CHAPTER 1

Impact of Weather Extremes on Indian Foodgrains Production

G. S. L. H. V. Prasada Rao

Climate change and variability are concerns of humankind. The recurrent droughts and floods threaten seriously the livelihood of billions of people who depend on land for most of their needs. The global economy has adversely been influenced due to droughts and floods, cold and heat waves, forest fires, landslips and mudslips, icestorms, duststorms, hailstorms, thunder clouds associated with lightning and sea level rise (Fig. 1.1). The natural calamities, like earthquakes, tsunami and volcanic eruption though not related to weather disasters, may change chemical composition of the atmosphere. It will, in turn, lead to weather related disasters. The largest volcano erupted at El Salvador in 2005 was the first of its kind. It hurled out hot rocks and ash was pumped into the atmosphere. The smoke rose more than 16 km into the atmosphere, facing thousands of people to flew their houses. Recent studies also indicate that the Antarctic ice melting may be due to large volcano eruption? The tsunami that hit the East and West coasts of India along with Indonesia on 26th December, 2004 is still in our minds.

Increase in aerosols (atmospheric pollutants) due to emission of greenhouse gases including black carbon and burning of fossil fuels, chlorofluorocarbons (CFCs), hydrochlorofluorocarbons (HCFCs), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), Ozone depletion and UV-B filtered radiation, eruption of volcanoes, the "human hand" in deforestation in the form of forest fires and loss of wetlands are causal factors for weather extremes. The loss of forest cover which normally intercept rainfall and allow it to be absorbed by the soil, causes precipitation to reach across the land, eroding top soil, causing floods and droughts. Paradoxically, the lack of trees also exacerbates drought in dry years by attaining soil to dry out more quickly. Among the greenhouse gases, CO_2 is the predominant gas leading to global warming as it traps long wave radiation and emit back to the earth surface. The global warming is nothing but heating of surface atmosphere due to emission of greenhouse gases, thereby increasing global atmospheric temperature over a long period of time. Such changes in surface air temperature and rainfall over a long period of time is known as climate change. If these parameters show a year-to-year variations or cyclic trend, it is known as climate variability.

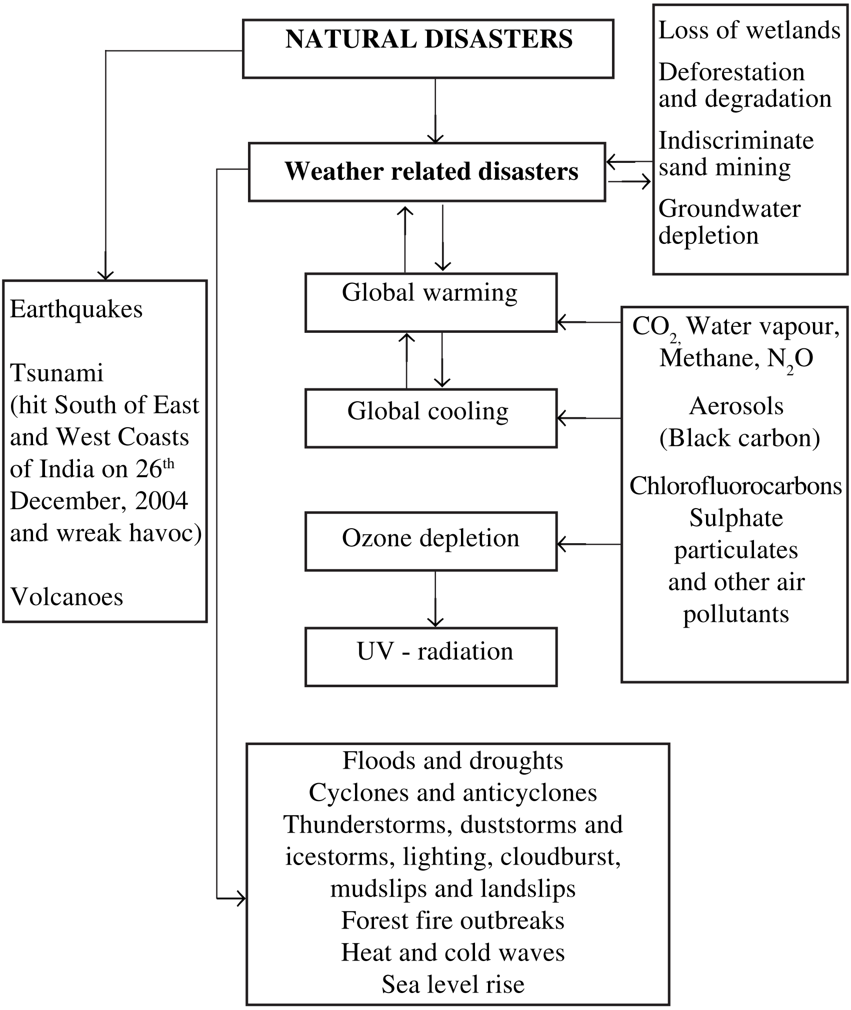


Fig. 1.1 Natural and weather related disasters

1.1 The global warm year - 1998

The year 1998 was the warmest and declared as the weather related disaster year. It caused hurricane havoc in Central America and floods in China, India and Bangladesh. Canada and New England in the U.S suffered heavily due to icestorm in January while Turkey, Argentina and Paraguay with floods in June 1998. In contrast, huge crop losses were noticed in Maharashtra (India) due to unseasonal and poor distribution of rainfall during 1997-98. The 1997/1998 El Nino event, the strongest of the last century affected 110 million people and costed the global economy nearly US$ 100 billion. A string of 16 consecutive months saw record high global mean temperature in 1997-98. Statistics compiled from insurance companies for 1950-1999 showed that major natural catastrophes, which were weather related, caused estimated economic losses of US$960 billion. Most of the losses were recorded in recent years as the top ten warmest years occurred from 1995 to 2007.

1.2 The global warm year - 2003

It was the year of heat and cold waves across the world. The European Union suffered to a large extent due to heat wave that occurred in summer 2003. It was the worst heat wave in the European Union since the inception of weather records. Spain, Portugal, France and Itali along with the United Kingdom suffered an economic loss of $7billion and the human losses accounted for 35,000. The forest fires wreck havoc across the Europe. The plant growth dropped by 30% in the European union due to heat wave. Such heat waves are not uncommon in India during the summer season. Uttar Pradesh, Bihar, West Bengal, Orissa and Andhra Pradesh are the States experience summer heat waves. When the European Union suffered heat wave during the summer in 2003, India experienced severe cold wave from December 2002 to January, 2003. Some parts of Jammu, Punjab, Haryana, Himachal Pradesh, Bihar, Uttar Pradesh and the North Eastern States experienced the unprecedented cold wave. The crop yield loss varied between 10 and 100% in the case of horticultural crops and seasonal crops (Table 1.1). The fruit size and quality were also adversely affected in horticultural crops. However, temperate fruits like apple, perch, plum and cherry gave higher yield due to extremely chilling. The damage was more in low-lying areas where cold air settled and remain for a longer time on the ground (Samra *et al.,* 2004).

Table 1. 1 Occurrence of cold wave (frost and cold spell) during December, 2002 – January 2003 and its effects

States affected	Crops suffered	Percentage loss	How to reduce the impact (?)
Parts of Jammu, Punjab, Haryana, Himachal Pradesh, Bihar, Utter Pradesh, and North Eastern States	Mango, Litchi, Guava, Papaya, Ber, Kinnow, Pine Apple, Sapota, Amla, Assam Lemon, Jack Fruit and PeachBoro rice (Assam) Maize in Bihar (early sowing), Gram Mustard	10-100% depending upon crop and variety with in the crop (Mango)	Proper selection of fruit species / varieties, wind breaks or shelter belts, frequent smoking, covering young fruit plants with thatches or plastic shelter and air mixing
	Fruit size and quality were affected in horticultural crops Damage is more in low lying areas where cold air settled and remain for a long time on ground	Temperate fruits such as apple, plum and cherry gave higher yield due to extended chilling	Weather forewarning

1.3 Heat wave in summer 2004

Occurrence of high maximum temperature in March 2004 adversely affected the crops like wheat, apple, mustard, rapeseed, linseed, potato, vegetables, pea and tea across the State of Himachal Pradesh in India. The yield loss was estimated between 20% and 60% depending upon the crop. Wheat and potato harvest was advanced by 15-20 days and the flowering of apple was early by 15 days. The optimum temperature for fruit blossom and fruit set is 24^0C in the case of apple while it experienced above 26^0C for 17 days (Table 1.2). The entire region recorded between 2.1 and 7.9^0C higher maximum temperature against the normal across the State of Himachal Pradesh in March 2004 (Prasad and Rana, 2006). A decline of 39% in annual cocoa yield was noticed in 2004 when

Table 1.2 Effect of heat wave in March 2004 on various crops across Himachal Pradesh

Apple	Wheat	Tea	Rapeseed, Mustard and Linseed	Potato, vegetables and Pea
Flowering was early by 15 days Large scale flower drop due to acute moisture stress Heavy rainfall during second fortnight of April accompanied by short fall in temperature caused poor fruit set Optimum temperature for fruit blossom and fruit set is 24°C while the region experienced above 26°C for 17 days	8-10°c above normal in Palampur and surrounding areas during 16-23, March 2004 from ear head emergence to soft dough stage led to yield loss, which was more than 20% Advanced harvest by 15-20 days	About 50% reduction in green tea leaves in April when compared to 2003 and 2005 The yield reduction was seen only after one month	Flower drop and pod infertility in late sown *Brassica spp.* and forced maturity in normal sown crop Yield reduction was up to 60% in rape seed while 50% in linseed due to flower withering and poor seed formation	Potato- matured ahead Heavy losses in yield were noticed in the case of potato vegetables and pea

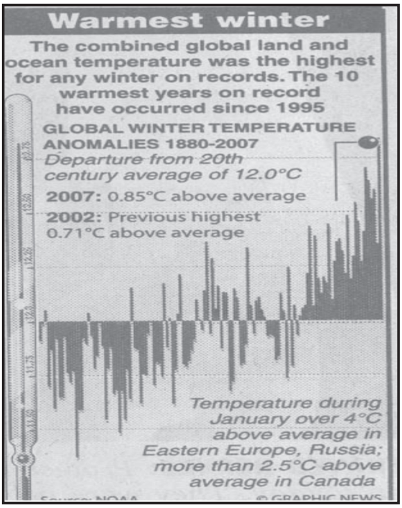
compared to that of 2003 due to rise in maximum temperature of the order of 1-3^{0}C from 14th January to 16th March in Central part of Kerala, India. Such trend was noticed whenever summer temperature shot up by 2-3^{0}C when compared to that of normal maximum temperature of 33-36.5^{0}C. The adversity of weather aberration on rhythm of normal growth of cocoa is reflected in yield after a lag period of 4-5 months.

1.4 The global warm year - 2005

The year 2005 was another historic worst warm year on record for hurricanes. The hurricane Katrina over new Orleans (USA) in

August; the hurricane Rita in Texas, central and western Cuba and southern Florida and typhoon over Hainan Province in South China and Vietnam during the last week of September, while early October over Mexican's Gulf coast; heavy downpour over Mumbai on 26^{th} July, 2005 (Single-day the highest record rainfall of 944 mm) and 3^{rd} September, 2005 over Bangalore; severe tropical storms in Andhra Pradesh in September; floods in Kerala, Karnataka, Maharashtra, Gujarat, Orissa and Himachal Pradesh during the Southwest monsoon (June-September), 2005 in India devastated cropped area to a large extent in addition to losses of thousands of human lives. In contrast, it was declared as a famine year in 24 sub-Sahara African countries due to drought and attack of locusts in 2005. Reports indicate that increase in sea surface temperature is likely to increase the frequency of hurricanes. Increase in its frequency during the last decade across the Pacific and Atlantic oceans was explained due to global warming in addition to several other factors involved in the earth-atmosphere continuum.

1.5 The global warm year - 2007



The global warm year 2007 was equated to that of 1998. However, the winter 2007 was the warmest for the entire Northern Hemisphere since it began keeping records 128 years ago. It recorded 0.85^{0}C above average of 12^{0}C. The previous highest of 0.71 ^{o}C above average, occurred in 2002 in Northern Hemisphere. Temperature during January was over 4^{0}C above average in Eastern Europe and Russia, more than 2.5^{0}C above average in Canada. Wheat was harvested a month early and vegetables were abundant, normally not seen until later in the season in Itali. The entire European Union recorded the warm winter, having more than 2^{0}C above average. New York experienced the highest temperature of 21.7^{0}C on a day in January, 2007 and the second highest was recorded as 17.2 ^{o}C in 1950. Beijing in China had temperature as high as 16^{0}C in February 2007, the highest since the meteorological record began in 1840. Untimely rains and hailstorms destroyed wheat crop of 15,000 ha over UP, Haryana ands Punjab in rabi 2007 in India. In contrast, heavy snowfall over Kashmir valley was recorded on 13.3.2007 due to western disturbances.

Heavy snowfall over Kashmir valley on 13.3.2007 due to western disturbances

Floods and excess rains were also noticed due to hurricanes and tropical storms worldwide in 2007. Similar was the case during monsoon 2007, causing floods across several continents (Hurricane Dean in August slammed into Mexico) including India and Bangladesh. Torrential downpour in June, 2007 over Kerala, Karnataka, Andhra Pradesh and Maharashtra while in July and August over Gujarat, West Bengal, Orissa, Bihar, Uttar Pradesh and Assam, led to floods. Heavy rains again in September in Andhra Pradesh, Karnataka and Kerala led to floods and thus the year 2007 can be declared as the flood year in India. A huge crop loss was noticed in several states of the Country due to floods in *kharif*, 2007. A major food shortage is expected in majority of African countries due to heavy floods, which devastated several crops in the region. Mali, a west African country more often plagued by droughts, received unprecedented rains during 2007. Similar was the case in Algeria, Uganda, Sudan, Ethiopia and Kenya. Bangladesh suffered heaviliy due to super cyclone ‘ Sidr’ that hit in November 2007.

1.6 Cold wave in winter 2008

Beijing in China had temperature as high as 16^0C in February 2007, the highest since the meteorological record began in 1840, followed by one of its coldest and snowiest winter in 2008. As a result of heavy snow for a period of three weeks since 10^{th} of January, 2008, 104 million ha of farm land was damaged in addition to 22,000 houses were destroyed and the economic loss was estimated at $ 7.5 billion. The snowstorms forced nearly 1.8 million people to relocate over the past three weeks. The abnormal atmospheric circulation in some region of Europe and Asia, which has persisted for nearly twenty days since mid-January, was responsible for the impact of chilly weather, rain and snowstorm. The snowstorm that hit 19 provinces

The worst snowstorm on January 29th, 2008 over Huanghua city in China's Anhui Province

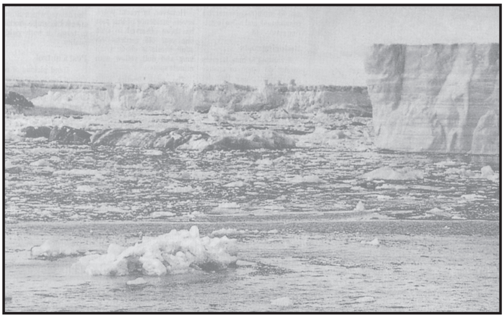
in southern and central China was the worst in 50 years. The La Nina phenomena may be another reason for severe snow storms as the sea surface temperature during the past six month was 0.5^0C lower than normal years.

It is expected to prevail at least till the end of spring. The La Nina is a large pool of unusually cold water in the equatorial Pacific that develop over few years and influences global weather, which is opposite to El No. The El Nino is nothing but warming of Pacific. The cold wave influenced in North India too. The freezing temperature in January-February, 2008 led to cold wave and extended even to Gujarat and Maharashtra from the Kashmir valley. The hill station of Mahabalipuram experienced freezing temperature on 27th and 28th, January 2008, leading the famous Venna lake turned white on 27th January as it was covered by a very thin ice layer known as frost. The mercury dipped to a new low of 9.4^0C over Mumbai on 6.2.2008. The frequency of such unusual weather phenomena is likely to increase across the world and huge economic loss is expected.

1.7 Rise in sea level

The mean sea level rise is likely to be slightly less than 1mm/ year along the Indian coast. However, models vary in projection of sea level rise by 2100, ranging from 28 cm to 43 cm. Sea level rise may lead to disappearance of low lying areas of coastal belt in addition to changes in ocean biodiversity. It threatens health of corals and polar bear population. Greater number of high surges and increased occurrences of cyclones in post-monsoon period along with increased maximum wind speed are also expected as per Ministry of Environment and Forests (MoEF), Govt. of India and Department of Environment, Food and Rural Affairs (DEFRA), U.K. This phenomenon of sea level rise threatens the area of land availability for farming.

As per the United Nations Report of FAO, India stands to lose 125 million tonnes, equivalent to 18% of its rainfed cereal production



Antarctic ice shelf, just over thousand square miles, had disappeared

from climate change by 2015. China's rainfed cereal production potential of 360 million tonnes is expected to increase by 15% during the same period. It would also cause a worldwide drop in cereal crops, put 400 million more people at risk of hunger, and put up to three billion people at risk of flooding and without access to fresh water supplies. The crop production losses due to climate change may also drastically increase number of undernourished people, severely hindering progress in combating poverty and food security. The severest impact is likely to be in sub-Saharan African countries, which are the least able to adapt climate change or to compensate for it through increase in food imports. In 2004 and 2005, 24 sub-Saharan African countries faced food emergencies, caused by a lethal combination of locusts and drought. In addition, adverse hot and dry weather in United States and drought conditions in parts of the European Union lowered cereal output during 2005 when compared to that of 2004. The simulation models indicate that the global warming leads to reduction in rice and wheat production in northern India. The recent imports of wheat by the Government of India is an indication to that effect.

1.8 Impact of all India drought on foodgrains

The Indian economy is mostly agrarian based and depends on onset of monsoon and its further behaviour. The year 2002 was a classical example to show how Indian foodgrains production depends on rainfall of July and it was declared as the all-India drought, as the rainfall deficiency was 19% against the long period average of the country and 29% of area was affected due to drought. The All-India drought is defined as the drought year when the rainfall deficiency for the Country as a whole is more than 10% of normal and more than 20% of the Country's area is affected by drought conditions. The *kharif* foodgrains production was adversely affected by a whopping fall of 19.1% due to all – India drought during monsoon 2002. Similar was the case during all-India drought in 1979 and

1987. It reveals that the occurrence of droughts and floods during Southwest monsoon across the Country affects foodgrains production to a greater extent as evident from Fig. 1.2. On regional scale also, the adverse affect on foodgrains production is significant due to occurrence of droughts and floods. They devastated rice and other crops in Andhra Pradesh and 40% cereal production was affected in Karnataka in 2006.

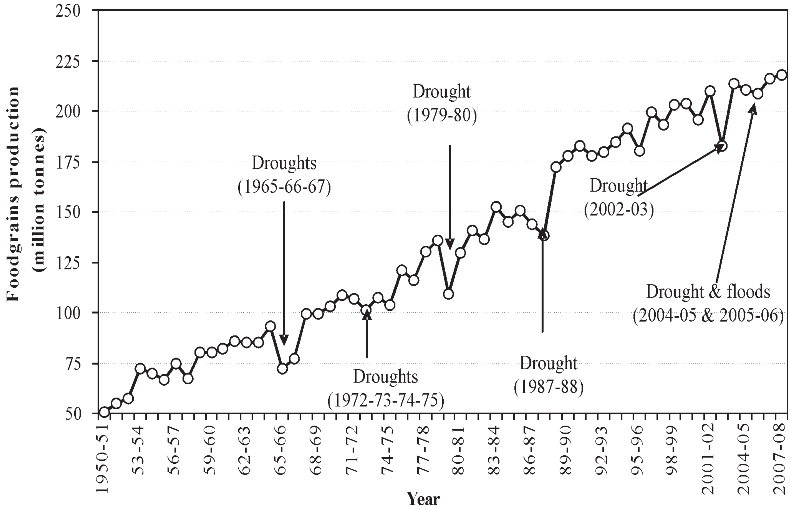


Fig. 1.2 Impact of droughts on Indian foodgrains production from 1950-51 to 2007-'08

It is one of the reasons that the foodgrains production is not in tune with plan estimates and likely to touch only a maximum of 260 million tonnes by 2020 (Fig. 1.3) at the present rate though it is

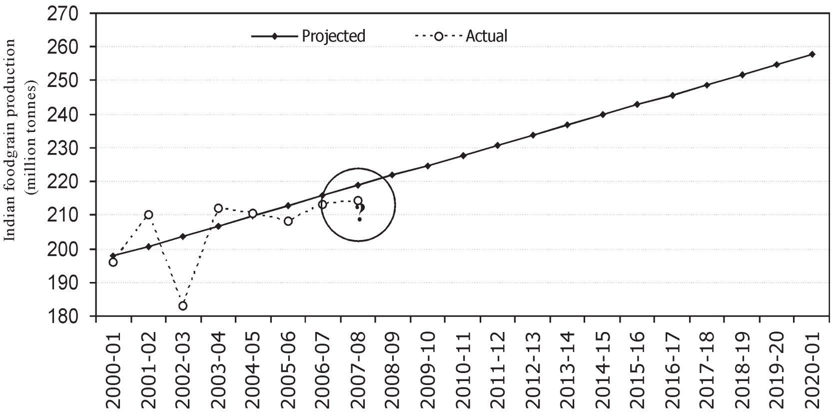


Fig. 1.3 Actual and projected Indian foodgrains production from 2000 - 01 to 2020 - 21

projected as 400 million tonnes to declare India as one of the developed countries.

1.9 Conclusions

From the above, it is clear that the occurrence of floods and droughts and heat and cold waves are common across the world. Their adverse impact on world economy is tremendous. It is more so in India as our economy is more dependent on Agriculture. Interestingly, weather extremes of opposite in nature like cold and heat waves and floods and droughts are noticed within the same year over the same region or in different regions. Reports indicate that they are likely to increase in ensuing decades. The human and crop losses are likely to be heavy. The global economy will be adversely affected as mentioned in the latest report of IPCC. If sea level increases as projected, the coastal areas which are thickly populated will be in peril and for the existing population, the safe drinking water will be a great problem. The whole climate change is associated with increasing greenhouse gases and human- induced aerosols and the imbalance between them may lead to uncertainty even in year-to-year monsoon behaviour over India. Therefore, there should be a determined effort from developed and developing countries to make industrialisation environment-friendly by reducing greenhouse gases pumping into the atmosphere. In the same fashion, awareness programmes on climate change and its effects on various sectors viz., agriculture, health, infrastructure, water, forestry, fisheries, land and ocean biodiversity and sea level and the role played by human interventions in climate change need to be taken up on priority. In the process, lifestyles of people should also be changed so as not to harm earth-atmosphere continuum by pumping greenhouse gases and CFCs into the atmosphere. From the agriculture point of view, effects of extreme weather events on crops are to be documented on regional scale so that it will be handy to planners in such reoccurrence events for mitigating the ill -effects. Also, there is need to guide planners on projected future crop scenarios based on climate change events, which will be more realistic at field level as models always overestimate the impacts. Finally, we have to foresee the weather extreme events and prepare ahead to combat them so that the losses can be minimised. Therefore, strategies on mitigation and adaptation against weather extremes are to be chalked out on war-footing. Similarly, attempts are to be made to forewarn local weather systems and weather extremes. In addition, weather insurance package to the farmers against weather related disasters should be made mandatory and operational in an event of their occurrence. It will help them to maintain their livelihood in an event of weather extremes who depend solely on the income of Agriculture.

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CHAPTER 2

Impact of Regional Climate Change over India

G. G. S. N. Rao, A. V. M. S. Rao, M. Vanaja, V. U. M. Rao and Y. S. Ramakrishna

Self sufficiency in Indian foodgrain production and its sustainability is in ambiguity due to the climate variability and change that occurred in the recent past. About 43 % of India's geographical area is used for agricultural activity. Agriculture accounts for approximately 33 per cent of India's GDP and employs nearly 62 per cent of the population. It accounts for 8.56 % of India's exports. About one third of the cropland in India is irrigated, but rainfed agriculture is central to the Indian economy. Despite technological advances such as improved crop varieties and irrigation systems, weather and climate are still playing key role in Indian agricultural productivity thereby national prosperity. Several climate models suggest that future global warming may reduce soil moisture over large areas of semi-arid grassland in North America and Asia. This climate change is likely to exacerbate the degradation of semi-arid lands that will be caused by rapidly expanding human populations during the next decade. It is predicted that there will be a 17 per cent increase in the world area of desert land due to the climate change expected, with a doubling of atmospheric CO_2 content.

Increasing evidence over the past few decades indicate that significant changes in climate are taking place worldwide due to enhanced human activities. The major cause to climate change has been ascribed to the increased levels of greenhouse gases due to the uncontrolled activities such as burring of fossil fuels, increased use of refrigerants and changed land use patterns related practices. The atmospheric concentration of carbon dioxide is increasing at alarming rates (1.9 ppm per year) in recent years than the natural growth-rate. The global atmospheric concentration of methane was at 1774 ppb in 2005 and nearly constant for a period of time. Nitrous oxide increased to 319 ppb in 2005 from pre-industrial value of about 270 ppb. Thus warming of climate system is unequivocal, as it is evident from the recent past trends of eleven warmest years out of twelve years (1995-2005). The increase in mean air temperature over last 100 years (1850-1899 to 2001-2005) is 0.76^0C which is influencing reduction of snow cover and discharge of river water in addition affecting the agricultural production system. The Fourth Assessment Report of Intergovernmental Panel on Climate Change (2007) concluded that 'there is high confidence that recent regional changes in temperature have had discernible impacts on many physical and biological systems'.

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 (Rajagopalan, 2007). Increase in sea surface temperature also adversely affects coral and coral associated flora (sea grass and sea weed) and fauna.

Model output estimates by IPCC (2002) indicate that the average global surface temperature could rise 0.6 to 2.5°C by 2050, and 1.4 to 5.8°C by 2100 (Fig. 2.1). The expected rise in temperature in higher latitudes will be much more than at equatorial regions. Also increase in rainfall is not expected to be uniform.

2.1 Water resources

In the predicted global climate scenarios, the widespread retreat of glaciers and icecaps in the 21st century will also lead to higher surface temperatures on land and increasing water stress. By 2025, as much as two-thirds of the world population, much of it in the developing world, may be subjected to moderate to high water stress.

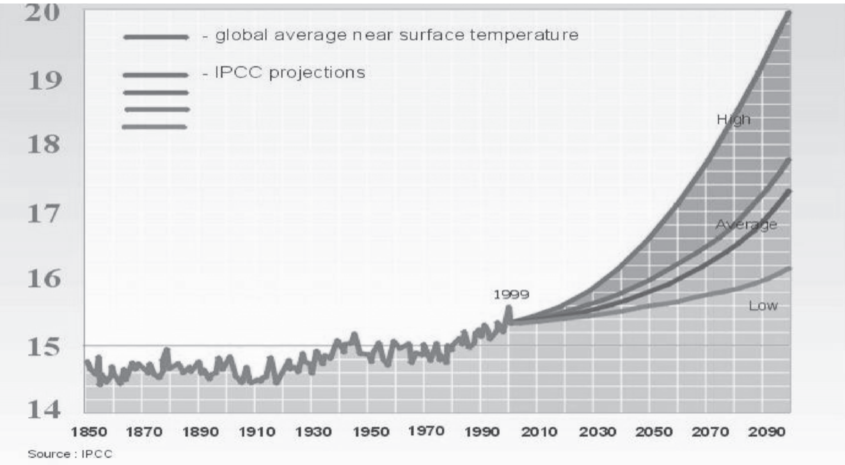


Fig. 2.1 Projected global mean temperature rise (°C)

Water resources will come under increasing pressure in the Indian subcontinent due to the changing climate. Presently, more than 45% of the average annual rainfall, including snowfall in the country, is wasted by natural runoff to the sea. Rainwater-harvesting schemes are now being implemented in the country to minimize this run-off loss based on present rainfall scenarios over the country, to increase groundwater levels. However, for the success of these schemes it is necessary that we focus on how the possible climate change will affect the intensity, spatial and temporal variability of rainfall, evaporation rates and temperature in different agro-climatic regions and river basins of India.

2.2 Retreat of Himalayan glaciers

The glaciers and the snowfields in the Himalayas are on the decline as a result of climate variability. The rate of retreat of the snow of Gangotri glacier demonstrated a sharp rise in the first half of the 20th century (Fig 2.2). This trend continued up to around the 1970s, and subsequently there has been a gradual decline in its rate of retreat. The diminishing rate of retreat of snow of the Gangotri glacier could be a consequence of the diminishing rate of rise in temperatures.

Although the warming processes continue unabated, the rate of rise in temperatures in the Gangotri glacier area has nevertheless demonstrated a marked gradual decline since the last quarter of the past century. However, Samudra Tapu, one of largest glaciers in

Chandra Basin in Lahul and Spiti receded by 862 m between 1963 and 2006, at a rate of 18.5 m in a year, with the rapid rate retreat being observed during past six years compared to earlier decades (India Today, 2006).

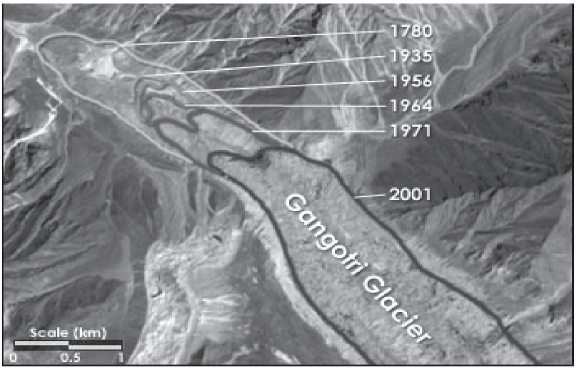


Fig. 2.2 Composite ASTER image showing retreat of the Gangotri Glacler terminus in the Garhwal Himalaya since 1780; Glacier retreat boundaries (courtesy, the Land Processes Distributed Active Archive Center).

Glaciers in the Himalayan mountain ranges will retreat further as tempera tures increase. They have already retreated by 67% in the last decade. Glacial melt would lead to increased summer river flow and floods over the next few decades, followed by a serious reduction in flows thereafter.

2.3 Climate change and agriculture

Impact of climate change on agriculture will be one of the major deciding factors influencing the future food security of mankind on the earth. Agriculture is not only sensitive to climate change but at the same time is one of the major drivers for climate change. Understanding the weather changes over a period of time and adjusting the management practices towards achieving better harvest is a challenge to the growth of agricultural sector as a whole.

The climate sensitivity of agriculture is uncertain, as there is regional variation of rainfall, temperature, crops and cropping system, soils and management practices. The interannual variations in temperature and precipitation were much higher than the predicted changes in temperature and precipitation. The crop losses may increase if the predicted climate change increases the climate variability. Different crops respond differently as the global warming will have a complex impact.

The tropics are more dependent on agriculture as 75% of world population lives in tropics and two thirds of these people main occupation is agriculture. With low levels of technology, wide range of pests, diseases and weeds, land degradation, unequal land distribution and rapid population growth, any impact on tropical agriculture will affect their livelihood.

Rice, wheat, maize, sorghum, soybean and barley are the six major crops in the world and they are grown in 40% cropped area, 55% of non-meat calories and over 70% of animal feed (FAO, 2006). Since 1961, there is substantial increase in the yield of all the crops. The impact of warming was likely offset to be minimized some extent, by fertilization effects of increased CO_2 levels. At the global scale the historical temperature- yield relationships indicate that warming from 1981 to 2002 is very likely off set some of the yield gains from technological advance, rising CO_2 and other non-climatic factors (Lobell and Field, 2007).

2.3.1 The Indian scenario

India, being a large country, experiences wide fluctuations in climatic conditions with cold winters in the North, tropical climate in South, arid region in West, wet climate in the East, marine climate in coastline and dry continental climate in interior.

A likely impact of climate change on agricultural productivity in India is causing a great concern to the scientists and planners as it can hinder their attempts for achieving household food security. Foodgrain requirements in the country (both human and cattle) would reach about 300 mt in 2020. The question that is of great concern is that, with the alarming increase in GHG concentration and its expected impact on climate, will it be possible to achieve the targeted production? Sinha *et al* (1998a) observed that during the past 25 years, significant changes in climate are observed over different regions of the country. For example, many parts of northern India show increase in minimum temperature by about 1^0C in *rabi* cropping season. However, mean temperatures are misleading as some of the individual regions could exhibit a larger variation with a larger impact on *rabi* crop production. Sinha and Swaminathan (1991) presented a case study of actual change in temperature in North India. They brought out that while the mean air temperatures over the wheat growing regions were high by 1.7°C over a period of 15 days (January 16 to February 1), the actual temperature rise was 2.3 to 4.5^0C in the major wheat-producing region of Punjab and

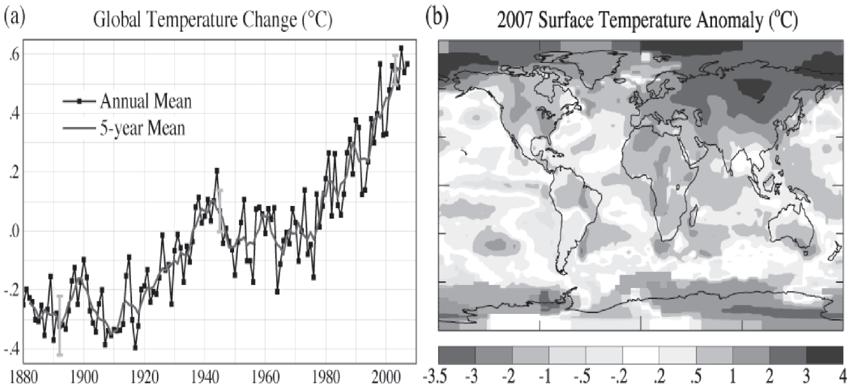
Haryana (Sinha *et al* 1998b). Through these studies they projected the serious effects of regional temperature on productivity of major crops. They further added that in view of the proportionate production changes in major food crops, viz., rice and wheat, over the years, the dependence on rice and wheat has increased considerably. Therefore, any factor that would influence the productivity through climatic change would affect the food security of the nation, as both these crops are sensitive to temperature variations.

The arrival and performance of the monsoon is no insignificant matter in India every year, and is avidly tracked by the national media. This is because most of the states in the Country are largely dependant on rainfall for irrigation. Any change in rainfall patterns poses a serious threat to agriculture, and therefore to the country's economy and food security. Owing to global warming, this already unpredictable weather system could become even more undependable. Semi-arid regions of western India are expected to receive higher than normal rainfall as temperatures soar, while central India will experience a decrease of between 10 and 20 per cent in winter rainfall by 2050. Agriculture will be adversely affected not only by an increase or decrease in the overall amounts of rainfall, but also by shifts in the timing of rainfall. For instance, over the last few years, the Chhattisgarh region has received less than its share of pre-monsoon showers in May and June. These showers are important to ensure adequate moisture in fields being prepared for rice crops.

