

# Impacts of Climate Change in Rainfed Agriculture

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## Introduction

Increasing evidence over the past few decades indicate that significant changes in climate are taking place worldwide as a result of enhanced human activities. The inventions that were discovered during last few centuries, more so in the last century has altered the concentration of atmospheric constituents that lead to global warming. The major cause to climate change has been ascribed to the increased levels of greenhouse gases like carbon dioxide (CO<sub>2</sub>), methane (CH<sub>4</sub>), nitrous oxides (NO<sub>2</sub>), chlorofluorocarbons (CFCs) beyond their natural levels due to the uncontrolled activities such as burning of fossil fuels, increased use of refrigerants, and enhanced agricultural related practices. These activities accelerated the processes of climate change and increased the mean global temperatures by 0.6°C during the past 100 years, a phenomenon known as global warming. It has also induced increased climatic variability and occurrence of extreme weather events in many parts of the world. Studies indicate that the years *viz.*, 1997, 1998 and 1999 during the past century, recorded more warmer conditions across the globe, and the process continued in this decade also. Summer 2002 and 2003 were declared as warmest years on record by NOAA especially in the Asian sub continent and in Europe where the temperatures remained extremely high for long periods resulting in death of 20,000 human populations in Europe alone. Scientists attribute this to a long-term warming trend over the globe.

In large part of Asia, agricultural production is mainly dependent on the monsoonal rains. Evidences also indicate that large-scale climatic variations are prevalent at micro-regional level influencing the rainfall distribution in different parts of Asia. The causes of these regional climate changes vary from global to region level. It is evident that there was, there is and there will be climate variability at global, regional and local levels. Since climate is closely related to human activities and economic development including agricultural system, there is a serious concern about its stability (Sinha *et al.*, 2000). The awareness of the magnitude of the impact of climate change on society by the various governments led to adoption of an International Convention on Climate Change by United Nations in 1992. Article 2 of this convention called the UN Framework Convention on Climate Change (UNFCCC) makes two relevant stipulations relevant and important to agriculture, which is (a) prevent dangerous anthropogenic interference with the climatic system, and (b) to ensure that food production is not threatened. The two are related and need in-depth analysis.

The global climate system is a consequence of a link between the atmosphere, the oceans, the biosphere, the cryosphere, and the geosphere and any change to this system produced by forcing agents - results in climate change.

Some of the atmospheric constituents such as water vapour, carbon dioxide, methane, and nitrous oxide are transparent to short wave solar radiation and opaque to

long wave radiation emitted by earth's surface, thus, trapping the heat from sunlight near the Earth's surface known popularly as green house effect. This effect keeps the planet 33°C warmer than it would otherwise be, allowing the earth to support life. With the advent of the industrial revolution, there has been a tremendous growth in the fossil-fuel utilization leading to increased carbon dioxide emissions over the globe especially since 1950s. In addition to this, the emission of chlorofluorocarbons (CFCs) and other chlorine and bromine compounds used in refrigeration and other industrial uses not only have an impact on the radiative forcing, but also have led to the depletion of the stratospheric ozone layer. Land-use change, due to urbanization and deforestation and agricultural practices, affect the physical and biological properties of the Earth's surface. Such effects also change the radiative forcing and have a potential impact on regional and global climate.

## **Climate Change**

### **Global Scenario**

Weather observations indicated that the global average surface temperature has increased by 0.6°C (IPCC, 2001) since the 19<sup>th</sup> Century. The rate of warming is faster than at any other time, during the past 100 years, which is attributed to the increase in the proportion of carbon dioxide and other greenhouse gases in the atmosphere over the last century. Observations also indicated that all the warmest years during the past century across the globe occurred in the last 2 decades (1981-1990 and 1991-2000). Among these years, 1998 was the warmest year on record (IPCC, 2001). Increasing concentrations of greenhouse gases are likely to accelerate the rate of climate change. Model output estimates that the average global surface temperature could rise 0.6 to 2.5°C in the next fifty years, and 1.4 to 5.8°C in the next century, by doubling the concentration of CO<sub>2</sub> with significant regional variation. The expected rise in temperature in higher latitudes will be much more than at equatorial regions. Also the increase in rainfall is not expected to be uniform.

Other than the changes in air temperature, global warming has potential impact on global precipitation patterns and the frequency of droughts and floods. Many researchers are of the opinion that an increase in temperature could lead to a more intensive use of water. The rates of evaporation from soils and water, as well as transpiration from plants, and the quantum of rainfall could increase. Climate models based solely on the effects of greenhouse gases predicted an increase in the amount of precipitation in the next 100 years.

