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IMPACT OF CLIMATE CHANGE ON FOOD SECURITY

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Abstract: *Climate change is the largest environmental threat facing India today. Climate change has potentially large and alarming consequences for India, which is home to the largest number of hungry and deprived people in the world–to be precise 360 million undernourished and 300 million poor people. Sustaining supply of food itself is emerging as a critical issue. Temperature and its associated seasonal patterns are critical components of agriculture production system. Rising temperatures associated with climate change will likely have a detrimental impact on crop production, livestock, fisheries and allied sectors. Because of climate change, Indian agriculture is doubly vulnerable. First as around 50 percent of India's total agricultural areas are rain fed, it is highly vulnerable to climate change impacts on monsoon. Secondly, more than 80 percent of farmers in India are small and marginal (having less than 1 hectare of land) thus having less capacity to cope with climate change impacts on agriculture. Climate change affects food security through its impacts on all components of global, national and local food production systems, which is projected to affect all dimensions of food security, namely food availability; access to food and food utilization. Thus achieving food and nutritional security in a scenario of degrading natural resources (water, soil, bio diversity) and climate change seems to be a biggest challenge for India.*
Keywords: *Climate change, food security, Agriculture, water, soil and biodiversity.*

Introduction: Climate change will affect all four dimensions of food security: food availability, food accessibility, food utilization and food systems stability. It will have an impact on human health, livelihood assets, food production and distribution channels, as well as changing purchasing power and market flows. Its impacts will be both short term, resulting from more frequent and more intense extreme weather events, and long term, caused by changing temperatures and precipitation patterns. In the long term, mitigating climate change will be critical to avoiding future breakdowns in food and livelihood systems and sharp increases in the number of food-insecure people worldwide. But food systems have enormous potential to mitigate climate change, however, particularly at the production end of the food chain. Investing in wider adoption of best practices for mitigation in the food and agriculture sector could therefore have multiple payoffs for food security, including contributing to the stability of global food markets and providing new employment opportunities in the commercial agriculture sector, as well enhancing the sustainability of vulnerable livelihood systems. Such practices include: reducing emissions of CO_2, such as through reduction in the rate of land conversion and deforestation, better control of wildfires, adoption of alternatives to the burning of crop residues after harvest, reduction of emissions from commercial fishing operations, and more efficient energy use by forest dwellers, commercial agriculture and agro-industries; reducing emissions of methane and nitrous oxide, such as through improved nutrition for ruminant livestock, more efficient management of livestock waste and of irrigation water on rice paddies, more efficient applications of nitrogen fertilizer on cultivated fields, and reclamation of treated municipal wastewater for aquifer recharge and irrigation; sequestering carbon, such as through improved management of soil organic matter, with conservation agriculture involving permanent organic soil cover, minimum mechanical soil disturbance and crop rotation (which also saves on fossil fuel usage); improved management of pastures and grazing practices on natural grasslands, including by optimizing stock numbers and rotational grazing; introduction of integrated agroforestry systems: use of degraded, marginal lands for productive planted forests or other cellulose biomass for alternative fuels; and carbon sink tree plantings. According to the most recent data released by IPCC, clearing of forested area for agriculture accounted for 17.4 percent of total greenhouse gas emissions in 2000, with emissions from intensive crop and livestock production contributing another 13.5 percent. By contrast, studies carried out by the World Resources Institute (WRI) indicate that energy sector emissions attributable to agricultural and food processing use of fossil fuels account for only 2.4 percent of greenhouse gas emissions [1]. In the United Kingdom, the Carbon Trust, established in 2001 with government funding, has promoted the concept of the "carbon footprint". By undertaking a carbon investigation of their supply chains, all businesses can minimize the carbon emitted at every stage of a product's life cycle, from source to shelf, consumption and disposal. The total amount of carbon emitted to arrive at a final product is that product's carbon footprint (Carbon Trust).

The carbon footprint of food processing and transport is negligible compared with the emissions generated by production processes in the food system. Therefore, although there are opportunities for reducing the carbon footprint of food at all stages of the food chain, the focus of mitigation efforts in the food system should be on introducing agricultural production practices that reduce emissions or increase carbon sequestration.

