demonstrated by the fact that, despite a record-breaking production of food grains in 2011–12 of 259.32 million tonnes, the delayed onset and insufficient first half of the South–West monsoon in 2012 had a negative impact on Kharif crop area coverage and yields [36]. In exchange, it further compelled farmers to take out high-interest loans from banks and moneylenders, which had an adverse effect on their social lives as well as those of others in the drought-affected rural communities [37, 38].

Flood

Flooding, or an excess of water, can be brought on by a lot of rain followed by a river's inability to contain the water inside its banks [39]. One of the most common and recurrent natural disasters in the world is flood. The economic damage and human casualties brought on by the flood have burdened the economy more than any other natural disaster because of its recurrent prevalence. Numerous floods have continuously caused great economic and human destruction in India. More than half of all the floods that occur in Asia each decade occur in India on average [40]. India has a vulnerable area of around 40 million hectares to flooding. Additionally, around 8 million hectares of land are typically damaged by floods each year. It has been discovered that flood incidents are rising quite quickly. Until recently, valleys in the states of Karnataka, Kerala, and Maharashtra were not thought to be at risk of flooding. In India over the past 100 years, flood disasters have caused about 47% of all disasters. Flood disasters have been continuously increasing in India. In the previous decade, there were around 100 flood disasters. The rise of flooding throughout time has a number of contributing factors. [41-45]. Climate change has significantly impacted flooding. According to several studies [46-49], the frequency and severity of flooding will certainly increase over time. Inability to work costs people their income, property damage costs money, telecommunications and transport services are disrupted, and infrastructure deteriorates as a result of flooding [50, 51]. Nearly 2% of India's GDP was lost overall between 2005 and 2015. When compared to prior decadal losses, the last ten years show a sharp increase in the economic burden brought on by floods. The economic burden per decade increased dramatically from USD 11.6 billion in 1995–2005 to USD 34.5 billion in 2005–2015. The largest floods in India during the past ten years have included the floods in Uttarakhand (2013), Leh-Laddakh (2010), Assam (2012), Jammu and Kashmer (2014), Manipur (2015), and Kerala (2018) [52, 52]. The overall damage caused by floods since 1953 was also cited by the Indian government in the Working Group on Flood Management and Region-Specific Issues for XII Plan report from 2011 (Table 4). In general, sunlight and little water are necessary for photosynthesis and plant growth, but excessive water flow may be dangerous for plant growth and agriculture. Since most of India's agrarian states are basins of rivers and their tributaries, particularly Uttar Pradesh, Bihar, West Bengal, Odisha, and Assam, proper channelization of excess rainwater during the monsoon is crucial in order to reduce the threat of flooding in flood plains [54]. Every year during the monsoon season, floods are the main natural hazard that many North-Eastern regions must contend with, which causes significant losses to crops (Table 5). For the vast majority of people living in India's north-eastern states, agriculture is their primary line of work and one of their most important sources of income. Manipur faced the worst flood in the previous 200 years in 2015. Every major river was overflowing, wreaking devastation and destroying bridges, bursting embankments, and shutting off several settlements from the mainland. Additionally, all of the major canals are overflowing, which causes the paddy fields to be flooded. One of the worst-affected states in India by flooding is Assam. Every year during the monsoon season, the Brahmaputra River and its tributaries flood the Brahmaputra Valley, resulting in a massive loss of arable land measured in lakhs of hectares. Such losses and risks have significant effects on the state's overall development of the agriculture industry. Frequent floods, which disrupt production in addition to other ways, are one of the reasons why contemporary production techniques are not widely used. As well as destroying standing crops, causing water logging, soil erosion, and sand deposition, frequent floods also have an impact on big crop regions [55]. Similar to this, Rafique [70] examined the financial effects of the monsoon flood that ravaged several West Bengal districts in 2000 and devastated numerous paddy fields. In the recent years, research on food security and agricultural planning has focused heavily on flood occurrences and the proper assessment of their effects on crops [56-62]. In addition to understanding the immediate loss of agricultural output, evaluating flood damage is crucial to recognise implications for the whole food market [63].

