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# A Review on Climate Change and its Impact on Agriculture in India

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***Authors' contributions***

*This work was carried out in collaboration among all authors. Author SK designed the study. Authors SGG, MRM, DBE, PK and DRMSVS wrote the protocol, and wrote the first draft of the manuscript. Authors SK and SGG managed the literature searches. All authors read and approved the final manuscript.*

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## ABSTRACT

Agriculture sector is of the utmost importance to the economy of a country and incidentally it is also most vulnerable to global climate change. Climate change is taking a toll on India's agricultural production and productivity. Intergovernmental panel on climate change (IPCC) has projected that by the end of 21$^{st}$ century temperature in India is likely to increase by 3-4$^{\circ}$C which would lead to a loss of 3-26% in net agricultural revenues. Aggravated climatic factors will ultimately decline plant productivity, which will result in increased prices and unaffordable rates for the common population. The absence of mitigation and adaptation measures may result in lower farm income by 12-40% in the coming years. This issue is an important concern for livelihood, economic development and ensuring food and job security of an agrarian nation like India. The causes that ultimately are contributing to increase in greenhouse gases, deterioration of soil and water ecology must be

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identified and rectified. Crop productivity in the countries of southern hemisphere is expected to decrease by as much as 20 per cent, with less developed countries suffering the greatest negative effects according to IPCC report 2007. Hence, adaptation to current agricultural scenario must be undertaken at once to avoid the risks incurred and tackle complications arising due to global climate change. How quickly Indian farmers are able to adjust in their farming practices to adapt to climate change and what policies or technologies will enable rapid adaptation are issues that merit attention of everyone. However, a rapid adaptation is less possible in a developing country like India, where availability to information and capital is limited among the majority of farmers.

*Keywords: Climate change; food security; mitigation; production; temperature; India.*

## 1. INTRODUCTION

Over the past several decades, the international and national research communities have developed a progressively clearer picture of how and why Earth's climate is changing and of the impacts of climate change on a wide range of human and environmental systems. Varying climate has resulted in quality and quantity of food, soil degradation, depletition of ozone layer, increasing air and marine pollution etc [1]. Changes which occurs beyond the average atmospheric conditions which is caused either by natural events such as sun's temperature, volcanic eruptions, crustal movements and human activities accelerates to global climate change but natural causes contributes very little compared to anthropogenic activities such as deforestation, emission from factories, vehicles, power stations, burning of fossil fuel releases huge amount of carbon dioxide and suspended particulate matter (SPM) into atmosphere. Every year 35 billion metric tons of carbon dioxide is emitted into the atmosphere through human activities (Perera, 2018). Future climate change extent rely on what all measures we adopt to reduce the emission of greenhouse gases. The more we release, the larger future alterations will be. There is no doubt that human activities has are adding fuel to the global climate change. Human-induced climate change and its impacts will continue for many decades, and in some cases for many centuries. Climate change can be warming or cooling of the climate. Emission of $CO_2$ from human activities is more than 100 times as compared to natural processes. Climate is warmed by 0.7$^{\circ}$ [2]. In 2019, the average temperature across global land and ocean surfaces was recorded to be 1.71°F (0.95°C) making it the second-warmest year on record. Global warming is a prominent cause of climate change which occurs due to the increased concentration of several gases such as carbon dioxide ($CO_2$), chlorofluorocarbons (CFCs), hydrogen ($H_2$), sulphur dioxide ($SO_2$) and nitrous oxide ($N_2O$) into the atmosphere and causing depletion of ozone layer. Anthropological activities are root cause of climate change which is affecting the earth's temperature, rainfall distribution pattern and hydrological cycles and posing severe threat to agricultural production, hence food security. Incidentally agricultural production is a major emitter of green house gases contributing about 18% of the total GHGs emissions in India [3,4] which eventuate at the primary production state [5].

Weather condition is altered by Climate change which has direct, indirect and biophysical effect on agricultural production. Climate change might have positive or negative impact on human population and crop production. Increase in temperature can lead to reduced yield of crops, increased incidence of pest and disease outbreak. Heat waves can cause more mortality in plants. Heat extremities results in reduced photosynthesis, reduced growth rate, increased leaf abscission and photooxidative stress Teskey et al. [6] and humans in shorter time span than any other climatic phenomenon. Agriculture sector is highly vulnerable to climate change. High temperature favours infestation of pest and obnoxious weeds. When the temperature is less than or equal to 25$^{\circ}$C, there is no spread of rust fungus which acts like a cancer but as soon as the temperature increases the climate becomes hot and dry, fastening the breeding process, covering and destroying entire crop/plantation which are more vulnerable to the temperature. Increased temperature can reduce crop duration, increased evapo-transpiration, crop respiration rate, rapid mineralization of nutrients, decreased nutrient use efficiency, breeding, survival and outbreak of any pest is greatly affected. Increase in temperature and reduction in rainfall adversely affects unirrigated areas compare to irrigated areas. Increased or reduced rainfall has impaired the soil fertility and productivity. Rainfall over India is likely to increase by 15-40%, by the 21st century end [7,2]. Such changes will hugely impact agricultural activities and will increase the pressure on Indian agriculture. It can disrupt food availability, affect nutritional quality of some foods and reduced access to food.

## 2. HUMAN-CAUSED CLIMATE CHANGE

The climate can shift because of natural changes either within the climate system (such as in the oceans or atmosphere) or outside of it (such as in the amount of solar energy reaching the Earth). Volcanic activity is an Earth-based event that is considered outside of the climate system but that can have a pronounced effect on it. An additional emerging factor is the effect of human activities on climate which has caused increase in greenhouse gases having significant implications on the environment and ecosystem [8]. Many of these activities are producing effects comparable to the natural forces that influence the climate.