Agriculture production is directly dependent on climate change and weather. Possible changes in temperature, precipitation and CO_2 concentration are expected to significantly impact crop growth. The overall impact of climate change on worldwide food production is considered to be low to moderate with successful adaptation and adequate irrigation [2] Global agricultural production could be increased due to the doubling of CO_2 fertilization effect. Agriculture will also be impacted due to climate changes imposed on water resources [3] India will also begin to experience more seasonal variation in temperature with more warming in the winters than summers [4]. India has experienced 23 large scale droughts starting from 1891 to 2009 and the frequency of droughts is increasing. Climate change is posing a great threat to agriculture and food security. Water is the most critical agricultural input in India, as 55% of the total cultivated areas do not have irrigation facilities. India is home to 16% of the world population, but only 4% of the world water resources. Agriculture is directly dependent on climate, since temperature, sunlight and water are the main drivers of crop growth Indian agriculture consumes about 80-85% of the nation's available water [5].

Today's agriculture is at a crossroads. Climate change is already calculated to be having a negative impact on food production in some areas of the world [6] while there are expectations for the sector to meet a rise in demand by 70 to 100% within the next 40 years. Climate change refers to any significant change in the measurement of climate lasting for an extended period of time. Over the past century, human activities have released large amounts of carbon dioxide (CO_2) and other greenhouse gases into the atmosphere. Major greenhouse gases are generated from burning fossil fuels. Deforestation, industrial processes, and some agricultural practices also emit gases into the atmosphere. As a result, average global temperatures increased by 0.74ºC during 1906 – 2005, and a further increase of 0.2ºC to 0.4ºC in the next 20 years is expected (IPCC). Small changes in the average temperature of the planet can translate to large and potentially dangerous shifts in climate and weather. Many places have seen variations in rainfall - resulting in more droughts or intense rain and more floods, as well as more frequent and severe heat waves (IPCC Reports). Climate change refers to a change in the state of the climate that can be identified (using statistical tests) by changes in the mean and/or the variability of its properties, which persist for an extended period, typically decades or longer. The world's climate is changing, and the changes will have an enormous impact on people, ecosystems, and energy use. According to the latest report of the Intergovernmental Panel on Climate Change (IPCC), average global temperature is likely to rise by another 2 to 8.6 degrees F by 2100. Further UNEP (2015) reported that there is alarming evidence that important tipping points, leading to irreversible changes in major ecosystems and the planetary climate system, may already have been reached or passed. It is a growing crisis with economic, health and safety, food production, security, and other dimensions. The shifting weather pattern has threatened food production and food security on the globe. At the end of this century, different locations will experience different levels of increases in temperature, with the greatest impact toward the North Pole and the least increase toward the South Pole and in the tropics. Many potential agricultural adaptation options have been suggested, representing measures or practices that might be adopted to alleviate expected adverse impacts. They encompass a wide range of forms (technical, financial, managerial), scales (global, regional, local) and participants (governments, industries, farmers) [7-8].

Effect of Climate Change: One of the biggest issues confronting Indian agriculture is low productivity. India's cereal yields are drastically lower than those of developed regions such as North America (6671 kg per ha), East Asia and the Pacific (5,184 kg per ha), and the Euro area (5855.4 kg per ha) (see Table 1). Table 2 shows that yield per hectare of food grains has stagnated in India since the 1980s.

Table 1: Cereal yields (kg per ha, 2013)

Country/ Region	Kg per hectare
East Asia & Pacific (developing only)	5,184.0
Central Europe and the Baltics	4,131.1
Sub-Saharan Africa	1,433.5
Europe & Central Asia (all income levels)	3,661.6
Euro area	5,855.4
North America	6,671.0
India	2,961.6
World	3,851.3

Source: World Bank Database

Table 2: Growth rate of yield per hectare (%) of foodgrains

	Rice	Wheat	Coarse Cereals	Pulses	Total Foodgrains
1980-81 to 1990-91	2.7	3.4	2.6	2.0	3.0
1990-91 to 2000-01	0.9	1.7	1.3	-0.6	1.7
2000-01 to 2010-11	1.6	1.0	4.1	2.4	1.7
2010-11 to 2014-15	1.6	-1.0	3.1	1.9	1.8

Source: Reserve Bank of India database

Global warming: Global temperatures have risen by over 0.7°C in the last 100 years and eleven of the last twelve years (1995-2006) are the warmest on record. In the UK in 1990s were very warm about 0.6°C warmer than the mean 1961 - 1990 temperature. Warm winters have reduced the number of frosts, and the warmer summers have included record hot spells and high sunshine totals [10].