Hailstorm

According to Navalgund *et al.* (1996), hail is a solid, frozen kind of precipitation that significantly damages buildings and developing crops. Hailstorms are frequently seen in the country from March to April, when the pre-monsoon season begins. In certain years, it also happened early, at the end of February, and towards the middle of May. With a maximum likelihood of occurrence in the range of 91-95%, the State of Maharashtra is more susceptible to hailstorms than other States in the nation. Himachal Pradesh, Punjab, Assam, and Madhya Pradesh follow with probabilities in the range of 66-70%. Due to increased convective activities brought on by a rise in temperature as the season transitioned from winter to spring in 2014 and 2015, northern, central and southern India experienced abnormally widespread hailstorm outbreaks [64]. These resulted in widespread crop destruction in the Indian states of Uttar Pradesh, Madhya Pradesh, Maharashtra, Punjab, Gujarat, Uttarakhand, Haryana, Andhra Pradesh, and Karnataka, with the Deccan plateau region and central India suffering the most damage (Table 6). The size and density of the hailstones that fall per unit area, as well as the wind speed during the hail fall event, are typically factors that affect the level of hail damage [65]. The growth stage, the degree of damage to the stem, leaves, blossoms, and fruit must all be considered while assessing hail damage. Few studies suggest a strong positive correlation between hailstorm activity and subsequent hailstorm damage, which is likely to be exacerbated by global warming, despite the fact that there is much uncertainty regarding the effects of anthropogenic climate change on the frequency and severity of extreme weather events like hailstorms, and subsequent economic losses. According to estimates by Bal and Minhas (2017), unprotected farms could sustain yearly hailstorm damage of up to 50% by the year 2050.According to reports, a hailstorm that hit Marathwada and Vidarbha in February 2018 devastated standing crops and caused $313 million in crop damage (Anonymous, 2018). Similar hailstorms were seen in Meghalaya's Umiam region on April 3, 16, and 17, 2018, which caused damage to horticulture crops, particularly Khasi mandarin [66, 67]. Damage to leaves (8.33%), flowers (46.66%), and fruits (42.76%) in Khasi mandarin was noted, while flower drop (62.66%) and fruit drop (53.67%) were also noted. In peaches, hailstorm caused 32.0% leaf damage, 22.5% fruit drop, and 61.3% damage to mature fruit. Damage is expressed in terms of broken shoot tips and damaged stalks in all ornamental flower crops. Damage to gerbera leaves and flowers occurred 86.66% and 92.33% of the time, respectively. Gladiolus flowers and foliage were damaged at a rate of 96.66% and 13.66%, respectively. The dolichos bean loses its flower (53.54-61.48% for the pole type and 55.86-57.69% for the bush type) and fruit (17.53-23.68% for the pole type and 59.09- 66.67% for the bush type). Fruit decline (14.29-31.43%) and blossom drop (31.25-89.41%) in tomatoes were observed. Vegetable flower and fruit drops may cause hailstorm-related yield losses of 35–58% in dolichos bean and 30-45% in tomato. Particularly on a wide spatial scale, the present methods of hailstorm damage identification and assessment have limitations. The conventional approach to damage assessment calls for labour- and money-intensive field assessments. The assessment of crop damage can be done using multiple methods with the use of remote sensing. Because hailstorm events are occurring more frequently, suitable action was required to reduce their negative effects on agricultural products. Therefore, field tests were carried out in Maharashtra, India, in 2014 and 2015 to evaluate some of the post-hail measures, such as nutritional supplements, plant bio-regulators, and canopy management. One of these was the resilient, indeterminate eggplant crop, which was pruned to encourage productive branches that resulted in more flowers and fruits. While humic acid drenching and potassium nitrate spraying boosted onion productivity, urea drenching and the stress-relieving effects of salicylic acid encouraged recovery in maize. These studies show that using technology to deal with extreme phenomena like hailstorms is a viable option.