Agriculture will be worst affected in the coastal regions of Gujarat and Maharashtra, where agriculturally fertile areas are vulnerable to inundation and salinisation. Standing crop in these regions is also more likely to be damaged due to cyclonic activity. In Rajasthan, a 2^0C rise in temperature was estimated to reduce production of pearl millet by 10-15 per cent. The State of Madhya Pradesh, where soybean is grown on 77 per cent of all agricultural land, could dubiously benefit from an increase in carbon dioxide in the atmosphere. According to some studies, soybean yields could go up by as much as 50 per cent if the concentration of carbon dioxide in the atmosphere doubles. However, if this increase in carbon dioxide is accompanied by an increase in temperature, as expected, then soybean yields could actually decrease. If the maximum and minimum temperatures go up by 1^0C and 1.5^0C respectively, the gain in yield comes down to 35 per cent. If maximum and minimum temperatures rise by 3^0C and 3.5^0C, respectively then soybean yields will decrease by five per cent compared to 1998. Changes in the soil, pests and weeds brought by climate change will also affect agriculture in India. For instance, the amount of moisture in the soil will be affected by changes in factors such as precipitation, runoff and evaporation.

2.3.2 Observed changes in temperature

The global surface temperature is projected to be 0.54°C above the long-term average of 14°C beating the current record of 0.52°C which was set in 1998. Global average surface temperature in 2007 was still tied for the second warmest year in the instrumental record compiled by scientists at NASA's Goddard Institute for Space Studies, which goes back to 1880. The record warmest year was 2005, with 1998 - now tied with 2007 - in second place. The global average temperature anomaly for 2007 was 0.57 °C above the 1950 - 1980 base line.



In India, Earlier work of Hingane *et al*. (1985) on long-term trends of surface temperature covering the period of 1900-82 from 73 well distributed stations also showed a warming trend of 0.04°C per decade for the period 1901-82. Using the all-India mean surface air temperatures during 1901-2000 from network of 31 well-distributed representative stations, the trends in mean annual temperatures over the country were highlighted by Rupa Kumar *et al*., (2002). Warming trends were also observed during all the four seasons with higher rate of temperature increase during winter and post-monsoon seasons compared to that of annual (Table 2.1). Evaluation of trends in minimum and maximum temperatures for the entire country and also for the six homogenous regions in the Country indicated that the minimum temperature showed a decreasing trend during summer monsoon while an increasing trend during the winter monsoon. An increasing trend

Table 2.1 Trends in Mean Surface Air Temperatures over India during 1901-2000

Season	Trends (°C / Decade)
Annual	0.03*
Winter	0.04*
Pre-Monsoon	0.02*
Monsoon	0.01
Post-Monsoon	0.05

* *Significant at 95% and more* (Source: Rupa Kumar et al., 2002)

during both the seasons for maximum temperature are noticed. It may influence production in *kharif* and wheat production in *rabi*. Analysis of observed spatial patterns of maximum temperature indicate more than 45°C in central India, 35-40°C along the West coast, about 25°C in Himachal Pradesh in North India (NATCOM Report, 2004).

Kothawale and Rupakumar (2005) reported that while all-India mean annual temperature has shown significant warming trend of 0.05 °C/10yr during the period1901-2003, the recent period 1971-2003 has seen a relatively accelerated warming of 0.22 °C/10yr, which is largely due to unprecedented warming during the last decade. Further, in a major shift, the recent period is marked with by rising temperatures during the monsoon season, resulting in a weakened seasonal asymmetry of temperature trends reported earlier. Arora *et al*. (2005) reported that annual mean temperature, mean maximum and minimum temperatures have increased at the rate of 0.42, 0.92 and 0.09 °C/100yr, respectively.

On a regional basis, stations of southern and western India show a rising trend of 1.06 and 0.36 °C/100yr respectively. While stations of the North Indian Plains show a falling trend of -0.38 °C/100yr. The seasonal mean temperature has increased by 0.94 °C/100yr for the post monsoon season and by 1.1 °C/100yr for the winter season. Similarly, extreme minimum temperatures were observed in the region North of 25°N and West of 80°E. Some of the instances of observed spatial variability in the temperature phenomena during last few years include extreme cold winter during 2002-03, wide spread prevailing drought situations during July, 2004, 20-day heat wave in A.P. during May, 2003 (Ramakrishna, 2007).

2.3.3 Rainfall variability

On the rainfall front, the scenario is highly variable with greater spatial variability across regions and seasonal (summer and winter monsoon) rainfall did not show any significant trend over the historical period. The rainfall trends evaluated on sub divisional basis (Fig. 2.3a & 2.3b) for the two monsoons have shown significant variations due to high spatial variability of rainfall during monsoon season (Rupa Kumar *et. al*., 2002).

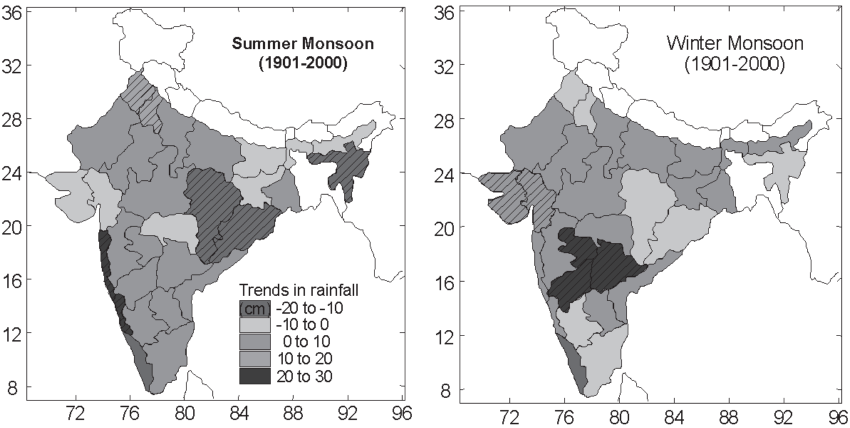


Fig.2.3a&b Trends in sub-divisional summer and winter monsoon rainfall in India during 1901-2000 (Source : Rupa Kumar, 2002

The summer monsoon rainfall during 1901-2000 has shown significant decreasing trends in the subdivisions of northeast India, *viz.,* Nagaland, Manipur, Mizoram and Tripura (-12.5 mm/decade), Orissa (-11.0 mm/decade) and East Madhya Pradesh (-14.0 mm/decade). Significant increasing rainfall trends in Konkan & Goa (27.9 mm/decade) and coastal Karnataka (28.4 mm/decade) along the West Coast and in Haryana, Chandigarh and Delhi (13.6 mm/decade) and Punjab (18.6 mm/decade) were noticed in north India. Similarly, the winter monsoon rainfall (Fig. 2.3b) has shown significant increasing trend in the subdivisions of Marathwada (5.4 mm/decade), Telangana (4.4 mm/decade) and North interior Karnataka (4.5 mm/decade) in central India and also in Gujarat (1.2 mm/decade) and Saurashtra & Kutch (0.64 mm/decade).

A four-degree polynomial equation of the annual rainfall shows a cyclic trend in the rainfall pattern for a lag period of 40 years in case of Hyderabad and other stations located in Peninsular and in northern parts. However, similar clear cut variability is not observed the stations that are located in eastern and extreme western parts of the Country.

The trend analysis of rainfall data from 1140 meteorological stations carried out at CRIDA showed negative trend among the stations situated in deep southern parts, southern peninsular, Central India, Parts of North Indian region and N.E. regions (Fig. 2.4). Positive

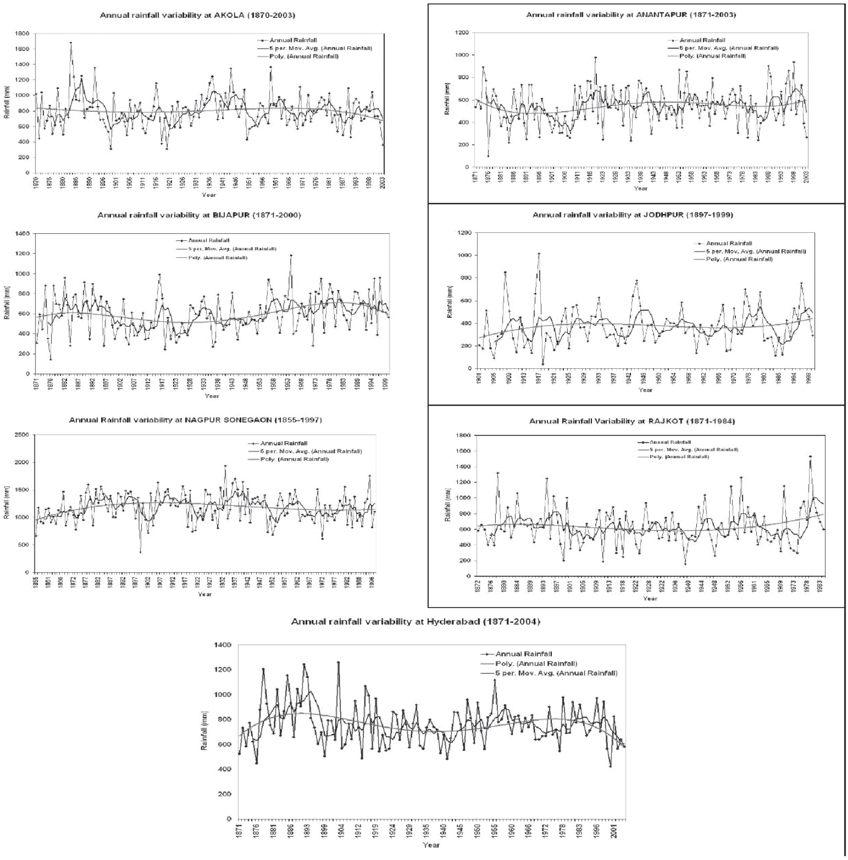


Fig. 2.4 Trend in rainfall over southern penusula, centeral India parts of north Indian region and north east region of India

deviations are seen at Gujarat, Maharashtra, Coastal A.P., Rayalaseema and Orissa. However, part of the country comprising the areas in central parts covering eastern U.P., eastern M.P., west coast and greater parts of North west India did not show any changes. Among the rainfed districts, 40 per cent stations showed negative trend, 48 per cent with positive trend and 12 per cent no change in rainfall (Rao, 2007).

Spectral analysis of long term data indicated majority of the stations showd a cyclic trend with a certain periodicity. Greater number of stations showed periodicity of less than seven years indicating that 73 per cent of stations of rainfed areas in the Country are subjected to short-term fluctuations in rainfall. It was observed that a periodicity of approximately ten years annual rainfall cycle has been noticed for Hyderabad (Rao, 2007). An analysis of extreme rainfall events at selected AICRPAM centers covering the data of last 100 years indicated the increased probability of occurrence of deficit rainfall for the recently concluded period and indicated any definite trend over a long period (Table 2.2). Significant negative

Table 2.2 Mean annual rainfall variability over different periods

Station	Period	Excess	Normal	Deficit
Anantapur	1901-1930	33	30	37
	1931-1960	33	44	23
	1961-1990	27	43	30
	1991-2003	39	38	23
Bangalore	1901-1930	13	64	23
	1931-1960	23	67	10
	1961-1990	20	70	10
	1991-2001	46	36	18
Bijapur	1901-1930	13	34	54
	1931-1960	23	57	20
	1961-1990	55	28	17
	1991-1999	45	33	22

Station	Period	Excess	Normal	Deficit
Kanpur	1901-1930	30	47	23
	1931-1960	20	50	30
	1961-1990	30	37	33
	1991-2003	15	54	31
Raipur	1901-1930	23	57	20
	1931-1960	37	57	6
	1961-1990	20	40	40
	1991-2003	0	39	61
Solapur	1901-1930	10	53	37
	1931-1960	23	57	20
	1961-1990	43	34	23
	1991-2003	15	46	39

trends were observed in the eastern parts of Madhya Pradesh, Chhattisgarh and parts of Bihar, Uttar Pradesh, parts of N-W and N-E Indian and a small part in Tamil Nadu.

2.3.4 Shifts in monthly rainfall

Selected locations in central and southern India indicated a shift in monthly rainfall pattern moving towards the latter part of the south-west monsoon season (Fig. 2.5). A study by Rajegowda *et al.*

(2001) for Karnataka covering the last decade (1991-2000) indicate shifts in rainfall peaks by 2-3 weeks. This has a direct bearing on agricultural crops, as it influences the time of sowing and subsequent crop growth, necessitating shifts in crops and cropping patterns to match the modified rainfall regime. Similarly, trends of decreasing pattern in pre-monsoon rainfall were also observed in some parts of Chhattisgarh region (Sastri and Urkurkar, 1996) in May and June, proving detrimental to pre-sowing operation of rice crop.

Western parts of India indicated increase in rainfall during October and November months, followed by decline in December to February months (Sastry, 1998).

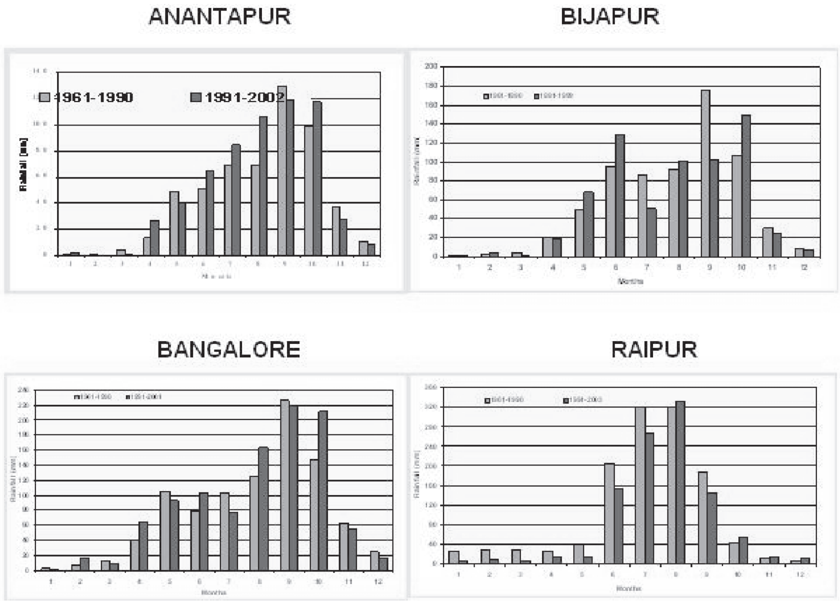


Fig. 2.5 Shifts in monthly rainfall patterm

2.3.5 Droughts and desertification

Drought is a regular part of the natural cycles affecting productivity and leading to desertification. Impacts of shifts in climatic pattern becomes more prominent when one considers the climatic spectrum of the dryland and arid regions (Ramakrishna et al, 2000) as these marginal areas provide early signals of the impacts of climate variability and change (Sinha *et al*, 2000). The rainfed regions encompassing the arid, semi-arid and dry sub-humid regions (covering regions less than 1150 to 1200 mm) are more prone to climatic variability (Ramakrishna *et al.,* 2007).

Historical analysis of droughts over past 200 years (Kulshreshta, 1997) shows the occurrence of 5 phenomenal droughts (> 47.7% area of the country affected) of which two have occurred in the last quarter of the 20th Century. Though the technological developments thereafter could lead to improved resilience to drought and better measures for food security, the recent spell of drought for three consecutive years 1998, 1999 and 2000 over Rajasthan and Gujarat regions is a fresh reminder of the likely impacts of climate on agriculture and society. Pratap Narain *et al.*, (2000) witnessed an increase in moderate and severe droughts in the last decade 1991-2000 compared to the earlier decades in the last century in the arid zone (Table 2.3).

Table 2.3 Frequency of moderate and severe droughts in the Indian arid zone

District	Moderate droughts		Severe droughts	
	Total period (1901-2000)	In the last decade (1991-2000)	Total period (1901-2000)	In the last decade (1991-2000)
Barmer	14	1 (1977)	20	4 (1991, 98, 99 & 2000)
Bikaner	19	2 (1993 & 97)	19	4 (1991, 98, 99 & 2000)
Jaisalmer	19	3 (1991, 93 & 94)	28	6 (1992, 94, 97-2000)
Jodhpur	23	4 (1991, 93, 97 & 98)	14	2 (1999 & 2000)

(Source : Pratap Narain et al., 2000)

Major parts of rainfed areas of India is having the probability of three to four year drought in every ten year period in which, there is again a probability of getting one to two years moderate and half year to one year severe droughts (Fig. 2.6). Due to the variability of climate in the recent past, more intense and longer droughts have been observed over wider areas since 1970, particularly in the tropics and subtropics (IPCC, 2007).

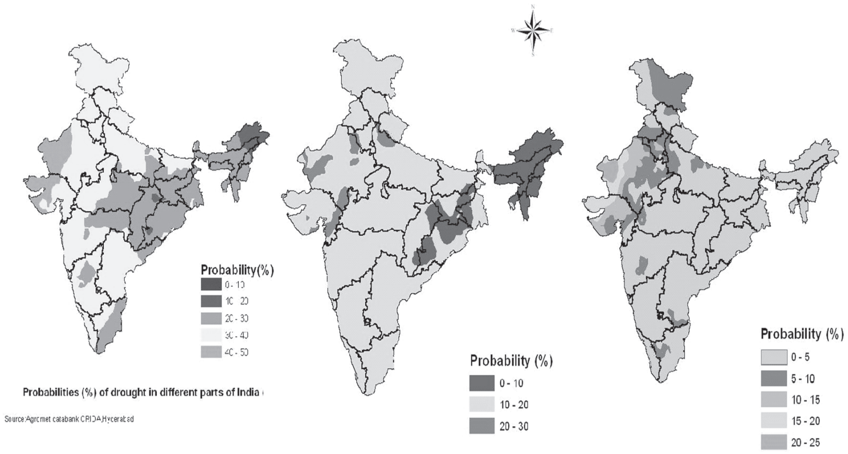


Fig. 2.6 Probabilities (%) of drought in different parts of India

2.3.6 Impact of weather extremes

There is preliminary evidence to indicate that decrease in rice yields in recent past in Indo-Gangetic plains was associated with a slight rise in minimum temperature. Wheat production showed loss of 4-6 million tonnes in recent years due to increased heat in February-March. Increasing temperatures in Himachal Pradesh has resulted in a decrease in apple productivity and the apple belt is gradually shifting upwards (higher elevation). The cyclone that hit Orissa State (India) in October 1999 affected the livelihoods of 12.9 million people and resulted in the loss of 1.6 million houses, nearly 2 million hectares of crops and 40,000 livestock. Poor labourers and rickshaw drivers formed the highest proportion of the 1,000 people who died in India during an intense heat wave in May 2002 and the 1,400 deaths in the heat wave in 2003. Continuous floods in different parts of Andhra Pradesh during 2005, 06 and '07, followed by continuous deficit rainfall for a period of four years led to significant economic losses in these regions (Fig.2.7).

This increase in the disaster frequency across India is reflected in the corresponding losses in different regions of the Country. Here too, we see a general trend towards higher losses, although the losses caused by the Gujarat flood in 1993 still mark the record. It also clearly shows that, in India insured losses account for a very small proportion of the overall economic loss (below 10%). This means that the people affected by these disasters are not covered by weather insurance and eventually the State as a financial source have to cope with these losses as a last resort. In a country where the majority of the population still relies on

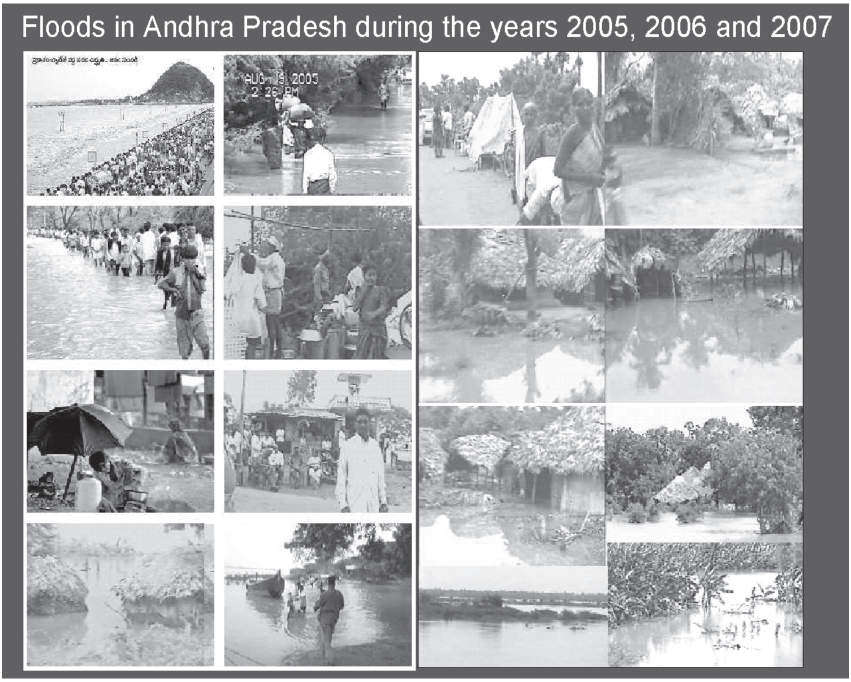


Fig. 2.7 Floods in Andhra Pradesh during the years 2005, 2006, 2007

agriculture for their livelihood, the effects of extreme weather events are severe and adversely affect livelihoods of many (Fig.2.8).

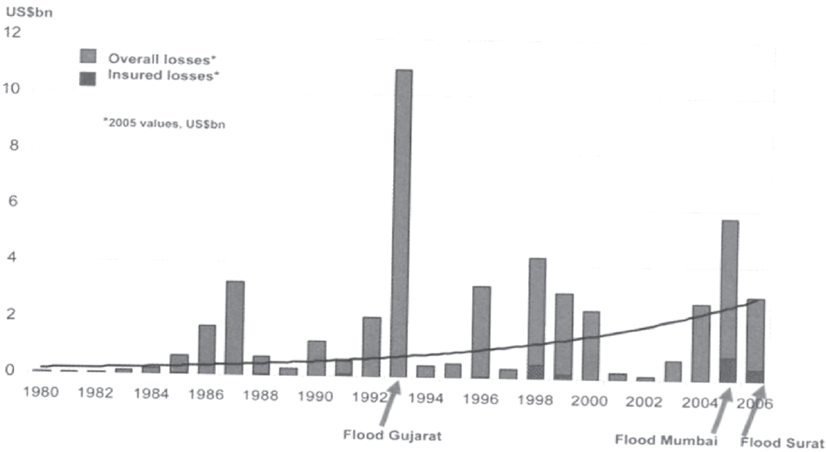


Fig. 2.8 Economic and insured losses in India from Natural Disasters (1980-2006)

The regional distribution of natural disasters in India between 1980 and 2005 (Fig. 2.9) showed that there is hardly any state in

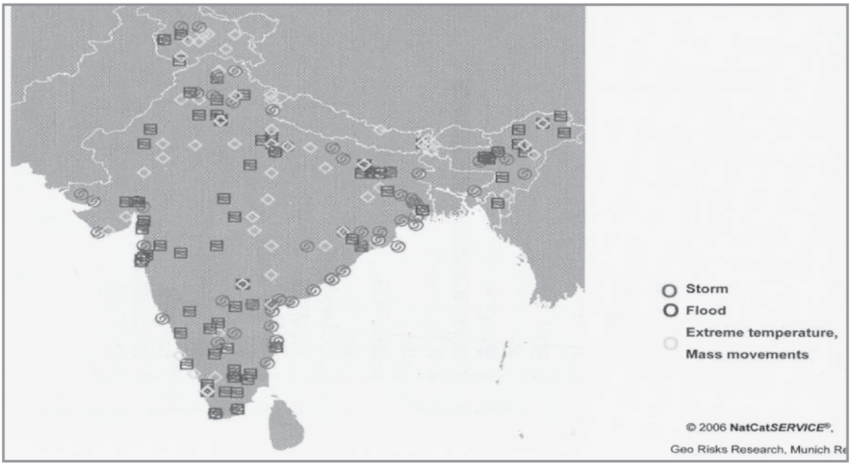


Fig. 2.9 Regional distribution of Natural Disasters in India between 1980 and 2005 (Source : Peter Hoppe, 2007)

India which has not been affected by such disasters and that windstorms (cyclones) mostly affect the States along the East Coast while floods and disasters caused by extreme temperatures are distributed more evenly over almost all states. In India, the highest ever 24-hour precipitation was measured (944 mm) in Mumbai. This extreme flood killed more than 1,000 people and caused economic losses of US$ 5 bn and issued losses of US$ 770m next only to the huge losses recorded in Gujarat during 1993. In 2006, there were again major floods in several Indian states, especially Gujarat and Andhra Pradesh.

2.3.7 Projected climate change scenarios for India

According to Lal *et al.*, (2001), 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 3^0C or more by 2050. The study also suggests that during winter the surface mean air temperature could rise by 3^0C in northern and central parts while it would rise by 2^0C in southern parts by 2050. In case of rainfall, a marginal increase of 7 to 10 per cent in annual rainfall is projected over the sub-continent by the year 2080. However, the study suggests 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 (Table 2.4). It was also reported that the date of onset of summer monsoon over India could become more variable in future. Though some of the projected

Table 2.4 Climate Change Projection for India

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)

changes in climate will have both beneficial and adverse effects on the environmental and socio-economic system, the larger changes will have more adverse effects. The expected changes in climate for India indicated that increase in temperature is likely to be less in *kharif* than in *rabi* season and the *rabi* rainfall is largely uncertain whereas *kharif* rainfall is likely to increase by as much as 10 per cent. Such global climate changes will affect agriculture considerably through its direct and indirect affect on crops, livestock, pest and diseases and soils, thereby threatening the food security, an important problem for most of the developing countries.

The impact of climate change on different crop management levels viz., fertilizer, water management improving rainwater management through watershed development, increasing water availability and water use efficiency needs to be looked into it. All the soil processes with respect to changes in precipitation pattern and increased air and soil temperatures can influence available soil water content, runoff and erosion and need to be studied further.

2.3.8 Potential impacts of climate change on agriculture

Agriculture is one sector, which is immediately affected by climate change, but 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. Seasonal precipitation distribution patterns and amounts could change due to climate change. With warmer temperatures, evapotranspiration rates would rise, which would call for much greater efficiency of water use. Also weed and insect pest ranges could shift. Perhaps most important of all, there is general agreement that in addition to changing climate, there would likely be increased variability in weather, which might mean more frequent extreme events such as heat waves, droughts and floods.

If no climate policy interventions are made to mitigate the effects of climate change on agriculture the result would be a significant decrease in potential yield in most tropical and subtropical regions due to increase in temperature. Similarly, in mid-latitudes, crop models indicate that warming of less than a few degree celsius and the associated increase in CO_2 concentrations will lead to positive responses in agricultural productivity. 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 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 to 200-300 km for every 1°C increase (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 adopted to higher temperature. Morey and Sadaphal (1981) reported a decrease of wheat yield by 400 kg ha^{-1} for a unit increase of 1°C maximum temperature and 0.5 hr sunshine.

As temperature rises, the weather will be affected in different ways all over the planet. Drought is likely to get worse in some areas, where rainfall is expected to decrease and become more unpredictable from year to year. Rise in temperature will also cause more moisture to evaporate quickly from the surface of the earth. As air and soil become drier, it may be more difficult to grow crops with higher water needs. Vijay Cuddeford (2002) reported that the area under rice crop is likely to decrease because:

1. Many current varieties of rice may not set grain if temperatures become hotter, and
2. There will be less water for crops if rainfall decreases and evaporation increases.

These concerns can lead scientists and farmers to adopt low water use techniques for rice cultivation with preferences like Systems Rice Intensification (SRI) and the aerobic rice.

2.3.8.1 Impact studies

From the model projected temperature data of 2020, the potential evapotranspiration (PET) ratio was computed for few locations in the State of Andhra Pradesh estimating the crop water requirement and compared it with the water requirement of the crops that were computed using the measured weather parameters up to 2005. The differences in water requirements provide a clue to the climate change impact studies. Similarly, change in the total crop duration estimated from the computation of GDD by the year 2020 also provide information on impacts of climate change. Increase in crop water requirement and the reduction in length of crop duration of important crops in respect of few selected stations in Andhra Pradesh are given in Table 2.5. It was noticed from the results that overall water requirement of the major crops grown under rainfed conditions in Andhra Pradesh showed increasing trend. This is mainly attributed to the increase in average temperature by ~1⁰C over the base year.

There is not much significant decrease in the crop duration due to fulfilling of the required growing degree-days at an early date. Over all, the crop duration is expected to decrease by one to two weeks by 2020 for all the major crops of the State.

Table 2.5 Projected Crop Water Requirements and Changes in Crop Duration

Station	Crop	Increase in water requirement in mm (2020-2005)	Reduction in crop duration (weeks)
Anakapalli	*Maize*	*51.7*	*1*
	Groundnut	61.3	1
Anantapur	Groundnut	70.1	1
	Red gram	174.3	1
Jagityal	Cotton	60.5	2
	Maize	49.0	1
Rajendranagar	Red gram	114.5	2
	Groundnut	73.0	1
Tirupathi	Groundnut	73.0	1

2.3.8.2 Crop responses to increased CO_2, temperature and moisture stress

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. Increase in CO_2 concentration can lower pH, thereby, directly affecting both nutrient availability and microbial activity. The changes in the crop yield depend not only on the change in rainfall but also on the changes in CO_2 concentration. While the above two parameters led to increase in crop yield, the impact of temperature is generally negative in the tropics. Thus it is necessary to ascertain whether the impact of increased rainfall and CO_2 associated with the global warming phenomenon will overwhelm the impact of increased temperature and hence, evapotranspiration. Rosenzweig and Parry (1994) estimated that the net effect of climate change on global cereal production would be up to 5 per cent. They further indicated that production in the developed world would increase while it can decline in developing countries. Doubling of CO_2 concentration may increase the photosynthetic rates by as much as 30-100 per cent in C_3 plants such as wheat, rice and soybean and will become more water efficient as they quickly grow. While the response in C_4 plants such as maize, sorghum, sugarcane and millets may not be spectacular (IUCC, 1992).

Rogers and Dahlmann (1993) have compiled a synopsis of the dry mass production and yield increase of the world's ten most important crop species in response to elevated CO_2. Their work shows that in some species the relative increase of total biomass and in others that of economic yield is greater. It is well known that elevated CO_2 stimulates photosynthesis. For sorghum, the stimulation was much less, only about 9%, which is C_4 crop. However, under water stress the sorghum had a larger response of about 23%, which was probably more due to the effect of elevated CO_2 on plant water relations than a direct stimulation of photosynthesis (Wall *et al*., 2001). Brooks *et al.,* (2001) observed that wheat canopies with ample nitrogen and water were stimulated about 19% by FACE, while those subjected to low nitrogen exhibited only a 9% increase in net photosynthesis. Elevated CO_2 causes partial stomatal closure, which reduces the conductance for the exchange of gases between the internal tissues of plant levels and the atmosphere. Kimball and Idso (1983) mol [1], calculated an average transpiration reduction of 34%, due to increasing CO_2 from 330 to 660 ìmol. When there was no stress, elevated CO_2 reduced stomatal conductance by 21.3 and 16.0% for C_3 and C_4 species respectively. Water and nutrient stresses did not significantly change the response of C_4 grasses. Vanaja *et al.* (2006a) evaluated the food and oil seed crops in OTCs at CRIDA, Hyderabad for their response to elevated CO_2 at vegetative stage and observed that the pulse crop has responded better than other. The OTC studies with blackgram (*Vigna mungo* L. Hepper) indicate that under increased CO_2 levels proportioning of assimilate was greater to the roots than to the shoots under moisture stress (Vanaja *et al.,* 2006b). Plants grown with elevated CO_2 were taller and attained greater leaf area along with more biomass than ambient CO_2 levels under irrigated and stress conditions (Fig.2.10). Because elevated CO_2 causes a decrease in stomatal conductance, transpiration per unit leaf area is decreased while canopy temperature is increased. The increase in temperature raises the water vapor pressure inside the leaves, which tends to increase leaf transpiration, thereby negating some of the reduction due to decrease in stomatal

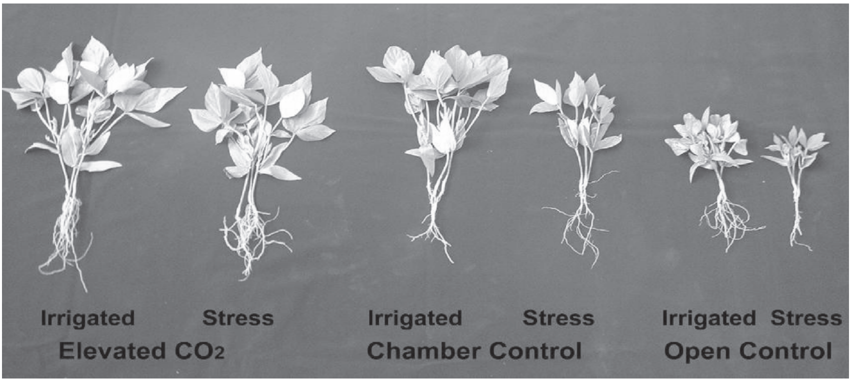


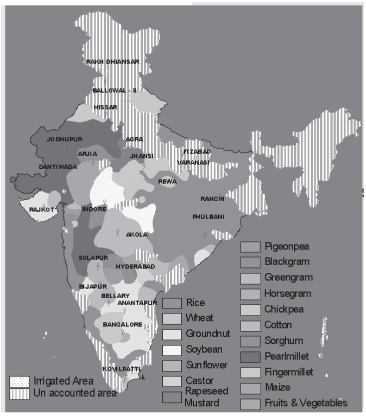
Fig. 2.10 The response of blackgram crop to increased CO_2 (600 ppm) both under irrigated and moisture stress condition

conductance (Kimball *et al.*, 1993). Thus, the resultant effect of elevated CO_2 on ET is a combination of individual effects of the CO_2 on decreasing stomatal conductance, increasing leaf area and increasing canopy temperature. When seasonal water supply is severely growth limiting, one would expect plants to utilize all the water available to them, so that effects of elevated CO_2 on seasonal ET would be minimal.

Atmospheric CO_2 enrichment often stimulates plants to develop more robust root systems to probe greater volumes of soil for scarce and much needed moisture. Atmospheric CO_2 enrichment increases plant water acquisition by stimulating root growth, while it reduces plant water loss by reducing stomatal conductance and these dual effects typically enhance plant water use efficiency, even under conditions of less than optimal soil water content, hence delay in the onset of the water stress (Lin and Wang, 2002). It may be concluded that further increase in atmospheric CO_2 content will likely lead to increased crop and yield production, even in areas where reduced soil moisture availability leads to plant water stress.

2.3.8.3 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 gain 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.2.11a 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. 2.11b.



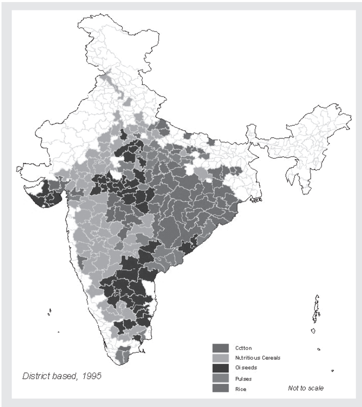


Fig. 2.11a Distribution of rainfed crops *b Rainfed production systems of India*

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.

2.4 Drought management strategies in rainfed agriculture

In the absence of any assured irrigation facility and with ever growing changing patterns of temperature and precipitation, rainwater management technologies would play a greater role in rainfed areas. Renewed focus with incentive measures for in-situ especially in low to medium rainfall regions with farmers themselves taking the leadership in conservation should be the focal theme. The predominant interventions to overcome climate related impacts in rainfed areas include

- Soil and water conservation practices
- Agronomic interventions
- Nutrient management practices

- Livestock based interventions
- Development of alternate land use plans

These interventions have a role to play in all agro-eco systems except that their order of priority changes, which basically depends on rainfall, status of natural resources like soil and water.