Source: Adapted from University of Southampton (2000)

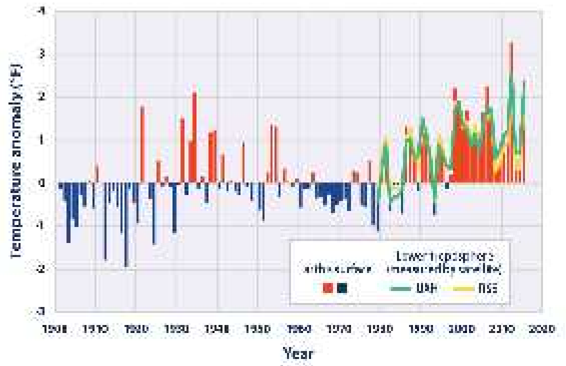
Predicted effects of climate change on agriculture over the next 50 years

Climatic element	Expected changes by 2050's	Confidence in prediction	Effects on agriculture
CO_2	Increase from 360 ppm to 450 - 600 ppm (2005 levels now at 379 ppm)	Very high	Good for crops: increased photosynthesis; reduced water use
Sea level rise	Rise by 10 -15 cm Increased in south and offset in north by natural subsistence/rebound	Very high	Loss of land, coastal erosion, flooding, salinisation of groundwater
Temperature	Rise by 1-2°C. Winters warming more than summers. Increased frequency of heat waves	High	Faster, shorter, earlier growing seasons, range moving north and to higher altitudes, heat stress risk, increased evapotranspiration
Precipitation	Seasonal changes by ± 10%	Low	Impacts on drought risk' soil workability, water logging irrigation supply, transpiration

Storminess	Increased wind speeds, especially in north. More intense rainfall events.	Very low	Lodging, soil erosion, reduced infiltration of rainfall
Variability	Increases across most climatic variables. Predictions uncertain	Very low	Changing risk of damaging events (heat waves, frost, droughts floods) which effect crops and timing of farm operations

Source: Climate change and Agriculture, MAFF (2000)

Climate Change Indicators: U.S. and Global Temperature



This figure shows how annual average temperatures in the contiguous 48 states have changed since 1901. Surface data come from land-based weather stations. Satellite measurements cover the lower troposphere, which is the lowest level of the Earth's atmosphere. "UAH" and "RSS" represent two different methods of analyzing the original satellite measurements. This graph uses the 1901–2000 average as a baseline for depicting change. Choosing a different baseline period would not change the shape of the data over time.

Data source: NOAA, 2016 [11]; *Web update: August 2016*

How will climate change impact on agriculture & forestry?: Climate change could have an effect on both agriculture and forestry, changing the conditions for crop and plant growth and in turn food supply, increasing the pressure on soil and water availability as well as farming methods with a reliance on fertilisers or other chemical products. The effect of climate change on forests over different European bioclimatic regions are expected to be multiple and complex, but rising CO2 concentration, higher temperatures, changes in precipitation, flooding, drought duration and frequency will all have significant effects on tree growth. Forest ecosystems will also be affected. Climatic changes will have consequences for the frequency of pests and disease outbreaks (biotic disturbances) and bring changes in wild fire occurrence or veracity as well as in wind storm frequency and intensity (abiotic disturbances) [12].

Climate and Climate System: Climate refers to the characteristic conditions of the earth's lower surface atmosphere at a specific location; weather refers to the day-to-day fluctuations in these conditions at the same location. The system of climate is highly complex. Under the influence of the sun's radiation, it determines the earth's climate [13] and consists of:

- The atmosphere: gaseous matter above the earth's surface;
- The hydrosphere: liquid water on or below the earth's surface;
- The cryosphere: snow and ice on or below the earth's surface;
- The lithosphere: earth's land surface (e.g., rock, soil and sediment);
- The biosphere: earth's plants and animal life, including humans.

Food Security: FAO stressed that "Food security depends more on socio-economic conditions than on agroclimatic ones, and on access to food rather than the production or physical availability of food". To evaluate the potential impacts of climate change on food security, "it is not enough to assess the impacts on domestic production in food-insecure countries. One also needs to-

- Assess climate change impacts on foreign exchange earnings;
- Determine the ability of foodsurplus countries to increase their commercial exports or food aid; and
- Analyse how theincomes of the poor will be affected by climate change" [14].

Food System: Food systems encompass (i) activities related to the production, processing, distribution, preparation and consumption of food; and (ii) the outcomes of these activities contributing to food security (food availability, with elements related to production, distribution and exchange; food access, with elements related to affordability, allocation and preference; and food use, with elements related to nutritional value, social value and food safety). The outcomes also contribute to environmental and other securities (e.g. income). Interactions between and within biogeophysical and human environments influence both the activities and the outcomes.