Adaptation to extreme events

Farmers can implement climate-resilient technologies by utilising traditional management techniques and agro ecological management systems, such as bio diversification, soil management, and water collection [68-70]. According to Lal *et al*. [43], these management techniques result in resilient soils and agricultural systems that eventually assure food security throughout climate change. They also boost soil health, soil quality, and carbon sequestration. Due to a lack of information, small and marginal farmers are less able to adapt to climate change, which makes them more vulnerable to losses [71, 93]. There are a number of agronomic practises, such as changing sowing dates, that can be used to reduce the effects of climate change. The best times to plant wheat in Punjab, India, have been determined to be October 22–28 in the northeast, October 24–30 in the centre, and October 21–27 in the southwest [75]. Changes in planting dates and types are examples of straightforward adaptation measures that could lessen the effects of climate change [72, 91]. Since conservation agriculture promotes minimal soil disturbance, crop diversity, and the maintenance of soil cover, it has the ability to reverse the deterioration brought on over time by conventional tillage. Additionally, conservation agriculture results in increased terrestrial carbon sequestration, decreased fertiliser usage, and fewer GHG emissions [73, 96]. The guiding principles of conservation agriculture, which lay the groundwork for sustainable agricultural practises, include minimal soil disturbance, crop rotation, and soil cover. Farmers in south Asia are switching to zero tillage for growing wheat mostly due to a 15–16% decrease in production costs. Furthermore, zero tillage increases wheat and maize yields while reducing variability [76-80, 97]. Modified farming practises are the key adaptation strategy for climate change, and policy choices that take into account climatic variability and extremes as well as social, political, and economic factors have a significant impact [81, 98]. No-till farming, cover crops, manuring, nutrient management, agroforestry, and soil restoration can all help to promote carbon sequestration, or an increase in soil organic carbon (SOC). In comparison to transplanted rice, direct-seeded rice emits fewer greenhouse gases (GHGs) [82]. Sustainable rice production can be achieved through the cultivation of aerobic rice employing micro-irrigation technologies. According to Parthasarathi *et al.* (2012), it also aids in lowering rice field methane emissions. One irrigation method being encouraged to lessen groundwater overdraft and shocks brought on by climate change is drip irrigation. It potentially minimises the need for groundwater for irrigation and is climate change resistant. Sprinkler irrigation and drip irrigation are two water-saving irrigation methods that can both help us adapt to and lessen the effects of climate change [83]. Farmers' ineffective fertiliser management in northwest India has resulted in less effective nitrogen use. According to Singh *et al*. (2007), a leaf colour chart (LCC) was proven to be extremely suitable for enhancing fertiliser rate and timing. Crop yields and farmer revenue have grown as a result of the use of laser land levelling (LLL). According to reports, LLL increased the production of paddy crops in the Raichur area of Karnataka by 0.5 metric tons/ha, which might result in an increase in net agricultural income of INR 5000 per year. Additionally, it has lowered agricultural expenses and limited losses brought on by climatic fluctuation [100-101]. By implementing a number of interventions, such as water-smart practises, nutrient-smart practises, weather-smart activities, carbon-smart activities, and knowledge-smart activities, climate smart agriculture tries to adapt to climate change. Building evidence, improving the efficiency of local institutions, promoting climate-responsive agricultural policies and tying agricultural funding to climate are all ways that climate-smart agriculture increases resilience to climate change [84-90]. The most effective climate-smart technologies are those that sustain soil structure, deliver nutrients or water, or both.

Total Number of events

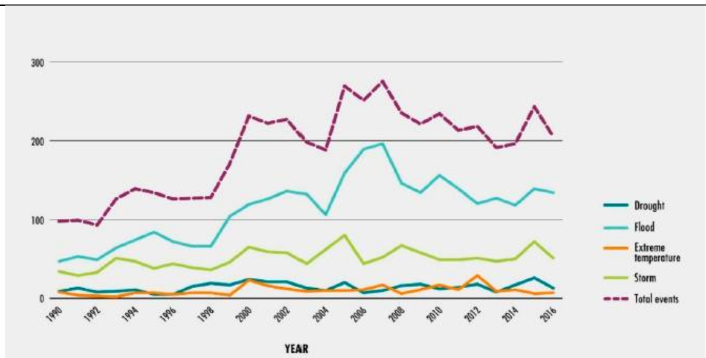

Figure 1. Increasing number of extreme climate-related events occurred during 1990–2016. Source:
Food and Agriculture Organization (FAO) based on data from Emergency Events Database (EM-DAT) (https://www.emdat.be/)