Changes in land use through activities such as deforestation, the building of cities, the storage and use of water, and the use of energy are all important factors locally. The urban heat island is an example of very local climate change. In urban areas, the so-called concrete jungle of buildings and streets stores up heat from the Sun during the day and slowly releases it at night, making the nighttime warmer (by several degrees F in major cities) than in neighboring rural regions. Appliances, lights, air conditioners, and furnaces all generate heat. Rainfall on buildings and roads quickly runs off into gutters and drains, and so the ground is not moist, as it would be if it were an open field. By contrast, when the Sun shines on a farmer's field, heat usually goes into evaporating surface moisture rather than increasing the temperature; the presence of water acts as an air conditioner. In fact, in some places a reverse of urban warming, a suburban cooling effect, has been found because of lawns and golf courses that are excessively watered. Changes in the properties of the surface because of changes in land use give rise to these aforementioned climate changes. Nevertheless, these effects are mostly rather limited in the areas they influence.

## 3. THE ENHANCED GREENHOUSE EFFECT

Outmost concern globally is the gradually changing composition of the atmosphere caused by human activities, particularly changes arising from the burning of fossil fuels and deforestation. These lead to a gradual buildup of several greenhouse gases in the atmosphere, with carbon dioxide being the most significant. They also produce small airborne particulates aerosols that pollute the air and interfere with radiation. Because of the relentless increases in several greenhouse gases, significant climate change will occur sooner or later. The greenhouse-gas component of this change in climate is called the enhanced greenhouse effect. While this effect has already been substantial, it is extremely difficult to identify in the past record. This is because of the large natural variability in the climate system, which is large enough to have appreciably masked the slow human-produced climate change.

The amount of carbon dioxide in the atmosphere has increased by more than 30% since the beginning of the industrial revolution, due to industry and the removal of forests. In the absence of controlling factors, projections are that concentrations will double from pre-industrial values within the next 60 to 100 years. Carbon dioxide is not the only greenhouse gas whose concentrations are observed to be increasing in the atmosphere from human activities. A recent World Bank report studied two drought-prone regions in Andhra Pradesh and Maharashtra and one flood-prone region in Orissa on climate change impacts. It found that climate change could have the following serious impacts:

- In Andhra Pradesh, dry land farmers may see their incomes plunge by 20%.
- In Maharashtra, sugarcane yields may fall dramatically by 25-30%.
- In Orissa, flooding will rise dramatically leading to a drop in rice yields by as much as 12% in some districts.

With melting glaciers, flood risks would increase in the near future. In the long-term, there can be no replacement for the water provided by glaciers that could result in water shortages on an unparalleled scale. Floods and drought are thus projected to multiply as a consequence of climate change. This will lead to a huge crop loss and leave large patches of arable land unfit for cultivation.

**Parameters which are evidence of climate change phenomenon are:**

- In the past 60 years significant increase in mean maximum temperature has been

observed in many states of India and the world.
- Variation in the rainfall pattern has increased, random and intense rainfall.
- Increased frequency and severity of drought and floods (Ledger et al., 2013).
- Globally, the number of warm days and nights has increased and the number of cold days and nights has decreased.
- Increased frequency of intense heat waves in large parts of Asia, Europe and Australia.
- Decrease in snow cover and sea ice.
- Rise in sea surface temperature/ temperature over ocean (IPCC, 2007).
- Acidification of oceans.
- Vanishing of Arctic ice sheets.
- Changes in sea levels.

**How climate change is impacting agriculture?**

**Impact on forest:** Climate change will likely increase the risk of drought in some areas and the risk of extreme precipitation and flooding in others. Increased temperatures alter the timing of snowmelt, affecting the seasonal availability of water. Although many trees are resilient to some degree of drought, increases in temperature could make future droughts more damaging than those experienced in the past In addition, drought increases wildfire risk, since dry trees and shrubs provide fuel to fires. Drought also reduces trees' ability to produce sap, which protects them from destructive insects such as pine beetles.

**Impact on crops:** Agriculture is severally affected in the regions by drought, floods, hurricanes, freezes, and other forms of climatic changes [9]. Climate variability and extreme weather conditions increase multiple stresses not only for crop plants but also for animals by endangering the habitats and the organisms themselves, the animals may not genetically evolve fast enough with the rate at which the climate is changing [10]. Research showed that developed countries have more severe (8-11%) threats due to climate change than developing countries [11].

Climate and its variability impact all sectors of the economy in several ways like an abnormality in rainfall results in severity and frequency of floods. Any increment in maximum temperature may increase mean sea levels, and it would affect large populations in peninsular and coastal areas. It may increase 15% to 40% rainfall there and raise the annual mean temperature by 3° to 6°C. Climate change adversely affects food security in four dimensions which are food availability, food accessibility, food utilization, and food system stability.