Food Chain: The sum of all the processes in a food system is sometimes referred to as a food chain, and often given slogans such as "from plough to plate" or "from farm to fork". The main conceptual difference between a food system and a food chain is that the system is holistic, comprising a set of simultaneously interacting processes, whereas the chain is linear, containing a sequence of activities that need to occur for people to obtain food. The concept of the food system is useful for scientists investigating cause and effect relationships and feedback loops, and is important for the technical analyses that underpin policy recommendations. A food system comprises multiple food chains operating at the global, national and local levels. Some of these chains are very short and not very complex. Climate is a particularly important driver of food system performance at the farm end of the food chain, affecting the quantities and types of food produced and the adequacy of production-related income. Extreme weather events can damage or destroy transport and distribution infrastructure and affect other non-agricultural parts of the food system adversely.

Climate, Agriculture and Food Security: Agriculture is important for food security in two ways: it produces the food people eat; and (perhaps even more important) it provides the primary source of livelihood for 36 percent of the world's total workforce. In the heavily populated countries of Asia and the Pacific, this share ranges from 40 to 50 percent, and in sub-Saharan Africa, two-thirds of the working population still make their living from agriculture [15].

Agriculture, forestry and fisheries are all sensitive to climate. Their production processes are therefore likely to be affected by climate change. In general, impacts are expected to be positive in temperate regions and negative in tropical ones, but there is still uncertainly about how projected changes will play out at the local level, and potential impacts may be altered by the adoption of risk management measures and adaptation strategies that strengthen preparedness and resilience.

The food security implications of changes in agricultural production patterns and performance are of two kinds:

- Impacts on the production of food will affect food supply at the global and local levels. Globally, higher yields in temperate regions could offset lower yields in tropical regions. However, in many low-income countries with limited financial capacity to trade and high dependence on their own production to cover food requirements, it may not be possible to offset declines in local supply without increasing reliance on food aid.
- Impacts on all forms of agricultural production will affect livelihoods and access to food. Producer groups that are less able to deal with climate change, such as the rural poor in developing countries, risk having their safety and welfare compromised.

Food Security and Climate Change: A Conceptual Framework: Climate change variables influence biophysical factors, such as plant and animal growth, water cycles, biodiversity and nutrient cycling, and the ways in which these are managed through agricultural practices and land use for food production. However, climate variables also have an impact on physical/human capital–such as roads, storage and marketing infrastructure, houses, productive assets, electricity grids, and human health – which indirectly changes the economic and socio-political factors that govern food access and utilization and can threaten the stability of food systems. All of these impacts manifest themselves in the ways in which food system activities are carried out. The framework illustrates how adaptive adjustments to food system activities will be needed all along the food chain to cope with the impacts of climate change. The climate change variables considered in the CCFS framework are: the CO_2 fertilization effect of increased greenhouse gas concentrations in the atmosphere;

- Increasing mean, maximum and minimum temperatures;
- Gradual changes in precipitation:
- Increase in the frequency, duration and intensity of dry spells and droughts;
- Changes in the timing, duration, intensity and geographic location of rain and snowfall;
- Increase in the frequency and intensity of storms and floods;
- Greater seasonal weather variability and changes in start/end of growing seasons.

Impacts of Climate Change on Food Availability

Production: There has been a lot of research on the impacts that climate change might have on agricultural production, particularly cultivated crops. Some 50 percent of total crop production comes from forest and mountain ecosystems, including all tree crops, while crops cultivated on open, arable flat land account for only 13 percent of annual global crop production. Production from both rainfed and irrigated agriculture in dryland ecosystems accounts for approximately 25 percent, and rice produced in coastal ecosystems for about 12 percent [16]. This is expected to occur primarily in temperate zones, with yields expected to increase by 10 to 25 percent for crops with a lower rate of photosynthetic efficiency (C3 crops), and by 0 to 10 percent for those with a higher rate of photosynthetic efficiency (C4 crops), assuming that CO_2 levels in the atmosphere reach 550 parts per million [17]; these effects are not likely to influence projections of world food supply, however [18]. Mature forests are also not expected to be affected, although the growth of young tree stands will be enhanced [19]. Moderate warming (increases of 1 to 3 ºC in mean temperature) is expected to benefit crop and pasture yields in temperate regions, while in tropical and seasonally dry regions, it is likely to have negative impacts, particularly for cereal crops. Warming of more than 3 ºC is expected to have negative affects on production in all regions [17].