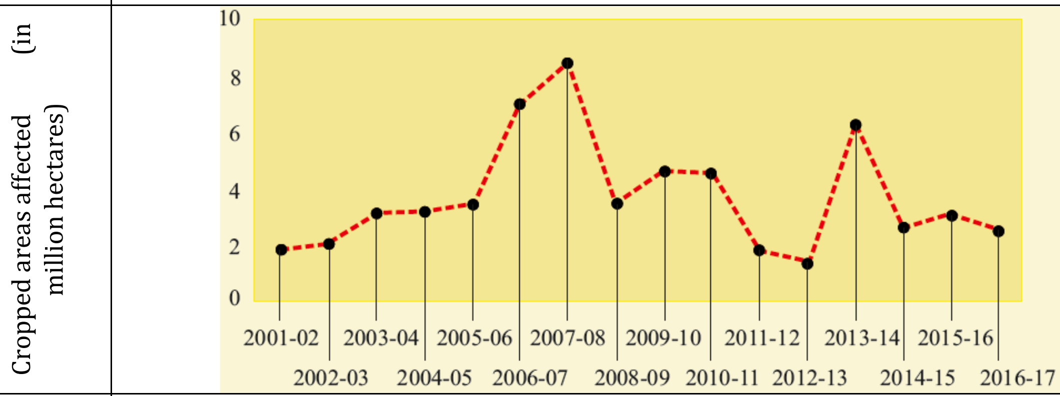

Figure 2: Year-wise damage due to natural extreme events in India
[Source: Envistats India 2018 (Website: http://mospi.nic.in/publication/envistats-india-2018)]

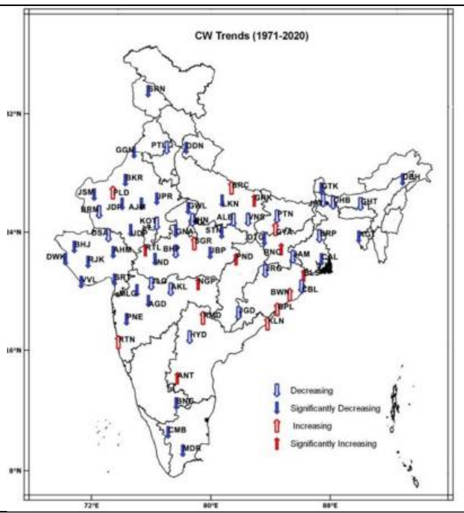

Figure 3. Map showing the increasing and decreasing trends of cold wave spell over India (NDMA, 2021)

Table: 1: The list of the vegetables, sensitive to chilling temperatures and the symptoms of chilling injury

Crop	Lowest safe temperature (°C)	Chilling injury symptoms
Asparagus	0-2	dull, gray-green, limp tips
Bean(snap)	7	pitting and russeting
Cucumber	7	pitting, water-soaked lesions, decay
Eggplant	7	surface scald, *Alternaria* rot, seed blackening
Okra	7	discoloration, water-soaked areas, pitting, decay
Pepper	7	pitting, *Alternaria* rot, seed blackening
Potato	7	mahogany browning, sweetening
Pumpkin	10	decay, especially *Alternaria* rot
Squash	10	decay, especially *Alternaria* rot
Sweet potato	10	decay, pitting, internal discoloration
Tomato(ripe)	7-13	water-soaking, softening, decay

(Source: Prasad and Chakravorty, 2015)