Crop based interventions need to be planned based on amount and distribution of rainfall, availability and further augmentation of water resources with watershed programme. Based on the resource availability, broad guidelines for watershed programme are given below:

Regions with rainfall < 500mm

Priority should be given for ensuring drinking water facility even during lean season. *In situ* conservation coupled with farm/field boundaries should be given emphasis. Deep soils only should be encouraged for cultivation. Livestock based farming system should be encouraged. Fodder needs can be met by growing grasses in soils with low to medium soil depth. Runoff harvesting can be possible only if watershed receives runoff from upstream areas.

Regions with rainfall of 500-700mm

Crops can be grown in medium to deep soils with high available water content. Runoff harvesting could be possible in few cases for critical/ supplemental irrigation. Horticulture can be promoted to a larger scale. Land capability based land use planning with emphasis on alternate land use need to be promoted.

Regions with rainfall of 700-1100 mm

Farming systems can be promoted. Medium to deep soils with medium to high available water content can be promoted for cultivation. Cropping and livestock based systems can be promoted. Runoff harvesting is possible on small farms also. *In-situ* conservation with water harvesting for supplemental irrigation can be planned within watershed. In few cases, residual moisture within fields or pre sowing irrigation for *rabi* crop is also possible and there is a need to explore the possibilities based on location specificity. In areas where the rainfall of 1000-1100 mm is received through southwest monsoon, integrated aqua based farming system with fisheries in medium to low lands of rainfed rice (rice-fish-duck) system also can be encouraged.

2.4.1 Rainwater management in rainfed areas

Various soil and water conservation measures relevant for rainfed agriculture include

***In-situ* measures for rainwater management in rainfall areas.**

- Off season land treatment:
- *Conservation furrows*
- Ridges and furrows system in cotton
- Cover cropping
- *Micro catchments for tree systems*

Medium term measures rain water management in rainfed areas.

- Stone and vegetative field bunds for soil and water conservation
- Graded line bund helps in efficient drainage.
- Trench cum bund for soil and water conservation

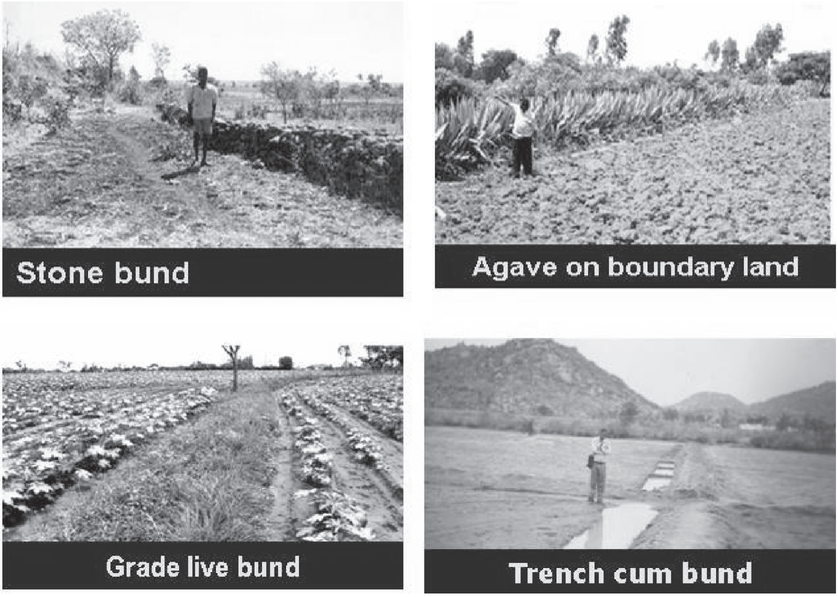
Long term measures for rainwater management in rainfed areas

Water harvesting

- Contour trenching for runoff collection
- On-farm reservoirs
- Ground water recharge structure (percolation tanks).
- Recharge through defunct wells.

These rainwater management strategies have good scope for adoption in regions receiving more than 700 mm rainfall. Based on the rainfall regime, the above interventions can be prioritized. Before planning for long term measures, availability of runoff may need to be assessed for ensuring judicious investment. On the other hand, *in-situ* conservation measures have large scale applicability in every region as they ensure well distributed moisture regime and may provide succor against short term dryspells.

While there should be continuous endeavour to ensure the rainfed areas to overcome from the fluctuations of monsoon, it is also necessary to ensure the sustainability of the limited irrigated facilities available (through well, tank, small scale lift irrigation schemes) by following the improved methods of water management (furrow, sprinkler and drip). Crop diversification is to be promoted towards low water consuming crops which may enhance the overall water productivity of rainfed areas. In order to bring awareness among the farming community on water availability and utilization pattern in watersheds, groundwater monitoring on watershed / hydrological unit basis through farmer participatory mechanism need to be promoted with proper water budgeting approach encompassing water needs for all sectors within the watershed.



Soil and Water conservation measures for rainwater management in rainfed areas

With the emphasis of watershed programme shifting from purely technical interventions to improve the livelihoods, the watershed programs need to be designed for more resilience to overcome the short term climate variability and change. An attempt is to be made to develop an upscalable and sustainable rural livelihood framework through:

convergence of all the existing programmes at the district/cluster level including the National Rural Employment Guarantee Programme (NREGP)

Linking the technical interventions on the watersheds with livelihood needs.

Complementing the on-farm and off-farm livelihoods opportunities.

Understanding the institutional issues at the village level and evolving an enabling environment including capacity building.

Create market linkages and evolve a dynamic interactive process between market needs and creation of new livelihoods and

evolve a working model of public-NGO and private-partnership at the district level. Such efforts are already been planed for implementation under the NAIP programme initiated by ICAR.

2.5 Future work for adaptation and mitigation of climate change in India

2.5.1 Adaptation strategies

Agricultural productivity is sensitive to two broad classes of climate-induced effects - (1) direct effects from changes in temperature, precipitation and carbon dioxide concentrations, and (2) indirect effects through changes in soil moisture and the distribution and frequency of infestation by pests and diseases. Rice and wheat yields could decline considerably with climatic changes (IPCC 1996; 2001).

Kumar and Parikh (1998) show that economic impacts would be significant even after accounting for farm-level adaptation. The loss in net revenue at the farm level is estimated to range between 9% and 25% for a temperature rise of 2^0C–3.5^0C. Sanghi, Mendelsohn and Dinar (1998) also attempted to incorporate adaptation options while estimating agricultural impacts. They calculate that a 2^0C rise in mean temperature and a 7% increase in mean precipitation would reduce net revenues by 12.3% for the country as a whole. Agriculture in the coastal regions of Gujarat, Maharashtra, and Karnataka is found to be the most negatively affected. Small losses are also indicated for the major food-grain producing regions of Punjab, Haryana, and western Uttar Pradesh. On the other hand, West Bengal, Orissa and Andhra Pradesh are predicted to benefit – to a small extent – from warming.

2.5.2 Projected priorities for adaptation and mitigation Strategies of Planning Commission are as follows:

- **Altered agronomy of crops**: Small changes in climatic parameters can often be managed reasonably well by altering dates of planting, spacing and input management. Alternate crops or cultivars more adapted to changed environment can further ease the pressure.

- **Development of resource conserving technologies:** Recent researches have shown that surface seeding or zero-tillage establishment of upland crops after rice gives similar yields to when planted under normal conventional tillage over a diverse set of soil conditions. This reduces costs of production, allows earlier planting and thus higher yields, results in less weed growth, reduces the use of natural resources such as fuel and steel for tractor parts, and shows improvements in efficiency of water and fertilizers. In addition, such resource conserving technologies restrict release of soil carbon thus mitigating increase of CO_2 in the atmosphere.
- **Increasing income from agricultural enterprises:** Rising unit cost of production and stagnation yield levels are adversely affecting the income of the farmers. Global environmental changes including climatic variability may further increase the costs of production of crops due to its associated increases in nutrient losses, evapotranspiration and crop-weed interactions. Suitable actions such as accelerated evolution of location-specific fertilizer practices, improvement in extension services, fertilizer supply and distribution, and development of physical and institutional infrastructure can improve efficiency of fertilizer use.
- **Improved land use and natural resource management policies and institutions**: Adaptation to environmental change could be in the form of social aspects such as crop insurance, subsidies and pricing policies related to water and energy. Necessary provisions need to be included in the development plans to address these issues of attaining twin objectives of containing environmental changes and improving resource use productivity. Policies should to be evolved that would encourage farmers to enrich organic matter in the soil and thus improve soil health such as financial compensation/incentive for green manuring.
- **Improved risk management though early warning system and crop insurance**: The increasing probability of floods and droughts and other uncertainties in climate may seriously increase the vulnerability of eastern India and of resource-poor farmers to global climate change. Policies that encourage crop insurance can provide protection to the farmers in the event their farm production is reduced due to natural calamities. In view of these

climatic changes and the uncertainties in future agricultural technologies and trade scenarios, it will be very useful to have an early warning system of environmental changes and their spatial and temporal magnitude. Such a system could help in determining the potential food insecure areas and communities given the type of risk. Modern tools of information technology could greatly facilitate this. Agriculture sector contributed 29% of the total GHG emissions from India in 1994. The emissions are primarily due to methane emission from rice paddies, enteric fermentation in ruminant animals, and nitrous oxides from application of manures and fertilizers to agricultural soils. These emissions can be minimized through knowledge transfer to the farming community through ICT on appropriate methodologies that can be adopted not only to reduce water use and increase WUE in rice cultivation but also decrease the methane emission significantly.

2.5.3 Mitigation options of GHG in agriculture

- Approaches to increase soil carbon such as organic manures, minimal tillage, and residue management should be encouraged. These have synergies with sustainable development as well.
- Changing land use by increasing area under horticulture, agro-forestry could also mitigate GHG emissions
- Improve the efficiency of energy use in agriculture by using better designs of machinery
- Improved management of rice paddies, both for water and fertilizer use efficiency could reduce emissions of GHGs
- Use of nitrification inhibitors and fertilizer placement practices need further consideration for GHG mitigation
- Improve management of livestock population, and its diet could also assist in mitigation of GHGs

2.6 Conclusions

Climate change, it appears is now underway. Climate change is a global problem and India will also feel the heat. Nearly 700 million rural people in India directly depend on climate-sensitive sectors (agriculture, forests and fisheries) and natural resources (water, biodiversity, mangroves, coastal zones and grasslands) for their subsistence and livelihood. Under changing climate, food security of the Country might come under threat. In addition, the adaptive capacity of dry-land farmers, forest and coastal communities is low. Climate change is likely to impact all the natural ecosystems as well as health. Increase in weather extremes like torrential rains, heat waves, cold waves and floods besides year-to-year variability in rainfall affects agricultural productivity significantly and leads to stagnation/ decline in production across various agro-climatic zones.

To mitigate the climate change effects on agricultural production and productivity, a range of adaptive strategies need to be considered. Changing cropping calendars and pattern will be the immediate best available option with available crop varieties to mitigate the climate change impact (Rathore and Stigter, 2007). The options like introducing new cropping sequences, late or early maturing crop varieties depending on the available growing season, conserving soil moisture through appropriate tillage practices and efficient water harvesting techniques are also important. Developing heat and drought tolerant crop varieties by utilizing genetic resources that may be better adapted to new climatic and atmospheric conditions should be the long-term strategy. Genetic manipulation may also help to exploit the beneficial effects of increased CO_2 on crop growth and water use (Rosenzweig and Hillel 1995). One of the promising approaches would be gene pyramiding to enhance the adaptation capacity of plants to climatic change inputs (Mangala Rai, 2007).

There is thus an urgent need to address the climate change and variability issues holistically through improving the natural resource base, diversifying cropping systems, adapting farming systems approach, strengthening of extension system and institutional support. Latest improvements in biotechnology and information technologies need to be used for better agricultural planning and weather based management to enhance the agricultural productivity of the Country and meet the future challenges of climate change in the dryland regions of the World.

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CHAPTER 3

Impact of Climate Change on Plantation Crops over the Humid Tropics of Kerala

G. S. L. H. V. Prasada Rao, D. Alexander, K. N. Krishnakumar and C. S. Gopakumar

The monsoon behaviour in 2007 over Kerala was totally different to that of previous years and heavy rains were noticed from June to September, leading to floods in low lying areas. The length of rainy season was also extended. In contrast, severe summer droughts were noticed in 1983 and 2004 during which the surface water resources became scarce, led to hydrological droughts and the State's economy was hit very badly. The wetlands or paddy lands in Kerala are the rich water source during summer and act as sink during the rainy season and such wetlands were declining very fast. The decrease in wetlands might be one of the reasons for frequent floods and droughts in recent years. The recent drought during summer 2004 over Kerala, led to increase in maximum temperature of 1-3°C during February and March and thermo-sensitive crops like black pepper, cocoa and cardamom across the highranges and several other perennial crops in the State suffered to a larger extent. It resulted to severe crop loss to the tune of 9.0 ha of coconut, 14.0 ha arecanut, 6.0 ha banana, 80.0 ha black pepper and 6.0 ha of nutmeg from the catchment area of Pananchery alone (Thrissur District).

The average yield of paddy in farmers fields of Kuttanad, which is one of the rice bowls of Kerala, was only 3.0 t/ha as against the expected harvest of 5.0 t/ha. Out of 9,118 ha of total cultivated land, 5623 ha of paddy was damaged in the Alappuzha belt of Kuttanad alone in Kharif 2007 due to floods. The prolonged rains also led to delay in "puncha" sowing (second crop). No rains were noticed after "puncha" sowing since 24th November onwards. The high acidic nature and salinity of the Kuttanad soil were intensified due to floods and bund breaches during the monsoon season. It revealed that prolonged flooded rains during the monsoon, followed by no rains during the "puncha crop" led to heavy damage in paddy fields in Kuttanad during 2007-08. The recent abnormal weather phenomena like droughts and floods may be due to global warming or as a part of natural climatic variability/change.

Global warming is the result of the rising atmospheric concentration of carbon dioxide mainly owing to the burning of hydrocarbons or fossil fuel such as petrol and diesel. Deforestation and degradation too have contributed to the rise in carbon dioxide levels. 93 per cent of greenhouse gas emission over Kerala is due to burning of petroleum products and firewood. Out of this, the share of carbon dioxide emission from burning fuel is 80.47 per cent according to the State of Environment Report (SoER), 2005. Methane emission in terms of global warming potential accounts for 17.58 per cent while two per cent in the case of nitrous oxide emission in Kerala. The total consumption of petroleum products in the State in 2003-04 was 30.88 lakh tonnes, out of which 85 per cent is carbon. Methane is emitted from water bodies including paddy fields and during coir retting. A total of 13.6 lakh tonnes of husk is processed annually through retting in the State.

Ozone depletion is also taking place at faster rate due to man made interventions in the form of chlorofluorocarbons (CFCs). The CFCs are used in a variety of industrial, commercial, and household applications. These substances are non-toxic, non-flammable and non-reactive. They are used as coolants in commercial and home refrigeration units, aerosol propellants and electronic cleaning solvents. The diurnal variation of UV-B radiation recorded at KAU, Vellanikkara revealed that the UV-B filtered radiation (>1MED) reaches the ground surface between 1030 hrs and 1430 hrs (Fig. 3.1), which may be detrimental to biological activities. The ozone loss, means more UV radiation reaching the earth, has the potential to increase incidence of skin cancer, cataracts and damage to people's immune system. In addition, mosquito transmitted diseases are increasing year – after – year due to global warming. Little is known on impact of ozone depletion and increasing UV-B radiation on ontogeny of tropical plants and human and animal diseases since studies in this direction are lacking. Because CFCs remain in the atmosphere for100 years, continued accumulation of these chemicals pose ongoing threats, even after their use is discontinued.

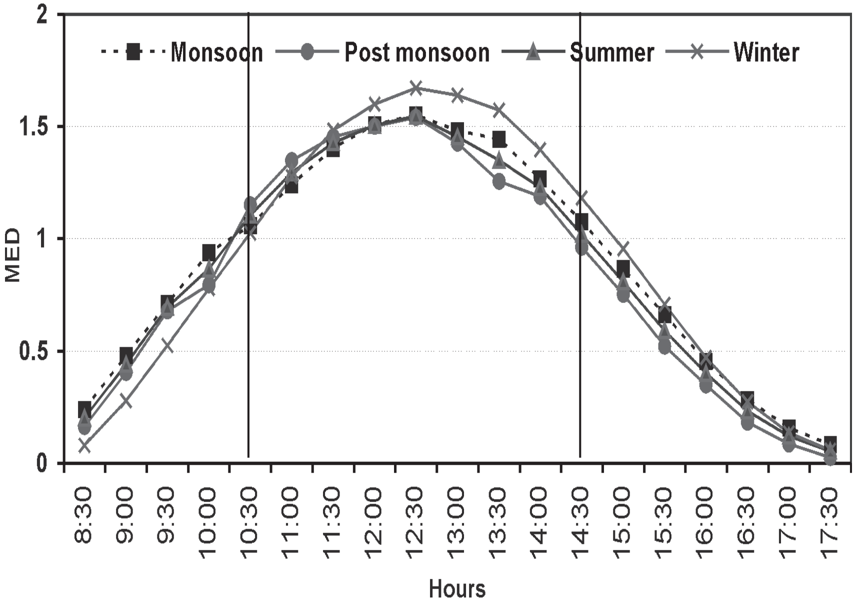

Fig. 3.1 Diurnal profile of UV - B radiation in different seasons at Vellanikkara (Thrissur), Kerala from 2002 to 2005

3.1 Biophysical resources

3.1.1 Annual rainfall over Kerala

The long – term mean annual rainfall of the State is 2817 ± 406 mm. The coefficient of variation of annual rainfall is only 14.4 per cent, indicating that it is highly stable and dependable though the monthly coefficient of variation varied from 28.4% in June to 146.1% in January. The monthly rainfall is also relatively stable in June (CV -28.4%) and July (33.2%) during the Southwest monsoon while October (CV-37.5%) in northeast monsoon as the coefficient of variation is relatively low (Table 3.1). June and July are the rainiest months while January and February receive the least rainfall.

Table 3.1 Mean monthly normal rainfall (1871-2005) over Kerala

Month	Rainfall (mm)		
	Normal	Standard deviation	CV (%)
January	12	17	146.1
February	17	19	115.4
March	36	28	78.5
April	112	52	46.5
May	246	159	64.6
June	684	194	28.4
July	632	209	33.2
August	373	157	42
September	224	122	54.7
October	288	108	37.5
November	156	85	54.4
December	38	39	102.1
Annual (mm)	2817	406	14.4

3.1.2 Seasonal rainfall over Kerala

The season-wise rainfall contribution over Kerala indicate that 68 per cent of annual rainfall is received during the monsoon, followed by post-monsoon (16%). The least is seen in winter (Table 3.2). The seasonal rainfall during monsoon is dependable as the CV is 19.7%. At the same time, the rainfall during winter is undependable as the CV is very high (91.8%), followed by summer (41.5%).

Table 3.2 Season-wise normal rainfall over Kerala (1871-2005)

Season rainfall	Normal (1871-2005)	Percentage contribution to annual rainfall	Standard deviation	Coefficient of variation
Monsoon (June-Sept)	1913.5	67.9	377.7	19.7
Post-monsoon (Oct-Nov)	444.1	15.8	138.4	31.2
Winter (Dec-Feb)	65.3	2.3	46.8	91.8
Summer (Mar-May)	393.7	14.0	163.5	41.5
Annual	2817.3	100	406.3	14.4

3.1.3 Spatial distribution of rainfall

The highest rainfall (5883.8 mm) is recorded at Neriamangalam (Ernakulam Dist.) and the lowest (651.3 mm) at Chinnar (Idukki Dist.). The annual rainfall increases from 1479 mm at Parassala in the South to 3562 mm at Hosdurg in the North of Kerala. The annual rainfall increases from the Coast to the foot hills and then decreases on the hill tops. This trend is partially disrupted over the Palakkad region (Fig. 3.2). Though the annual rainfall in the northern region is more, the effective rainfall is relatively high in the southern region due to even distribution of rainfall. July is the rainiest month

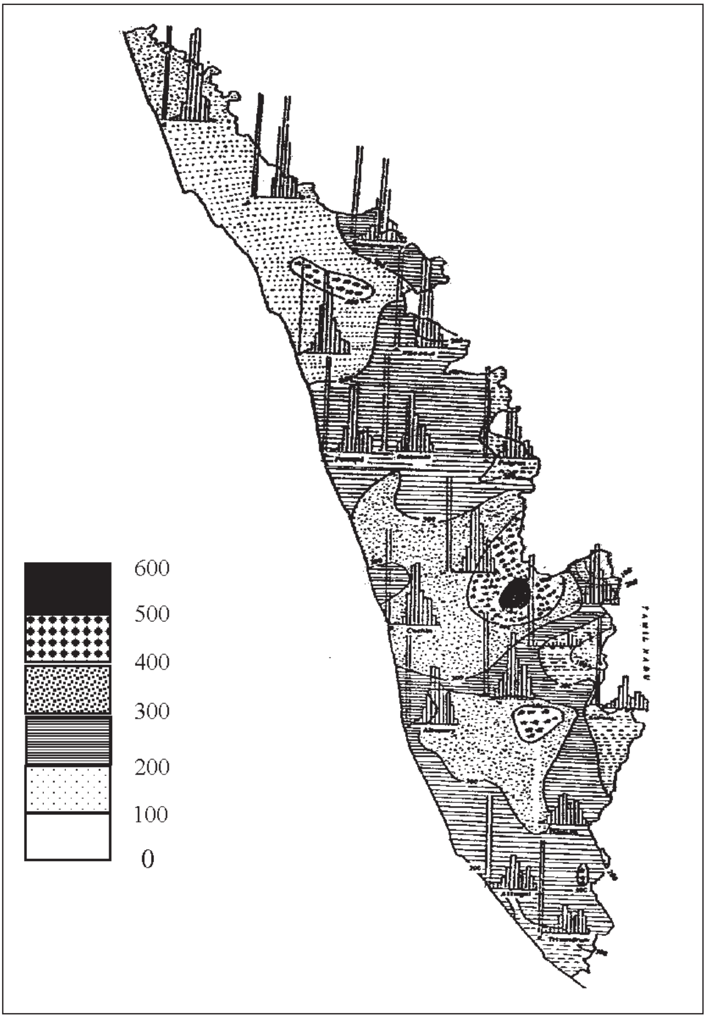

Fig. 3.2 Spatial distribution of rainfall over Kerala

in the northern districts while June is the rainiest month in the southern districts. The southern parts extending from Ponnani to Thiruvananthapuram (except Devikulam) show bimodel monthly rainfall due to the influence of both the monsoons *viz.* Southwest and Northeast monsoons. The northern districts, especially Kasaragod and Kannur, show only unimodel monthly rainfall (Southwest monsoon only) and experience a prolonged dry spell if the pre-monsoon showers fail.

The monthly high rainfall distribution during the monsoon season is favourable for paddy cultivation in Kerala under rainfed conditions and no irrigation is required at any stage of the crop under wetland situations and more than 90 per cent of paddy growing area is rainfed during Virippu *(kharif)* while it could be grown only under assured irrigated conditions during Mundakan *(rabi).* Many of the plantation crops also require irrigation, starting from December to May. The above situation is more prevalent in northern districts of Kerala where predominantly unimodel rainfall is noticed. This is true in Palakkad and Thrissur Districts also. Heavy winds from November to January over the above two districts due to Palakkad gap are detrimental to crops.

3.2 Agroecological zones of Kerala

Kerala is predominantly a Plantation State. Based on topography, soils, altitude and rainfall distribution, the entire Kerala has been divided into thirteen agroecological zones (Table 3.3). In highranges of Kerala, tea, coffee, cardamom and rice in valleys are only grown. The crops that are grown in other regions are different to that of highranges. Ofcourse, banana and vegetables are grown across the State Irrespective of altitutinal difference.

3.3 Landslides

High rainfall and manmade interventions lead to landslides in Kerala as it consists of undulated topographical features like plains, valleys, slopes and mountains, where agriculture is intensively practiced. It results in damage to crops and lands in addition to human and infrastructure losses. As projected, the landslides are likely to be more frequent in ensuing decades. In 2005 and 2007, the number of landslides noticed across the State was more due to heavy rains received during the monsoon season. Indiscriminate construction of checkdams and rainwater harvesting systems could

Table 3.3 Agroecological zones of kearala

Zone	Name	Area In (km)	Propor-Tion in per cent	Alti-tude	Rain-fall	Soil	Topography	Principal crops
1	Onattukara	519	1.6	Low	Pattern 1	Sandy loam	Model 1	Rice, Coconut, Tapioca, Arecanut
11	Coastal sandy	1564	4.8	Low	Pattern 1	Sandy loam	Model 1	Rice, Coconut
111	Southern Midland	3224	10.0	Low	Pattern 1	Laterite without B-Horizon	Model 111	Coconut, Rice, Tapioca Arecanut
1V	Central Midland	2666	8.2	Low	Pattern 1&11	Laterite	Model 11a	Rice, Coconut Tapioca, Arecanut,Banana
V	Northern Midland	3765	11.6	Low	Pattern 11	Laterite	Model 11b	Coconut ,Rice, Arecanut,Cashewnut
V1	Malappuram	4254	13.1	Low	Pattern 11	Laterite	Model 11c	Rice, Arecanut, Coconut, Cashew
V11	Malayoram	8861	27.4	Low	Pattern 1	Laterite without B-Horizon	Model 111	Rubber, Coconut, Pepper, Rice,
V111	Palakkad	1280	3.9	Low	Pattern 11	Red loam	Model 11	Rice, Cotton, Groundnut, Millets
1X	Red loam	317	1.0	Low	Pattern 1	Red loam	Model 111	Coconut ,Tapioca, Rice
X	Chittoor Block	508	1.6	Low	Pattern 11	Black soil	Model 11 a	Rice,Sugarcane,Cotton, Groundnut, Millets
X1	Kuttanad	284	0.9	Low	Pattern 1	Peat (Kari)	Model 1	Rice, Coconut
X11	River Bank Alluvium	-	-	Low	Pattern 1	Alluvium	Model 1	Rice, Coconut, Sugarcane, Arecanut,
X111	Highranges	5140	15.9	High	Pattern 1&11	Red loam	Model 111	Tea, Coffee, Cardamom, Rice
	Total	32283	100.0					

have triggered the destructive landslide in Vadakara and Koilandy taluks of Kozhikode District in early July in 2005. It resulted in destruction of standing crops about large tracts in the downhill areas. Rainwater harvesting pits, in the absence of adequate run off, may lead to landslides as water retained may lead to saturation of the slope. At the same time, the checkdams overflow during the rainy season. Increase in rain in catchment areas lead to the formation of under-ground reservoirs, which exert pressure on the dam, causing it to burst. The strategy to mitigate landslides should be a two pronged one to improve slope stability.

- Terrain specific guidelines for construction of rainwater pits and checkdams
- Dewatering the slope before every monsoon to reduce the vulnerability. It can be done by opening up all the streams, filling up the soak pits and checking all the contour bunds for waterlogging
- In addition to the above the landslide prone areas are to be identified. Those areas can be avoided for domestic and agricultural purposes thereby human and crop losses can be minimized.

Landslide at Kuthiran hills (Thrissur district) during the Southwest monsoon, 2007

3.4 Wayanad and Idukki agro - ecosystems

The normal average annual rainfall over the Wayanad District is 3417 mm, having 2760 mm in southwest monsoon, 340 mm in northeast monsoon and the rest in other months. Since last 15 years, the annual rainfall and rainfall during the monsoon were declining in the Wayanad District. The District had a deficit (186 cm) of 55 per cent in 2002 and 35 per cent (191 cm) in 2003. In 2000 and 2001, it was only 2550 and 2070 mm, respectively (Table 3. 4). Continuous decline in rainfall and rise in temperature in addition to severe summer drought in 2004 led ecosystem of Wayanad is in peril. Rainfall decline and temperature increase are projected over Ambalavayal. Several black pepper gardens were wiped out during summer 2004.

Table. 3.4 Annual rainfall (cm) from 1991 to 2006 over highranges across Kerala

Year	1991	92	93	94	95	96	97	98	99	00	01	02	03	04	05
Wayanad	280	325	240	343	250	270	280	240	220	255	207	191	186	195	217
Idukki	410	380	310	385	350	387	390	425	388	322	394	315	315	383	213

There was a time when oranges were plenty in Wayanad District. At present such agro-eco systems are extinct. It was attributed to change or variability in climate and deforestation. Conversion of large tracts of paddy fields into banana garden in addition to excessive use of chemical fertilizer and pesticides and large-scale mining of sand from rivers which began in the 1980s, has now been identified as the causal factors for severe drought with continuous decline in annual rainfall. Introduction of banana in paddy lands has deprived the District of large areas of wetlands that are needed to store water. With banana cultivation so extensive, nature lovers said the very name of the District (Wayanad means land of paddy fields) has lost its meaning. Groundwater depletion is so much (25%) due to over exploitation. The natural habitat of cardamom under the forest eco-system is also in peril over Idukki district due to climate variability. Rise in maximum temperature and fall in minimum temperature are projected over Pampadumpara. Widening temperatures along with deforestation may be detrimental to cardamom and black pepper.

3.5 Rice wetland ecosystem

It was on February 2, 1971 that delegates from various countries signed the international convention on wetlands during their meeting in the Iranian city of Ramsar on the shore Caspian Sea and decided to observe February 2nd as the 'World Wetland Day'. As per the Ramsar convention the theme for "Wetland Day" in 2002 was

"Wetland: water, life and culture". Prolonged presence of water in wetlands elevate conditions that favour the growth of specially adapted flora and fauna. In fact, wetlands are often referred to as biological diversity providing water and primary productivity upon which countless species of plants and animals depend on their survival. Wetlands are extremely effective ecosystems for the control of flood and storms and extra-ordinarily good storehouses of water for drinking, irrigation and recharging of groundwater sources. Conservation of wetlands has significance from a tourist and a cultural point of view. Wetlands comprise all types of natural and manmade water bodies including paddy fields, reservoirs, mangroves, rivers, lakes, inundated areas and kole lands. Area under rice requirement was 7.53 lakh ha with an annual production of 13.52 lakh tonnes in 1961-62. The State could meet nearly 30 per cent of its rice production from internal production. Now the area has come down to 2.7lakh ha (2005-06) with a production of 6.67 lakh tonnes, meeting only 15 per cent of its requirement (Fig 3.3). During this past four decades, the rice areas has declined by more than 60 per cent and the present level of production was possible because of the productivity has risen from 1575 kg to 2301 kg/ha during the years. Paddy fields are being converted to grow other profitable crops like banana, coconut, arecanut and alike, construction of structures, mining and other purposes.

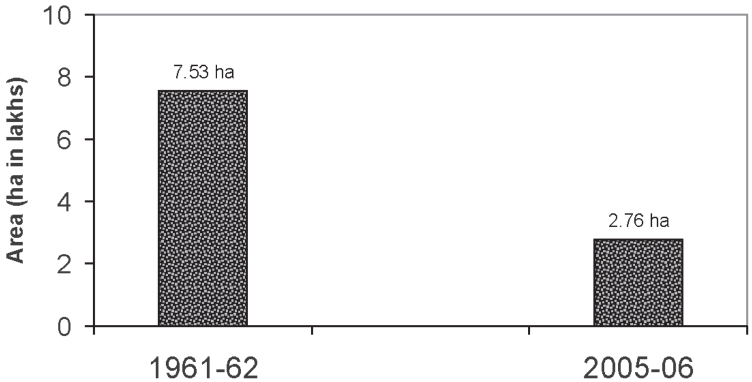

Fig. 3.3 Wetland decline in Kerala from 1961-62 to 2005-06

One of the reasons for decline in rice cultivation in Kerala is that rice cultivation is less profitable compared to other crops. Studies at Regional Agricultural Research Station, Kumarakom proved that the system of rotating paddy cultivation with aquaculture in Kuttanad has helped to improve the rice production besides bringing in a yield up to 1000 kg of fish from one hectare of land without incurring any cost on feeds or manures. This system will also maintain the natural ecosystrems in the area. It is a fact that the rice land ecosystem promotes emission of gases like methane which add to the emission of greenhouse gases. This harmful effect can be reduced and at the same time the positive influence of the system can be utilized. In the semi dry system of rice cultivation practiced during the first crop season, the first four to six weeks of rice cultivation, the field is dry and aerobic condition prevails. In the later part of second crop season, the filed is intermittently irrigated, which results in alternate wetting and drying. During the third crop season, paddy is cultivated under irrigated systems and intermittent wetting and drying is followed. In places where Systems of Rice Intensification (SRI) method of rice cultivation is practiced, it reduces the production of harmful greenhouse gases. Growing of oil seeds, pulses, vegetables and green manure crops in rice fallows will definitely result in an eco - friendly atmosphere. Salt water intrusion and salinization of fertile rice land is a problem in Kuttanad (Alappuzha and Kottayam Districts), Pokkali land (Ernakulam and Alappuzha), Kaipad lands (Kannur District) and Kole land (Thrissur and Malappuram). The main problem lies in the fact that crop discipline is not followed-such as puncha crop in Kuttanad must not be retained beyond March15th. Ensuring crop discipline and scientific cultivation will definitely help in reducing the ill - effects and maintain the natural ecosystem. The intensity of ill-effects due to occurrence of droughts and floods can be minimized if wetlands are intact in a state like Kerala, where the topographic features play a permanent role in agricultural scenario.

3.6 Deforestation reduction and the carbon market

At present, forests utilize about 686 gigatonnes (Gt) of carbon - about 50 per cent more than atmosphere - and are being cleared at an average rate of about 13 million hectares per annum over the World. It makes deforestation responsible for between 20 and 25 per cent of global greenhouse gas emissions. As many as 572 fires broke out in the forest of Kerala during 2004 summer and the average loss of forest per year during the 12 - year period (1991-2003) came to about 2,093 ha It was more than two-and-a-half times the average annual loss that used to occur in the early eighties. The average area damaged by fire annually was only 831 ha, between

1981 and 1986. The higher incidence of fire (9152 ha) during summer 2004 was attributed to severe drought. The forest cover over Kerala declined from 70% to 24% over a period of one-hundred-and-fifty years (Fig. 3.4). The share of carbon dioxide emission from burning fuel, emission of methane and nitrous oxide resulting in global warming over Kerala is accounted for 80.4 %, 17.5 % and 2%, respectively. The main causes of forest fires are lightning, self-combustion and man-made. Out of these, lightning is the major cause of forest fires. Catchment and coastal areas are too ecologically sensitive areas in Kerala. Land use planning of catchment areas with afforestation of native species through natural growth, shola protection and aerial seeding with native seeds and closing the area from human interference for varying periods can help develop natural forests without much expenditure. This would enhance the biodiversity of the area, allow soil conservation and increase the discharge of rainwater without siltation into manmade dams.