Storage, Processing and Distribution: Food production varies spatially, so food needs to be distributed between regions. The major agricultural production regions are characterized by relatively stable climatic conditions, but many food-insecure regions have highly variable climates. The main grain production regions have a largely continental climate, with dry or at least cold weather conditions during harvest time, which allows the bulk handling of harvested grain without special infrastructure for protection or immediate treatment. Depending on the prevailing temperature regime, however, a change in climatic conditions through increased temperatures or unstable, moist weather conditions could result in grain being harvested with more than the 12 to 14 percent moisture required for stable storage. Because of the amounts of grain and general lack of drying facilities in these regions, this could create hazards for food safety, or even cause complete crop losses, resulting from contamination with microorganisms and their metabolic products. It could lead to a rise in food prices if stockists have to invest in new storage technologies to avoid the problem.

Distribution depends on the reliability of import capacity, the presence of food stocks and when necessary access to food aid [20]. These factors in turn often depend on the ability to store food. Storage is affected by strategies at the national level and by physical infrastructure at the local level. Transport infrastructure limits food distribution in many developing countries. Where infrastructure is affected by climate, through either heat stress on roads or increased frequency of flood events that destroy infrastructure, there are impacts on food distribution, influencing people's access to markets to sell or purchase food [21].

FAO projects that the impact of climate change on global crop production will be slight up to 2030. After that year, however, widespread declines in the extent and potential productivity of cropland could occur, with some of the severest impacts likely to be felt in the currently food-insecure areas of sub-Saharan Africa, which have with the least ability to adapt to climate change or to compensate through greater food imports.

Climate Change on Soil and Water: Climate change effects on agriculture also include the effects of changing climate conditions on resources of key importance to agricultural production, such as soil and water. Seasonal precipitation affects the potential amount of water available for crop production, but the actual amount of water available to plants also depends upon soil type, soil water holding capacity, and infiltration rate. Healthy soils have characteristics that include appropriate levels of nutrients necessary for the production of healthy plants, moderately high levels of organic matter, a soil structure with good aggregation of the primary soil particles and macro-porosity, moderate pH levels, thickness sufficient to store adequate water for plants, a healthy microbial community, and absence of elements or compounds in concentrations toxic for plant, animal, and microbial life. Several processes act to degrade soils including, erosion, compaction acidification, salinization, toxification, and net loss of organic matter. Several of these processes are sensitive to changing climate conditions. Changes to the rate of soil organic matter accumulation will be affected by climate through soil temperature, soil water availability, and the amount of organic matter input from plants. Erosion is of particular concern. Changing climate will contribute to the erosivity from rainfall, snowmelt, and wind. Rainfall's erosive power will increase if increases in rainfall amount are accompanied by increases of intensity. Shifts of rainfall intensity have begun to occur in the United States with more extreme events expected for the future. Although there is a general lack of knowledge about the rates of soil erosion associated with snowmelt or rain-on-thawing-soil erosion, if decreased days of snowfall translate to increased days of rainfall, erosion by storm runoff is likely to increase.

Implications of Climate Change for Food Security: Food security is one of the leading concerns associated with climate because any variability in climatic factor can directly affect a country's ability to feed its people [22]. Climate change affects food security in complex ways. It impacts crops, livestock, forestry, fisheries and aquaculture, and can cause grave social and economic consequences in the form of reduced incomes, eroded livelihoods, trade disruption and adverse health impacts [23]. However, it is important to note that the net impact of climate change depends not only on the extent of the climatic shock but also on the underlying vulnerabilities. According to the Food and Agriculture Organization (2016), both biophysical and social vulnerabilities determine the net impact of climate change on food security (Climate change and food security: risks and responses, 2016). What are the implications of climate change for the India's food security system? To answer this it is necessary to examine the effects of climate change on all dimensions of food security such as: food production, access and utilization.

Impact of climate change on Agriculture Production and Food Security: Indian agriculture, and thereby India's food production, is highly vulnerable to climate change largely because the sector continues to be highly sensitive to monsoon variability. After all, about 65 percent of India's cropped area is rain-fed. From ancient times India's agriculture has been dependent on monsoons. Any change in monsoon trends drastically affects agriculture. Even the increasing temperature is affecting Indian agriculture.

Acute water shortage conditions, together with thermal stress, will affect rice productivity even more severely. Recent studies done at the Indian Agricultural Research Institute indicate the possibility of a loss of between 4 and 5 million tonnes in wheat production in the future with every rise of 1^{o}C temperature throughout the growing period. Rice production is slated to decrease by almost a tonnes/hectare if the temperature rises by 2 degree celsius. In Rajasthan, a 2 degree rise in temperature was estimated to reduce production of pearl millet by 10 to 15 percent. If maximum and minimum temperatures rise by 3 and 3.5 degrees respectively, then soya bean yields in M.P will decline by 5 percent compared to 1998. Agriculture will be affected in the coastal regions of Gujarat and Maharashtra, as fertile areas are vulnerable to inundation and salinization.