Kumar and Parikh (2001a) show for rice and wheat crop the projected large-scale changes in the climate would lead to significant reductions in their crop yields, which in turn would adversely affect agricultural production by 2060 and may affect the food security of more than one billion people in India. Geethalakshmi et al. (2011) concluded that productivity of rice crop has declined up to 41% with a 40°C increase in temperature in Tamil Nadu. Saseendran et al. (2000) analyzed the projected results for duration 1980–2049 and found that increment in temperature up to 50°C can lead to a continuous decline in the yield of rice and every one-degree increment of temperature will lead up to 6% decline in yield in Kerala (India). Hundal and Prabhjyot-Kaur (2007) concluded that an increase in minimum temperature up to 1.0°C to 3.0°C above normal has led to declining in productivity of rice and wheat by 3% and 10%, respectively, in Punjab. Temperatures as low as 25°C can reduce grain-filling period in wheat, after which a 1°C temperature rise shortens the reproductive phase by 6% and shortens the grain-filling duration by about 5%; grain yield and harvest index are also reduced proportionately [12]. Karim et al. [13] also said that an increase in 4°C temperature would have severe impact on food grain production, especially for wheat production. A rise in temperature cause significant decrease in production, some 28 and 68 per cent for rice and wheat, respectively. On the other hand, doubling of atmospheric concentration of $CO_2$ in combination with a similar rise in temperature would result into an overall 20 per cent rise in rice production and 31 per cent decline in wheat production. It was found that Boro rice would enjoy good harvest under severe climate change scenario. Gram and ragi productivity also get negatively affected due to increase in maximum temperature, whereas arhar and wheat productivity is positively affected due to increase in maximum temperature. (Kumar & Parikh, 2001a, 2001b; Hundal & Prabhjyot-Kaur, 2007). Kumar et al. (2011) mentioned that decline in the irrigated area for maize, wheat, and mustard in northeastern and coastal regions and for rice, sorghum, and maize in Western Ghats of India may cause loss of production due to climate change. Kaul and Ram (2009) found that excessive rains and extreme variation in temperature have adversely affected the productivity of Jowar crop, thereby this has affected the incomes as well as food security of farming families in Karnataka (India).

Empirical result for nonfood grain (commercial) crops shows that any increments in maximum temperature have a negative and statistically significant impact on sugarcane, cotton, and sesamum crops. Any variation in minimum temperature from normal has a negative and statistically significant impact on linseed productivity. Fluctuation in rainfall from average has negatively affected the sugarcane productivity. It can be predicted that climatic factors negatively affect the cash crop production. (Singh, 2012). Boopen & Vinesh, 2011 also stated that climate change has significantly affected cane productivity in Uttar Pradesh and Uttarakhand.

## 4. TEMPERATURE ALTERATIONS

In general, crops are most sensitive to high temperatures at the reproductive stage and grain-filling/fruit maturation stage (Hatfield et al., 2011). However, plant responses to each type of temperature alteration is species-specific and mediated through both photosynthetic activities for biomass accumulation, which is responsible for plant growth, and the phenological and morphological changes, which occur during plant development.

1. The increase in average temperature during the growing season typically causes plants to use more energy for respiration for their maintenance and less to support their growth. With a 1°C increase in average temperatures, yields of the major food and cash crop species can decrease by 5 to 10 percent [14].
2. With higher average temperatures plants also complete their growing cycle more rapidly (Hatfield et al., 2011). With less time to reproduce, reproductive failures are more likely and this will also lower yields [15].
3. In general, photosynthesis in C3 plants is more sensitive to higher temperatures compared with C4 crops [16].
4. Higher temperatures can also affect the marketability of fruits and vegetables. The increased rates of respiration caused by higher temperatures lead to a greater use of sugars by the plants. As a result, less sugar remains in the harvested product, and this can reduce its market value [17]. These effects become more serious as temperatures continue to rise during the grain-filling or fruit maturation stage (Simpson, 2017).
5. Most crops can tolerate higher daytime temperatures during vegetative growth, with photosynthesis reaching an optimum at between 20°C and 30°C (Wahid et al., 2007). During the reproductive stage, yields decline when daytime high temperatures exceed 30°C to 34°C (FAO, 2016b)
6. Extremely high temperatures above 30°C can do permanent physical damage to plants and, when they exceed 37°C, can even damage seeds during storage. The type of damage depends on the temperature, its persistence, and the rapidity of its increase or plants' capacity to adjust (Wahid et al., 2007). It also depends on the species, the stage of plant development. As the climate changes, the frequency of periods when temperatures rise above critical thresholds for maize, rice and wheat is predicted to increase worldwide (Gourdji et al., 2013).
   Rice, a major cereal crop, is sensitive to low and high temperature stresses. High temperature (>35 °C) negatively affects the growth of roots and shoots, hampers pollination, causes poor anther dehiscence, and leads to spikelet sterility. Low temperature (<20°C) delays rice germination and seedling establishment, hampers tiller formation, affects flowering, causes panicle sterility, and finally leads to lower grain yield (Husain et al., 2019).
7. Temperatures above 31°C just before anthesis causes reduction in the grain number due to pollen sterility. Narayanan, [18] reported 4% reduction in number of wheat grains per unit area for each degree increase (from 15–22°C) in mean temperature during the one month period before anthesis. reported that 10°C increase in maximum temperature at mid anthesis caused 40% reduction in grain number per spike.