Other impacts of global warming include mean sea level rise as a result of thermal expansion of the oceans and the melting of glaciers and polar ice sheets. The global mean sea level is projected to rise by 0.09 to 0.88 meter over the next century. Due to global warming and sea level rise, many coastal systems can experience increased levels of inundation and storm flooding, accelerated coastal erosion, seawater intrusion into fresh groundwater and encroachment of tidal waters into estuaries and river systems. Climate change and global warming also affect the abundance, spawning, and availability of commercially important marine fisheries. Increase in sea surface temperature adversely affects coral and coral associated flora (sea grass, sea weed etc.) and fauna.

### **Global Level Projections on Future Changes in Climate**

Some of the global level projections on future changes in climate as given by IPCC Reports are as follows:

- For the next two decades, a warming of about 0.2°C per decade is projected for a range of IPCC Special Report on Emission Scenarios. Even if all the greenhouse gases are kept constant at the year 2000 levels, a warming of about 0.1°C per decade would be expected due to the slow response of the oceans.
- Continued greenhouse gas emissions at or above current rates would cause further warming and induce many changes in the global climate system during the 21<sup>st</sup> Century.
- Different estimates of temperature change by the end of the Century (2090 – 2099) compared to the temperatures 1980 – 1999 ranged from 1.8 to 4.0°C under different greenhouse gas emission scenarios.
- Projected warming in 21<sup>st</sup> Century is expected to be greatest over the land and high over the northern latitudes and least over the southern ocean and parts of North Atlantic Ocean.
- It is very likely that heat waves and precipitation events will continue to come more frequent.
- Sea ice is projected to shrink in both Arctic and Antarctic under all greenhouse gas emission scenarios.
- Extra tropical storm tracks are projected to move pole-ward.

### **Current Climate and its Variability in India**

- The monsoon rainfall at All India level does not show any trend and is random in nature over a long period of time.
- The presence of pockets of significant long-term changes in rainfall has been recorded.
- Areas of increasing trend in monsoon rainfall are found along the west coast, north Andhra Pradesh and north-west India and those of decreasing trend over east Madhya Pradesh and adjoining areas, north-east India and parts of Gujarat and Kerala (-6 to -8% of normal over 100 years).
- Surface air temperature for the period 1901-2000 indicated a significant warming of 0.4°C for 100 years.
- The spatial distribution of temperature changes indicated a significant warming trend has been observed along the west coast, central India, and interior Peninsula and over northeast India. However, cooling trend has been observed in northwest and some parts in southern India.
- Instrumental records over the past 130 years do not show any significant long-term trend in the frequencies of large-scale droughts or floods in the summer monsoon season.
- The only change is the alternating sequence of multi-decadal periods of more frequent droughts followed by periods of less frequent droughts.

- The total frequency of cyclonic storms that form over Bay Bengal has remained almost constant over the period 1887-1997. However, the frequency of severe cyclonic storms appears to have taken place in the recent decades.
- A slight decrease in trend in the frequency of cyclonic disturbances is apparent during the monsoon season.
- The model-simulated data shows a balance between simulated and observed extreme maximum temperatures in the peninsular regions. However, the model underestimates high temperature estimates in the mountainous regions of Kashmir, Sikkim, Arunachal Pradesh and overestimates by 5°C over northern place.

### Projected Climate Change Scenarios for India

The climate change scenarios for the Indian subcontinent as inferred by Lal *et al.* (2001) from simulation experiments using atmosphere-ocean GCMs under the four SRES marker scenarios are presented below. These results suggest an annual mean area-averaged surface warming over the Indian subcontinent to range between 3.5 and 5.5°C over the region by 2080s. These projections showed more warming in winter season over summer monsoon. The spatial distribution of surface warming suggests a mean annual rise in surface temperatures in north India by 3°C or more by 2050. The study also suggests that during winter the surface mean air temperature could rise by 3°C in northern and central parts while it would rise by 2°C in southern parts by 2050. In case of rainfall, a marginal increase of 7 to 10 percent in annual rainfall is projected over the sub-continent by the year 2080. However, the study suggest a fall in rainfall by 5 to 25% in winter while it would be 10 to 15% increase in summer monsoon rainfall over the country. It was also reported that the date of onset of summer monsoon over India could become more variable in future.