According to the 2006 Human Development Report of the UNDP, 2.5 billion people in South Asia will be affected by water scarcity by the year 2050 (UNDP, 2006). Rising temperature, changing precipitation patterns, and an increasing frequency of extreme weather events are expected to be the main reasons for reducing regional water availability and impacting hydrological cycles of evaporation and precipitation. This will drastically affect agriculture production in a region where over 60 percent of the agriculture is rained, such as in India.

The impact of climate change on water availability will be particularly severe for India because large parts of the country already suffer from water scarcity, to begin with, and largely depend on groundwater for irrigation. According to the decline in precipitation and droughts in India has led to the drying up of wetlands and severe degradation of ecosystems [24]. About 54 percent of India faces high to extremely high water stress [24].

About 54 percent of India faces high to extremely high water stress [25]. Large parts of north-western India, notably the states of Punjab and Haryana, which account for the bulk of the country's rice and wheat output, are extremely water-stressed. Figure 2 shows that groundwater levels are declining across India. About 54 percent of India's groundwater wells are decreasing, with 16 percent of them decreasing by more than one meter per year. North-western India again stands out as highly vulnerable; of the 550 wells studied in the region, 58 percent had declining groundwater levels. With increased periods of low precipitation and dry spells due to climate change, India's groundwater resources will become even more important for irrigation, leading to greater pressure on water resources. According to the World Bank projections, with a global mean warming of 2°C above pre-industrial levels, food water requirements in India will exceed green water availability (Turn Down the Heat, 2013). The mismatch between demand and supply of water is likely to have far-reaching implications on food grain production and India's food security.

Impact of Climate Change on Indian Agriculture: Rainfall in India has a direct relationship with the monsoons which originate from the Indian and Arabian Seas. A warmer climate will accelerate the hydrologic cycle, altering rainfall, magnitude and timing of run-off. In arid regions of Rajasthan state an increase of 14.8 per cent in total ET demand has been projected with increase in temperature [26]. Therefore, change in climate will affect the soil moisture, groundwater recharge, and frequency of flood or drought, and finally groundwater level in different areas [27 & 28]. India's agriculture is more dependent on monsoon from the ancient periods. Any change in monsoon trend drastically affects agriculture. Even the increasing temperature is affecting the Indian agriculture. In the Indo-Gangetic Plain, these pre-monsoon changes will primarily affect the wheat crop (>0.5^oC increase in time slice 2010-2039 [29]). In the states of Jharkhand, Odisha and Chhattisgarh alone, rice production losses during severe droughts (about one year in five) average about 40% of total production, with an estimated value of $800 million. Increase in CO_2 to 550 ppm increases yields of rice, wheat, legumes and oilseeds by 10-20%. A 1oC increase in temperature may reduce yields of wheat, soybean, mustard, groundnut, and potato by 3-7%. Productivity of most crops to decrease only marginally by 2020 but by 10-40% by 2100 due to increases in temperature, rainfall variability, and decreases in irrigation water. The major impacts of climate change will be on rain fed or un-irrigated crops, which is cultivated in nearly 60% of cropland. A temperature rise by 0.5^oC in winter temperature is projected to reduce rain fed wheat yield by 0.45 tonnes per hectare in India [30]. Possibly some improvement in yields of chickpea, rabi maize, sorghum and millets, and coconut in west coast. Less loss in potato, mustard and vegetables in north-western India due to reduced frost damage. Increased droughts and floods are likely to increase production variability.

Climatic element	**Expected changes** by 2050's	Confidence in prediction	Effects on agriculture
CO_2	Increase from 360 ppm to 450 - 600 ppm (2005 levels now at 379 ppm)	Very high	Good for crops: increased photosynthesis, reduced water use
Sea level rise	Rise by 10 -15 cm Increased in south and offset in north by natural subsistence/rebound	Very high	Loss of land, coastal erosion, flooding, salinization of groundwater
Temperature	Rise by 1-2^oC. Winters warming more than summers. Increased frequency of heat waves	High	Faster, shorter, earlier growing seasons, range moving north and to higher altitudes, heat stress risk, increased evapotranspiration
Precipitation	Seasonal changes by ± 10%	Low	Impacts on drought risk' soil workability, water logging irrigation supply, transpiration
Storminess	Increased wind speeds, especially in north. More intense rainfall events.	Very low	Lodging, soil erosion, reduced infiltration of rainfall
Variability	Increases across most climatic variables. Predictions uncertain	Very low	Changing risk of damaging events (heat waves, frost, droughts floods) which effect crops and timing of farm operations