Table 2. Identification of drought prone area

Moisture index	Climatic zone	Per cent area of India
<–66.7	Arid	19.6
–66.7 to –33.3	Semi-arid	34.0
–33.2 to 0	Dry sub-humid	21.1
0 to + 20	Moist sub-humid	10.2
+20.1 to + 99.9	Humid	7.8
> + 100	Per-humid	8.3

(Source: Gautam and Bana, 2014)

Table 3. Decline in output of foodgrains in drought years compared to preceding years

Drought years	Production of foodgrains (million tones)	Decline in production, %
1950-51	50.8 (54.9)	7.4
1957-58	64.3 (69.9)	7.9
1965-66	72.3 (89.4)	19.0
1966-67	74.2 (72.3)	16.9*
1972-73	97.0 (105.2)	7.7
1974-75	99.8 (104.7)	4.6
1976-77	111.2 (121.0)	8.2
1979-80	109.7 (131.9)	16.8
1982-83	129.5 (133.3)	2.8
1984-85	145.5 (152.4)	4.5
1986-87	143.4 (150.4)	4.6
2002-03	184.1 (212.0)	13.2

Notes:1.* The figure indicates decline in output over 1964-65 since 1965-66 was the worst drought year; 2. The figures within the parentheses indicate the food grains production during the previous year. (Source: Badatya KC, 2005)

Table 4: Highlights of flood damages in India during the period of (1953-2010)

Item	**Unit**	**Average annual damage**
Area affected	mha	7.21
Population affected	million	3.91
Human lives lost	Nos	1612.00
Cattle lost	Nos	89345.00
Cropped area affected	mha	3.70
Damage to the crops	million	693.87
House damaged	Rs in crore	1194637
Damage to houses	Rs in crore	275.48
Damage to public utilities	Rs in crore	814.60
Total damage	Rs in crore	1804.42

(Source:Tripathi, 2015)

Table 5:Extent of damage by flood in Assam during 2000–2006.

Year	Area Affected (% of total area)	Crop area affected (% of gross cropped area)	Value of crop lost (Rs. In million)
2000	12.32	9.48	1735.16
2001	2.59	1.07	83.58
2002	15.14	8.40	1456
2003	11.88	8.34	1470
2004	30.14	15.15	3747.06
2005	2.84	2.95	234.73
2006	0.74	0.33	11.10

(Source: Mandal , 2010)

Table 6: State wise crop area affected due to hailstorm and unseasonal rains in country

S/No.	States	Total crop area (lakh ha) (as on 16th April, 2015)
1.	Gujarat	1.75
2.	Madhya Pradesh	5.70
3.	Maharashtra	9.89
4.	Rajasthan	16.89
5.	Haryana	22.24
6.	Punjab	2.94
7.	Uttar Pradesh	29.64
8.	Uttarakhand	0.39
9.	Himachal Pradesh	0.67
10.	Bihar	1.86
11.	J&K	1.33
12.	Telangana	0.01
13.	Kerala	0.01
14.	West Bengal	0.49
	Total area	93.81

(Source: Chattopadhyay et al., 2017)

CONCLUSIONS

India, a tropical nation, is already experiencing the effects of droughts, floods, cyclones, heat waves, and hailstorms, which may endanger agricultural productivity in the years to come. The majority of the Sustainable Development Goals (SDGs) are projected to be met by the agriculture sector, which employs about 70% of India's population directly or indirectly. Temperature, precipitation, and greenhouse gas emissions from human activity have a major negative impact on plant metabolism, soil fertility, pest infestation, and plant physiology. To counteract the negative effects of climate change on the sustainability of agriculture, a number of adaption measures have been developed. These technologies include water-smart techniques (laser land levelling, rainwater harvesting, micro-irrigation, crop diversification, raised-bed planting, direct-seeded rice), nutrient-smart techniques (precision nutrient application, leaf colour charts, crop residue management), weather-smart techniques (stress-tolerant varieties, ICT based agrometeorological services), carbon-smart techniques (zero tillage, legumes, crop residue management. By minimising the unfavourable consequences, these technologies greatly lessen the effects of climate change on crops and improve their climatic suitability.

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