Year	Season	Temperature Change (°C)		Rainfall Change (%)	
		Lowest	Highest	Lowest	Highest
2020s	Annual	1.00	1.41	2.16	5.97
	Rabi	1.08	1.54	-1.95	4.36
	Kharif	0.87	1.17	1.81	5.10
2050s	Annual	2.23	2.87	5.36	9.34
	Rabi	2.54	3.18	-9.22	3.82
	Kharif	1.81	2.37	7.18	10.52
2080s	Annual	3.53	5.55	7.48	9.90
	Rabi	4.14	6.31	-24.83	-4.50
	Kharif	2.91	4.62	10.10	15.18

(Source: Lal *et al.*, 2001)

### Potential Impacts of Climate Change on Agriculture

Agriculture is one sector, which is immediately affected by climate change, and it is expected that the impact on global agricultural production may be small. However, regional vulnerabilities to food deficits may increase. Short or long-term fluctuations in weather patterns - climate variability and climate change - can

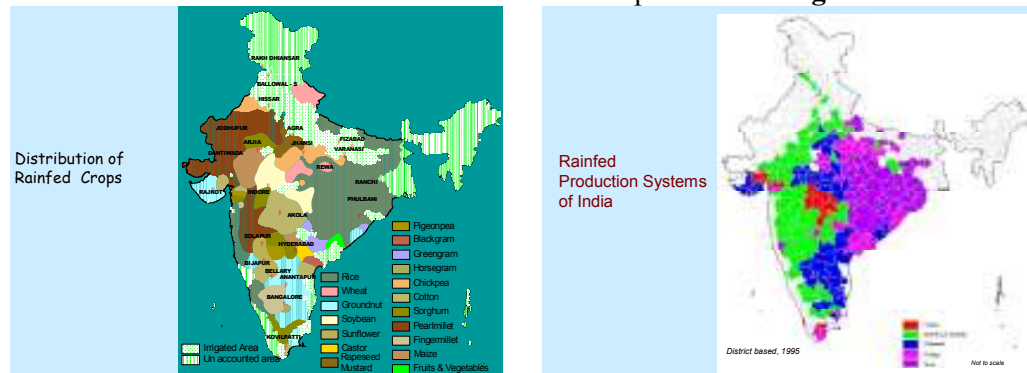
influence crop yields and can force farmers to adopt new agricultural practices in response to altered climatic conditions. Climate variability / change, therefore, has a direct impact on food security.

- The potential effect of climate change on agriculture is the shifts in the sowing time and length of growing seasons geographically, which would alter planting and harvesting dates of crops and varieties currently used in a particular area.
- In most tropical and sub-tropical regions potential yields are projected to decrease for most projected increases in temperature.
- In mid-latitudes, crop models indicate that warming of less than a few °C and the associated increase in CO<sub>2</sub> concentrations will lead to generally positive responses and generally negative responses with greater warming.
- In tropical agricultural areas, similar assessments indicate that yields of some crops would decrease with even minimal increases in temperature because they are near their maximum temperature tolerance (IPCC, 2001).
- The change in atmospheric concentration caused by the anthropogenic Greenhouse Gases (GHG) is observed to affect the plant metabolic activity and also the production directly.
- The effect of temperature rise will lead to an increase in biological activity as well as the physical and chemical processes. Increase in CO<sub>2</sub> concentration can lower pH, thereby, directly affecting both nutrient availability and microbial activity.
- The average atmospheric temperatures are expected to increase more near the poles than at the equator. As a result, the shift in climatic zones can be more pronounced in the higher latitudes. In mid-latitudes, the shift is expected in 200-300 km for every increase of 1°C (IUCC, 1992).
- Increased temperature resulting from global warming is likely to reduce the profit from wheat cultivation and will compel farmers of lower latitudes to opt for maize and sorghum which are better adapted to higher temperature.
- Morey and Sadaphal (1981) reported a decrease of wheat yield by 400 kg ha<sup>-1</sup> for a unit increase of 1°C maximum temperature and 0.5 hr sunshine.

Climate change is also expected to increase both the evaporation and precipitation in some regions. However, if the rate of evaporation exceeds the rate of precipitation, soil becomes drier, lake levels will drop and rivers will carry less water. Warm water will likely increase Blue Green Algae and other unproductive algae that can reduce the levels of dissolved oxygen. As temperature increases many fishes try to look out for the cooler regions. Either they may try to move upstream of river or in to greater depths, which is not possible in smaller rivers and lakes. Researchers forecast substantial shift in fish habitats, disrupt pattern of aquatic plant and animal distribution, which may alter the fundamental ecosystem process and will result in major ecological change.

## Impacts of Weather on Rainfed Agriculture

Rainfed agriculture is practiced over 90 m.ha. area out of 142 m. ha. total net cultivated area in India. Accounting for 60% of net cultivated area. Though rainfed agriculture contributes 44% of food grain production its contribution in coarse cereals, pulses, oilseeds and cotton is about 91%, 91%, 80% and 60% respectively. Significant amount of livestock population (66%) is also dependent on rainfed areas. The distribution of rainfed crops growing regions is shown in **Fig. 1a** and the same were organized into dominant rainfed production systems i.e. rainfed rice, oilseeds, pulses, cotton and nutritious cereals and their distribution in presented in **Fig. 1b**.