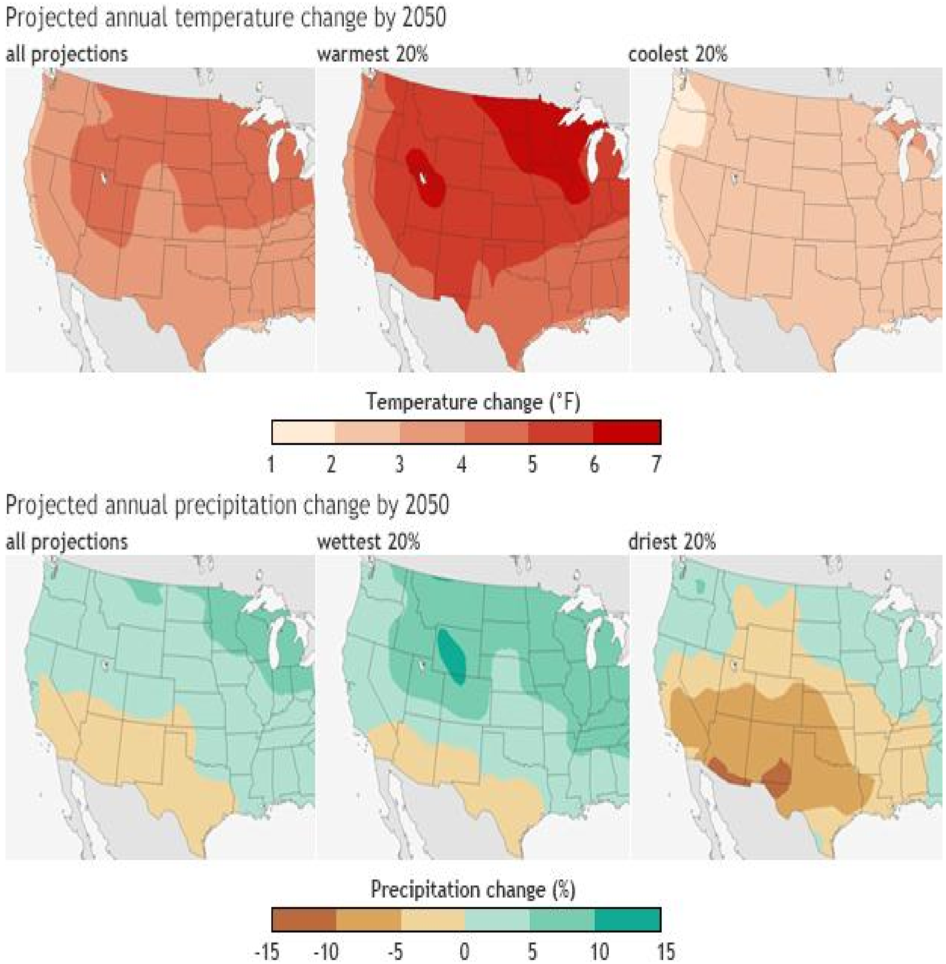


**Fig. 1. Study map**

## 5. IMPACT ON PRECIPITATION

Changes in precipitation regimes include changes in seasonal mean, the timing and intensity of individual rainfall events, and the frequency and length of droughts. Each of these factors is critical to crop productivity. The impact of changes in precipitation is considerable when they are combined with temperature alterations that affect the crop's evaporative demands. Leading to different forms of moisture stress depending on the phenological stage the crop has reached. The general prediction is that, with climate change, areas that already receive high levels of rainfall will receive more, and those that are dry will become drier (Liu and Allan, 2013). The reduction in seasonal mean precipitation will have a greater impact on areas with degraded soils. With varying rainfall patterns, farmers may no longer be able to rely on their knowledge of the seasonality of climatic variables. Shifting planting seasons and weather patterns will make it harder for farmers to plan and manage production. For example, a later start of the rainy season or an earlier end, or both, reduces the time that crops have to complete their growth cycle and, ultimately, causes yield losses (Linderholm, 2005). Heavy rain, hail storms and flooding can physically damage crops. Extremely wet conditions in the field can delay planting or harvesting or even stunt the growth. Prolonged droughts can cause complete crop failure (Tubiello and Velde, 2010). Frequently, heat and drought stress occur in field conditions, which substantially impact the performance of plants and can permanently damage plants [19]. Heat stress reduces grain yield and grain-filling period, frost causes sterility and abortion of grains [20] and drought stress adversely affects the physiology, morphology and biology of plants [21].

## 6. IMPACT OF CLIMATE CHANGE ON CROP PHYSIOLOGY

Temperature increase up to a certain level will enable plants to produce more energy but beyond these limits the photosynthesis of the leaves decreases sharply and is irreversibly lost [22]. Drought decreases the turgor pressure of plants which ultimately limits cell growth. Deficiency of water also influences the activity of photosynthetic enzymes and reduces the efficiency of metabolic processes and consequently dysfunctions the photosynthetic apparatus [23]. Increase in concentration of $CO_2$ due to changing climatic conditions results in declined plant respiration and increased temperature. Crop respiration increases with increase in temperature up to the range of 15-40ºC and then decline [24]. In periods of high temperature, there is a very severe damage to the chlorophyll, as heat stress changes the structural arrangement of the thylakoids, thus affecting its functionality, and also reducing the chlorophyll content of the plant. The above adverse effects on the plant reduces the ability of the plant to photosynthesize because by reducing the chlorophyll content, the photosynthetic pigments are reduced, thereby leading to physiological impairment and reduced growth of the plant [25]. The leaf of the plant also loses water under high temperatures thus leading to stomatal closure due to reduced leaf water potential [25]. According to Greer et al., [26] stomatal closure is the major factor affecting photosynthesis in plants. High temperatures according to Hassanuzzaman et al. [27] cause impaired pollen and ovary development which adversely leads to the bad reproductive health of plants. Plants also undergo denaturation of protein and enzymes under extreme temperature conditions which gives rise to the programmed death of the tissues and cells [28]. Hence, it can be concluded that agricultural productivity in India is climate sensitive, and the fluctuations in temperatures and rainfall pattern adversely affect the food grain crops productivity, and thus it may threaten food security in India. On the basis of our empirical findings, we can provide a policy implication that irrigation is an important factor that may mitigate the adverse effect of climate sensitivity of rice, wheat, sorghum, arhar, and bajra productivity (Kar & Kar, 2008; Ranuzzi & Srivastava, 2012; Singh, 2012).

## 7. IMPACT OF CLIMATE CHANGE ON LIVESTOCK

The climate changes will directly and indirectly impact the production and health parameters of livestock and also the interacting biophysical parameters that influence growth performance like meat and milk yield and quality, egg yield, weight, and quality; reproductive performance; metabolic and health status [29]. The global demand of milk and meat production predicted for 2050 to meet the global demand is estimated to increase 1,077 and 455 million tonnes, respectively, equating to almost double that of 2006 production Alexandratos and Bruinsma, [30] which seems difficult to achieve with the drastically changing climate and its impact on the livestock.