Predicted effects of climate change on agriculture over the next 50 years

Source: Climate change and Agriculture, MAFF (2000)

Climate Change Impact on Livestock: The effects of climate change on food production are not limited to crops. It will affect food production and food security via its direct or indirect impact on other components of the agricultural production systems, especially livestock production which is closely linked with crop production. India owns 57 % of the world's buffalo population and 16 % of the cattle population. It ranks first in the world in respect of cattle and buffalo population, third in sheep and second in goat population. The sector utilizes crop residues and agricultural by-products for animal feeding that are unfit for human consumption. Livestock sector has registered a compounded growth rate of more than 4.0% during last decade, in spite of the fact that a majority of the animals are reared under sub-optimal conditions by marginal and small holders and milk productivity per animal is low. Increased heat stress associated with rising temperature may, however, cause distress to dairy animals and possibly impact milk production.

Climate Change–Mitigation and Adaptation in Agriculture

- An early warning system should be put in place to monitor changes in pest and disease outbreaks. The overall pest control strategy should be based on integrated pest management because it takes care of multiple pests in a given climatic scenario.
- Preventive measures for drought that include on-farm reservoirs in medium lands, growing of pulses and oilseeds instead of rice in uplands, ridges and furrow system in cotton crops, growing of intercrops in place of pure crops in uplands, land grading and levelling, stabilization of field bunds by stone and grasses, graded line bunds, contour trenching for runoff collection, conservation furrows, mulching and more application of Farm yard manure (FYM).
- Efficient water use such as frequent but shallow irrigation, drip and sprinkler irrigation for high value crops, irrigation at critical stages.
- Efficient fertilizer use such as optimum fertilizer dose, split application of nitrogenous and potassium fertilizers, deep placement, use of *neem, karanja* products and other such nitrification inhibitors, liming of acid soils, use of micronutrients such as zinc and boron, use of sulphur in oilseed crops, integrated nutrient management.
- Adopt resource conservation technologies such as no-tillage, laser land levelling, direct seeding of rice and crop diversification which will help in reducing in the global warming potential. Crop diversification can be done by growing non-paddy crops in rain fed uplands to perform better under prolonged soil moisture stress in kharif.
- Provide incentives to farmers for resource conservation and efficiency by providing credit to the farmers for transition to adaptation technologies.
- Provide technical, institutional and financial support for establishment of community banks of food, forage and seed.

Recommendations to Overcome Climate Change

Adoption of Sustainable Agricultural Practices: The main problem of Indian agriculture is low productivity. To meet India's growing food demand, there is an acute need for increasing productivity in all segments of agriculture. But given the vulnerability of Indian agriculture to climate change, farm practices need to be reoriented to provide better climate resilience. India needs to step up public investment in development and dissemination of crop varieties which are more tolerant of temperature and precipitation fluctuations and are more water and nutrient efficient. Agricultural policy should focus on improving crop productivity and developing safety nets to cope with the risks of climate change.

Stronger Emphasis on Public Health: India has historically had a poor record in public health. With the worsening challenges of climate change, the country's policymakers have also paid little attention to its impacts on health. Despite the fact that the disease burden from vector-borne and diarrheal diseases is very high in urban slums and tribal areas of India, this area was overlooked when the original National Action Plan for Climate Change (NAPCC) was formulated. The Ministry of Health is currently formulating a National Mission for Health under the ambit of NAPCC but given the close relationship between climate change, infectious diseases and food absorption, public expenditure on health needs to be stepped up drastically.

Long-term Relief Measures in the Event of Natural Disasters: India's disaster management strategies are mostly inadequate, short lived and poorly conceived. Also, much of the emphasis is laid on providing quick relief to the affected households as opposed to developing long-term adaptation strategies. Little effort is made towards addressing the long-term impacts of natural disasters on agricultural productivity and under nutrition. A recent report by NITI Aayog suggests that “the government should transfer a minimum specified sum of cash to affected farmers and landless workers as an instant 58 relief. For richer farmers who may want insurance above this relief, the report recommends a separate commercially viable 59 crop insurance programme.