**Fig.1a: Distribution of rainfed crops      b: Rainfed production systems of India**

Even the completion of envisaged river linkage project covering various parts of India, it is estimated that 50% would still remain dependent on monsoon. Thus the projected changes in temperature, precipitation (quality and distribution) would significantly affect the rainfed areas.

Some of the outputs from the crop growth models on climate change on crop growth and yield are as follows:

### Direct Effects on Crop Growth and Yield

- Most of the simulation studies have shown a decrease in the duration and yield of crops as temperature increased in different parts of India.
- Yields of both *kharif* and *rabi* crops decreased as temperature increased; a 2°C increase resulted in 15-17 per cent decrease in the grain yield of both crops, but beyond that the decrease was very high in wheat.
- Since, there is greater probability of increase in temperature in *rabi*, it is likely that the productivity of wheat and other *rabi* crops would be significantly reduced.
- Wheat yields in central India are likely to suffer by up to 2 per cent in the pessimistic scenario but there is also a possibility that these might improve by 6 per cent if the global change is optimistic
- Sorghum, being a C<sub>4</sub> plant, does not show any significant response to increase in CO<sub>2</sub> and hence the different scenarios do not affect its yield.
- However, if the temperature increases are higher, western India may experience some negative effect on productivity due to reduced crop durations.

- The impact of warming scenarios becomes apparent at higher levels of fertilizer application from 2030 onwards.
- In future, therefore, much higher levels of fertilizer may need to be applied to meet the increasing demand for food.
- The production of fruits may be significantly affected if the changes in climate happen to coincide with the critical periods. Global warming will push the snow line higher and dense vegetation will shift upwards. This shift will be selective and species specific due to the differential response of plants to changing environmental conditions.
- The nutritional quality of cereals and pulses may also be moderately affected which, in turn, will have consequences for our nutritional security.
- The loss in farm-level net revenue may range between 9 per cent and 25 per cent for a temperature rise of 2-3.5°C.

### **Crop-Pest Interactions**

- The change in climate may bring about changes in population dynamics, growth and distribution of insects and pests.
- Changes in rainfall, temperature and wind speed pattern may influence the migratory behaviour of the locust.
- Most crops have C<sub>3</sub> photosynthesis (responsive to CO<sub>2</sub>), while many weeds are C<sub>4</sub> plants (non-responsive to CO<sub>2</sub>). The climate change characterized by higher CO<sub>2</sub> concentration will favour crop growth over weeds.

### **Irrigation Water Availability**

- Temperature increase associated with global warming will increase the rate of snow melting and consequently snow cover will decrease.
- In the short term, this may increase water flow in many rivers that, in turn, may lead to increased frequency of floods, especially in those systems where water carrying capacity has decreased due to sedimentation.
- In the long run, however, a receding snow line would result in reduced water flow in rivers.
- Under the climate change scenario, the onset of the summer monsoon over India is projected to be delayed and often uncertain.
- This will have a direct effect not only on the rainfed crops, but water storage will also be affected, placing stress on the irrigation water.
- Since the availability of water for agriculture would have to face tremendous competition for other uses of water, agriculture would come under greater strain in future.

## **Soil Processes**

- Changes in precipitation patterns and amount, and temperature can influence soil water content, run-off and erosion, workability, temperature, salinization, biodiversity, and organic carbon and nitrogen content.
- Changes in soil water induced by global climate change may affect all soil processes and ultimately, crop growth.
- An increase in temperature would also lead to increased evapotranspiration, which may result in the lowering of the groundwater table at some places.
- Increased temperature coupled with reduced rainfall may lead to upward water movement, leading to accumulation of salts in upper soil layers.
- A rise in sea level associated with increased temperature may lead to salt-water ingress in the coastal lands, making them unsuitable for conventional agriculture.
- An increase of 1°C in the soil temperature may lead to higher mineralization but N availability for crop growth may still decrease due to increased gaseous losses.