Changing climate is considered as a threat to livestock production because of the impact on the quality of concentrate and roughage feeds, availability of clean drinking water, meat and milk production, disease prevalence and incidence, reproduction, and biodiversity [31].

Temperature plays a central role on livestock by affecting rainfall, forage, production, reproduction, and health. Forage productions are influenced by increased temperature, $CO_2$, and/or combination of precipitation variation [32]. The direct effect of climate change on livestock health includes temperature related to frequent disease incidence and death. The indirect effect includes the climate influences on pathogen density and distribution and multiplication of vectors as well as vector-borne diseases and soil, food, and water-borne diseases. The direct effect of climate change on animal health has been described as a reduced competence of the host to mount a response to infection [33]. These effects are compounded by thermal stress or HS conditions. Depending on the degree, duration, and severity of heat exposure, livestock health can be affected by causing metabolic disorder, oxidative stress, immune suppression, decreased reproductive performance, and death. Increased temperature and fluctuation in rainfall causes heat stress (HS) which can simply be defined as the point when animals cannot dissipate an adequate amount of heat from the body to balance the body thermal condition [34]. Holstein–Friesian dairy cows are renowned for their milk production but predominantly susceptible to HS [35]. When the ambient temperature is over 25°C, high yielding dairy cows become heat stressed with primary signs shown as increased body temperature and respiration rates (Staples and Thatcher, 2011).

The climate change also affects animal health by hampering endocrine status, liver functionality, glucose, protein and lipid metabolism [36]. The emergence and re-emergence of vector borne pathogens have globally provided evidence for the relationship between climate change and effects on the human/animal health interface [37]. Several researchers reported that the warmer conditions accelerated disease transmission into the host [38]. About 18% of body weight can decrease by tick infestation in climate change condition in Australian livestock simulated by White et al. [39].

In order to contradict the effects of climate change on livestock some measures need to be undertaken like following good farm practice and herd health management. Development of updated vaccines and therapeutics combating for endemic and emerging diseases. Design the animal sheds considering HS, animal comfort, animal behaviour, and climate change. Conservation and development of local animal genetic resources (Ali et al., 2020).

## 8. IMPACT OF CLIMATE CHANGE ON FISHERIES

The impact of climate change on ocean and fisheries are linked to changes in water temperature and pH levels, shifts in ocean circulation patterns, rising sea levels and altered rainfall and storm patterns causing species to change their distributions and productivity, corals to bleach, and aquatic diseases to become more common, among others. The frequency and intensity of climate-related extreme weather events affecting fisheries is predicted to increase (FAO, 2018).

Arctic and tropical fishes have been found occupying new habitats as temperatures change, further demonstrating the likelihood of continued poleward range shifts under ocean warming [40]. Tropical fish species with larger body sizes, greater swimming capacities, larger sizes of settlement, and pelagic spawning behavior have exhibited greater success when colonizing temperate habitats, while habitat and food limitation during juvenile stages were likely to constrain movement [41]. Polar species are likely to be more vulnerable to climate change due to constrained ecological niches (e.g., Cheung et al., [42], and further suggest that tropical and temperate fauna may experience substantial range expansion under the combined influence of ocean warming and deoxygenation [43]. Indeed, in some locations, it is thought that hypoxia may function as a greater driver of poleward shifts than warming (e.g., poleward shifts of southern groundfish communities in the Pacific Northwest basin [44].

Empirical evidence of reductions in body sizes has been found for six of eight commercial fish species over a 40-year period in the North Sea, which coincided with a 1-2°C increase in water temperature and resulted in a 23% reduction of the mean yield [45]. In Mexico, 10 of the top 12 highest fished species-including the South American pilchard (*Sardinops sagax*) and Penaeus shrimp were projected to decline in catch by 2050 under the severe climate change scenario [46]. A reduced supply of nutrients resulting from greater stratification may also yield a reduction in the average size of phytoplankton and increase the number of trophic links within food webs, which in turn would reduce energy transfer efficiency [47]. Latest studies continue to indicate that oxygen-depleted hypoxic conditions are a major global environmental issue influenced by anthropogenic and climatic drivers, with particular relevance to tropical and temperate coastal ecosystems and sectors [48].

Adaptation strategies suggested in AR5 included the restoration or ecosystem engineering of marine vegetative habitats to assist with buffering climate-related impacts and to provide shelter for fish nurseries and important coastal habitats [49]. Hybrid engineering structures can provide an integrated way of conserving ecosystems and ecosystem services (e.g., carbon storage and sequestration; regulating nutrient fluxes; maintaining species biodiversity). This could in turn increase coastal protection [50] Spalding et al., 2014). Evidence that the preservation of coastal vegetative habitats and wetlands can yield a net uptake of atmospheric $CO_2$ has continued to emerge, with examples found for boreal, temperate, and subtropical seagrasses [51] and agreement that coastal wetlands aid in regulating GHG emissions continues to accumulate [52].

## 9. EFFECT ON CORAL REEFS

Coral reefs are likely to degrade rapidly over the next 20 years, presenting fundamental challenges for the 500 million people who derive food, income, coastal protection, and a range of other services from coral reefs. Although they occupy less than 0.1% of the ocean floor, tropical coral reef ecosystems provide habitat for at least 25% of known marine species, with many reef species still to be discovered [53]. Despite their biological diversity, productivity and importance to humans, both warm and cold-water coral reefs are being heavily impacted by human activities due to both local and global influences [54,55]. As a result, many coral reefs are rapidly declining across the world. While local factors can have significant impact on coral reefs (e.g., pollution, overfishing, and the physical destruction of reefs), changes in ocean temperature and chemistry due to anthropogenic activities are dramatically reducing the distribution, abundance, and survival of entire coral reef ecosystems (Gattuso et al., 2014b; Hoegh-Guldberg et al., 2014). Warm-water coral reefs, for example, have declined by at least 50% over the past 30-50 years in large parts of the world's tropical regions [56] De'ath et al., 2012.