Climate change poses an unprecedented challenge to the aim of eradicating hunger and poverty. In order to meet the growing demand for food security and nutrition under increasingly difficult climatic conditions and in a situation of diminishing resources, the world must urgently move towards embracing a two-fold approach: First, we must invest in and support the development of more efficient, sustainable and resilient food production systems. Second, we must improve access to adequate food and nutrition by the most vulnerable and at risk populations and communities and enhance social protection systems and safety nets as part of the adaptation agenda. Our findings indicate with climate change producing more food with limited resources will be a big challenge in the absence of adaptation and mitigation strategies. It is therefore imperative to promote uptake of sustainable agricultural practices to overcome the potential threats to food security. It is estimated that India needs 320 MT of food grains by the year 2025. For a country like India, sustainable agricultural development is essential not only to meet the food demands, but also for poverty reduction through economic growth by creating employment opportunities in non-agricultural rural sectors.

Thus Climate change is an important obstacle in the sustainable development of agriculture and food security of India. Along with the measures and policies being implemented by the government the education, knowledge and awareness among the people about the adverse impact of climate change the active and whole hearted participation of the people and society as whole is very much necessary.

Achieving food security means ensuring that an adequate amount of nutritious food is available, accessible, and usable for all people. The universal food security is one of the greatest human development challenges facing the world, despite significant progress in recent decades. There were about 1.01 billion (19% of global population) people who were estimated to be food insecure in 1990–1992. This number has fallen to about 805 million people today, or 11% of the global population. Hence the number of food-insecure people in the world has been reduced by about 20%, but at least 2 billion live with insufficient nutrients and about 2.5 billion are overweight or obese, though not necessarily receiving adequate nutrition. Food insecurity is widely distributed, afflicting urban and rural populations in wealthy and poor nations.

Global average temperature is projected to increase by another 1–2°C by 2050 and 1–4°C by 2100, with accompanying increases in precipitation, precipitation intensity, floods, extreme heat events (day and night), droughts, and sea level, as well as changes in precipitation patterns, and decreased soil moisture. Climate change is very likely to affect global, regional, and local food security by disrupting food availability, decreasing access to food, and making utilization more difficult. The potential of climate change to affect global food security is important for food producers and consumers in the world. Climate change risks extend beyond agricultural production to other elements of global food systems that are critical for food security, including the processing, storage, transportation, and consumption of food. Climate risks to food security increase as the magnitude and rate of climate change increases. Higher emissions and concentrations of greenhouse gases are much more likely to have damaging effects than lower emissions and concentrations Effective adaptation can reduce food-system vulnerability to climate change and reduce detrimental climate-change effects on food security, but socioeconomic conditions can impede the adoption of technically feasible adaptation options. The context of climate change allows for the identification of multiple food-security intervention points that are relevant to decision makers at every level.

Conclusion: Increase in temperature increases transpiration and in drier regions leads to water stress causing yield reduction. In India, only about 41% area is irrigated and remaining 59% is rainfed. Even if we realize full irrigation potential in the country, nearly 50% area will still remain rainfed. Under such circumstances, increase in temperatures and changes in rainfall patterns .The current fertilizer-use efficiency that ranges between 2% and 50% in India is likely to be reduced further with increasing temperature. High temperature increases the rate of development in plants. A short life cycle, though less productive, can be beneficial for escaping drought and frost and late maturing cultivars could benefit from faster development rate. In colder regions, global warming could lead to longer of growth period and optimal assimilation at elevated temperatures. The changed climate will probably lead to a decrease in crop productivity, but with important regional difference. Rapid melting of glaciers in Himalayas could affect availability of water for irrigation especially in the Indo-Gangetic plains as well as neighboring countries. Small changes in temperature and rainfall will have significant impact on quality of fruits and vegetables with resultant implications in domestic and external trade. Changes in temperature and humidity will also change insect pest and disease population. Climate change affects all dimensions of food security and nutrition [9].Changes in climatic conditions have already affected the production of some staple crops, and future climate change threatens to exacerbate this. Higher temperatures will have an impact on yields while changes in rainfall could affect both crop quality and quantity.Climate change could increase the prices of major crops in some regions. For the most vulnerable people, lower agricultural output means lower incomes. Under these conditions, the poorest people—who already use most of their income on food—sacrifice additional income and other assets to meet their nutritional requirements, or resort to poor coping strategies.Climate-related risks affect calorie intake, particularly in areas where chronic food insecurity is already a significant problem. Changing climatic conditions could also create a vicious cycle of disease and hunger. Nutrition is likely to be affected by climate change through related impacts on food security, dietary diversity, care practices and health.

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