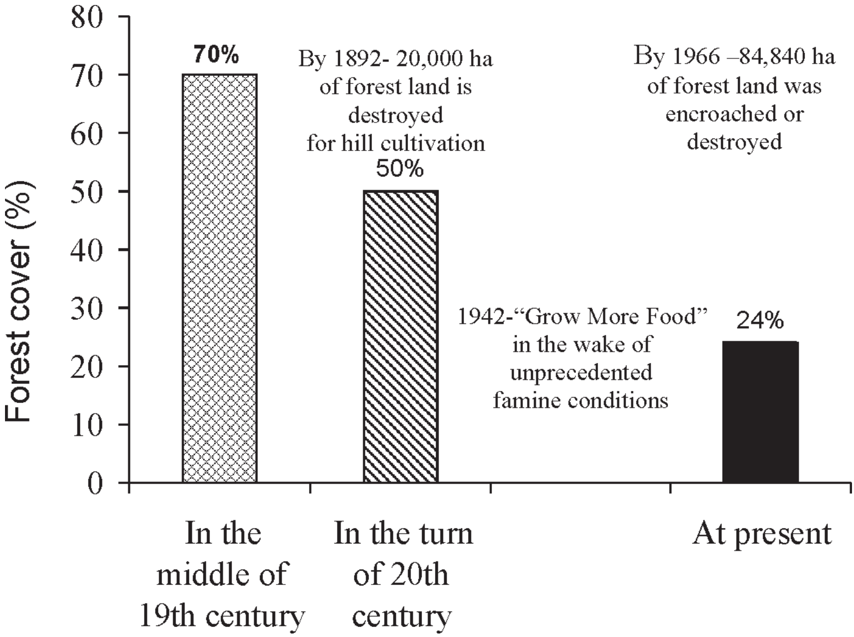

Fig. 3.4 Forest cover over Kerala

3.7 Biodiversity

The Economic Review, prepared by the State Planning Board, 2003 warns that a third of the State's biodiversity would vanish or would be close to extinction by 2030 unless steps are taken to check extinction of species. Of the 300 rare, endangered or threatened species in the Western Ghats, 159 are in Kerala. Of these 70 are herbs, 23 climbers, eight epiphytes, 15 shrubs and 43 trees. Besides, 10 species of fresh water fish are identified as most threatened. Kerala has a flora of 10,035 species, which represents 22 per cent of Indian flora. Of these, 3,872 are flowering plants of which 1,272 are endemic. As many as 102 species of mammals, 476 birds, 169 reptiles, 89 amphibians and 262 species of fresh water fish are reported from Kerala. Many of these are endemic. The review recalls that during the 20th century, at least 50 plant species have become extinct in the Country. Three species of birds – Himalayan mountain quail, forest spotted owlet and pink-headed duct – have become extinct. Besides, as many as 69 bird species have been categorized as extinct. The mammals, Indian Cheetah and lesser one horned rhinoceros have also perished. The Malabar civet is on the threshold of extinction and 173 species have been listed as threatened. Describing a conservation strategy, the review says that ecologically sensitive areas have to be identified with reference to topography, hydrological regimes and this has to be networked with species diversity.

3.8 Groundwater depletion

An increased demand and unregulated exploitation are threatening to accelerate depletion of groundwater resources in Kerala . Study by the Ground Water Department in 2004 reveals heavy imbalance in the availability of groundwater resources in the State for the past five years, with one third of the development blocks reporting higher exploitation though all the blocks were in the safe category in 1992 (Fig 3.5). The data from the survey reveal that Kasaragod District taps 79 per cent of the water reservoir, the highest rate of exploitation in Kerala. Thiruvananthapuram comes second with 67 per cent and Wayanad the last with 25 per cent. On an average, Kerala extracts 47 per cent of the net annual groundwater availability. Athiyannur in Thiruvananthapuram tops the list of blocks with over exploited resources followed by Kozhikode, Kasaragod, Chittur in Palakkad and Kodungallur in Thrissur. The monsoon rainfall was low against the normal consecutively since last six years (1999-2004) and over exploitation of groundwater in addition to the lack of water discharges from major surface reservoirs led to severe hydrological drought in 2004 resulted in severe crop losses and the State's economy was adversely affected. As the opportunity for natural percolation of rainwater is on the decrease, only negligible portion of rainwater is recharged by natural percolation from available open area. As a result, the major portion of rainwater

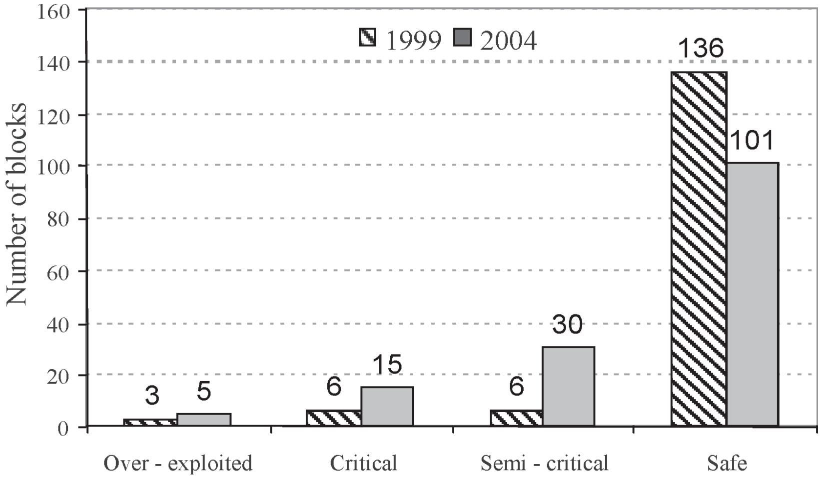

Fig 3.5 Comparison of groundwater between 1999 and 2004

is wasted as run off through drainage into the ocean. Because of heavy extraction of groundwater, the water level has fallen alarmingly. The destruction of forest in the catchments areas had led to the drying up of reservoirs and the extensive sand dredging has drastically reduced the rivers' water holding capacity and percolation to groundwater. Thus, The groundwater is depleting at a faster rate than that of its recharge mainly due to rainfall decline, more run-off, overuse of water for irrigation, more land is brought under irrigation for cultivation, more water need for drinking and for other uses due to increase in population, deforestation, riverbed sand-mining, decline in wetland area and disappearance of lakes and ponds in recent times. Some of the above factors also led to drying up of open and surface wells. Silting over a

Water level in the reservoirs across the State is depleting fast – parched earth on the Chimmini dam site in Thrissur district in February, 2004 period of time also led to the reduction in the storage capacity in existing major reservoirs and surface wells. These factors lead to impending disaster in the form of severe water scarcity and saline water intrusion along the coastal areas. The saline water intrusion was not there when traditional fresh water lakes were built in wetlands. On destruction of fresh water lakes or conversion of wet lands aggravated the scarcity of fresh water, especially in deficit rainfall years during summer in places like Kuttanad.

3.9 Climate variability / change

3.9.1 Rainfall trends

Rainfall in June and July was in declining trend. A decrease of 142.5 mm and 102.5 mm of rainfall was noticed in June and July, respectively over a period of 135 years (1871 to 2005). In contrast, a marginal increase was noticed in rainfall of August and September. The trend in monsoon and annual rainfall of Kerala was declining since last 60 years though it is stable if we consider annual rainfall since 1871 onwards (Fig 3.6).

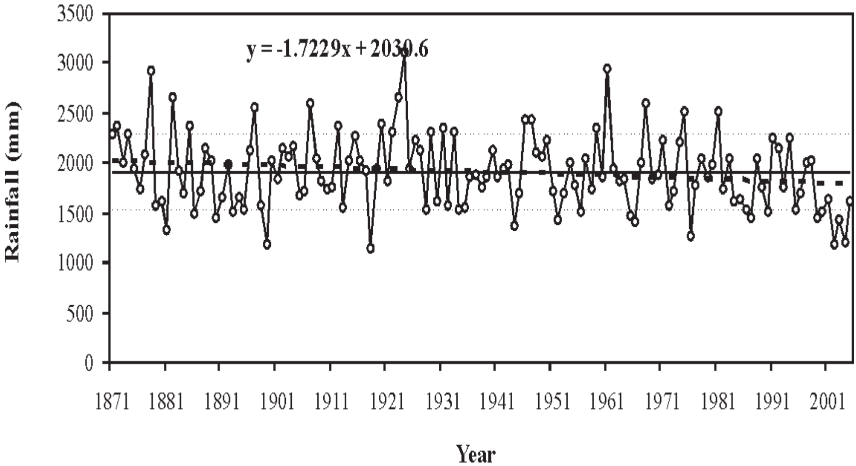

Fig. 3.6 Trend in southwest monsoon rainfall over Kerala from 1871 - 2005

The monthly rainfall in October and November was increasing while December decreasing An increase of 51.7 mm and 42.9 mm of rainfall was noticed in October and November, respectively over a period of time. Overall, there was an increase of 96.7 mm in northeast monsoon rainfall over a period of 135 years (Fig. 3.7).

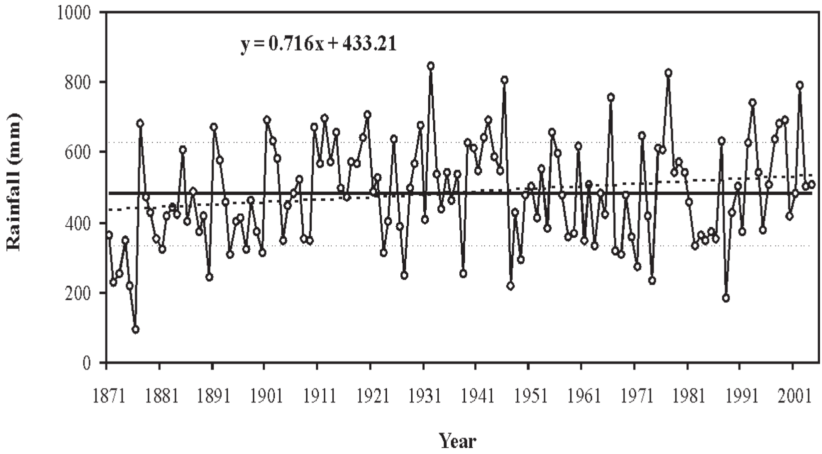

Fig. 3.7 Trend in northeast monsoon rainfall over Kerala from 1871 - 2005

3.9.2 Temperature trends

During the last 43 years, the mean maximum temperature has risen by 0.8 degree Celsius, the minimum by 0.2 degree Celsius and the average by 0.5 degree Celsius over Kerala according to India Meteorological Department in the wake of the Intergovernmental Panel on Climate Change (Fig. 3.8). February and March are the hot months in Kerala, with a mean maximum of

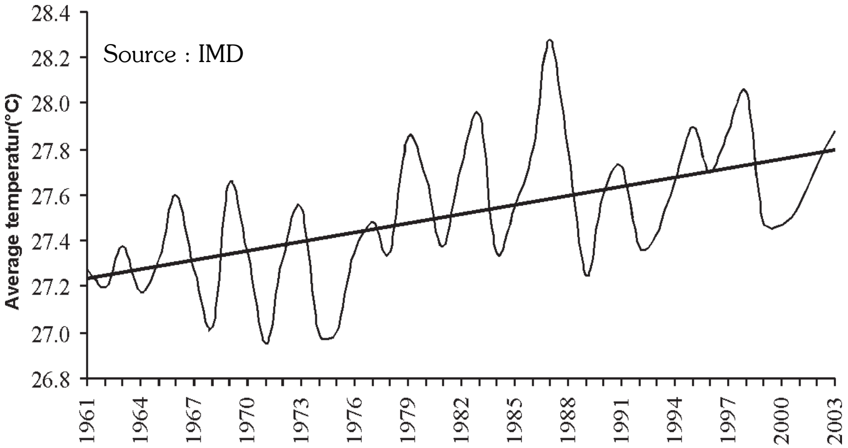

Fig. 3. 8. Trend in average temperature over Kerala from 1961 - 2003

33^0C. Palakkad recorded the highest temperature of 41°C on April 26, 1950. This was 8^0C more when compared to the normal maximum temperature in March. Similar temperatures were recorded over the Palakkad region in February and March of 2004, which was one of the severe summer droughts in Kerala. The year 1987 was the warmest year over Kerala. The lowest temperature recorded was 12.9^{0}C at Punalur on January 8, 1968. Kerala experienced severe summer droughts in 1983 and 2004 while recently floods during monsoon season in 2005 and 2007. The Crop losses were considerably high during the above weather extremes.

3.9.3 Climate shifts

The State of Kerala falls under the climatic type of "B_4-humid" based on the moisture index. The moisture index shifted from B_4 to B_3 - humid climatic type during the study period. It revealed that Kerala state moved from wetness to dryness (Fig. 3.9) since last fifty years (1951-2005).

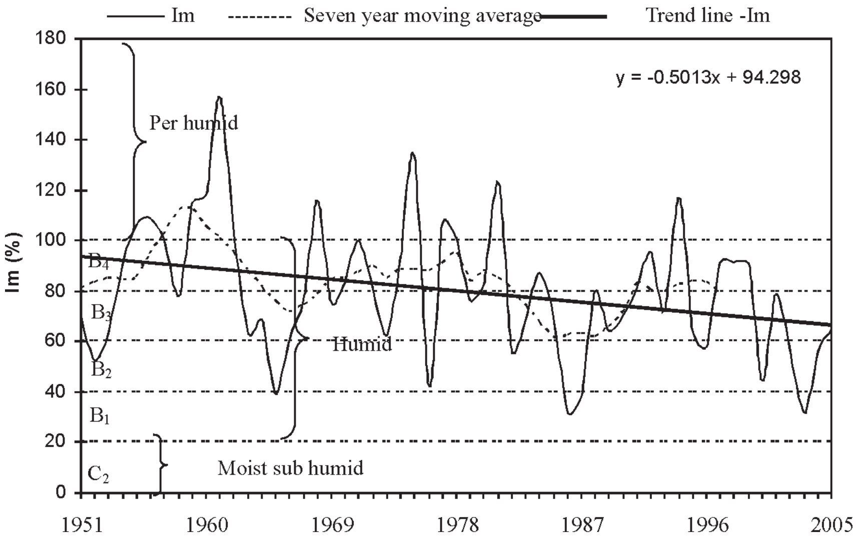

Fig. 3.9 Moisture index from 1951 to 2005 over Kerala

3.10 Impacts of climate variability on plantations

The habitat of plantation crops is different as they are perennials traditionally grown in the humid tropics under the rainfed conditions. Within the tropics, crops like coffee, cardamom and tea prefer cool-temperate climate as they grow along the highranges. Interestingly, black pepper is in the buffer zone as an intercrop between warm and cool climates, stretching between tropical and temperate climates within the tropics due to its adaptability. The forests exert a domineering influence on soil, water resources and microclimate of the above crops. In the turn of twenty-first century, forests constituted only 24% when compared to 70% in the middle of nineteenth century in Kerala. The fast-dwindling forest cover and its consequence over climate are the concern across highranges of the Western Ghats, were cardamom, coffee and black pepper are predominant.

3.10.1 Cardamom

The production and productivity of small cardamom show an increasing trend though a sharp decline was noticed in cardamom area across the Western Ghats. This could be attributed to technological interventions since last three decades. However, the inter-annual fluctuations in cardamom production were common due to weather aberrations. For example, the cardamom production was badly hit during 1983 due to unprecedented drought that occurred from November 1982 to May 1983 across the cardamom tract of the Western Ghats. Similar was the case during 2003-04 over Kerala. It is noticed that the cardamom production over Kerala in recent years was also badly hit due to dry spells that occurred during the monsoon seson of 2002 and 2003. There existed a strong relationship between dry spells and cardamom production (Fig. 3.10) .The climate risk is more over the Karnataka region when compared to other regions across the Western Ghats in the case of cardamom.

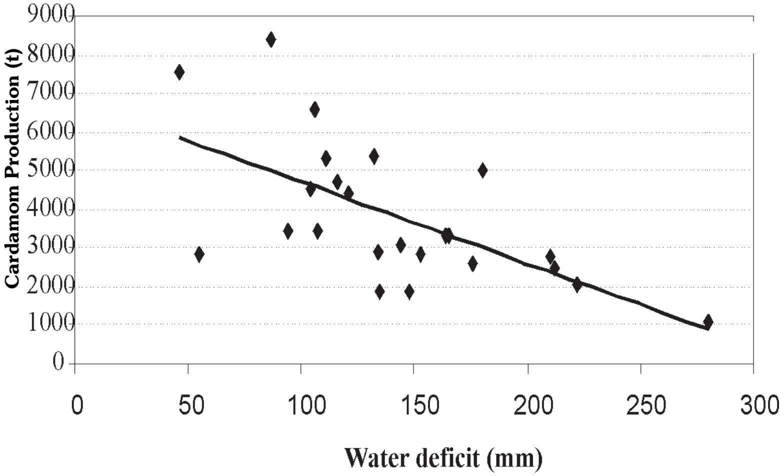

Fig 3.10 Water deficit during summer (Dec-May) and cardamom production over Kerala

3.10.2 Cocoa

A decline of 39 % in annual cocoa yield was noticed in 2004 when compared to that of 2003 due to rise in maximum temperature of the order of 1-3^{0}C from 14th January to 16th March, 2004 along with prolonged dry spell. Such trend was noticed whenever summer temperature shooted up by 2-3^{0}C when compared to that of normal maximum temperatures of 33-36.5^{0}C over the central region of Kerala. The adversity of weather aberrations on rhythm of normal growth of cocoa is reflected in yield after a lag period of 4-5 months.

3.10.3 Cashew

Cashew is also highly weather sensitive. Despite the advanced technologies in crop production and crop improvement, cashew productivity is declining over Kerala. The potent factor for low yield in recent years is nothing but weather aberrations in addition to other environmental factors as the area and production were declining very fast.

3.10.4 Black pepper and coffee

The monsoon variability along with pre-monsoon showers is likely to influence coffee production and its quality to a considerable extent. Similar is the case in black pepper too. A weather module suited to black pepper may not be suitable to coffee. Hence, mixed farming of coffee and black pepper may be a better option against climate risk instead of mono-cropping. Coffee required timely blossom and backing showers during summer. If they fail, coffee production is very poor.

Dried pepper vines due to summer drought, 2004 in Wayanad

3.10.5 Coconut

In the case of coconut, decline in monthly nut yield was noticed in the following year from February 1984 to January 1985 due to severe drought of summer 1983. The effect of drought on monthly nut yield was noticed in the eighth month after drought period was over with a maximum (64.1%) reduction in nut yield in July 1984 (ie, 13 months after the drought period was over) and the minimum (23.6%) in January 1985. Similar was the case during 1988-89 (Fig 3.11). The recent summer drought during summer 2004 also

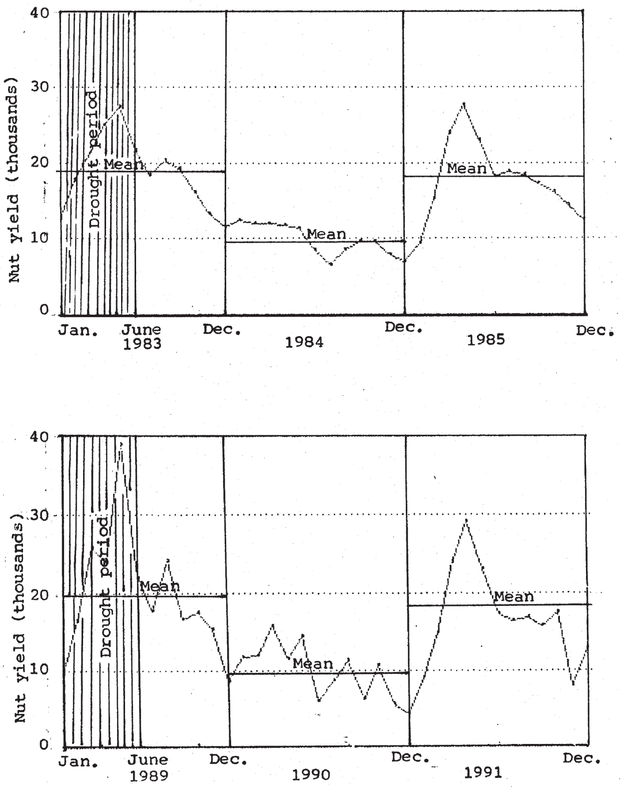

Fig. 3.11 Effect of drought on coconut yield at RARS, Pilicode (Kerala)

adversely affected coconut yield to some extent over Kerala. In the semiarid tropics like Tamil Nadu, heavy crop loss was reported due to continuous failure of rains in 2001 and 2002 and lack of irrigation due to poor water recharge in wells.

As discussed above, crops like coffee, cardamom and tea prefer cool-temperate climate as they grow along the highranges, where mean annual temperature varies between 14 and 20^{0}C while coconut, cashew, cocoa and rubber are seen cultivated in mid - and - high lands, where the annual mean temperature revolves between 25 and 29^{0}C. According to thermal regime, black pepper is grown under "Meso therms and Micro therms-I and II" while cardamom, coffee (arabica) and tea under "Micro therms III" (Table 3.5). Black pepper likes moderate and low surface air temperature to some extent while cardamom low temperature only round-the-year, thus indicating different habitat under which they grow in rainfed conditions.

Table 3.5 Thermal regime and plantation crops distribution across the Western Ghats of Kerala

Class	Region	Temperature conditions	Altitude above MSL	Crops
Mega therms	Low land	High to moderate temperature throughout the year	0-10 m	Coconut, arecanut and cashew
Meso therms	Mid land	Moderate temperature throughout the year, winter temperatureis relatively low	10-100 m	Coconut, cocoa arecanut, rubber, cashewand black pepper
Micro therms - I	High land	Moderate to low temperature throughout the year, winter temperatureis low	100-500 m	Rubber, coconut, cashew, arecanut and black pepper
Micro therms – II	High land	Low temperature throughout the year, winter temperatureis low	500-1000 m	Coffee (robusta), rubber, arecanut and black pepper
Micro therms - III	High ranges	Low temperature throughout the year, winter temperature occasionally goes below 0^0 C.	1000-2500 m	Tea, coffee (arabica) and cardamom

3.11 Climate projections

Rainfall and number of rainy days showed declining trend during the southwest monsoon (June-September) at four selected locations viz., Pilicode, Vellanikkara, Amabalavayal and Pampadumpara across Kerala with a maximum rate of 22.0 mm/year at Vellanikkara in the case of rainfall. Significant decline in rainfall from 2000 to 2005 reflected in the above trend at Vellanikkara. Ambalavayal and Pampadumpara showed a rise in maximum temperature at the rate of 0.006^{0}C/year and 0.04^{0}C/year, respectively on annual basis. At Pampadumpara, the difference between maximum and minimum temperatures is likely to rise as maximum temperature was increasing while minimum temperature declining. Cooler summers are expected at all the locations and may be significant at Vellanikkara (-0.05^{0}C/year) due to pre - monsoon showers.

Ambalavayal and Vellanikkra are likely to experience warmer nights while cooler nights at Pampadumpara and Pilicode. Warmer days are likely at Ambalavayal and Pampadumpara while cooler days at Pilicode and Vellanikkara (Table 3.6). The above trends are based on short - term climatological data. These trends are likely to vary if the analysis is done based on long series of data or in extreme weather events like abnormal surplus rainfall like floods.

Table 3.6 Climate projections at selected stations over Kerala

Locations	Projections
Pilicode	Cooling with decline in rainfall
Vellanikkara	Cool days with warm nights (except in summer) and decline in rainfall. Decline in temperature range is also expected.
Ambalavayal	Warming with decline in rainfall
Pampadumpara	Warm days with cool nights and increase in rainfall except during southwest monsoon. Increase in temperature range is also expected.

3.12 Climate change and cropping systems

The climate projections indicated that rainfall during southwest monsoon is likely to decline while temperature showing an upward trend. It shows that performance of crops like cocoa, black pepper, coffee and cardamom may not be consistent with technological inputs due to weather abnormalities and deforestation as these crops are grown under the influence of peculiar forest - agro - ecosystems. Cashew is another crop under threat as the area, production and productivity are in declining trend in recent years. It could be attributed to weather abnormalities in addition to tea mosquito incidence as the reproductive phase of cashew is weather sensitive.

From the above, it is clear that there is a change in cropping systems across the State of Kerala as the index in foodgrain crops was declining while increasing in index of non- foodgrain crops. It is also evident that there is a change in climate as rainfall during the southwest monsoon is declining and temperature rise was projected in tune with global warming. The occurrence of floods and droughts as evident in 2007 (floods due to excess monsoon rainfall by 41% against normal) and summer 2004 (drought due to no significant rainfall from November, 2003 to May, 2004), adversely affected food crops like paddy and plantation crops production to a considerable extent. Deforestation, shift in cropping systems, decline in wetlands and depletion of surface water resources and groundwater may aggravate the intensity of floods and droughts in excess and deficit rainfall events. The frequency of weather abnormalities is likely to be high as projected across the Country. At the same time, climate change/ variability may lead to shift in crop boundaries which are thermosensitive and adversely affect crop production to a considerable extent, reflecting on State's economy. It is more so across mid - and - high ranges of Kerala, where thermosensitive crops are grown.

3.13 Mitigation and adaptation

3.13.1 Organic farming

The indiscriminate use of fertilizers and plant protection chemical and weedicides are polluting the soil, air and water beyond the tolerable limit. This is true in case of certain areas in Kerala where the practice is creating problem. There was drastic decline reduction in the use of organic manure for the past years. Awareness has been created on the use of organic manures among the farmers with the reasonable use of chemicals without affecting productivity. There are certain crops and areas where organic farming can be practiced in Kerala. Organic farming plays an important role as an alternative food production process. It is a crop production system that avoids or largely excludes the use of synthetically produced

Vermicompost tank

fertilizers, pesticides, growth regulators and livestock feed additives. As far as possible it relies on crop rotations, crop residues, animal manures, legumes, green manures, organic wastes, biofertilizers and aspects of biological pest control to maintain soil productivity and tillage to supply plant nutrients and to control insets weeds and other pests. Input availability, productivity, premium price and marketing aspects have to be considered. In other areas, good agricultural practice with the minimum dependence of agrochemicals will definitely reduce the pollution of soil, air and water and reduce its influence in greenhouse gas emissions.

3.13.2 Rainwater harvesting /groundwater recharging

Efforts are needed for effective rainwater harvesting in farm lands. Wherever water is running we should make it walk. This is done by terracing, contour bunding, and increasing the soil vegetative cover. All walking water should be lies down. Rain water harvesting

Rainwater collection and goundwater recharging is an unique and traditional system of recharging of the under groundwater bodies for sustained water availability. There are several techniques in rainwater harvesting which can be practiced in house hold (roof top rainwater harvesting) as well as fields. Traditional sources of water like very shallow, small diameter wells known as 'keni' in Waynad district, horizontal wells/ tunnels called 'Surangams' in Kasaragod district, natural wells, ponds, tanks, springs, lakes, and wind breaks and shelter belts should form an integral part of the watershed development programme. Groundwater utilization has to be based on location specific investigations and over exploitation has to be avoided.

3.13.3 Drought management

The State of Kerala always appears to be greenery due to heavy monsoon rainfall supported by rains during northeast monsoon. At the same time, the northern districts of Kerala and Palakkad experience prolonged dry spell from December to May if premonsoon showers fail, leading to soil moisture stress. The occurrence of drought for the State as a whole was noted during summer 1983 and 2004. It is the lack of emphasis on conservation measures which results in the recurring of drought situation. Rainwater during the monsoon should be harnessed with small investments. If careful arrangements for conserving of water are not done in time, it could result in the drying up of even bore wells and tube wells. In order to keep rivers and wells adequately replenished with water during the dry season, small sub-surface dams and anicuts up to 40-odd rivers originating from Western Ghats and flowing into the Arabian Sea are necessary. Implementation of irrigation and hydel development projects in all the valleys would automatically take care of domestic water supply, sanitation and partial flood control. As even partial mea-

Coconut husk burial in palm basin–a durable soil moisture conservation practice sures have not been undertaken in all the river systems, the water potential in the state remains poorly harnessed. Watershed based participatory natural resource development and management schemes such as tanks, vented cross bars, diversion weirs and lift irrigation can increase and sustain irrigation, ground water recharge, crop production and drinking water supply considerably.

Even in the worst of drought conditions, Kerala's rainfall statistics shows annual average as 1600 mm. This much of water if properly conserved and used would be plenty even to spare. The rivers of the State except one or two cease their flow with the cessation of the northeast monsoon and thereafter practically all the rivers dry up and remain dry until June for six months. It is during this period that the State tends to become drought prone recurrently. In addition, drought management practices have to be followed under field condition. Cultivation of drought tolerant crops and varieties, proper soil and water conservation practices like ploughing before the receipt of southwest monsoon and immediately before the cessation of the northeast monsoon, opening basins of crops like coconut before southwest monsoon, covering the basins before north east monsoon, organic manuring, organic mulching and husk burial can definitely conserve the available moisture in the soil and use water judiciously. Judicious use of water in day- to- day life and for agriculture purposes can reduce the impact of drought in Kerala. Awareness on drought management practices is the need of the hour to sustain agricultural production in the State against the weather abnormalities.

Coconut leaf mulching in basins

3.13.4 Crop insurance and weather forecasting

Natural calamities like flood, drought, landslides, lightening, heat and cold waves are not uncommon now - a - days. Both crop and farmer are to be safeguarded against these calamities. Often, the farmer who takes loan not able to repay it due to crop failure leading to hard up and suicides. Insuring farmers as well as crop become necessary against weather abnormalities. In this context, precise and accurate information on weather changes are necessary. Short, medium and long range forecasting will definitely help in weather-tune-farming so as to minimize the adverse effect of weather abnormalities taking suitable precautionary measures to lessen the harmful effects. The meteorological network has to be strengthened to disseminate agroadvisory service based on integrated weather forecasting. Pro-active measures against weather aberration will go a long way in minimizing the crop losses against the climate disasters.

3.14 Conclusions

Awareness programmes on "Climate change and its impact on various sectors" with reference to Kerala must be organised at every level across the State for mitigation and adaptation against the ill – effects of climate change.

Deforestation is responsible for between 20 - 25% of global greenhouse gas emissions. It is warned that a third of the State's biodiversity would vanish or would be close to extinction by 2030. There is urgent need for action plan in protecting natural forests at the State and National levels to slow down global warming and to check extinction of forest species. In addition, tree planting should be on top priority under various schemes viz., afforestation, agro-forestry, social forestry and farm level plantations as a part of carbon sequestration.

Wetlands in Kerala act as "the water sink" during the rainy season and "the water source" during summer. The wetland decline results to occurrence of floods and droughts. In addition to sand mining, decline in wetlands also lead to groundwater depletion. Change in cropping pattern in wetlands across Wayanad District also led to groundwater depletion. The wetlands should be protected along with the conservation of forests to improve the status of water resources and to obtain clean water. Indiscriminate sand mining should be stopped and it should be planned scientifically.

Technologies in rainwater harvesting, water conservation, judicious use of water and *in-situ* soil moisture conservation should be popularised to mitigate the effects of drought during summer as the State experiences prolonged dryspell if pre-monsoon showers fail, which is not uncommon phenomena in northern districts and the District of Palakkad.

As high intensity of rainfall is projected more frequently, landslides are a threat to human life and crops. The demarcation of landslide zonation across the State is the urgent need and the people of the landslide prone areas need to be educated.

Agroadvisory services based on weather forecasting should be intensified at the District level across the State involving multi-institutes to mitigate the ill - effects of climate change /variability.

The green economy and development are likely to be the major policy decision over the world to combat the climate change effects and generate employment opportunities during this century as the industrial revolution, technology revolution and our modern era of globalization were the three economic transformations led to better world economy during the last century. Non-conventional and renewable energies can create more number of jobs even if 20 per cent of electricity is replaced by renewables. More people will be employed in Germany's enviro-technology industry than in the auto industry by the end of the next decade as per the greenpeace policies adapted. In India also Maharashtra farmers took up to raise trees to meet Kyoto protocol provisions. They expect to sell their carbon abatement credits through the international commodities market. Internationally, the carbon finance market is expanding steadily as 107 million tonnes of carbon dioxide equivalents were exchanged in 2004 as against 78 million tonnes in 2003. The FoCs (Friends of Carbon - a Pune based NGO) is already moving among farmers in Karnataka, Andhra Pradesh, Kerala, Tamil Nadu, Goa, Chhattisgarh and Madhya Pradesh to bring more and more farmers all over India and become viable to attract the environment in the carbon commodity market. By sequestering such farm based and matured forests in addition to deforestation reduction, a long term storage of carbon in living and dead vegetation is possible. These steps will reduce the greenhouse gas emissions and it will be an eco-friendly transformation of global economy in terms of green economy and development in the 21^{st} century. Fuel efficiency and low emission technologies, energy efficiency and power saving technologies along with changes in lifestyles should be a part of green economics and development.

The Bali Roadmap under UNFCCC highlighted the conclusions of IPCC on climate change. It indicates that the global warming is real. The Polar ice is melting and sea level will increase. One-third of our plant and animal species is likely to vanish. There will be famine around the World, particularly in Africa and central Asia. A consensus was also arrived on two major issues in the recently concluded Convention at Bali, Indonesia. The Reduction of Emissions from Deforestation and Degradation (REDD) in developing countries is on top priority as the deforestation alone causing 20-25 % increase in greenhouse gas emissions in the atmosphere. The second major issue is on Adaptation Fund designed to help developing countries dealing with impact of climate change. Therefore, it is pertinent to follow the guidelines at the regional scale so as to mitigate the ill - effects on war footing against climate change.

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CHAPTER 4

Impact of Climate Change on Agriculture over Tamil Nadu

V. Geethalakshmi and Ga. Dheebakaran

Agriculture and forestry are well adjusted to mean climatic conditions, but sensitive to variability, extremes and changes in the mean state. Agriculture, especially crops, displayed a high sensitivity to climate change. Temperature is very important in determining crop yields, particularly in cold latitudes. Outside these zones, rainfall is the most important regional variable for crop production. Cropping is particularly susceptible to rainfall variability in the arid and semi-arid subtropics, Mediterranean and monsoon regions. Soil moisture deficits limit growth, especially in areas of rainfed agriculture. The Southern Oscillation is a major cause of natural climate variability, especially in tropical area.

Climate change is likely to have a significant impact on agriculture. In general, the faster the climate changes, the greater will be the risk of damage. Agronomic studies suggested that extensive warming could cause significant reduction in yield. If temperature rose by 4 °C, grain yield would fall 25-40 per cent, rice yields will fall by 15-25 per cent (Kumar *et al.,* 1996). Food security is unlikely to be threatened at the global level, but some regions are likely to experience food shortages and hunger. Water resources will be affected as precipitation and evaporation patterns change around the world. Physical infrastructure will be damaged, particularly by sea-level rise and extreme weather events. Economic activities, human settlements and human health will experience many direct and indirect effects. The poor and disadvantaged are the most vulnerable to the negative consequences of climate change.

It is now widely accepted that even after introducing significant measures to reduce greenhouse gas emissions, changes in the climate are inevitable. Climatic variables, such as temperature and precipitation, significantly influence the hydrologic cycle of a region and thereby the crop productivity and food supply scenario. The impact of climatic change affects not only producers of food and fibre products, but also the supporting industries including seed, fertilizer and pesticide industries and their management and services. To sustain food and fibre production, it is important to decrease the vulnerability to climate with appropriate measures. In the decades to come, Tamil Nadu agricultural sector is expected to be significantly impacted by the concurrent processes of climate change and globalization. Climate change could lead to sea level rise, increased weather variability, more droughts and the spread of infectious diseases.