## **Implications of Climate Change on Water Availability**

- The preliminary assessment has revealed that under the GHG scenario, the severity of droughts and intensity of floods in various parts of India is projected to increase.
- There is a general reduction in the quantity of the available run-off under the GHG scenario.
- Luni, the west flowing river of Kutchh and Saurashtra occupying about one-fourths of the area of Gujarat and 60 per cent of the area of Rajasthan are likely to experience acute physical water scarce Conditions.
- The river basins of Mahi, Pennar, Sabarmati and Tapi are likely to experience constant water scarcities and shortage. The river basins of Cauvery, Ganga, Narmada and Krishna are likely to experience seasonal or regular water-stressed conditions.
- The river basins of the Godavari, Brahmani and Mahanadi are projected to experience water shortages only in a few locations.

## **Possible Effects of Climate Change on Ground Water:**

- It is apparent that the projected climate change leading to global warming, sea-level rise and melting of glaciers will disturb the water balance in different parts of India and quality of ground water along the coastal track.
- Changes in precipitation and evapotranspiration may influence ground water recharge



- Rising sea levels may lead to increased saline intrusion of coastal and island aquifers
- Increased rainfall intensity may lead to higher run-off and less recharge; and
- Increased flood events may affect groundwater quality in alluvial aquifers.

***Socio-economic Impacts due to Shifts in Major Forest Types***

- Nearly 200,000 villages in India are situated in or on the fringe of forests.
- Further, about 200 million people depend on forests for their livelihood, directly or indirectly. Forest ecosystems in India are already subjected to socio-economic pressures leading to forest degradation and loss, with adverse impacts on the livelihoods of forest dependent communities.
- Climate change will be an additional pressure on forests, affecting biodiversity as well as biomass production. According to the assessment of projected climate impacts on forests, significant changes in the forest boundary of different forest biomes as well as biodiversity are projected.
- However, during the transient phase, large-scale forest dieback may occur. This may affect the production and supply of non-timber forest products to the forest dependent communities, affecting their livelihoods.
- In the transient phase, there could be an increased supply of timber, due to forest dieback, depreciating timber prices.

**Climate-related Coastal Hazards— Future Scenario**

- The past observations on the mean sea level along the Indian coast show a long-term rising trend of about 1.0 mm/year.
- However, the recent data suggests a rising trend of 2.5 mm/year in the sea level along Indian coastline.
- Model simulation studies, based on an ensemble of four AOGCM outputs, indicate that the oceanic region adjoining the Indian subcontinent is likely to warm at its surface by about 1.5-2.0°C by the middle of this century and by about 2.5-3.5°C by the end of the century.
- The corresponding thermal expansion, related sea-level rise is expected to be between 15 cm and 38cm by the middle of this century and between 46 cm and 59 cm by the end of the century.
- A one-meter sea level rise is projected to displace approximately 7.1 million people in India, and about 5,764 km<sup>2</sup> of land area will be lost, along with 4,200 km of roads.
- An increase in the frequency of severe cyclonic storms is likely under the climate change scenario; this may enhance the vulnerability of those districts that are already ranked as vulnerable under the current climate scenario.

## **Climate Change and World Food Security**

Climate change over the long-term, in particular global warming, could affect agriculture in a number of ways the majority of which would threaten food security for the world's most vulnerable people:

- The success rate of predictability of weather and climate would decrease, thus making planning of farm operations more difficult.
- Climate variability at regional scale might increase, putting additional stress on fragile farming systems.
- Weather extremes - which are very difficult to plan for - might become more frequent.
- The sea level would rise, threatening submergence of valuable coastal agricultural land, particularly in low-lying small islands.
- Biological diversity would be reduced in some of the world's most fragile environments, such as mangroves and tropical forests.
- Climatic and agro-ecological zones would shift, forcing farmers to adapt, as well as threatening natural vegetation and fauna.
- The imbalance of food production between cool and temperate climates tropical and subtropical regions could worsen.
- Distribution and quantities of fish and seafoods could change dramatically, wreaking havoc in established national fishery activities.
- Pests and vector-borne diseases would spread into new regions where they were previously not known.

## **Research Thrusts**

Several experts have identified research areas that would reduce uncertainty and improve knowledge to face the consequences of climate change and provide improved planning. The following are some of the points for consideration.

- Quantitative assessment of specific crop responses at different crop stages to enhanced levels of GHG, precipitation and UV-B radiation.
- Breeding agricultural crops for tolerance to high temperatures.
- New area that is made available for agriculture is to be properly categorized and mapped to avoid chances of inappropriate land-use choices.
- Probabilities of occurrence of extreme weather events (droughts & floods) and their impacts on plant growth.
- The impacts of elevated CO<sub>2</sub> on plant soil-water balances and the corresponding crop growth should be linked.

- Water balance for drought or flood prone regions in different parts of the world for changing climatic conditions.
- The quality of global modeling projections is further improved with suitable modifications in the global circulation models.
- The databases for all the parameters need to be strengthened.

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