This leaves us with two clear options with respect to preserving invaluable ecosystems such as coral reefs. The first is to stabilize planetary temperature and $CO_2$ concentrations as quickly as possible. Only then will biological responses such as acclimation and genetic adaptation have any chance of operating.

## 10. IMPACT OF CLIMATE CHANGE ON INSECTS

The basic climate parameters, i.e. temperature and humidity, influence insects both directly and indirectly. The direct influence can be observed through limiting and stimulating the activity of larvae and adults, insect's dispersal in the environment, phenology and growing length, as well as through the possibility of surviving in adverse weather conditions population genetics, etc. Indirect influence includes a climate influence on environment where insects appear, such as influence on plant formations, plant phenology, food quality, predators, parasitoids and activity of entomopathogens. Insects as poikilothermic animals change their activity visibly depending on the temperature of the surrounding environment [57,58]. Increasing the temperature to the thermal optima level causes acceleration of the insect metabolism. Hence, it directly influences their activity increase. In the temperate climate zone conditions, the average temperature increase is followed by a more intensive and longer total day and night's activity of implied as feeding and mating, as well as time spent on finding proper place for laying eggs [59,60]. Early and timely planting become more uncertain under climate change. During the 2009 rainy season, delay in onset of monsoons by 45 days lead to delay in plantings of pigeonpea that made the crop susceptible too insect attack and experienced heavy damage due to Helicoverpa armigera [61]. As with temperature, precipitation changes can impact insect pest predators, parasites, and diseases resulting in a complex dynamic. Some insects are sensitive to precipitation and are killed or removed from crops by heavy rains, this consideration is important when choosing management options for onion thrips [62].

**How climate change will affect global Food Security?**

*"Food security exists when all people, at all times, have physical and economic access to sufficient, safe, and nutritious food to meet their dietary needs and food preferences for an active and healthy life"*

(World Food Summit, 1996)

Food security means having a reliable and safe access to nutritious and affordability. According to Food and Agriculture Organization, food security has three dimensions.

- Food availability.
- Food accessibility.
- Food absorption.

According to FAO, estimated that in The State of Food Security and Nutrition in the World, 2017 report,

- 7 million people are undernourished in India i.e. 14.5% of the world population.
- 4% of women in reproductive age between 15 to 49 years are anemic.
- 4% of the children aged under five in India are stunted.
- 21% suffer from wasting, meaning their weight is too low for their height.
- The Global Hunger Index 2016 ranks India at 97 out of 118 countries on the basis of three leading indicators - the prevalence of wasting and stunting in children under 5 years, under 5 child mortality rate, and the proportion of undernourished in the population.

Agriculture and food production are likely to be significantly affected by climate change. A recent

IPCC report also warned that in the years to come, food security will stand threatened due to climate change coupled with increasing demands of the rising population.

The impact of climate change on India's food security has three dimensions - availability, access, and absorption. Thus, adequate food production alone is not a sufficient condition for a country's food security.

Climate change affects food security in complex ways. They are,

Affect on food availability
Affect on groundwater
Affect on food absorption

The direct impact of climate change on agriculture and food supply has been expected to includes shortage in grain production resulting in less availability of food items, especially to the economically poor people, changes in agricultural inputs such as fertilizers and pesticides, shift in planting dates of agricultural crops, preference of crop genotypes due to adaptation to changing climate, soil erosion, soil drainage and lower soil fertility levels. High anthropogenic production of greenhouse gases and associated changes in climate are also being looked upon as a great challenge to food and livelihood security in India.

Providing food and nutritional security to an entire population needs some serious planning and effective implementation. Achieving food security in the context of climate change calls for an improvement in the livelihoods of the poor and food-insecure to not only help them escape poverty and hunger but also withstand, recover from, and adapt to the climate risks they are exposed to.

**Five key interventions which matter foremost are:**

1. Promote good agricultural practices to increase incomes.
2. Implement adaptation methods that reduce loss risk from extreme weather events. Adoption of basic agronomic techniques can reduce losses from droughts, floods and other extreme weather events.
3. Incorporate a whole-farm integrated crop management approach. It is crucial to prioritize risk reduction through diversification of both crops and buyers and markets.
4. Support research, development and adoption of new varieties. We need demonstration trials to promote faster-maturing varieties that are more tolerant of drought, heat, pest, virus, disease and saline.
5. Expand capacity in remote weather stations, disease modeling and index insurance systems.

**Adaptation undertaken by farmers and scientists to combat climate change:** The ability of tropical species to withstand such "heat peaks" is poorly understood, particularly with regard to how plants prevent precocious senescence and retain photosynthesis in the leaves during these high temperature (HT) conditions. Such environmental stresses are among the main causes for declining crop productivity worldwide leading to billions of dollars of annual losses. Throughout history, farmers have adopted new crop varieties and adjusted their practices in accordance with changes in the environment. But with the global temperatures rising, the pace of environmental change will likely be unprecedented. Furthermore, with the expansion of crop cultivation to non-optimal environments and non-arable lands, development of climate resilient crops is becoming increasingly important for ensuring food security [63].

**Strategies to cope with this climate change:** For adaptation of crop in changing climatic conditions following strategies are needed.