4.1 Biophysical Resources

4.1.1 Land use and rainfall

The land used for agriculture purpose is decreased by 30 per cent and at the same time the land used for non agriculture purpose is increased to the same extend during the last three decades. The conversion will be more in future due to increase in population (Table 4.1). Both Southwest and Northeast monsoons are crucial for the successful harvest of crops in the State. The State has three distinct rainfall seasons viz., (1) southwest monsoon (June-September), northeast monsoon (October-January), and dry season (February-May). The State's cropping system centers on the northeast monsoon season. The State has a normal annual rainfall of 979 mm, with 45 rainy days (Table 4.2). Long- term State annual rainfall does not show any significant upward or downward trend and is almost static with annual variations along this long term flat average (Fig 4.1). The intra - year variability also does

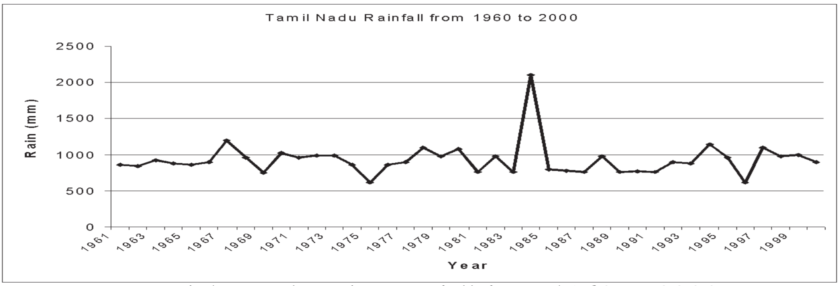

Fig. 4.1 Tamil Nadu Rainfall from 1960 to 2000

not show significant trends, though it exhibits a slightly higher declining trend compared to annual rainfall pattern. Inter district annual variability in rainfall levels, however, showed a markedly

Table 4.1 The land utilization in Tamil Nadu

	Area in lakh. ha					
Land Use Classification	**1970**	**1980**	**1990**	**2000 -01**	**2001 -02**	**2002 -03**
Forest	20.05 (15.40)	20.76 (16.00)	21.44 (16.48)	21.34 (16.40)	21.32 (16.40)	21.32 (16.40)
Barren and uncultivable land	7.05 (5.40)	5.57 (4.30)	4.95 (3.80)	4.75 (3.70)	4.77 (3.70)	4.78 (3.70)
Land put to non agricultural uses	16.00 (12.40)	17.95 (13.80)	19.07 (14.73)	19.86 (15.30)	19.98 (15.40)	20.12 (15.50)
Permanent pastures and other grazing land	1.98 (1.50)	1.45 (1.10)	1.25 (0.95)	1.23 (1.00)	1.18 (0.90)	1.18 (9.00)
Cultivable waste	4.15 (3.20)	3.08 (2.40)	3.25 (2.53)	3.52 (2.70)	3.87 (3.00)	3.89 (3.00)
Land under crops and groves	2.15 (1.70)	1.82 (1.40)	2.25 (1.78)	2.55 (2.00)	2.71 (2.10)	2.78 (2.10)
Current fallow	12.02 (9.20)	16.18 (12.40)	10.57 (7.95)	11.34 (8.70)	10.26 (7.80)	15.03 (11.60)
Other fallow	5.31 (4.10)	7.03 (5.40)	10.93 (8.45)	12.28 (9.40)	14.09 (10.80)	14.91 (11.50)
Net Area Sown	61.35 (47.50)	56.22 (43.20)	56.32 (43.34)	53.03 (40.80)	51.72 (39.80)	45.90 (35.30)
Area sown more than once	13.21	10.55	10.97	10.35 (8.00)	10.56 (8.10)	6.01 (4.60)
Gross cropped area	74.56	66.77	67.29	63.38 (48.80)	62.26 (47.97)	51.91 (40.00)
Cropping intensity (%)	121.56	118.80	119.46	119.48	120.38	113.09
Total (geographical) area	130.06	130.06	130.16	129.91	129.91	129.91

(Figures given in parentheses are in %)

higher declining trend. Perhaps, it indicates that the rainfall environment of the State is tending towards more homogeneity with ecological and environmental differences being narrowed due to human intervention activities. Based on rainfall distribution, irrigation pattern, soil characteristics, and other physical, economic and social characteristics, Tamil Nadu is classified into seven agroclimatic zones viz., northeast, northwest, west, south, Cauvery delta zone, high rainfall zone and high altitude zone.

Table 4.2 District - wise rainfall (mm) in Tamil Nadu

S.No.	Mean Annual Rainfall (mm)	Districts
1.	<800	Coimbatore
2.	800-1000	Pudukottai, Tirunelveli, Ramanathapuram, Madurai, Salem, Dharmapur, Cuddalore, Trichy
3.	1000-1200	Vilupuram and Thanjavur
4.	1200-1400	Chennai and Kancheepuram
5.	1400-1800	Kanyakumari
6.	>1800	The Nilgiris

Source: Season and Crop Reports published by Directorate of Economics and Statistics

The northwest zone has an annual rainfall range of 560-1080 mm, while the hilly regions in this zone receive 1,300 mm annually and 45% of their annual rainfall is from the Southwest monsoon. The districts of Periyar, Coimbatore, Salem and North Madurai are in the west zone, which has a mean annual rainfall of 635 mm. This zone has a semiarid to sub humid climate with frequent droughts. In this region, almost half the rainfall is from the northeast monsoon.

The cauvery delta zone has a tropical climate, with a mean annual rainfall of 1,278 mm. The southern zone of Tamil Nadu, comprising the districts of Ramanathapuram, Tirunelveli, Dindigul, South Madurai and Pudukottai, is under the rain shadow region, having a prolonged dry climate. Only northeast monsoon rainfall is dependable here. Tamil Nadu has eight drought-prone districts (Coimbaotre, Dharmapuri, Kanyakumari, Madurai, Ramanathapuram, Salem, Tirunelveli and Tiruchirapalli) covering

833,997 km^2 or about 64% of the total area of the State. 30 per cent of the districts receive rainfall during the southwest monsoon while 50 per cent during the northeast monsoon through cyclonic activity. Generally, rainfall decreases from North to South.

The two monsoons viz., Southwest and Northeast monsoons are dominant source of precipitation providing almost 80 per cent of the total annual rainfall. Northeast monsoon is associated with cyclonic storms causing wide spread damage to property. Inter annual rainfall variability causes significant damage to agriculture. The annual co-efficient of variation is around 30 per cent. Despite of inter annual variability, intra-seasonal variability also causes frequent crop failures and loss to major agricultural resources.

As per 2003-04 Season and Crops Report of Government of Tamil Nadu, total area cultivated under food crops was 3500788 ha and the total food grain production was 8616783 tonnes with a productivity of 2461 kg / ha. If we assume that at present we are in self sufficient condition, per capita foodgrain availability per day works out to be 350 g / person / day. Even with low population projection scenario and assuming that only 350 g/person/day is the foodgrain consumption, we need to increase our productivity by 85 per cent by the end of this century. Against this situation, area under cultivation is shrinking constantly due to land put under non-agricultural uses. Against this situation, area under cultivation is shrinking constantly due to land put under non-agricultural uses.

4.1.2 Water resources

Considering the agroclimatic zone wise dominance of the sources of irrigation (Table 4.3) again, the position is similar. Out of seven identified zones five were dominated by surface sources by early seventies and gradually two more zones moved away leaving only three regions as of late nineties. Two more zones – Cauvery and southern zones are in the process of change.

Though groundwater has begun to raise its share over the decades, surface sources as a whole still retain the dominant share in the State. Among the twelve composite districts as many as 10 were dominated by surface irrigation in early sixties, with only Salem and Coimbatore being dominated by groundwater sources. Progressively the position changed. By early eighties three districts

Table 4.3. Decadal shift in surface and ground water sources in different agroclimatic zones over Tamil Nadu

1970-79		1980-89		1999-00	
Surface	Ground	Surface	Ground	Surface	Ground
North Eastern			North Eastern		North Eastern
	North western		North western		North western
Cauvery Delta		Cauvery Delta		Cauvery Delta	
Southern		Southern		Southern	
High Rainfall		High rainfall		High rainfall	
High altitude		High altitude			High altitude
STATE		STATE		STATE	

Cuddalore, Vellore and Madurai moved under groundwater fold and by early nineties another two districts Kancheepuram and The nilgiris followed suit leaving only five districts still dominated by surface sources overall. The trend in Ramanathapuram and Tirunelveli is to increase the number and depth of wells and may end up as groundwater dominated soon. In Thanjavur district, the situation is turning favourable towards groundwater with growing uncertainties in the receipt of Cauvery waters from the neighbouring State. Efforts are under way to promote alternate crops in the place of rice and may lead to growing dependence on wells in decades to come. Thus over a period of about half - a - century the share position of surface and groundwater sources seemed to have interchanged positions geographically and quantitatively.

4.2. Climate change scenario

4.2.1 Rainfall

District level daily rainfall data for the period of 30 years from 1971-2000 was taken and mean was worked out to produce baseline data. The rainfall data was then grouped to annual (Jan – Dec), Southwest monsoon (Jun – Sep) and Northeast monsoon

(Oct – Dec). Monthly means of climate change scenario for the year 2020, 2050 and 2080 were then linked to the base line data and the changes were analyzed. Different regions of Tamil Nadu exhibit diverse changes over the next century. During Southwest monsoon, rainfall is expected to increase in the southern parts of Tamil Nadu, while it is expected to decrease in the central regions and remains the same in the northern parts of Tamil Nadu. During Northeast monsoon only in the central parts of Tamil Nadu, rainfall is expected to decrease and in southern and northern parts not much change is expected.

4.2.2 Maximum and minimum temperatures

District level daily maximum and minimum temperature data for the period of 30 years from 1971-2000 was taken and mean was worked out to produce baseline data. Monthly means of climate change scenario for the year 2020, 2050 and 2080 were then linked to the base line data and the future changes were analyzed. As far as temperature is concerned both maximum and minimum temperatures are expected to rise by 2 to 5 degree Celsius. Warming is expected more in the central and north eastern parts of Tamil Nadu.

4.2.3 Impact of climate change on rice

Impact of rice yield on climate change was studied for two rice growing seasons viz., Kharif and Rabi seasons for different districts of Tamil Nadu using INFOCROP model. Standard package of practices and CO43 rice variety which suitable for all over Tamil Nadu was considered for the study. Only the climate data was changed for different districts and crop weather model was run individually for each district for the base line data. Monthly means of climate change scenario for the year 2020, 2050 and 2080 were then downscaled to daily data and then linked to the base line data for analyzing the changes. Expected deviation of rice yield during the Southwest monsoon and Northeast monsoon of 2020, 2050 and 2080 over the base year is presented in Figure 4.2.

Change in climate is expected to create both positive as well as negative impact on rice yield of Tamil Nadu. Impact is more during *kharif* season (Southwest Monsoon) than in *rabi* (Northeast monsoon) season. During *kharif* season in 2020, 10 to 15 per cent reduction in rice yield is expected due to increase in temperature and change

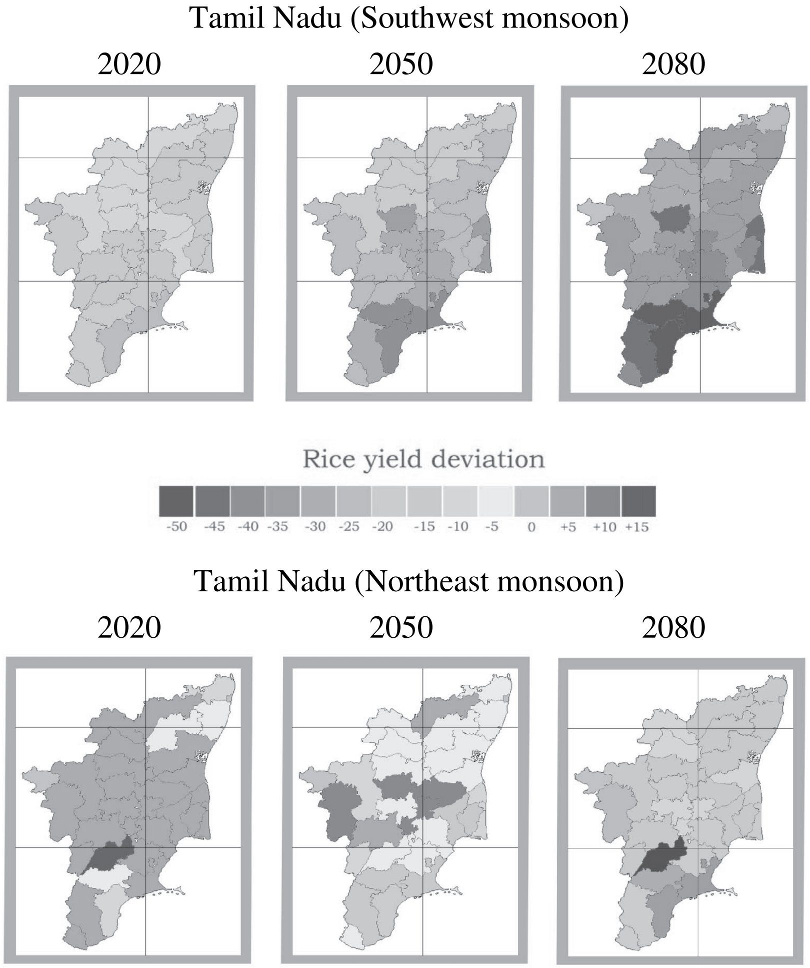

Figure 4.2 Deviation of rice yield due to climate change

in rainfall. In 2050, 30 to 35 % yield reduction and in 2080, up to 80 % yield reduction is expected. Though the reduction is found in all most all the districts, it is more pronounced in the major rice growing districts such as Thanjavur and Nagapattinam. In contrast to this, during Northeast monsoon, there is increase in rice yield up to 10 % due to change in climate. This might be due to the positive effect of slight increase in temperature during the rabi season. As the major rainy season and the winter season of Tamil Nadu fall in the rabi season, most of the time the water temperatures are low. Increase of 1 to 2 degree Celsius temperature must have created a positive impact by 2020. In 2050, rabi rice yields are almost same as that of the current productivity and further increase in temperature during 2080, it had negative impact and reduced the yields up to 25 % in most of the districts of Tamil Nadu.

The impact of climate change on agriculture remains uncertain, not only because of uncertainties in climate projections, but also because the agronomic and economic models used to predict these changes are not fully integrated. These models do not include changes in insects, weeds and disease; direct effects of climate change on livestock; changes in soil management practices; or changes in water supply. The mean value of a 30 per cent increase in C3 crop yield for a doubled CO_2 environment has been demonstrated by recent experiments, but the variation is wide (-10 to + 80 per cent), so this result cannot be extrapolated to a large scale or over an entire growing season.

4.2.4 Impact of climate change on crop duration of maize

Impact of climate change on maize productivity in Coimbatore was studied using INFROCROP model. Different climate change scenarios were created and the model was run for three different rainfall situations. Weather data of Coimbatore for the year 1992 was used where the rainfall received was 553.2 mm in the crop growing season and was considered as a good year. The year 1991 was considered as a bad agriculture year as the rainfall received was only 117.7 mm during the crop growing period. The year 1995 was considered as a normal year wherein 352.8 mm of rainfall was received (Fig. 4.3). The crop was sown on September 17th in all the years. Normally in Coimbatore, farmers take up pre-monsoon sowing on September 17th for the rainfed northeast monsoon crop. No irrigation was considered and the crop was taken as pure rainfed

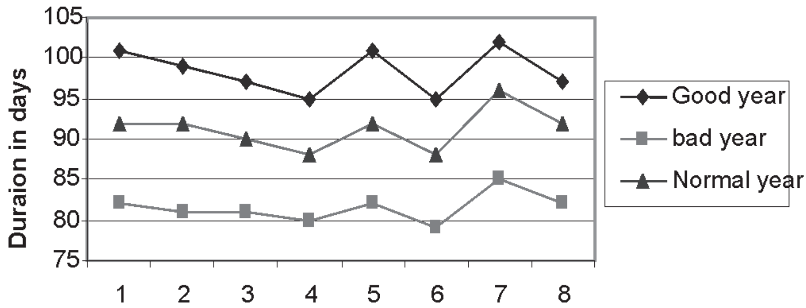

Fig. 4.3 Climate Change scenarios and crop duration in maize

crop and the model was run for eight different climate change scenarios as listed: T1 - No climate change; T2 - Uniform increase in maximum temperature alone by 1°C; T3 - Uniform increase in minimum temperature alone by 1°C; T4 - Uniform increase in both maximum and minimum temperatures by 1°C; T5 - Increase in CO_2 level alone to 450 ppm; T6 - Increase in CO_2 level to 450 ppm + Uniform increase in both maximum and minimum temperatures by 1°C; T7 - Increase in precipitation by 10 %; T8 - Increase in CO_2 level to 450 ppm + Uniform increase in both maximum and minimum temperatures by 1°C+ Increase in precipitation by 10%.

In general, crop duration increased in good rainfall years. In bad agricultural years, due to very less amount of rainfall, the crop duration reduced on an average by 20 days. Among the climate change scenarios, increase in temperature reduced the crop duration. The magnitude of reduction was more during good agricultural year. Increase in night temperature had more impact on reducing the duration of the crop. The effect of minimum temperature was almost double as that of the maximum temperature. When both maximum and minimum temperatures were increased by 1°C, the crop duration was reduced by as much as six days in good years and four days in bad and normal years. Increase in CO_2 alone did not influence the duration of the crop. But together with temperature, it reduced the crop growing period. Increasing rainfall by 10 % increased the duration of the crop especially in bad and normal rainfall years by four days.

Although increase in CO_2 is likely to be beneficial to several crops, associated increase in temperatures and increased variability of rainfall would considerably impact food production. Recent IPCC report indicates considerable probability of loss in crop production with increases in temperature in tropical regions. Indian studies do confirm this trend, although there is considerable disagreement among the studies on the magnitude of loss. Among cereal crops, important for food security, rice has relatively greater tolerance to increase in temperature. It is, however, possible for farmers to adapt to a limited extend and reduce the losses. Increasing climatic variability could, nevertheless, result in considerable seasonal/annual fluctuations in food production. All agricultural commodities are sensitive to such variability. Food production needs to be increased considerably in future to meet increasing demand associated with population and income growth. There is considerable biological yield gap still available for most crops that can be utilized for meeting these demands given the support of policy and economic development. Climate change, is however, likely to considerably reduce this biological gap. This could lead to stagnation in food production growth much sooner than otherwise expected. Increasing temperature in future is likely to reduce fertilizer use efficiency. This could lead to increased fertilizer requirement for meeting future food production demands (higher due to income and population growth), leads to higher emissions of greenhouse gases. This could become a cause for concern, in case of reducing GHG emissions in future.

Global warming in short-term is likely to favour agricultural production in temperate regions (largely Europe, North America) and negatively impact tropical crop production (South Asia, Africa). This is likely to have consequences on international food prices, trade, and could lead to a problem of food security. Small changes in temperature and rainfall could have significant effect on quality of fruits, vegetables, tea, coffee, aromatic, and medicinal plants. This needs to be quantified. Pathogens and insect populations are strongly dependent upon temperature and humidity. Any increase in the latter, depending upon their current base values, could significantly alter their population, which ultimately results in yield loss. Greater research is needed to understand population dynamics of pathogens and insects in relation to climate change. Droughts, floods, tropical cyclones, heavy precipitation events, hot extremes and heat waves are known to negatively impact agricultural production and farmers' livelihood. The projected increase in these events could result in greater instability in food production, as well as further threaten livelihood security of farmers.

4.2.5 Impact of climate change on maize yield

The analysis of data indicated that the expected change in climate will benefit maize crop production in Coimbatore area. Maximum increase could be noticed for increase in rainfall by 10 per cent and for the combined increase of temperature rainfall and CO_2 levels (Table 4.4). Though this particular case study indicates the beneficial effect of expected climate change, we can not come to any solid conclusion as it is a single location data for a specific case. Hence in depth analysis need to be undertaken for deriving valid conclusion.

Table 4.4 Effect of climate change on Maize yield (Kg/ha)

Climate change Scenario	Good year		Bad year		Normal year	
	Maize yield	% deviation	Maize yield	% deviation	Maize yield	% deviation
No climate change	2132	0	267	0	601	0
Increase in maximum temperature alone by 1°C	2265	6.2	236	-11.7	581	-3.2
Increase in minimum temperature alone by 1°C	2189	2.7	290	8.6	673	12.1
Uniform increase in both maximum and minimum temperatures by 1°C	2192	2.8	254	-5.0	652	8.5
Increase in CO_2 level to 450 ppm	2144	0.6	275	2.9	618	2.9
Increase in CO_2 level to 450 ppm + increase in both maximum and minimum temperatures by 1°C	2215	3.9	268	0.5	671	11.7
Increase in precipitation by 10 %	2367	11.0	376	40.7	1026	70.8
Increase in CO_2 level to 450 ppm + Uniform increase in both maximumand minimum temperatures by 1°C + Increase in precipitation by 10 %	2528	18.6	359	34.3	1143	90.3

4.3. Mitigation of climate change impacts

4.3.1 Changes in land use and management

Small changes in climatic parameters can often be managed reasonably well by altering dates of planting, spacing and input management. Development of alternate cultivars, farming systems (such as mixed cropping, crop-livestock) that are more adapted to changed environment can further ease the pressure.

4.3.2 Development of resource conserving technologies

Recent researches have shown that surface seeding or zero-tillage establishment of upland crops after rice gives similar yields to when planted under normal conventional tillage over a diverse set of soil conditions. In addition, such resource conserving technologies restrict release of soil carbon thus mitigating increase of CO_2 in the atmosphere. Greater emphasis on water harvesting and improving the efficiency of regional as well as farm water use efficiency could help to face uncertain rainfall.

4.3.3 Improved land use and natural resource management policies and institutions

Adaptation to environmental change could be in the form of crop insurance, subsidie, and pricing policies related to water and energy. Necessary provisions need to be included in the development plans to address these issues of attaining twin objectives of containing environmental changes and improving resource use productivity. Policies are needed that would encourage farmers to conserve water, energy and soil resources. For example financial compensation/ incentive for enriching soil carbon and increasing the efficiency of irrigation water uses could encourage farmers to improve soil health, manage with less water and assist in overall sustainable development. Improved climatic risk management through early warning system and crop insurance will go a longway to build up confidence in farmers towards sustainable agriculture.

Improved water and fertilizer management in rice paddies could reduce emissions of GHGs. Improved management of livestock population and its diet could also assist in mitigation of GHGs. Approaches to increase soil carbon such as organic manures, minimal tillage and residue management should be encouraged. These have synergies with sustainable development as well. Use of nitrification inhibitors, such as neem-coated urea and fertilizer placement practices need further consideration for GHG mitigation. Improve the efficiency of energy use in agriculture by using better designs of machinery and by conservation practices. Changing land use by increasing area under bio-fuels and agro-forestry could also mitigate GHG emissions. This, however, may have trade-offs with goal of increasing food production.

4.4 Conclusions

Agriculture has an ability to adjust to limited climatic change with the use of proper technology and agronomic manipulations. This capability, however, varies greatly between regions. Hence, vulnerable regions for climate change should be identified. It is important to establish in more details the nature of this adaptability and the critical rates of climatic change that agriculture can adapt to under local conditions. In order to improve our understanding of the significance of climatic change and its consequences for agriculture and humankind, considerable research is needed into how agriculture can best adapt to avoid or gain from annual, seasonal and intra-seasonal variability in climate in different agroclimatic regions of the country.

Improved knowledge is needed to effects of changes in climate on crop yields and physical processes such as rates of soil erosion, salinisation, nutrient depletion, insect pests, diseases and hydrological conditions. Information is also needed on the range of potentially effective agronomic adjustments such as irrigation, crop selection, sowing time fertilization. Keeping in mind the increase in population, the foodgrain requirement and the impact of change in productivity due to climate change and management options should be tailored to increase the yield of important crops even under changing climate scenarios. New research programme should be aimed at identifying or developing cultivars and management practices appropriate for altered climates. Though, many model projections on future climate change scenarios are available, more precise scenarios with finer spatial dimension is required to asses the impacts.

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CHAPTER 5

Impact of Climate Change on Agriculture over Karnataka

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Climate has a vital role on biosphere of the earth. A very slight change in the climate will lead to major changes in plant and animal life. For example, some crops will not tolerate even a minute variation in temperature. The entire habitat of vegetation of an area depends on a particular climate and they are accustomed to that. Variation in climatic parameters will alter the very process of soil formation from parent material, growth and reproduction of plants and animals and their health. The major climatic parameters are rainfall, temperature, sunshine hours, relative humidity and wind speed, of which rainfall is one of the important factors which has greater significance on agriculture, especially under Indian conditions. Global climate change and its impact on agriculture is becoming an important issue even at the microlevel to meet the future food requirement at the regional level. Innumerable number of scientists are working in this area. In view of these problems, a case study has been taken up to analyze the rainfall pattern of few districts in Karnataka State, where rainfall is showing definite trend and its impact on cropped area is felt on major crops.

5.1 Agroclimatic zones

The Karnataka State is located between 11.5^{0}N and 18.5^0 N latitude and between 74^0 E and 78.5^0 E longitude. The mean elevation varies between 600 m to 900 m above the mean sea level (Rajegowda, 1990). The State comprises of ten Agroclimatic zones (Fig. 5.1).

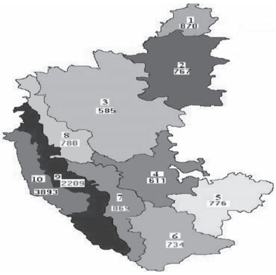

Fig. 5.1 Agroclimatic zones of Karnataka

5.1.1 Seasonal rainfall

The rainfall data averaged for the period from 1901 to 1970 has been analysed. The Hilly and Coastal zones receive the highest of about 2209 mm and 3893 mm rainfall and the Northern Dry zone and Central Dry zone receive the lowest of 585 mm and 611 mm rainfall, respectively over the State (Table 5.1).

Table 5.1 Mean annual seasonal rainfall in different Agroclimatic zones of Karnataka

Sl. No.	Season / Zone	WTR Jan-Feb	SMR Mar-May	SWM Jun-Sep	NEM Oct-Dec	Annual Jan-Dec	Percentage of rainfall (mm)			
							WTR	SMR	SWM	NEM
1	N-E transition	10	58	680	112	860	1.1	6.7	79.1	13
2	N-E Dry	8	59	576	124	767	1.0	7.7	75.1	16.2
3	Northern Dry	4	83	359	139	585	0.7	14.1	61.4	23.8
4	Central Dry	7	116	303	185	611	1.1	19.0	49.6	30.3
5	Eastern Dry	10	139	404	223	776	1.3	17.9	52.1	28.7
6	Southern Dry	8	193	301	232	734	1.1	26.3	41.0	31.6
7	Southern Transition	7	169	486	207	869	0.9	19.4	55.9	23.8
8	Northern Transition	3	126	484	167	780	0.4	16.2	62.0	21.4
9	Hilly	4	150	1842	215	2209	0.1	6.8	83.4	9.7
10	Coastal	5	182	3416	290	3893	0.1	4.7	87.7	7.5
	Mean	6.6	127.5	885.1	189.4	1208.4	0.5	10.5	73.3	15.7

Out of 1140 mm of average annual rainfall of the State, about 805 mm (71%) received in the period of June to September (Southwest monsoon), 195 mm (17%) in the period of October-December (North-East monsoon) and only 139 mm (12%) from January to May. June receives highest monthly rainfall of 283 mm, followed by 190 mm in August (Fig.5.2). In total, the crop growth period in rainfed areas extends from June to October. Thus, performance of southwest monsoon decides the fate of agriculture in Karnataka.

Pre-monsoon is purely a local phenomena depending upon the local conventional current. Southwest monsoon is a global phenomena influenced by the oscillation in the Indian ocean in the Southern Hemisphere. The rainfall contribution and its distribution during this period (June to September) is depending upon the physical changes taking place in the Southern Hemisphere, hence it is not much influenced by the local environment. Northeast monsoon rains, though not assured to the State, it is influenced by the cyclonic winds generated in Bay of Bengal. Eastern part of Karnataka is

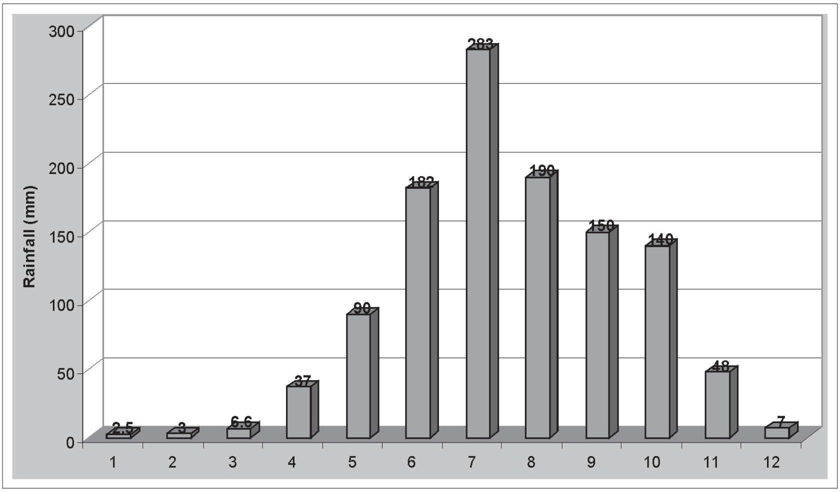

Fig. 5.2 Normal monthly rainfall in Karnataka State (1901-1970)

beneficial from Northeast monsoon. Udupi district receives highest of 4119 mm annual rainfall whereas Bagalkote receives the lowest of 561.7 mm rainfall. Coastal districts receive higher annual rainfall. The probebility of occurrence of materiological droughts in different agroclimatic zones is given is Table 5.2. It reveals all the zones are prone to drought occurrence. However, the probabilty of occurrence of drought over the coastal zone is relatively less while more over the northeast transsition zone.

Table 5.2 Probability of occurrence of meteorological droughts in different agroclimatic zones of Karnataka State

Sl. No.	Zone	Deficit years (annual)		Percentage of moderate and severe nature			
				S- W		N- E	
		Moderate	Severe	Moderate	Severe	Moderate	Severe
1	N-E transition	23.7	5.6	27.8	8.8	15.9	26.1
2	N-E Dry	21.1	1.9	24.3	6.1	16.9	19.1
3	Northern Dry	24	2.4	24.6	6.6	18.2	23.9
4	Central Dry	22.5	3.1	25.4	8.3	20	21.4
5	Eastern Dry	25.6	2.3	27	6.2	23.2	18.7
6	Southern Dry	22.2	1.5	24.2	8.3	23.4	16.3
7	Southern Transition	24.3	1.7	25	4.7	24.3	18.2
8	Northern Transition	23.8	1	25.5	1.8	22	21.6
9	Hilly	19.2	1	20.9	2.2	24.8	17.7
10	Coastal	14.6	0.3	15.3	0.8	23.6	16.6

5.1.2 Annual rainfall trends

The mean rainfall of the State for the period from 1951 to 2000 is found to be reduced to 1140 mm (DMC Report 2002). The time series of the mean annual rainfall of the State indicates a definite cycle of sixteen years starting 1950 to 1964 and so on. The first half of the cycle received less than the normal rainfall for the period from 1950 to 1958 and the second half of the cycle received more than the normal for the period from 1959 to 1964. During this half of the cycle, two or three of eight years have received the rainfall opposite to their trends. This cycle is repeated up to 2004 and the State is in the positive half of the cycle from 2004 and will continue till 2012 (Fig. 5.3).

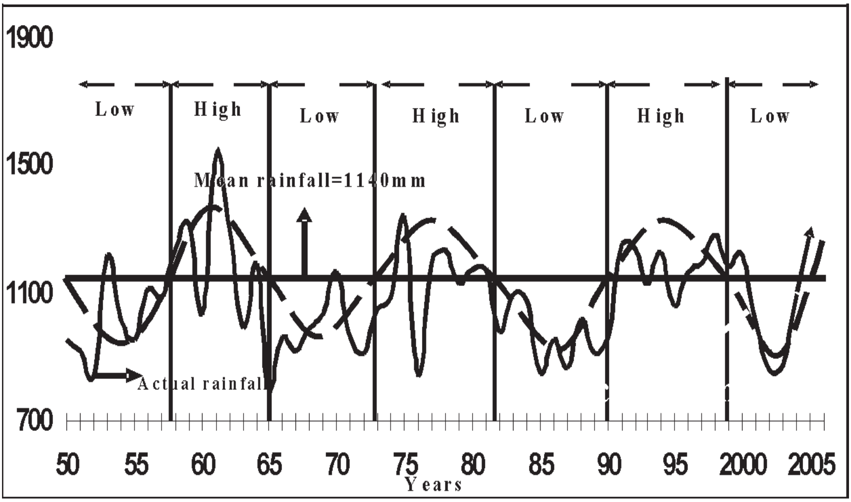

Fig. 5.3 Mean annual rainfall over Karnadaka for the period from 1950 to 2006

The mean annual rainfall trend of the State for the period from 1901 to 2000 indicated a definite declining trend (Fig 5.4) as per Panduranga *et al.,* 2006.

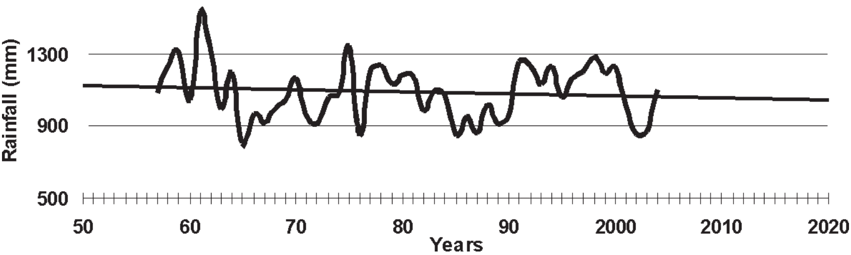

Fig. 5.4 Trend in mean annual rainfall of Karnataka for the period from 1950 to 2006

The mean annual rainfall data of few districts have been analyzed and a particular trend in rainfall has been observed. There is s definite declining trend in rainfall in Kodagu (Guruprasanna et al 2006), Chikkamagalur and South Canara districts. In Kodagu district, the mean annual rainfall for the period 1901-1950 has been reduced from 2725 mm to 2625 mm during the period 1951-2006. Chikkamagalur district's mean annual rainfall of 1927 mm has been reduced to 1872 mm and South Canara district's mean annual rainfall of 3976 mm has been reduced to 3960.3 mm for the corresponding periods which clearly indicated the decline in mean annual rainfall and indicates decline trend (Fig. 5.5).

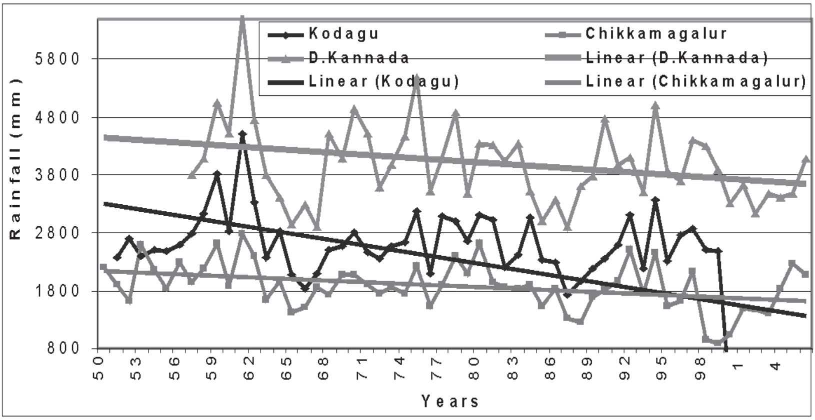

Fig. 5.5 Declining trend of rainfall in Kodagu, Chikkamagalur and South Canara districts

Further few districts of the State have shown increasing trend in the annual rainfall. Bangalore, Kolar and Tumkur districts have shown the considerable increasing trend in annual rainfall. Their mean annual for the period from 1901 to 1950 are 867 mm, 745 mm and 687.9 mm, respectively and for the period from 1951 to 2006 are 882.8 mm, 767.2 mm and 730 mm, respectively (Fig.5.6).