## 11. CULTURAL PRACTICES

A few studies conducted to understand the farmer's managing strategies to mitigate climate hazards for crop adaptation. The coping strategies of farmers in eastern Uttar Pradesh, India that mitigate or minimize stressful events (temperature and rainfall) include change in timing of sowing and harvesting, use of short duration cultivar, inter cropping, change in cropping pattern, use of ground-water for irrigation and agro-forestry. All these practices are useful to reduce the effects of climate change on crop adaptation as stated by Tripathi and Mishra [64]. Some adaptation practices such as sowing time adjustments, adopting drought tolerant varieties, and shifting to new crops are very useful for crop adaptation. 8-13 % higher food security level and reduced exposure to weather risks are observed by adapting these practices at farm level [65]. Application of nitrogen fertilizer is very important mitigation option and helps in adaptation of plants to global warming. It is an indirect energy source and is important to maintain soil fertility and to increase crop adaptability and yield as observed by Celikkol Erbas and Guven-Solakoglu [66].

## 12. CONVENTIONAL METHODS

Plant breeding plays vital role in crop improvement strategies for both abiotic and biotic stresses. It provides solutions for food security under unfavourable climatic conditions and to avoid stresses during critical periods of crop life cycles through creation of varieties with different duration and stress tolerant. ICARDA and CIMMYT (CIGEAR Group) in collaboration with scientists in Iran, Algeria, Jordan, Eritrea, Morocco and Tunisia has recently started evolutionary participatory programmes for barley and durum wheat. These measures will go hand in hand with breeding for resistance to biotic stresses and with an efficient system of variety delivery to farmers [67,68]. Landraces are major sources of genetic diversity such as wheat landrace collections stored in gene banks contain wider genetic diversity and useful source of stress tolerance and includes varieties adaptable to different environmental conditions [69].

## 13. NON-CONVENTIONAL METHODS

Marker assisted selection: Marker-assisted selection plays vital role in improvement of quantitative traits for speeding up the breeding process. Developments in crop genomics are sources of useful information to identify DNA markers, which are useful for marker-assisted breeding programs. Genomics along with bioinformatics and metabolomics resources are globally important for crop improvement [Da, 2015]. For heat tolerance in bread wheat, three major genomic regions on chromosome 2B, 7B and 7D has been identified. The World Vegetable Center (AVRDC) has also used genetic markers for disease-resistant breeding program in tomatoes. Disease resistant tomato varieties are now available for farmers [70].

## 14. GENETIC ENGINEERED APPROACHES

The genetic modification through Biotechnology is a powerful strategy. Promising material is identified from genetic resources that can be used directly in plant breeding to adapt them in abiotic stresses (heat, drought and salinity, etc.). The expressions of stress-induced transcription factors are tools for improvement of stress tolerance in plants. It can regulate the expressions of downstream genes linked to abiotic stress responses in transgenic plants [71]. Several transgenic plants have been developed by different researchers against abiotic stresses. These transgenic plants show tolerance to the environmental extremes as compared to non-transgenic plants [72]. Gupta et al. [73] reports the generation of rice plants with improved adaptation towards multiple abiotic and biotic stresses with reduced yield penalty through manipulation of the glyoxalase pathway. Methylglyoxal (MG) is a cytotoxic metabolite that is accumulated as a consequence of many abiotic and biotic stresses. MG accumulation may therefore be a linking factor in plant responses to diverse stresses. This paper reports that genetic manipulation of the two-step glyoxalase pathway that removes MG led to improved tolerance of rice to multiple abiotic and biotic stresses. Dixit et al. [74] highlights the role of novel stress-associated proteins (SAPs) in providing tolerance to the multiple abiotic stresses experienced by plants. The Arabidopsis and rice genomes were found to contain 14 and 18 genes encoding SAP-related proteins, respectively. Most of the SAP genes in plants are differentially regulated in response to multiple environmental stresses such as low temperatures (LTs), salinity, drought, heavy metals, wounding, and submergence. The role of abscisic acid-responsive transcription factors (ABFs) in the regulation of drought tolerance in cotton is described in detail inthe paper by Kerr et al. [75]. An understanding of plant responses to HT, particularly when the stress is imposed at flowering, is crucial for the development of stress tolerant genotypes because plant reproductive organs are very sensitive to HT stress, Farooq et al. [76]. HT reduce pollen viability and shorten the grain-filling period, temperature increases of 3–4°C are likely to cause crop yields to fall by 15-35% in Africa and Asia and by 25–35% in the Middle East (Ortiz et al., 2008). Pearl millet (*Pennisetum glaucum*) has a higher HT tolerance than many other cereals and is hence considered to be an important climate resilient crop. Hence, like sorghum (*Sorghum biclor*), pearl millet is an important cereal crop in the agriculture of arid and semiarid regions. The screening of pearl millet germplasm and identification of HT tolerant lines in this paper will be extremely useful in future breeding programs designed to develop parental lines or hybrids with HT tolerance. Like ABA and GA, brassinosteroids (BR) play important roles in developmental processes as well as abiotic and biotic stresses tolerance [77, 78]. The BR-mediated regulation of chilling stress in tomato plants was studied in the paper by Xia et al. [79]. BR is shown to positively regulate chilling tolerance through a signalling cascade.

Climate adaptation and mitigation measures would need to be evolved if not at the global level but at least at regional levels. Climate-resilient economy need to be premised on three key principles: Adapt, Mitigate, and Diversify. Such an economy would require greater investments in i) protection of livelihood and food security for vulnerable populations; ii) water conservation; iii) rainwater harvesting; iv) soil conservation; v) water desalination to maximize its usage; and vi) intelligent irrigation systems.

These efforts can help ensure that food systems at every level are more resilient to future climate variability and change.

**Various government initiatives taken to tackle the impact of climate change on Indian agriculture.**

1. Pradhan Mantra Fasal Bima Yojana (PMFBY):- It was Launched by The government of India in April 2016 to Financial support will be provided to farmers in distress due to loss and damage of crops caused by unexpected calamities.
2. Pradhan Mantra Krishi Sinchayee Yojana (PMKSY) - micro irrigation: - It aims to provide protective irrigation to all farms in the country, to produce “per drop more crop”, thus bringing much desired rural prosperity it has 3 major components:

a. Accelerated Irrigation Benefit Programme (AIBP):- It aims to focus on faster completion of ongoing major and medium irrigation including national projects.
b. PMKSY (Har Khet Ko Pani):- It aims to creation of new water sources through minor irrigation (both surface and ground water) by the people as it also provide employment.
c. PMKSY (Watershed Development):-Its main objective is to provide effective management of runoff water and improved soil & moisture conservation activities and other allied activities on watershed basis.

3. National Food Security Mission (NFSM):- It aims to remove stagnating food production and to provide food to all even in famine conditions.
4. National Seed Corporation (NSC):- Established in 1963 and acts as a nodal agency for seed multiplication, in order to make the seeds climate adapted, the seeds are tested for its’s genotypes and its resistances against drought and heat.
5. Sub Mission on Agricultural Mechanization (SMAM):- SMAM aims to increase the reach of farm mechanization to small and marginal farmers where the climate is the major risk factor.
6. Sub Mission on Plant Protection and Plant Quarantine (SMPPQ):- It aims to minimize loss to quality and yield of agricultural crops from the ravage of insect pests, diseases, weeds, nematodes, rodents etc., where the climate change leads to adaptability of pests.
7. Central Research Institute of Dry Land Agriculture (CRIDA):- It provide district agricultural contingency plans (DACP) aimed to provide technological interventions to manage various weather aberrations addressing different sectors of agriculture.
8. National Mission on Sustainable Agriculture (NMSA):- It is a Mission launched under the National Action Plan on Climate Change (NAPCC) in 2008. The Mission aims to evolve and implement strategies to make Indian agriculture resilient to climate change. NMSA was approved for three major components i.e.

a. Rainfed Area Development (Rad):- it adopts an area based approach for development and conservation of natural resources along with farming systems through watershed development and soil conservation activities under MGNREGS, NWDPRA, RVP&FPR, IWMP etc.
b. On Farm Water Management (OFWM):- It focuses primarily on enhancing water use efficiency by promoting efficient on farm water management technologies and equipment, also will emphasize on effective harvesting & management of rain water.
c. Soil Health Management (SHM):- It aims to promoting location as well as crop specific sustainable soil health management including residue management. Organic farming practices by way of creating and linking soil fertility maps with macro-micro management, appropriate land use based on land capability, judicious application of fertilizers and minimizing the soil erosion/degradation.

   Subsequently, 4 new programmes were introduced under the ambit of NMSA:-

a. Soil Health Card (SHC):- It provides information to farmers on soil nutrient status of their soil and recommendation on appropriate dosage of nutrients to be applied for improving soil health and its fertility.
b. Parampragat Krishi Vikas Yojana (PKVY):- it aims to supporting and promoting organic farming, reduction in dependence on fertilizers and agricultural chemicals, in turn, resulting in improvement of the soil health while increasing the yields.
c. Mission Organic Value Chain Development in North Eastern Region (MOVCDNER):- It aims to development of certified organic production in a value chain mode to link growers with consumers and to support the development the development of entire value chain.
d. Sub Mission on Agroforestry (SMAF):- Agroforestry is known to have the potential to mitigate the climate change effects through microclimate moderation, conservation of natural resources and creation of additional source of livelihood and income opportunities.

9. Climate Change and Sustainable Agriculture: Monitoring, Modelling and Networking (CCSAMMN):- It provides creation and bidirectional (land/farmers to research/scientific establishments and vice versa) dissemination of climate change related information and knowledge by way of piloting climate change adaptation/mitigation research/model projects in the domain of climate smart sustainable management practices and integrated farming system suitable to local agro - climatic conditions.
10. National Mission on Strategic Knowledge for Climate Change. It will encourage private sector initiatives for developing innovative technologies for adaptation and mitigation.

**Some institutes supporting the government initiatives:**

1. ICAR (Indian Council of Agricultural Research) has initiated the National Innovations on Climate Resilient Agriculture (NICRA) network project since 2011 to enhance resilience of Indian agriculture to climate vulnerability through strategic research and technology demonstration as well as capacity building of all the actors in the system. The ICAR, the state agricultural universities (SAUs) and even the private sector have been pursuing their research works to develop new and more tolerant cultivars to multiple (both biotic and abiotic) stresses
2. CGIAR (Consultative Group on International Agricultural Research) Program on Climate Change, Agriculture and Food Security (CCAFS) is also promoting adaptable and resilient agriculture and food systems in many countries including India.
3. ICRISAT (International Crops Research Institute for the Semi-Arid Tropics) has also developed a pool of climate-smart technologies. Few such approaches highlighted by ICRISAT for building climate smart villages like the watershed management approach and the meteorological advisory and farm systems approach.

## 15. CONCLUSION

Climate change It has resulted in the large scale shifts in the weather pattern due to periodic modifications of earth’s climate. It has serious effect on human health, ecosystem, world’s water system etc. There is urgent need to recognize the innovative and creative strategies for climate change adaptation and mitigation. There is need to manage the net zero emission of anthropogenic green house gases to reduce the risks associated with it, to enable development in a sustainable manner, for improving human health and reducing vulnerability associated with it in long term.

## COMPETING INTERESTS

Authors have declared that no competing interests exist.

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