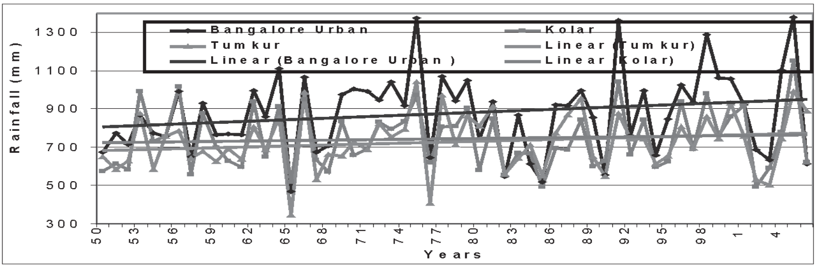

Fig. 5.6 Increasing trend of rainfall in Bangalore, Kolar and Tumkur districts

The rainfall data collected from 30 raingauge stations belonged to the Eastern Dry zone of Karnataka State has been analysed for different periods. This zone consists of Bangalore and Kolar districts and parts of Tumkur district. it is also known as the Tank fed region, which constitutes 9.42 per cent of the State's geographical area. Eighty per cent of the area is at an altitude of 800 -900 meteres above mean sea level (Rajegowda 1990). 47.16 per cent of its area is under agriculture/ horticulture crops. Rajegowda *et al.,* 2000 have shown that there is a predominant shift in the initiation and termination of rainfall to supply adequate moisture for crop growing period. This shift has been observed after 1990 and their mean monthly values also have changed. Before 1990, the annual rainfall ranged from 619 to 1119 mm with a mean of 869.2 mm. After 1990, the annual rainfall ranged between 611 and 1311 mm with a mean of 1011.2 mm. During the first period, on an average, the peaks were observed during May, July and September (Fig.5.7), and during the second period, the peaks are observed during May, August and October.

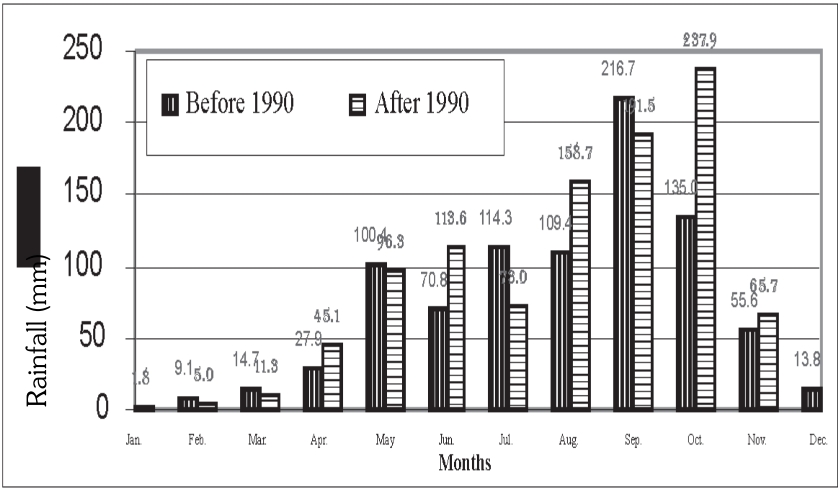

Fig. 5.7 Rainfall shift in the Eastern Dry zone of Karnataka

Consequences to this, individual crop growing area is varying, crop growing period is being changing and their productivity is also varying. The normal sowing season rains are being delayed due to the shift of July rains to the August (Fig.5.8). The terminal rain in the southwest monsoon that normally coincides with the September peak rainfall is gradually reducing and the beginning of the Northeast

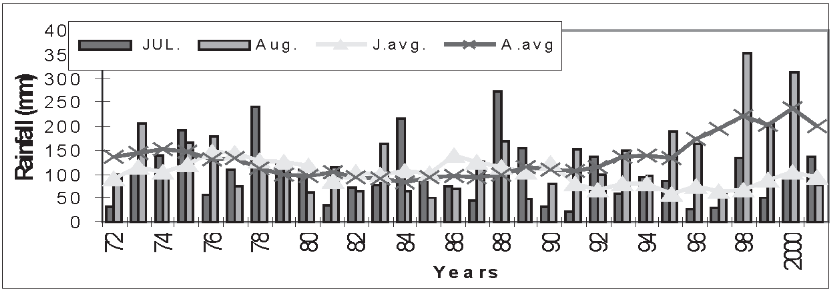

Fig. 5.8 Declining in July rains and increasing in August rains in the Eastern Dry zone of Karnataka

monsoon is getting higher rainfall than earlier. Consequence to this, the peak normally occurring during September now being shifted to October. The maximum water available period for the grand growth period is shifting towards the end of September and beginning of October in many eastern districts. The distribution of rainfall during the cropping season has high influence on the cropping area and crop selection. In both the periods considered for this study, the quantum of May rains received during both the periods more or less remains same. The rainfall received during the South-west monsoon, starting from June to October, is the crucial period for the growth of the crop apart from the hydrological utility. The quantum of rain received during June is low and it remains unchanged more or less in both the periods. The average rain during July, which was 114.3 mm during 1972-90, decreased to 73.0 mm during 1991-99. This reduction in July rains seems to be compensated by an increase in August rains (158.7 mm) during 1991-99 compared to the period 1972-90 (109.4 mm). This clearly shows that there is a perceptible shift in rainfall pattern from July to August and also from September to October in this agroclimatic zone. A distinguished peak was observed in September (216.7 mm) during 1972-90 and October was the next highest rainfall receiving month. The analysis of monthly rainfall beyond 1991 showed that the highest rains are now received during October (237.9 mm) and the next highest rainfall is received during September (191.5 mm). This implies that the peak, which was being observed during 1972-90, has shifted to October during 1991-99. There is a marginal increase even in rainfall of November after 1990.

The crop sown during July rains would reach the grand growth period viz., flowering to grain formation stage (long duration crops of about 115 days) during September which was receiving the highest rainfall till 1990, so that there was no moisture stress during the grand growth period. After 1990, as a result of reduction in July and September rains, the crops can not be sown during July, though the land preparation could be done using June rains. Even with scanty rains, if the sowing is done during July, the crop would suffer from moisture stress due to the reduction in rainfall during September and also the crop grown would be caught in October rains causing considerable loss in the grain yield at the harvest season. The change in the mean monthly rainfall pattern beyond 1990 does not favour the sowing of crops during July. This analysis reveals that sowing of crops (long duration variety crops of about 115 days) could be done during August preparing the land using June and July rains. In the years of early onset of south-west monsoon, sowing can be recommended during last week of July also. The crop sown during August would reach the grand growth period during October. As October receives higher rainfall the crop in its grand growth period would not suffer for want of moisture and as a result crop could yield to its maximum capacity. The crop sown beyond August may not be able to complete its life cycle as a result of inadequate moisture availability beyond 2^{nd} fortnight of November (in the event of the intensity of north-east monsoon being low) as crop maturity coincides during this period. Under such circumstances, the short duration variety crops have to be preferred. Further micro level studies in quantum of rainfall shift are needed.

5.2 Agroclimatic zones and cropping systems

The cropping systems along with the soil type for all the agro climatic zones are given in Table 5.3.

5.2.1 Trends in cropped area and production

Indian economy is based on the Southwest monsoon. It's setting in and withdrawal dates are different in different parts of India and its duration also varies. Again its intensity and quantum of precipitation are not uniform throughout the Country; different locations receive different amounts of precipitation. Rainfall quantum and distribution decide the type of crop to be grown in each area. resulted in changes of crop area and production. Though total food production is increasing, the decreasing trend and changes in distribution pattern has become the major limiting factor in achieving

Table 5.3 Existing cropping system in different agro-climatic zones of Karnataka State

Agro climatic zone	Soil type	Cropping system
North Eastern Transition Zone (800-900 mm)	Shallow to medium black clay soil	Sunflower - chickpea/rabi sorghum; Sesamum – rabi sorghum / sunflower Hy. Sorghum+ P. Pea (2:1) Black gram / Green gram + P. Pea (4:2) GN+ P.Pea (4:2), Sesamum + P. Pea (4:2)
North Eastern dry zone (630-807)	Deep to very deep black clay	Hy. Sorghum + p. Pea (2:1), Sunflower + P. Pea (2:1), Pearlmillet + P.Pea (2:1)
Northern dry zone (465-640)	Medium to very deep black clay	Pearl millet + pigeonpea (2:1) Setaria + pigeonpea (4:2);Chickpea+safflower (4:2) Groundnut+ pigeonpea (4:2) Rabi sorghum + pigeonpea (2:1)
Central dry zone (655-717)	Red loamy shallow to deep black	Hy. Sorghum + p. Pea (3:1), Fm + P. Pea (4:1), GN+ P. Pea (8:2);
Eastern dry zone (679-889)	Red sandy loam	Seamum –fingermillet/ horse gram/ cowpea Hy. Maize- trans. Fingermillet Fm + P. Pea (8:2)/(4:1) GN+ P. Pea (8:2); Maize+ P. Pea (1:1)
Southern Dry Zone (800-900)	Red sandy loam	Hy. Sorghum + P. Pea (3:1), Fm + P. Pea (4:1), GN+ P. Pea (8:2), Maize+ P. Pea (1:1) Seamum-fingermillet
Southern Transition zone (700-1050)	Lateritic and Red sandy loam	Potato – Fingermillet –Castor sunflower- Horsegram Fingermillet+ P. Pea (8:2) Fingermillet + Dolichos (4:2) Chilli+ Hy. Cotton (1:1), Chickpea + safflower (4:2) GN+ P. Pea (4 : 2)
Northern Transition Zone (619-1303)	Shallow to medium black	Potato- Wheat/Rabi sorghum GN- Wheat/Rabi sorghum Sunflower –chickpea Cotton+ GN (1:2), Maize+ P.Pea (2:1) Chilli + Cotton + onion (½ : ½ : 1) Chickpea + safflower (4:2)
Hilly Zone (1300-3800)	Red clayey loam	Rice – chickpea; Hy. Maize- chickpea Arecanut + pepper+ banana, Cordomum + cocoa
Coastal Zone (3000-4700)	Red Lateritic and coastal alluvial	Rice- Groundnut; Rice - Sesamum Coconut+ Banana; Coconut + Pepper + Banana Arecanut + Banana; Cordomum + Cocoa

the targeted crop yields. Areas under crops, such as Jowar and Redgram declining drastically, on the contrary area under crops like maize and paddy is showing an increasing trend. Similarly, production of crops such as maize and paddy has been increased, while that of Jowar has been reduced markedly (Figs. 5.9 and 5.10).

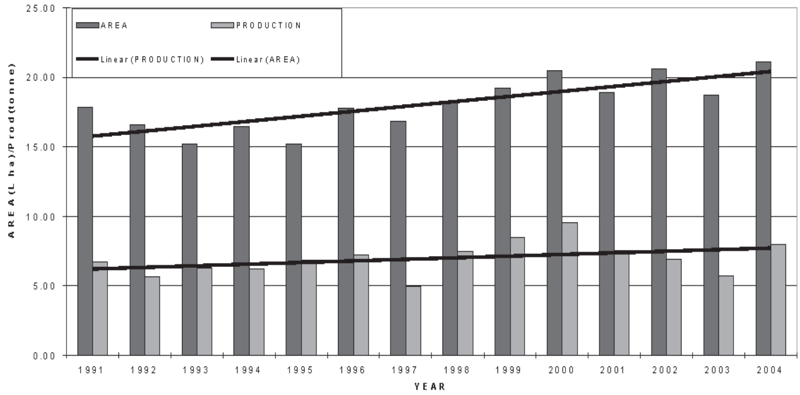

Fig. 5.9 Pulse production and area of cultivation for the period from 1991 to 2004

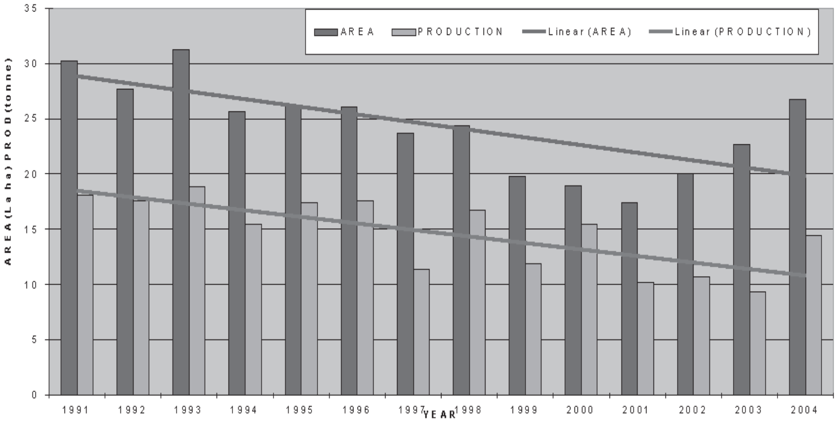

Fig. 5.10 Oil seed production and area of cultivation for the period from 1991 to 2004

The study of cropped area in the State before and after 1990 clearly reveals the changes in area under each crop. Groundnut area in the State has shown a clear cut trends in relation to changing climatic factors from region to region. The area under groundnut has increased drastically from 7.59 l.ha of 1980 to 11.94 l.ha 1990.

However, from 1990 onwards, it has shown a steep decline from 11.94 l.ha to 10.4 l.ha in 1997. This may be attributed to reduction in the quantum of rainfall and changes in distribution pattern of rainfall of which late onset and delayed receipt of rainfall play a major role in reducing the groundnut area. Hence, it is not advisable to go for groundnut beyond July as the harvesting time coincides with heavy rainfall period.

The study on area in Tumkur with respect to changing rainfall pattern which is one of the districts having major area under groundnut reveals the similar results (Panduranga et al 2006). The groundnut area has been increased in Tumkur from 0.79 l.ha in 1980 to 1.78 l. ha in 1990 at an average rate of 990 ha/year. However, after 1990, the area decreased rapidly. This may be due to erratic rainfall leading to frequent crop failures. This along with delayed receipts of monsoon rains have led to millets and minor pulses such as finger millet and horse gram replacing the area of groundnut. Similarly in Chickamagalur district finger millet area is increased from 0.45 l.ha in 1980 to 0.61 l.ha in 1990. This may be attributed to declining rainfall in the district leading to replacement of paddy by finger millet.

The changing climate has a long lasting effect on (cropping pattern) area and production of major crops leading to significant changes in agri-scenario. Hence, a detailed study of each zone with respect to climate change and its impact on the agriculture is the need of the hour in order to cope up with the demand on food production to feed the burgeoning population and to face the new challenges of the liberalization. The total cropped area under different crops in different districts has been studied for the period from 1950 to 2006. It is observed that area under some crops is increasing and some crops decreasing in some districts over years. A definite trend has been observed for the following crops. Rice area in Mysore and Mandya districts, fnger millet (Ragi) area in Chikkamagalur district, red gram in Bidar district and groundnut in Chitradurga and Tumkur districts is increasing (Figs. 5.11 -5.14). Whereas the decline in red gram area in Belgam and Tumkur districts, groundnut in Belgam and Gulbarga districts are shown in Figs. 5.15 and 5.16, respectively. Such change in the cropped area is found to be influenced mainly due to the availability of the rainwater during the cropping season.

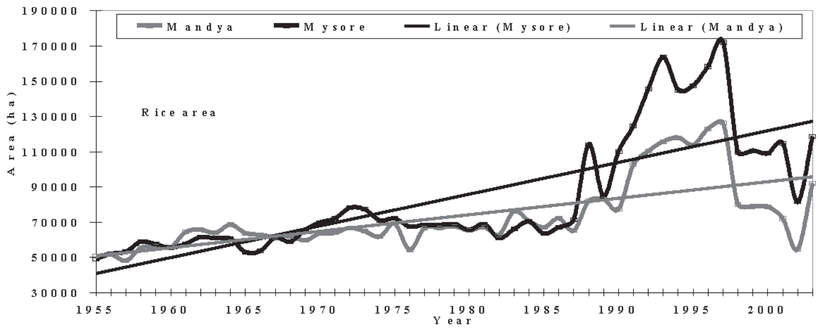

Fig. 5.11 Increase in Rice Area in Mandya and Mysore districts and their trends

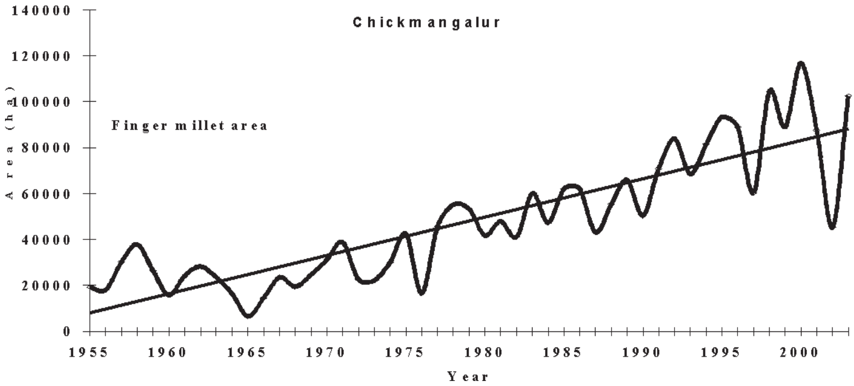

Fig. 5.12 Increase in Finger Millet Area in Chikkamagalur district and its trend.

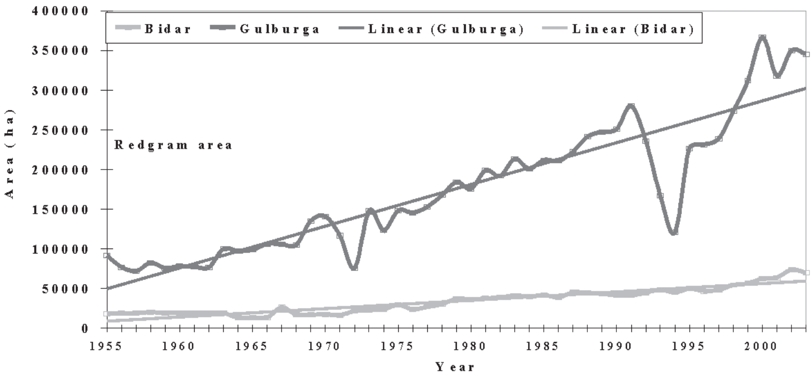

Fig. 5.13 Increase in Red gram Area in Bidar and Gulbarga districts and their trends

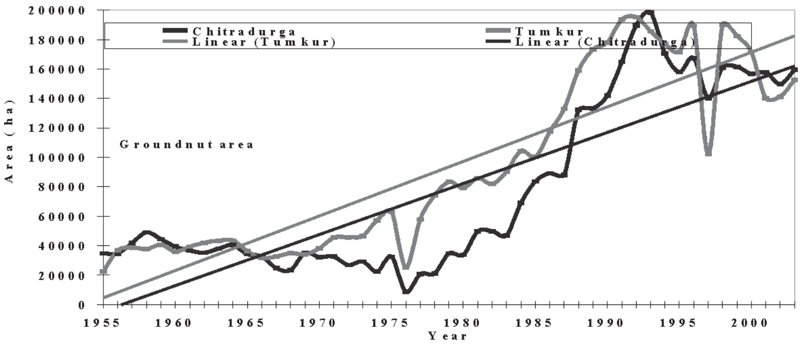

Fig. 5.14 Increase in Groundnut Area in Chitradurga and Tumkur districts and their trends.

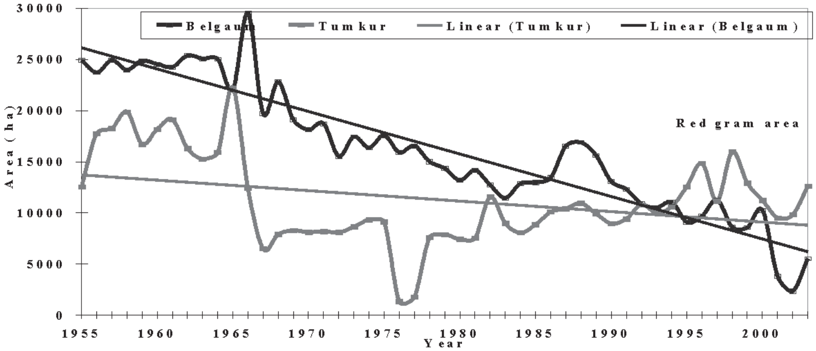

Fig. 5.15 Decrease in Red gram Area in Belgam and Tumkur districts and their trends

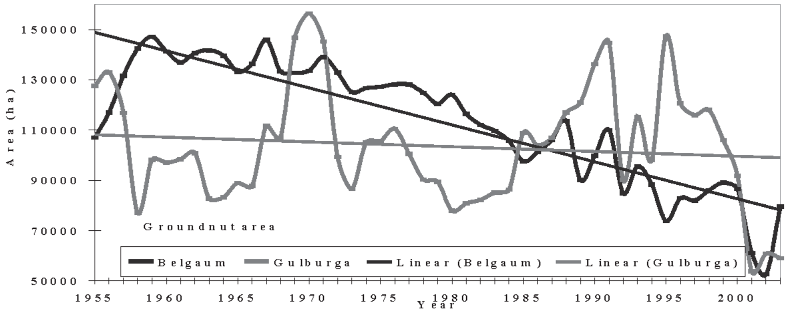

Fig. 5.16 Decrease in Groundnut Area in Belgam and Gulbarga districts and their trends

The declining trends of annual rainfall in Kodagu, Chikkamagalur and South Canara districts have been observed. This definite declining trend of rainfall in these districts indicates the deficiency of water requirement for the crops presently grown and suitable crop changes have to be adopted, so that the crops do not suffer with moisture stress due to the shortage of water under the declining trend of rainfall. The increasing trend of annual rainfall in Bangalore, Kolar and Tumkur districts have shown the considerable increasing in available rainwater and high water required crops can be raised to realise higher yield. Increasing in rice area in Mysore and Mandya districts is due to increase in irrigation area and also reduction in rainfed agriculture. In case of Chikkamagalur district, the fingermillet area is increasing due to the declining trend in rainfall. The farmers are changing their crops to raise better crops based on the available water through rainwater. Hence, the area under finger millet is increasing. Red gram in Bidar and Gulbarga districts and Groundnut in Tumkur and Chitradurga districts is increasing due to the decline in the terminal southwest monsoon rainfall marginal and increase in the northeast monsoon rainfall. In the same districts, the groundnut area is decreasing as the water requirement is not met during the pod filling and pod maturity of the crops as the September rainfall is decreasing. During this period, the redgram will not be affected as the crop is in vegetative stage and does not demand more water and hence the red gram area is increasing in these districts and groundnut area is decreasing.

Guruprasanna et al (2006) have shown that there is a decreasing trend in the mean annual rainfall in the Coorg district. There is decline in rainfall in coastal and hilly zones and increase in some interior zones. Increase in rainfall from 725 mm to 825 mm in the Eastern Dry zone is observed (annual Report of AICRP on Agrometeorology, UAS, GKVK, Bangalore 2002-03). The seasonal shift in the rainfall for Eastern dry zone and Southern Dry zone has been reported by Rajegowda *et al.,* (2000). The change in the seasonal rainfall in a particular zone also affected the rate of sowing which in turn affected the grain yield.

5.3 Economic impact of AAS

The economic benefit obtained by farmers following the Agromet advisory has been evaluated for both *Kharif* and Rabi seasons for the period from 2004 to 2006. The total cost of cultivation was found to be lower in the case of AAS farmers who have effectively adopted the ago-advisory compared to Non -AAS farmers. Further, the grain yield, straw yield and net returns were 2323 kg/ha, 1551 kg/ha and Rs.8728.5/ac, respectively in case of AAS farmers and 2148 kg/ha, 1295 kg/ha and Rs.5981.3/ac in case of Non-AAS farmers for finger millet crop.

Issual of AAS bulletins to the farmers helps to avoid the adverse effects of weather events like heavy rain, dry spell, high wind speed which influences the growth of the crops. It is a cumulative effect of services. Therefore, farmers save inputs like irrigation, pesticides and fertilizers and thumb rule is also applied for anticipating local weather situations. It is observed that the high benefit has been realized with the efficient management practices based on the AAS bulletins which contain the information mainly on weather parameters and not to depend on high input application. This helped the day-to-day agricultural operation and thus AAS farmers got higher benefit than non AAS farmers. It was created awareness in farmers to adopt the Agromet advisory in their daily activities.

5.4 Temperature trends

In another attempt Rajegowda and Nagaraj (1995) and Rajegowda (1992) indicated that the average raise in annual temperature was 1.3^{0}C in the State of Karnataka during 1950 to 1990 (Fig. 5.17).

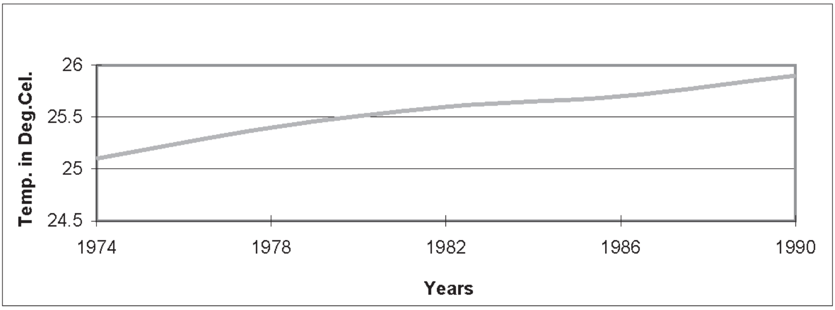

Fig. 5.17 Increase in mean Temperature in the State of Karnataka

Under the influence of changes in climatic parameters, increase in water demand is observed in many crops. In grape, recommended quantity of water is not sufficient to meet the crop water requirement in these days. On the basis of experiment conducted in the farmers' field on crop water requirement of grape, it indicated that the recommended quantity of water was sufficient to meet the water requirement of the crop up to 8th week after pruning, afterwards the water provided through drip irrigation was not sufficient and the crop growth was affected and this was verified through the water balance model with variable crop coefficient at different stages. This also lead to reduction in fruit size after some weeks. Then addition of adequate water based on water requirement using crop coefficient and using water balance model, the growth was adequate and increase in fruit size also observed. The water required at different weeks after pruning is shown in Fig. 5.18.

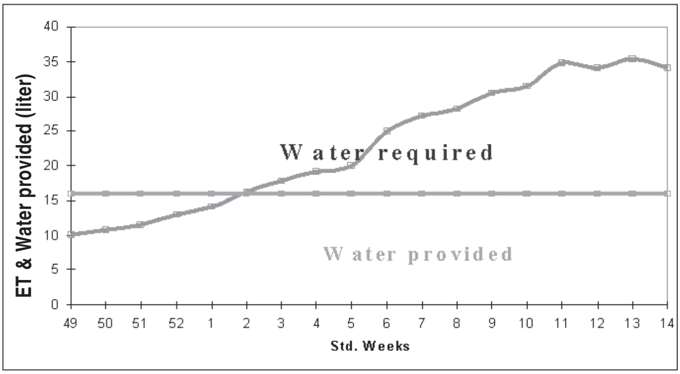

Fig. 5.18 Crop water requirement of grape after pruning at Bangalore

The area under forest cover has been plotted in Fig. 5.19. The data (Anonymous 1989 & 2003) of forest cover indicated that the forest area is being increased. Raise in temperature and forest area and decline in rainfall were is reported by Rajegowda, 1992.

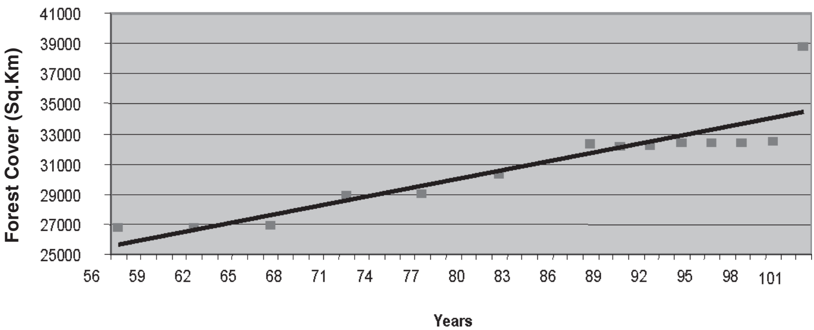

Fig. 5.19 Forest cover over Karnataka from 1956 to 2004

5.5 UV-B Radiation

The enhanced UV-B radiation has an ill-effect of decreasing photosynthesis, plant height and leaf area, dry matter production, yield and reduction of quality in many crops. The biological effectiveness of the UV radiation is measured in MED/hr (Minimum Erythema Dose per hour). The diurnal variation of the UV-B radiation (Fig. 20) showed that maximum UV-B radiation is received between 1200 and 400 hrs and 6th March 2004 had received the highest daily total UV-B radiation of 13.93 MED during the year, which is still below the threshold level. The monthly integrated values indicated that March received the highest of 315.27 MED and November received lowest of 144.32 MED during the year 2004. Remaining months received the UV-B radiation in between these two values. The annual total radiation received during the year 2004 is 2968.65 MED.

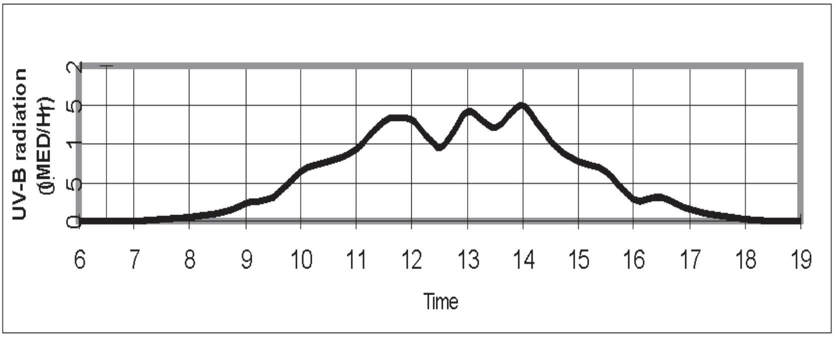

Fig. 5.19 Diurnal UV-B radiation on 06-3-2004 at Bangalore

5.6 Conclusions

The above studies reveal that there was a shift in rainfall over Karnataka during the crop seson. Shift in rainfall and its variability over a period of time led to change in croping systems in different regions of Karnataka. Unlike in other states, forest cover is increasing over Karnataka. Increasing temperature and decline in rainfall were noticed over different regions of the state. Though the models syndicate increase in temperature and rainfall over India, It appeares to be not realing in several states as they experience increase in temperature and decline in rainfall.

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CHAPTER 6

Impact of Climate Change on Agriculture over northern Karnataka

**H. Venkatesh, K. Krishna Kumar,
S. G. Aski and S. N. Kulkarni**

Rainfall during the initial years of this millennium in Northern Karnataka has been very low and erratic. This has created more apprehensions in the mind of the people, including farmers, whether it is due to the climate change. More queries were raised on industrialization and deforestation and their effect on global warming. This recent experience only points to the vulnerability of the agricultural system to the climate variability and climate change. Indian monsoon is noted for its vagaries. The rainfall patterns have shown considerable differences in both space and time, suggesting widely varying impacts on the economies of the respective regions (Rupa Kumar *et al*., 2002). Now, climate change has become an additional challenge or hurdle particularly to the farming community in the cultivation of various crops.

The northern Karnataka comprises of five agroclimatic regions. Of these, the Northern Dry Zone and Northeastern Dry Zone are characterized by high temperature and low and erratic rainfall. Further, vast areas in these zones are characterized by higher rainfall during the months of September and October, compared to early monsoon months of June, July and August. Hence, the rainfed crops like sorghum, wheat, chickpea and sunflower are grown under receding soil moisture conditions of *rabi* rainfall (September – October) in medium and deep black soils, and are therefore prone to moisture stress caused by variations in rainfall in the two months individually. Amongst these, sorghum being a more tolerant crop to moisture stress, and also being the dominant staple food of Northern

Karnataka, is grown in large areas, and therefore has been appropriately chosen for the present case study in the northern and the northeastern dry zones represented by the districts of Bellary, Bijapur, Gulbarga and Raichur.

In this chapter, we intend to present a case study on the deviations of climate variables, particularly rainfall and temperature, in northern Karnataka in the twentieth Century. We also present how the *rabi* sorghum genotypes were adopted during the period as a consequence to the changes in climate situations. Based on this, we have attempted to infer how the genotypes with different response functions to weather can be used in different climate epochs and therefore in changing climate scenarios.

6.1 Biophysical diversity

In the rainfed dryland areas of northern Karnataka, tremendous efforts have been made to arrest soil and water losses through recommendation and adoption of appropriate conservation measures. Simultaneously, attempts have also been made to control deforestation, but with limited success. Of late, *Vanamahotsava* programs have been accelerated in Karnataka to increase the area under forestry, particularly social forestry. Increase in the number of check dams, farm ponds, reservoirs and other soil and water conservation measures have not only reduced soil erosion to a considerable extent but also improved the groundwater levels and enhanced the water resources in the region. On the other hand, the cropping programs have seen numerous ups and downs during the past two decades. A couple of decades ago, single crop was grown in medium to deep black soils, while double cropping has come into vogue in recent years, which indicates better resource management. The crop diversification has been due to various factors like, both pest management during crop season and handling at the time of harvest, due to presence of thorns in case of safflower, pest problem in case of cotton and sunflower, and improved management strategies like double cropping in medium to deep black soils. In northern Karnataka, safflower has been replaced by sunflower, which in turn could survive only a few years, to pave way for cotton in rainfed areas of Gadag district. In command areas of Malaprabha, cotton has been replaced by maize-chickpea double cropping system. Rabi sorghum lost out to sunflower due to financial constraints, but sunflower faded out due to biotic stress menace of necrosis, powdery mildew and alternaria diseases. In spite of the fact that the pest-problem was the main constraint for crop diversification, none of the cropping shifts has been ascribed to changes in weather and climate, even though it is well known that most pests and diseases are weather dependent.

6.2 Climatology of northern Karnataka

Karnataka state covers a large latitudinal belt, and therefore is characterized by considerable differences in climate characteristics. The rainfall and temperature characteristics during cropping seasons in different districts of northern Karnataka are given in Table 6.1. It is noticed that, at Bellary and Bijapur, which are located in the Northern dry zone of Karnataka, September and October are the main rainfall months. The rainfall at Bellary during June-August is so low that only the crops with very little water requirement can be grown in the *kharif* season. At Gulbarga and Raichur, which are

Table 6.1 Climatological normals of temperature and rainfall in Northern Karnataka (1901-1999)

Month	Bellary			Bijapur		
	Temperature (°C)		Rainfall (mm)	Temperature (°C)		Rainfall (mm)
	Maximum	Minimum		Maximum	Minimum	
June	34.5	23.5	48.4	33.4	22.0	84.1
July	32.1	23.2	46.9	30.4	21.5	73.5
August	31.9	22.9	66.1	30.3	21.3	82.1
September	32.0	22.3	125.0	30.9	21.2	148.7
October	31.4	20.9	96.7	31.3	20.3	95.2
November	30.3	18.2	37.7	29.5	17.4	29.5
December	30.0	16.5	10.0	29.5	15.6	6.3
January	30.8	16.8	2.8	30.3	16.1	4.2
February	33.8	18.8	3.6	33.1	18.1	2.3
	Gulbarga			**Raichur**		
June	35.3	23.7	105.2	35.2	23.7	96.6
July	31.8	22.5	134.3	32.2	22.7	129.9
August	31.3	22.2	144.5	31.9	22.4	140.9
September	31.6	22.1	179.4	31.9	22.4	153.5
October	32.2	20.7	73.3	31.4	21.7	94.0
November	30.7	17.6	26.3	30.2	19.2	23.0
December	30.1	15.6	4.7	29.6	17.6	5.2
January	30.7	15.8	5.0	29.9	17.9	2.6
February	33.6	18.3	5.6	33.4	19.8	4.5

located in the Northeastern dry zone of Karnataka, rainfall period extends from June to October. In northern dry zone, Bijapur is cooler during this season by about 1.0^{0}C in terms of both maximum and minimum temperatures. On the other hand, in the northeastern dry zone Gulbarga is warmer by about 1.0^{0}C during daytime, but cooler by more than 1.5^{0}C during night time, particularly from November to February. During the flowering and grain formation stage of *rabi* sorghum (December-January), the minimum temperature at Raichur is above 17^{0}C. It is important to take these climate situations into consideration while selecting suitable crops, cropping systems, cultivars and sowing windows.

6.3 Climate variability

6.3.1 Rainfall

The variability patterns of four districts viz., Bellary, Bijapur, Gulbarga and Raichur are depicted in Figs. 6.1 to 6.4. In Bellary, September rainfall showed a decreasing trend during the 20th Century and a clear cyclic nature is found in three distinct periods centering from 1905-1926, 1927-1956 and 1957-1990. The first one was a high rainfall epoch followed by low rainfall epoch and once again a high rainfall epoch. Thus, the differences between rainfall of September-October were larger in the first and third periods (epoch), whereas in the intermediate period, the differences were very small. Looking to the tendencies, the low rainfall epoch of September is expected to follow next. At Bijapur, slightly increasing trend of rainfall was noticed in both September and October since 1940s. Low rainfall periods of September synchronized with high rainfall periods of October and *vice versa*. The differences in rainfall between September-October were large in high September rainfall epochs, since even in high October rainfall epochs, the October rainfall just neared the September rainfall. No linear trend is noticed in the case of Gulbarga for September rainfall, whereas rainfall in October showed a linear trend with an increase from about 60 mm at the beginning of the 20th Century to 100 mm at the end of the Century. A general decrease of rainfall in September and clear increase in October were observed during the 20th Century at Raichur. Rainfall profiles were similar for September and October till 1950s. It is from this time the tendencies became opposite - high rainfall epoch of October synchronizing with low rainfall epoch of September and *vice-versa*. This is similar to Bijapur pattern. These types of similarity

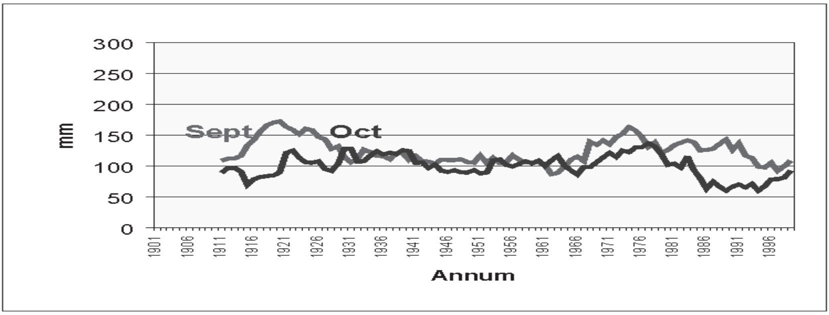

Fig. 6.1 Rainfall during rabi sowing months at Bellary

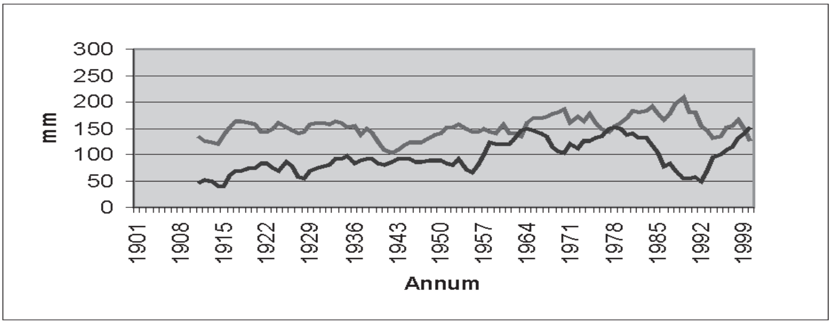

Fig. 6.2 Rainfall during rabi *sowing months at Bijapur*

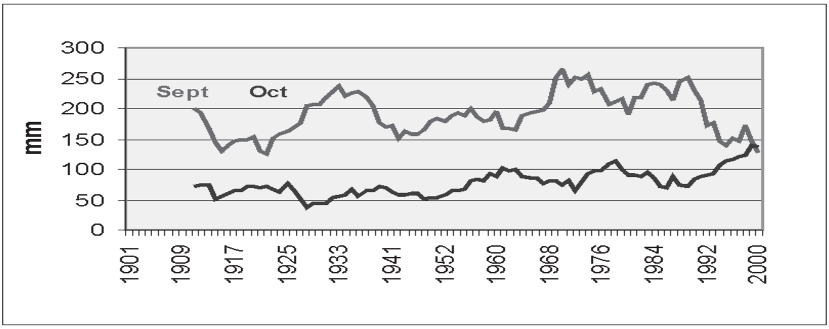

Fig. 6.3 Rainfall during rabi *sowing months at Gulbarga*

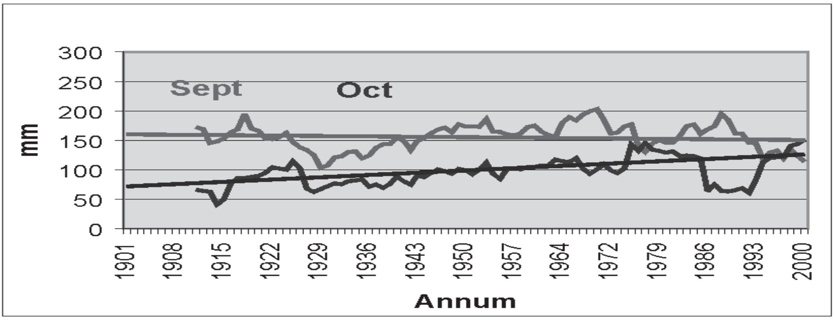

Fig. 6.4 Rainfall during rabi sowing months at Raichur

in climate variability scenarios – whether they are synchronous or out of phase – are to be considered beneficial for planning agricultural planning in the long run. The annual rainfall variability indicated that there is a periodicity of 13-17 years cycle across the northern districts of Karnataka.

6.3.2 Temperature

A general decrease of maximum temperature during November and December was noticed in Bellary during the twentieth century. In the second half, the maximum temperature showed considerable variability, with alternate high and low epochs. On the contrary, minimum temperature decreased sharply after 1960s. In addition, considerable inter-annual variations to the extent of more than 6°C were noticed. In individual years, maximum temperature varied between 28.0 °C and 31.5 °C. During the high rainfall epochs, rainfall and maximum temperature tendencies were opposing. The fluctuations of maximum temperature at Bijapur showed a general increasing trend, but large fluctuations were noticed after about 1960, resulting in high maximum temperature and low maximum temperature epochs.

The minimum temperature variations were nearly static till about 1950, after which mild low and high minimum temperature epochs prevailed alternatively, the sequence being exactly the opposite of maximum temperature. At Gulbarga, the maximum temperature in both November and December smoothened out in the later part of the century, indicating nearly stable day time temperature for crop growth. Minor high and low minimum temperature epochs were noticed. Looking to the above, lower minimum temperature epoch in December has arrived, which could result in poorer physiological activity of the crop and reduce the yields. At Raichur, a slightly increasing trend of maximum temperature is noticed in both November and December. Decreasing trend in minimum temperature also indicates an increase in diurnal temperature range, which could be physiologically important for sorghum crop, resulting in desiccation.

6.4 Climate change

The changes in rainfall and temperature in northern Karnataka during the past Century are given in Table 6.2. Rainfall at Bellary in September decreased from 111.4 mm in the first decade to

102.7 mm in the last decade of the twentieth century, while rainfall in October increased from 88.4 mm to 102.1 mm during the same period. Maximum temperature decreased by 1.7°C in October, 0.7°C in November and marginally by 0.4 °C in December. On the other hand, there was a drop in minimum temperature by 2°C in all the three months. Rainfall in September at Bijapur showed a marginal decrease by 7.7 mm (from 144.1 mm to 136.4 mm) from the beginning of the century to the end, whereas the October rainfall indicated a sharp increase by 121.6 mm (from 46.7 to 168.3 mm). Decrease in maximum temperature in October by 2.0 °C from 33.4°C to 31.3 °C could be ascribed to a large increase in rainfall. Practically no change in maximum temperature could be noticed in November while increased by 0.5°C (29.1°C to 29.6°C) in December. There was an increase in minimum temperature by 0.6°C in October, 2.7°C in November and 1.9°C in December.

Table 6.2 Climate change during the 20th century in northern Karnataka

a) Rainfall

District	September		October	
	1901-10	1991-2000	1901-10	1991-2000
Bellary	111.4	102.7	88.4	102.1
Bijapur	144.1	136.4	46.7	168.3
Gulbarga	206.4	131.0	76.2	131.7
Raichur	180.4	115.8	69.2	158.3

b) Maximum temperature

District	October		November		December	
	1901-10	1991-2000	1901-10	1991-2000	1901-10	1991-2000
Bellary	33.1	31.4	31.2	30.5	30.2	29.8
Bijapur	33.4	31.3	30.3	30.4	29.1	29.6
Gulbarga	32.7	32.1	30.9	31.7	29.5	30.6
Raichur	32.3	31.6	30.3	31.0	29.0	29.9

c) Minimum temperature

District	October		November		December	
	1901-10	1991-2000	1901-10	1991-2000	1901-10	1991-2000
Bellary	21.9	19.1	18.9	16.9	15.9	13.9
Bijapur	20.4	21.8	16.2	19.5	14.2	16.1
Gulbarga	20.5	22.2	16.9	18.9	14.8	15.7
Raichur	22.3	22.3	19.4	22.2	17.4	16.9

Rainfall at Gulbarga decreased by 65.0 mm (from 206.4 mm to 131.0 mm) in September and increased by 55.5 mm (from 76.2 mm to131.7 mm) in October over the 20th century. The maximum temperature increased by 0.8°C in November and 1.1°C in December. At Raichur, rainfall decreased by 64.6 mm in September, from 180.4 mm during 1901-10 to 115.8 mm during 1991-2000. In October, rainfall increased by 89.1 mm, from 69.2 mm to 158.3 mm in the corresponding periods. Maximum temperature decreased by 0.7°C in November and 0.9°C in December. On the other hand, minimum temperature increased by 2.8°C in November and decreased by 0.5°C in December.

Thus, there was a general decrease of rainfall in September and large increase in October over northern Karnataka during the 20th century. Corresponding decrease in maximum temperature during October was noticed. An increase of temperature in November and December could be observed, indicating greater thermal energy for better vegetative growth during November while greater thermal stress during flowering period in December for *rabi* sorghum crop.

6.5 Weather extremes

Northern Karnataka faced extreme drought situation during 2003-04, with all the *rabi* crops showed poor crop stand and the crops not even reached reproductive stage. The year 2004 experienced hotter in March. The maximum temperature during 2004 was more than the all time highest temperatures during March 18-25 (Figs. 6.5 - 6.7). On the other hand, the year 2007 was very eventful, because the heaviest rainfall event in the history of northern Karnataka occurred on June 23. On this day, Bijapur received as high as 180.8 mm rainfall, of which 168.4 mm occurred in just about six hours time, which was an all time record. Rainfall that occurred due to a depression moved slowly across northern Karnataka districts inundated many low lying areas, collapsed culverts and bridges, crops like sugarcane were submerged in the waters and hundreds of villages marooned. This was perhaps the worst physical damage to crops during recent years.

Lowest minimum temperature of sub-ten degrees prevailed at Bijapur during November 23-26, 2007. The all time record of 6.5 °C and 5.6 °C were recorded on November 23 and 24, respectively. In the past 25 years, the minimum temperature of less than 10 °C was reached only on a single day during November, and there were seven such occasions prior to 2007. In the year 2007, this situation prevailed consecutively for four days. Even though this extreme drop in minimum temperature did not affect the crops much, flower

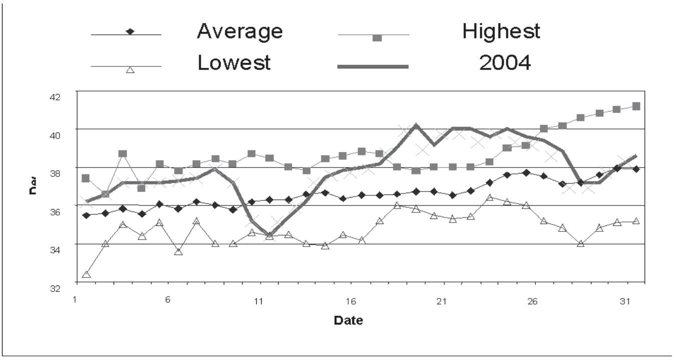

Fig. 6.5 Daily maximum temperature during March 2004 from 1995- 2003

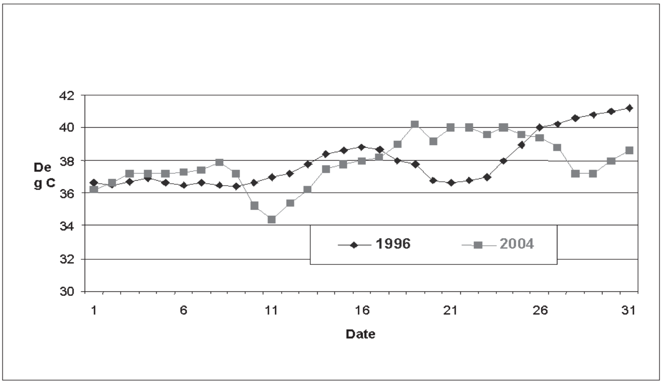

Fig. 6.6 Comparison of daily maximum temperature during March in the years 1996 and 2004

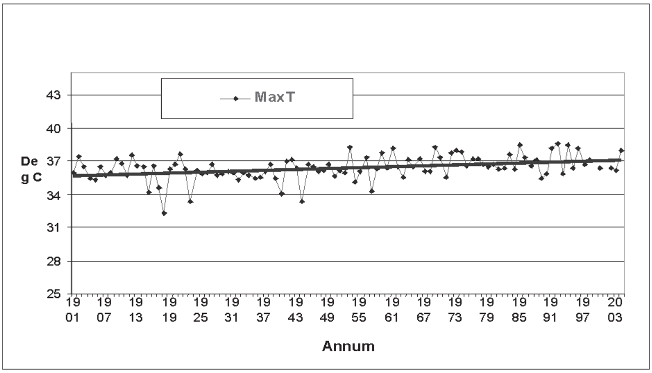

Fig. 6.7 Trend in maximum temperature in March at Bijapur

dropping in late sown pigeonpea was noticed at the time of the event. However, the pigeonpea crop has the ability to rejuvenate after such minor adverse situations.

6.6 Vulnerability assessment of climate variability

6.6.1 Selection of sorghum genotypes

- Farmers used Gundudeni variety during 1940-70 because it was the best available in terms of drought resistance and good quality grain and fodder
- About 40% of the farmers interviewed informed that, it was the only variety available at that time
- The released varieties, viz., SPV-86 and 109-R were not continued for longer periods, because of drastic reduction in yield after 2 to 3 years of their adoption
- The farmers shifted to cultivate M35-1, as they found it to be a high yielder having bold seeds and good fodder quality, thereby fetching better market value in addition to being a drought resistant variety
- Gundudeni was replaced by M35-1, particularly because the former was susceptible to insect damage to ear head stage

Profiles of popularity levels of two *rabi* sorghum cultivars, viz. M35-1 (Maldandi) and 5-4-1 (Muguti) as indicated by both the farmers and the scientists are presented in Fig. 6.8 . It can be found that, even though 33% of scientists mentioned that M35-1 was popular among the farmers in 1940s itself, it is noticed that among the farmers interviewed, it was put to use by just 1% of them even during the decade 1950-60. Eighty three percent of scientists viewed that the variety was popular among the farmers during 1960-90. It was only during 1980-90 that, the farmers said, they used the variety M35-1 predominantly (81%). These differences can be attributed to delay in adoption of transferred technology by the farmers. In case of Muguti too, it is noticed that even though 33% of scientists indicated that Muguti was popular among the farmers all through, only 7 to 7.5% farmers adopted the variety (1970-80 and 1980-90). Thus, we find that the farmers do not adopt new varieties as soon as they are released (i.e., with minimum time gap), and also only a limited number of them adopt it. Because of this time gap mentioned, there is always a possibility that, due to climate variability, the farmers might take up a new variety under relatively adverse climate epochs, thereby making them vulnerable to the changed climate scenario, and reject them straight away in view of their poor performance. This perhaps is the reason why some of the recently developed genotypes have failed in farmers' field, as in case of cultivars SPV-86 and 109R.

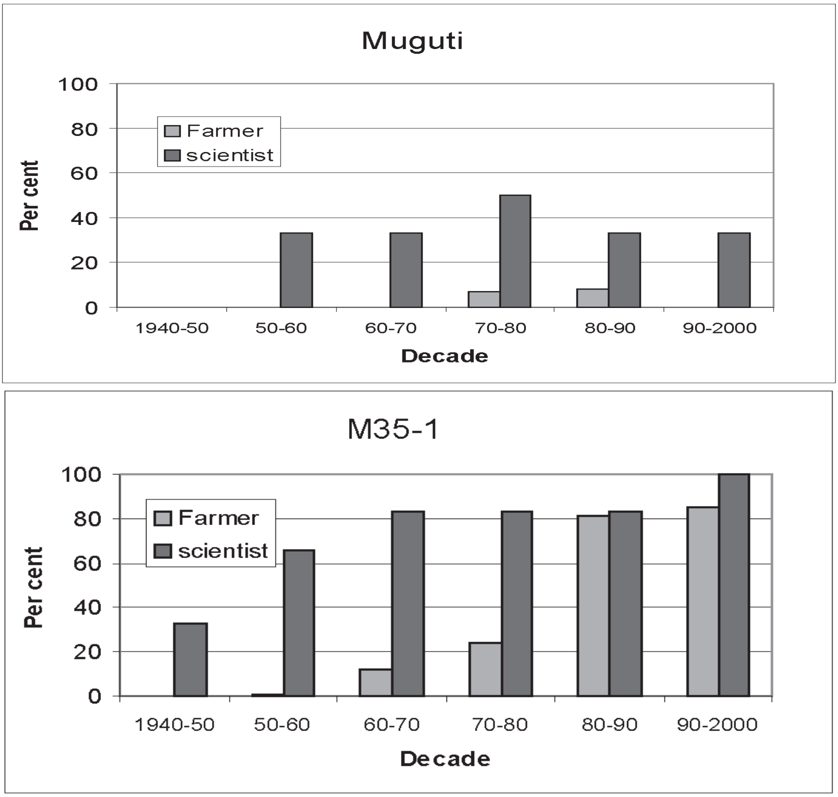

Fig. 6.8 Popularity of rabi *sorghum genotypes at different periods of time as expressed by scientists and farmers*

Any new variety developed should have the capability of out-yielding M35-1 variety in times of abiotic and biotic stresses. No variety developed so far has been able to do both. However, sorghum breeders have identified cultivars that are tolerant to these individual characters. These genotypes need to be selectively adopted in different climate epochs. These are found to be successful under favourable moisture conditions too. The list of *rabi* sorghum genotypes identified for different types of stress are given in Table 6.3.

It is inferred that in epochs of low September and high October rainfall, genotypes resistant to pest incidence should be opted. As discussed in the previous section, among the genotypes mentioned, the cultivars SPV-86, 9-13, GRS-1, CSV-216R (Phule Yashoda) could be used in high October rainfall epochs whereas, Muguti, M35-1 and Selection-3, which are of drought resistant type, could be used during epochs of high September (low October rainfall).

Table 6.3 Rabi *sorghum genotypes identified for different stress*

Genotypes identified for abiotic stress tolerance	
• Drought tolerance:	Var. M35-1 (Maldandi) Var. 5-4-1 (Muguti) Var. Selection-3
Genotypes identified for biotic stress tolerance:	
• Charcoal rot disease:	Var. 9-13 Var. GRS-1
• Rust disease:	Var. 9-13
• Shootfly pest:	Var. GRS-1 Var. Muguti (5-4-1) Var. SPV-86 Var. CSV-216R (Phule Yashoda)
Genotypes promising under optimum soil moisture conditions	
• Favorable soil moisture:	Var. 9-13 Var. GRS-1 Var. CSV-216R (Phule Yashoda) Var. SPV-86

Indication of climate tendencies in northern Karnataka

District	Parameter	1949-50	1950-60	1960-70	1970-80	1980-90	1990-2000
BELLARY	Rainfall (Sept)	Low	Low	High	High	High	Decreasing
	Rainfall (Oct)	Low	High	High	Low	Low	Increasing
	Max.T. (Dec)	Decreasing	Low	Increasing	Increasing	Decreasing	Increasing
	Mint.T. (Dec)	Low	Increasing	High	Decreasing	Decreasing	Very Low
BIJAPUR	Rainfall (Sept)	High	Low	High	Increasing	High	Decreasing
	Rainfall (Oct)	Low	High	Low	High	Low	Increasing
	Max.T. (Dec)	Low	Increasing	High	Decreasing	Decreasing	Low
	Mint.T. (Dec)	Low	Increasing	High	Low	High	Low
RAICHUR	Rainfall (Sept)	High	Low	Decreasing	Increasing	High	Low
	Rainfall (Oct)	Increasing	Increasing	Increasing	High	Low	High
	Max.T. (Dec)	Decreasing	Increasing	Decreasing	Increasing	High	High
	Mint.T. (Dec)	Low	Increasing	Decreasing	Increasing	Decreasing	Increasing

In view of the above it is necessary that:

❖ Genotypes that are already released or developed and are in successful cultivation should be preserved for future suitable climate scenarios similar to the ones in which they were developed.

❖ The breeders should develop cultivars with the objective of "Cultivars for specific rainfall epochs" approach and popularize them keeping this in view.

This would help in sustaining the *rabi* sorghum yields in the future climate change scenarios by synchronizing favorable cultivars in corresponding epochs. The analysis presented here has been on qualitative lines. It would be more pertinent to perform quantitative analysis using past records of yields of different cultivars in individual districts / talukas in relation to climate variability scenarios.

6.7 Short term rainfall projections

The observed and simulated rainfall variability patterns at Bijapur for September, October and *rabi* season (Anonymous, 2003) are presented in Fig. 6.9. The patterns of observed and simulated series are strikingly similar for September and *rabi* seasonal rainfall. In

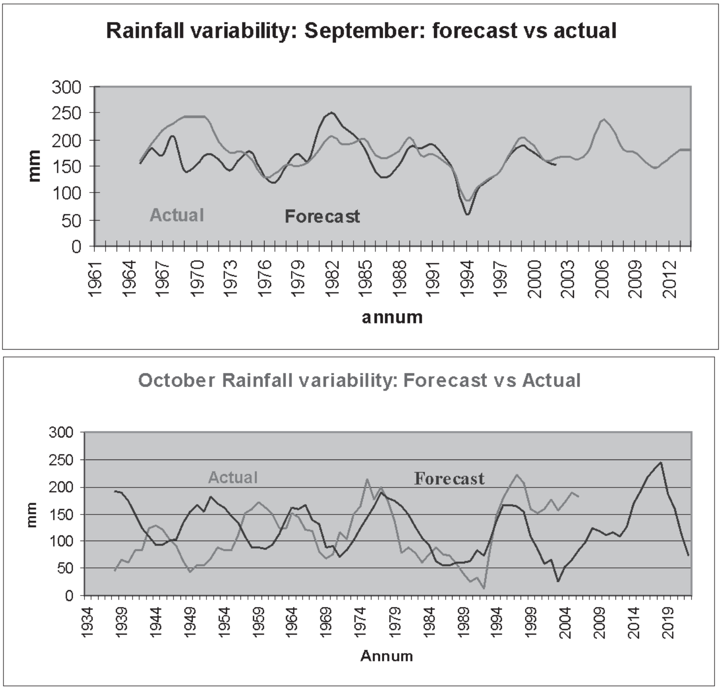

Fig. 6.9 Short term projection of rainfall for Bijapur

case of October rainfall the estimations are lower, but the pattern follows the actual. The immediate projections indicate high rainfall epoch in the next 4-5 years followed by low rainfall epoch for September, and reverse variability for October. This suggests that in the next 4-5 years, drought resistant genotypes like M35-1 and Muguti should be adopted, whereas the pest resistant genotypes like 9-13, GRS-1 and Phule Yashoda should be opted later on.

6.8 Long term rainfall projections

During early 2040s Bellary would experience rainfall of 50-70mm in both September and October. Hence during this period, varieties which are tolerant to extreme drought situations and are of short duration, should be opted. On the other hand, a rainfall situation of 200 mm in September and 50 mm in October is projected during 2050s and hence the genotypes like 9-13, Phule Yashoda and GRS-1, which thrive in good rainfall situation should be preferred (Fig.6.10). The pest tolerant cultivars would be vulnerable to abiotic stress during 2040s and drought tolerant genotypes would be

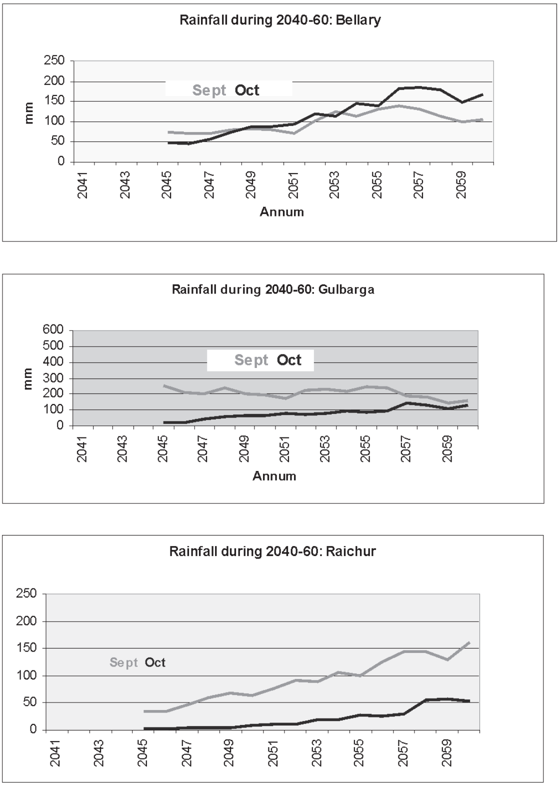

Fig. 6.10 Climate change projections for 2040-2060 in north Karnataka

vulnerable to biotic stress during the 2050s for the corresponding climate change scenarios. Climate change projections for Raichur indicate an increasing trend in both September and October rainfall. Hence, the pest tolerant genotypes would be susceptible in ensuing two decades. This suggests that selection of the drought resistant genotypes like M35-1, Muguti and Selection-3 for Raichur during the mid 21st Century.

Hence, it would be possible to avoid susceptible genotypes during adverse climate epochs and choose the cultivars that are tolerant to the corresponding climate epochs, in case of climate projections of both short term and long term nature.

This chapter thus provides a methodology to plan for selection or breeding of genotypic characteristics suitable to the different projected climate variability and climate change scenario. Such planning can, not only reduce production losses by 20 to 25 per cent, but also can address many problems associated with climate variability and climate change, which have become an additional challenge to the farming community in the cultivation of various crops.

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CHAPTER 7

Impact of Climate Change on Agriculture over Maharashtra

D. D Mokashi, J. D Jadhav and J. R. Kadam

Global climate varies naturally, but scientists agree that rising concentrations of anthropogenically produced greenhouse gases in the earth's atmosphere are leading to changes in the climate. According to the Intergovernmental Panel on Climate Change (IPCC), the effects of climate change have already been observed and scientific findings indicate that precautionary and prompt action are necessary. Increased frequency of storms and floods, increased occurrence and severity of droughts and forest fires, a steady expansion of frost-free intervals (potential growing season), more virulent attacks of diseases and insect pests and vanishing habitats of plants and animals are copiously reported in recent times due to climatic change. Some temporary measures to adopt existing forest ecosystems to limited changes are possible and have been suggested (Papadopol, 2000) and given in Table 7.1.

Table 7.1 Predicted effects of climate change on agriculture over the next 50 years

Climatic element	Expected changes by 2055's	Confidence in prediction	Effects on agriculture
$C0_2$	Increase from 360 ppm to 450-600 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	Rice 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, SOI, 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 farming operations
Source: Climate Change and Agriculture, MAFF (2000)			

7.1 Climate change/variability

Confirmed global warming in recent years with shift in precipitation zones would bring more areas under drought and exposing the vulnerability of the countries affected. Monitoring the occurrence of drought is helpful to the various disciplines like administration, planning, agriculture and hydrology to take remedial measures. Bhalme and mooley (1980) observed large scale drought in 1891-1920 and 1961-75. Mooley and Parthasarathy (1983) and Chowdhary *et al.,* (1989) discussed different aspects of drought in India. A method has been devised to monitor drought of Madhya Maharashtra based on historical data. The method of analysis is based on standardized precipitation index; SPI=Xi –X/δ

Where, Xi – Period of rainfall under consideration, X – Mean rainfall, d – Standard deviation of corresponding period. The intensity of drought categorised based on standardised participation Index is as follows:

Category	SPI
Normal	-055 to 0.55
Moderate drought	-1.0 to less than -0.55
Sever drought	less than -1.05

7.1.1 Drought prediction over Madhya Maharashtra

One of the drought prone areas in the Country is Madhya Maharashtra. When June receives normal rainfall, the chances of severe drought in next two months, next three months and next four months is less than 10%. However, normal rainfall during June does not necessarily rule out occurrence of moderate drought in subsequent periods. The chances of moderate drought in June + July is once in four years while for the next three months period (June + July + August) or season as a whole it is once in five years. When a moderate drought is felt in June, there exists nearly 15% probability for the severe drought to occur during the period June + Jul, June + July + August and the season as a whole. Chances of moderate drought being repeated in June + July and June + July + August are quite high (Nearly 35%), though for the season as a whole probability of moderate drought is comparatively less. The monitoring of drought is of vital importance not only to the agriculturist or the hydrologist but also the planners. Based on the above analysis , the monsoon features categorised are as follows:

Normal rainfall during *kharif* and *rabi* season; Normal rainfall during *kharif* and delayed in *rabi;*

Normal rainfall during *kharif* and weak in *rabi;* Delayed onset during *kharif* and normal in *rabi;*

Delayed onset during *kharif* and weak in *rabi;* Weak rainfall during *kharif* and normal in *rabi, and*

Weak rainfall during *kharif* and *rabi* seasons.

7.1.2 Rainfall variability

The available rainfall data of the Solapur centers of scarcity zone, which corner under MPKV Jurisdiction, was used for analysis by considering the decades and analysis was done for annual, monthly and seasonal basis. It was observed that during 1971-1990, the annual rainfall (792.2 mm) showed more stability (Fig. 7.1) as compared to normal rainfall (723.4 mm). However, the annual rainfall was decreased by 6% (678.6 mm) and 17% (601.1 mm), respectively during the decades of 1991-2000 and 2001-2007.

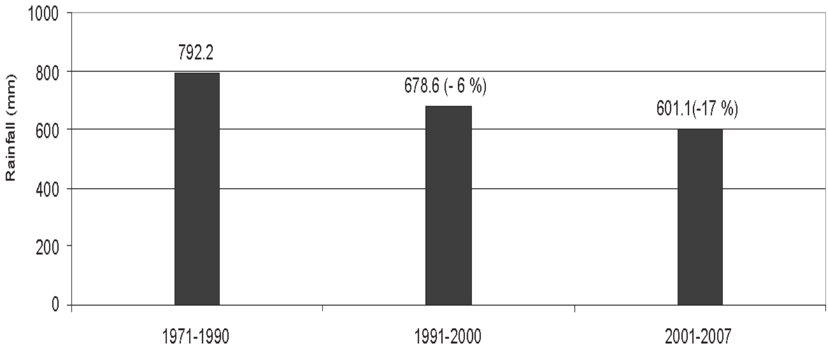

Fig. 7.1 Variation in annual rainfall at Solapur(M.S)

The variation of monthly rainfall in various decades (Fig. 7.2) indicated that the pre-seasonal rains in May showed increase in amount during 2001-2007. A close look showed that in the month of June and July, the rainfall amount was decreased during 2001-2007. Whereas, in the month of August and September the rainfall amount increased during the decade of 2001-2007. Further, in the month of October the rainfall amount showed the decreasing trend during 2001-2007.

It indicated that there is a shift of June rainfall to May, July rainfall to August and October rainfall to September. It showed that rainfall is assured in August and September during 2001-2007. But the shift of October rainfall may adversely affect on the productivity of the post rainy season sorghum.

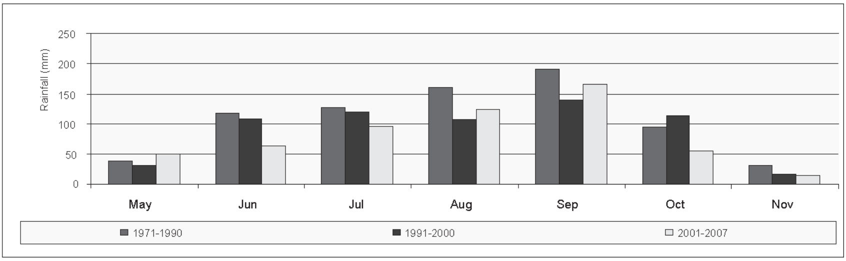

Fig. 7.2 Monthly rainfall variation at Solapur (M.S.)

7.2 Annual temperature variability

The annual maximum and minimum temperatures showed an increasing trend since last 39 years (1968-2007) over Solapur (Figs. 7.3 and 7.4).

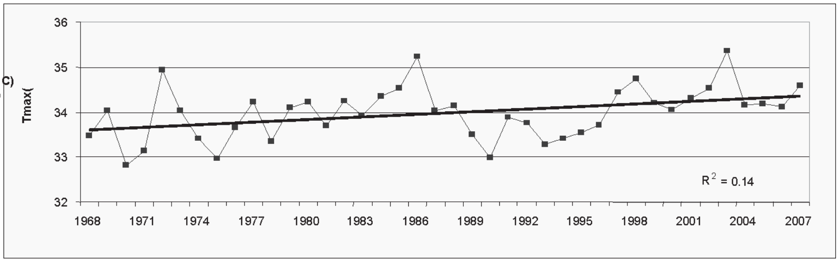

Fig. 7.3 Annual variation of maximum temperature at Solapur, M.S (1968-2007)

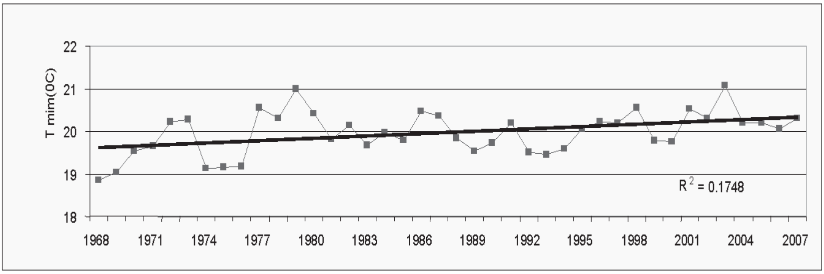

Fig. 7.4 Annual variation in minimum temperature at Solapur, M.S (1968-2007)

7.2.1 Maximum and minimum temperatures during *kharif*

In *kharif* season (Figs. 7.5 and 7.6), maximum temperature showed steady increase, however minimum temperature showed drastic increase during the study period. Further, it showed the stability in maximum temperature and steady increase in minimum temperature from 1968-1990. There is drastic increase in maximum and minimum temperatures from 1991 to 2007.

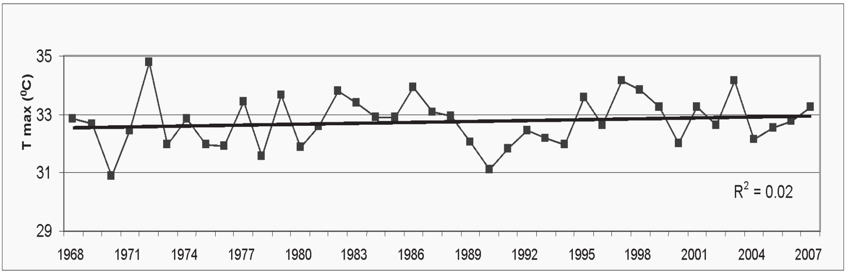

Fig. 7.5 Variation of maximum temperature in kharif *season at Solapur, M.S(1968-2007)*

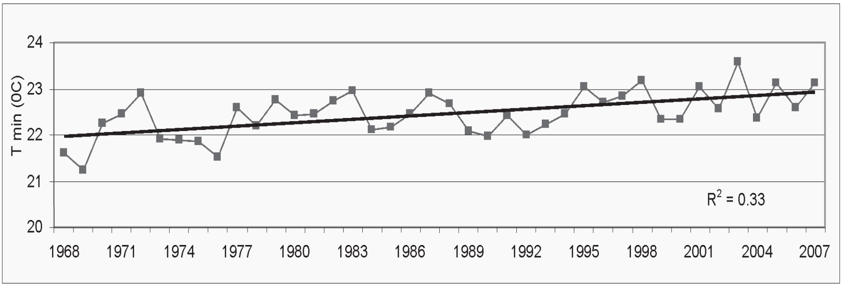

Fig. 7.6 Variation in minimum temperature in kharif *season at Solapur,M.S (1968-2007)*

It revealed that the maximum and minimum temperatures increased sharply during the last seven years in tune with global trends over the Solapur region during *kharif* season.

7.2.2 Maximum and minimum temperatures during *rabi*

The *rabi* season variation in maximum and minimum temperatures showed stability in increase of temperature from 1968-2006. It showed steady increase from 1968-1990 and drastic increase from 1991-2006 (Figs. 7.7 and 7.8).

It revealed that both the seasons experienced increase in temperature and it is sharp since last seven years, indicating that there is a need to crop varieties which can withstand and perform better under increased temperature scenarios.

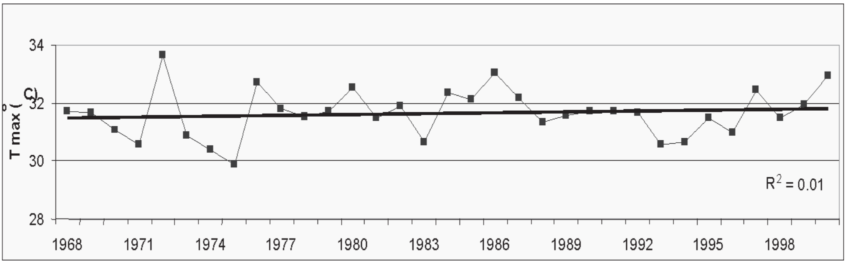

Fig. 7.7 Variation of maximum temperature in rabi season at Solapur, M.S (1968-2006)

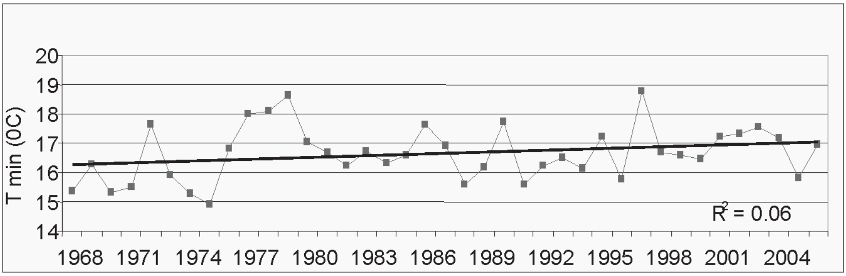

Fig. 7.8 Variation in minimum temperature in rabi season at Solapur, M.S (1968-2006)

7.2.3 Recommended cropping systems

Table 7.2 Suggested cropping pattern based on depth of soil and actual water holding capacity

Depth of Soil (cm)	AWC (mm)	Crops and varieties with duration (days)
< 7.5	15-20	Grasses (Marvel –8, 2 cuttings) and dryland horticulture (Ber, Custard apple, Anola, Pomegranate, Drumstick etc.)
7.5 – 22.5	30-35	Grasses (Marvel –8, 2 cuttings) , Kharif :Horse gram (Sina, Man) Mothbean (MBS-27), Castor (VI-9), Agroforestry & dryland horticulture.
22.5-45	40-65	Kharif : I. Sole Cropping : Sunflower (SS-56) ,Pearlmillet (Shradha), Pigeonpea (Vipula), Castor (VI-9), Groundnut (JL-286), Cotton II. Inter Cropping: Sunflower (SS-56) + Pigeonpea (Vipula), Pearlmillet (Shradha ,) + Pigeonpea (Vipula).
45-60	60-150	Rabi : Rabi Sorghum (M.35-1), Safflower (Bhima), Sunflower (SS-56), Gram, (Dig vijay).
> 60	> 150	Double Cropping : Kharif — Rabi Blackgram (TPU-4) — Rabi Sorghum (M.35-1) Greengram(Vaibhav) — Safflower (Bhima) Cowpea for fodder — Sunflower (SS-56, SS-2038(Bhanu) Pearlmillet(Shradha) — Gram (Vijay) Sunflower(SS-56) — Sunflower(Bhanu) Pearlmillet (Giant bajra) — Grarm (Digvijay) Sorghum for fodder (Ruchira) — Safflower (Bhima)

Table 7.3 Suggested cropping for mid-season correction during kharif *season with soils having depth of 45 cm for Scarcity Zone*

S N	Period	Suggested cropping pattern
1	Second fortnight of	All kharif crops
2	First fortnight of July	Pearlmillet (Shradha), Castor (VI-9), Pigeonpea (Vipula), Horsegram (Sina, & Man)
3	Second fortnight of July	Sunflower (SS-56), Pigeonpea, (Vipula), Horsegram(Sina-& Man), Castor (V-I)
4	First fortnight of August	Sunflower (SS-56,), Pigeonpea, (Vipula,), Castor (VI-9), Horsegram (Sina & Man).
5	Second fortnight of August	Sunflower (SS-56), Pigeonpea (Vipula),Castor (VI-9).
6	First fortnight of September	Rabi Sorghum for fodder.

7.3 Impacts on Indian Agriculture

1. Strengthen research on impact assessment of climate change on production resources, crops, livestock, fisheries and microbes using field and controlled environment facilities and simulation models as suggested below:
   - Spatial and temporal availability of surface and groundwater for irrigation
   - Sensitive processes such as pollen germination, spikelet sterility and grain development
   - Agricultural production (demand and supply of commodities, prices, trade, regional and societal differences)
   - Quality of produce
   - Germplasm variability and evolutionary trend
   - Diversity and dynamics of key insects and microbes including fungi, bacteria and viral pathogens
   - Livelihood of farmers and fishermen
2. Institutionalize the monitoring of phenology, especially of perennial crops, as a bioindicator of climatic variability and change.

7.3.1 Adaptation techniques

7.3.1.1 Develop new genotypes

- Intensify search for genes for stress tolerance across plant and animal kingdom.
- Intensify research efforts on marker aided selection and transgenic development for biotic and abiotic stress management.
- Develop heat and drought tolerant genotypes.
- Attempt transforming C_3 plants to C_4 plants.

7.3.1.2 Develop new land use systems

- Evolve new agronomy for climate change scenarios.
- Explore opportunities for maintenance /restoration/ enhancement of soil properties.
- Use multi-purpose adapted livestock species and breeds.

7.3.1.3 Enhance value-added weather management services

- Develop spatially differentiated operational contingency plans for temperature and rainfall related risks, including supply management through market and non-market interventions in the event of adverse supply changes.
- Enhance research on applications of short, medium and long range weather forecasts for reducing production risks.
- Develop knowledge based decision support system for translating weather information into operational management practices.
- Develop pests and disease forecasting system covering range of parameters for contingency planning and effective disease management.

7.3.1.4 Conduct an integrated study of 'climate change triangle' and 'disease triangle', especially in relation to viruses and their vectors

7.3.1.5 Develop a compendium of indigenous traditional knowledge and explore opportunities for its utilization

7.4. Further research needs

- Establish automatic weather station in each KVK for agromet observations. A system for remote access of data at a central place and its on-line distribution to ICAR/SAU scientists should be developed. Weighing lysimeters should also be established in key centers
- Develop specialized state-of-art on climate control facilities (CO_2, temperature, water and ozone). These are expensive, not available in the country, and hence international collaboration in this area, including research partnerships and training, should be developed
- Enhance national capacity on decision support systems, especially on integrated, dynamic, agro-economic modelling based systems
- Enhance national capacity on carbon trading in agriculture
- Intensify efforts for increasing climate literacy among all stakeholders of agriculture, including students, researchers, policy planners, science administrators, industry as well as farmers

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CHAPTER 8

Impact of Climate Change on Agriculture over Chhattisgarh

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It has now been well established that there is global warming due to increase in greenhouse gases in the atmosphere. The Inter-governmental Panel on Climate Change (IPCC) Working Group II had recently submitted its IV report which pertains to the impacts. In the report they observed that "a global synthesis of significant warming across the globe and the locations of significant observed changes in many systems consistent with warming is very unlikely to be due solely to natural variability of temperature or natural variability of the systems". They also felt that at regional scale other factors (such as land use change, pollution and invasive species) are influential.

It is, therefore, necessary to analyze the regional climate changes individually for better planning of agriculture as the other factors are also responsible for such climate changes/fluctuations. Usually the climate of any place is assessed on macro-regional scale. It is necessary to study the regional climate changes in view of the global changes that influence the agriculture in a given region like a district.

Attempts have been made to study the regional climate changes in different districts of Chhattisgarh state which directly affect the crop and influence the varietal selection as well as the cropping sequence in case water is available for irrigation purposes.

8.1 Historical rainfall pattern

When the historical rainfall pattern of Eastern Madhya Pradesh (now Chhattisgarh), as analyzed by IITM, Pune, was examined it is clearly seen that from 1960 onwards, the rainfall anomaly was negative in 28 years out of 40 years indicating decreasing rainfall trend in the entire state/region. (Fig. 8.1)

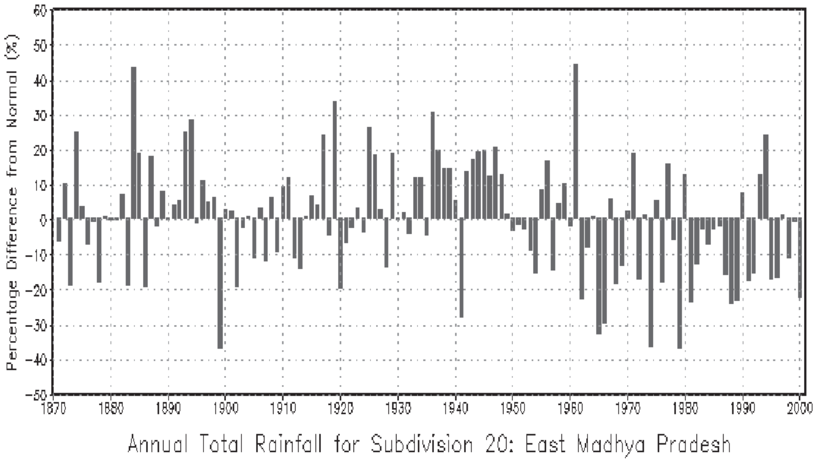

Fig. 8.1. Historical rainfall anomalies from 1870 to 2000 AD

8.2 Agroclimatic zones

Chhattisgarh State has three agroclimatic zones viz. i) Chhattisgarh plains, ii) Bastar Plateau and iii) Northern Hills. The climate in general is different in these three zones (Fig.8.2). In some parts (northern plateau areas) of the northern Hill zone resembles temperate climate while southern parts of Bastar zone resembles tropical type climate.

Fig. 8.2 Agroclimatic zones of Chhattisgarh State

8.3 Rainfall trends

When rainfall pattern at district level was analyzed it was found that at some pockets of the 16 districts of Chhattisgarh state the rainfall is significantly decreasing and as a result the climate is shifting from sub-humid type to semi-arid conditions. (Figs. 8.3 to 8.5)

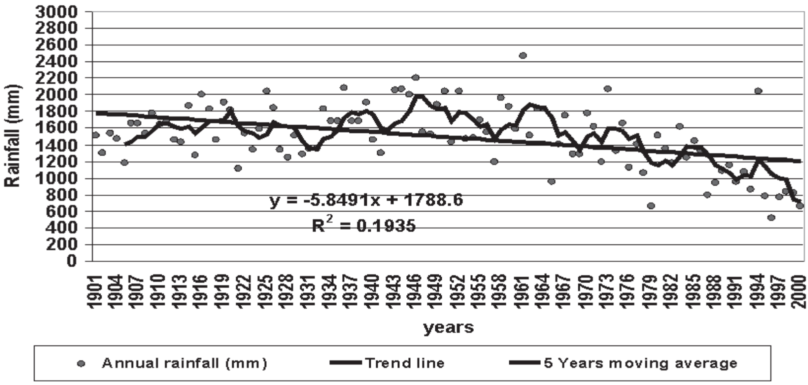

Fig. 8.3 Pattern of annual rainfall and its five year moving average and trend line at Raigarh from 1901 to 2000

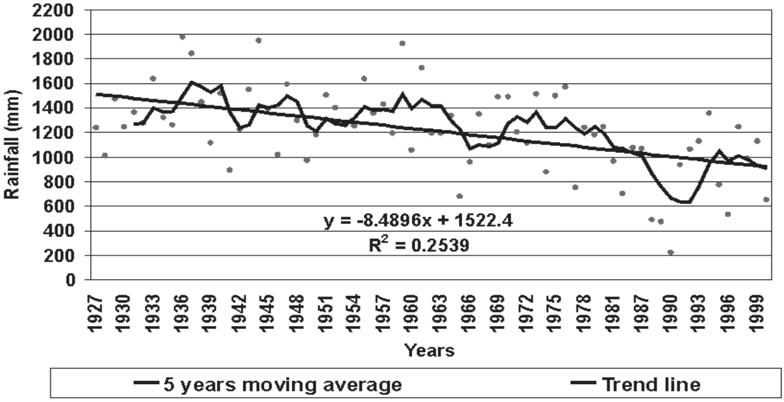

Fig. 8.4 Pattern of annual rainfall and its five year moving average and trend line at Kanker from 1927 to 2000

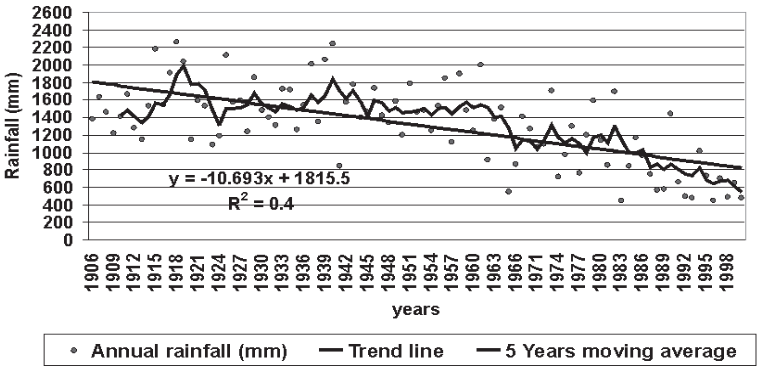

Fig. 8.5 Pattern of annual rainfall and its five year moving average and trend line at Mahasamund from 1906 to 2000

The UNEP earlier rightly observed that desertification can occur even in sub-humid climates and in Chhattsigarh state in some districts like Mahasamund desertification process has already been started. This resulted in stagnant/decrease in rice yields in those areas. Looking into the impact of these regional climate changes the Government of Chhattisgarh had taken up 'crop diversification' programme in a large scale on priority basis.

8.3.1 Temperature trends

Also, in the Northern Hills agro climatic zone (ACZ) of Chhattisgarh state, it was observed that the day temperatures are significantly increasing during October and November while the same are in decreasing trend in winter especially in March (Figs. 8.6 and 8.7)

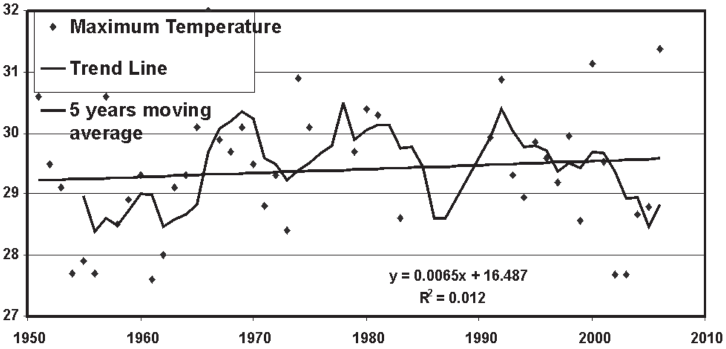

Fig. 8.6 Maximum temperature pattern during October at Ambikapur

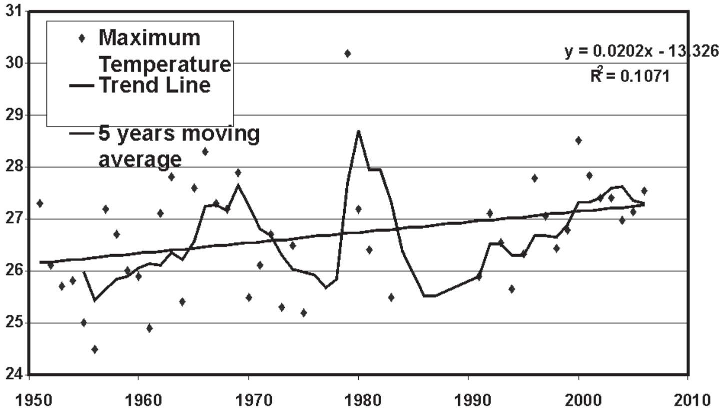

Fig. 8.7 Maximum temperature pattern during November at Ambikapur

This resulted in decreased crop duration during kharif (rainy) season and in addition decreased maximum temperature in March (Fig 8.8) facilitated farmers to take two crops of potato after harvest of early duration rice. Such changes are favourable for agriculture but the impact due to unfavourable conditions are more in rainfed agriculture.

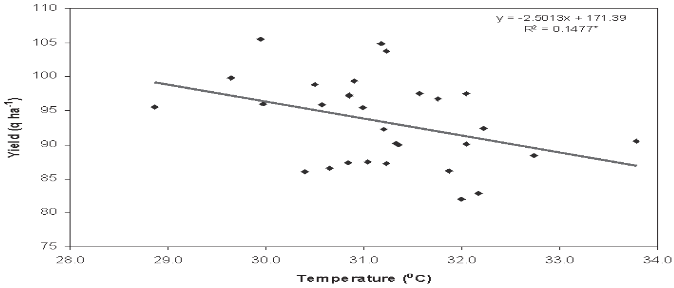

Fig. 8.8 Relationship between potential yields of rice and average maximum temperature during reproductive stage

8.4 Impact of temperature on crop production

The impact of increased temperatures and thereby decreased crop duration on crop yield was studied using CERES- Rice dynamic crop simulation model. The effect of increased temperature during reproductive stage on rice yield was studied by increasing temperatures by 1°C and 2° C (Fig. 8.9). It was found that if maximum temperature is increased by 1°C during reproductive stage, the rice yields under Raipur conditions decrease by 3-4 q/ha and if the temperature is increased by 2°C the rice yields decrease by 5-6 q/ ha.

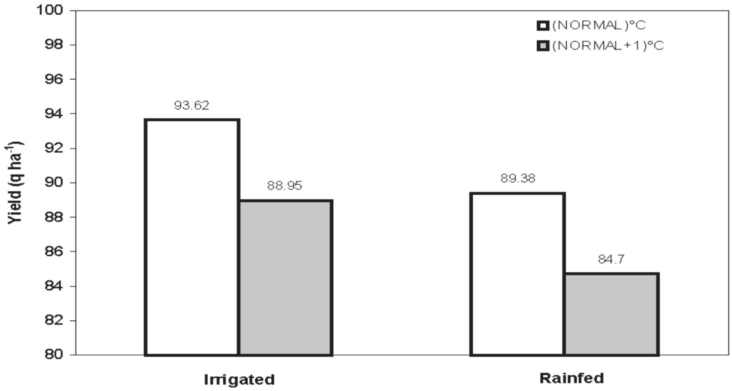

Fig. 8.9 Effect of increase in maximum temperature during reproductive stage of rice on potential yield in Raipur condition

The effect of increased temperatures on rice productivity both under irrigated and rainfed conditions was also examined.

It was also found that the effect of increased temperature during reproductive stage is equally detrimental to rice crop under both irrigated and rainfed conditions. Under irrigated conditions due to 1°C increase of temperatures during reproductive stage the potential rice yield decrease from 98.62 q/ha to 88.95 q/ha (a decrease of 4.67 q/ha) while under rainfed conditions the potential yield decrease from 89.38 q/ha to 84.7 q/ha (decrease of 4.68 q/ha). Also due to increased temperatures the duration of crop decrease and the relationship between duration of reproductive/flowering stage and potential yields of rice were examined through the model (Fig 8.10).

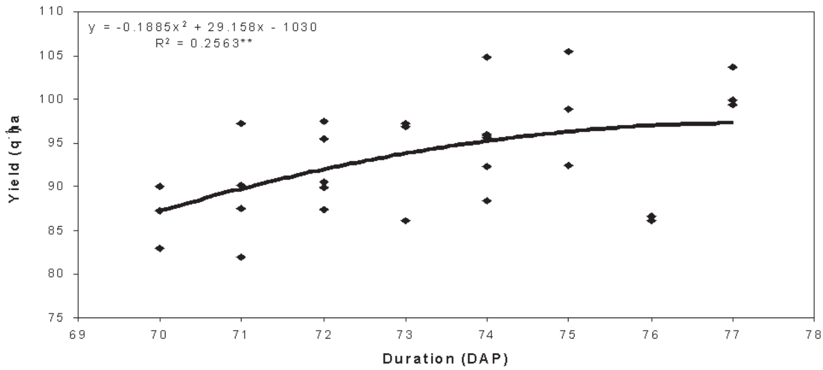

Fig. 8.10 Relationship between duration of flowering period and potential yields of rice in irrigated conditions.

According to the study, if the reproductive stage duration decreases by 7 days due to increased temperatures the potential yields of rice decrease by about 10 q/ha (Fig. 8.11). In the similar

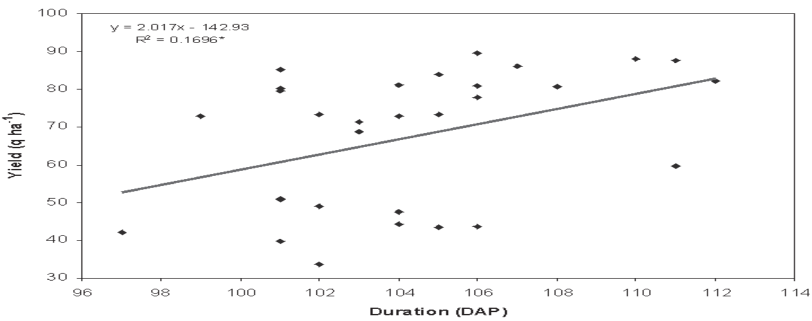

Fig. 8.11 Relationship between duration of maturity period and potential yield of rice in clayey soil under rainfed conditions

way if there is forced maturity due to water stress in heavy soils under rainfed conditions as well as due to increased temperatures, it was found that rice potential yield could decrease up to 15-18 q/ha

8.5 Conclusions

In Mahasamund district, the rainfall is decreasing rapidly and desertification process is going on and the climate had changed from moist-sub humid to semi arid conditions. In some part of Chhattisgarh state, rainfall is insignificantly in decreasing stage. In the northern districts of Chhattisgarh, the maximum temperature is increasing in October and November. As a result, the duration of rice crop is decreasing. Also, it was observed that the maximum temperature in March is decreasing in this area. As a result of decreased crop duration due to increased temperatures in October and November and also due to decreased maximum temperatures in March, the farmers are taking two crops of potato during winter season after rice. This is one favourable condition.

But the impact of increased maximum temperature by 1°C to 2^0C during reproductive stage is detrimental as the yields decrease by 3-4 q/ha under 1°c rise of temperature and 5-6 q/ha due to 2°C rice in temperatures during reproductive stage. Such detrimental effect is seen both under rainfed and irrigated conditions. The potential rice yield decrease by about 5 q/ha under both the conditions. Also, if the duration of reproductive stage is decreased by 7 days due to rise in temperatures, the rice yield can down by 10 q/ha. In the same way if there is forced maturity in the crop due to increase in temperatures during maturity stage, the potential rice yields can go down by 15-18 q/ha.

References/Suggested readings

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CHAPTER 9

Impact of Climate Change on Agriculture over Orissa

S. Pasupalak

The State of Orissa is situated on the East Coast of India, extending from $17^0$52' to $22^0$45' N latitude and from $81^0$45' to 87^0 50' E longitude. The State has a geographical area of 15.57 m ha out of which net cultivated area constitutes 39.8 % and forest 37.34%. The region is physically diverse and ecologically rich in natural and crop-related biodiversity. Out of 30 revenue districts in the State, nine are coastal and the rest 21 are landlocked. The present total population is 37 m, and the population is projected to increase to 50 m by 2025. Although 85% of this population is rural in 2001, urbanisation is on march with estimated urban population increasing to 45% by 2025. Exploitation of natural resources associated with rapid urbanization, industrialization, and economic development has led to increasing pollution, declining water quality, land degradation and other environmental problems.

Agriculture is the core economic sector in the State with cultivators and agricultural labourers constituting 65% of the total workforce. The monsoon season is the main cropping season; rice is the principal crop; and rainfed crop is dominant accounting 59% of the gross cultivated area. Besides rice, the climate-sensitive other crops important in the State are greengram and other pulses, groundnut and other oilseeds, maize, finger millet, vegetables and spices, namely ginger and turmeric. The state has 10 Agroclimatic Zones, differing on climate, land, soil and cropping pattern

9.1 Biophysical Resources

9.1.1 Physiography

Orissa includes the major land masses of peninsular nature, as well as the long coastal areas stretched along the Bay of Bengal. Physiographically, the State has four distinct physiographic regions: Coastal Plains, Southeren Ghats, Northern Plateaus and Western and Central High Lands. The Coastal Plain contains the largest brackish water lagoon of Asia. The mountains and the complex land-sea configuration have a strong influence on the weather and climate of the region. The State includes some large drainage basins, the sources of which extend into neighbouring states of Jharkhand and Chhatishgarh. These basins include the Mahanadi, Brahmani, Suvarnarekha, Rushikulya and Bansadhara rivers, which drain into the Bay of Bengal. Climate change impact can vary on the headwaters, broad valleys and deltaic mouths of these rivers.

9.1.2 Biogeography

Biogeographically, the region includes some of the greatest natural species diversity and productivity in India: mangroves in the coastal areas and Olive Ridley turtle in the river mouths are the prime examples of the marine environment. Mahendragiri, Gandha Mardana and Nilgiri mountains are the niches of some diverse plant species including medicinal plants. Ecological richness also is demonstrated by the region's crop and livestock diversity and by its large numbers of cultivars and varieties. In fact, Jeypore areas of the State is considered as the (secondary) place of origin of rice. Ghumusar goat breed is another species of national importance. A number of animals, insects and microbes have developed in parallel with the vegetation in this region. The diversity of cultivated plants and domesticated animals is a result of climate, soil and cultural and ethnic values. But the rich diversity is under threat due to global glimate change.

9.1.3 Climate characteristics

The climate of Orissa is dominated by the two monsoons: The summer monsoon popularly called as the Southwest monsoon, influences the climate of the region from June to September, and the winter monsoon known as the Northeast monsoon controls the climate from November to January. October is the transitional month between the two monsoons and it is the month of summer monsoon withdrawal. The annual rainfall is 1451 mm out of which the summer monsoon brings nearly 80%. Thus monsoon rainfall is the most critical climatic source for drinking water and water for rain-fed as well as irrigated agriculture. Total number of effective rainy days is 69 with July and August having 16 days each. The monthly mean maximum temperature varies from 27.3^{0}C in December to 37.7^{0}C in May. The corresponding values for minimum temperature are 13.6 and 25.7^{0}C. While the mean monthly maximum temperature of above 40^{0}C is recorded for more than two months in Titlagarh, but it does exceed 32.4^{0}C at Gopalpur.

As a result of the seasonal weather aberration, a large part of the State is exposed to annual floods and droughts. On an average drought occurs in two out of five years. The areas most hit by drought are the areas receiving low monsoon rainfall. These include Vansadhara and Rishikulya catchments, east of lake Chilka, eastern Koraput, Ganjam, western Puri, Bargarh, Bolangir and middle Brahmani catchments basin.

Three types of floods occur in the State: riverine flood, flash flood, and breached landslide-dam flood. The last one is mostly limited to mountainous regions of Kalahandi and Koraput Districts. Flash floods are common in the foothills, mountain borderlands, and steep coastal catchments. Riverine floods occur along the courses of the major rivers, broad river valleys, and coastal plains. For the period 1875-1987, total number of floods was 125 in Mahanadi, 100 in Brahmani and 92 in Baitarini river. The maximum frequency of the occurrence of floods of all magnitudes is experienced in two phases of the monsoon season, from 21 July to 7 August, and from 21 August to 7 September (Sinha, 1999). The first phase coincides with the transplanting and Bushening of rice, while the second one coincides with weeding and tillering stage in rice. Since the rice crop is at early stages at both the phases of floods, extensive crop damage occurs due to flood. Besides, there occurs heavy loss in life and property.

Tropical cyclones also are an important feature of the climate in the State. It occurs from May to November. October and November have witnessed some of the severe cyclonic storms. Generally, the storms from May to September originate in the north Bay, storms in October in the Central Bay (14 to 17^{0}N and 18 to 21^{0}N). The super cyclone that hit Orissa coast in October 1999 is still in people's mind as it devastated coastal belt to a large extent. The storms in November, which most severe, generally originate in the South Bay (10 to 13^{0}N). Other extreme events include heat wave due to high-temperature winds that come from the western India, entering the State through the western Orissa and proceeding to the coastal areas with culmination on the Bay. While some western places frequently record maximum temperatures exceeding 46^{0}C for more than a month, some coastal places have recently recorded more than 45^{0}C in some years. In the urban areas like Bhubaneswar, high temperatures and heat waves are exacerbated by the urban heat-island effect and air pollution.

9.1.4 Water resources

After the terrible famine in 1866, irrigation work was intensified, but irrigation was not made much headway with only 183.07 ha of net irrigation potential created up to independence. By the end of the 10th Plan, net irrigation potential was 2.192 m ha through major, medium and minor projects using surface and groundwater and another 0.567 m ha through unconventional sources like dug-well, water harvesting structures and small check dams.

9.2 Climate change/variability

9.2.1 Temperature and rainfall

The mean annual temperature showed a discernible increase during 1951 to 1990 at all the five places of the State (Table 9.1). However, between 1993 and 2006, coastal places showed increase

Table 9.1 Change in Temperatures in selected five districts of Orissa over two periods.

District	Annual mean Temperature in ^{0}C			Change in mean temperature, ^{0}C	
	Up to 1940* (Period I)	1951-90 (Period II)	1993-2006 (Period III)	During Period II	During Period III
Balasore	25.5	26.6	26.8	1.1	0.2
Puri	24.7	27.2	27.7	2.5	0.5
Gopalpur	26.0	26.7	27.2	0.7	0.5
Angul	26.5	26.8	26.5	0.3	-0.3
Sambalpur	26.1	26.7	26.5	0.6	-0.2
Average	25.8	26.8	26.9	1.0	0.1

* Starting year of observation varied between 1864 and 1880

in temperature, while the interior places recorded decrease in mean temperature. The mean change was 1.0^{0}C in the 40 years from 1951 to 1990 and 0.1^{0}C in the recent past of 14 years. The magnitude of increase was maximum in the coastal town Puri. Rainfall showed no deficit trend and appears to be stable. However, spatial variation in rainfall is noticed though insignificant.

9.3 Tropical cyclones

Identifiable changes in the number, frequency and intensity of tropical depressions or cyclones have been observed in the Bay of Bengal region over the last century. The average number of cyclonic storms / depressions in a year in the northern Indian Ocean (Bay of Bengal and Arabian Sea) during most frequently hit from October to December based on 80 years records from 1891 to 1970 was four (NCA, 1970). During 1958 to 1984, the average number was 5.5 (Climate Impact Group, 1992). In the Bay of Bengal alone, the number of cyclones per year was 2.7 between 1877 and 1980 (Panda and Kar, 1991). The frequency has increased significantly in the recent years. For example, the total number of storms including both the depressions and the upper atmospheric cyclonic circulation that caused heavy rainfall without leading to depression was 12 in 2006 and 14 in 2007. The frequency of its occurrence in the early monsoon period in June and July has increased with average number in June being less than one in the last century to one in 2006 and two in 2007. Moreover, the intensity of cyclones has increased in the recent years from the fact that super cyclones originated twice in the Bay during the last decade (1999 and 2007), although the second one skipped India.

9.4 Floods and droughts

Probability of occurrence of floods of both high and medium category was lower during 1956-87 as compared to 1855-1956 (Sinha, 1999). High floods decreased from once in 4 years to once in 4.88 years and medium floods decreased from once in 1.96 years to once in 2.87 years in the above period. During the same period, probability of low floods increased from once in 4.15 years to once in 2.54 years. The decreased trends detected in time-series data of flooded areas in various river basins of the State is more due to preventive control measures like creation of dams, and hence, it is difficult to relate the floods to rainfall alone. Similarly, during the 30 years from 1961 to 1990, there were floods in 15 years, occurring multiple times in a year (Government of Orissa, 2004). During the last 17 (1991 to 2007) years, floods has occurred in 9 years. Thus the recent data on frequency of floods do not give any conclusive increasing or decreasing trends.

Droughts also can reach devastating proportions in the State, although the incidence is variable in time and place. Between 1961 and 1990, drought occurred in 11 years with severe drought in five years. During the last 17 years (1991 to 2007), drought occurred in 6 years with severe drought in two years. No conclusive increasing or decreasing trend can be drawn from the above time series data.

9.4.1 Climate variability at Bhubaneswar

The mean annual Tmax (maximum temperature) ranged from 30.8 ^{0}C in 1971 to 33.5^{0}C in 1979. All the years since 1996 recorded mean annual Tmax more than the mean Tmax with its continuous gradual rise, reaching highest (33.1 ^{0}C) in 2006. The mean annual Tmin (minimum) ranged from 21.5 ^{0}C in 1971 to 23.1 ^{0}C in 1980. Most of the years since 1992 (except 1998, 2003, 2005) recorded mean annual Tmin less than the Tmin averaged over 38 years

9.4.1.1 Rainfall

- The mean decadal rainfall is increasing continuously. It increased by 231.3 mm from 1418.5 mm in 1978 to 1649.8 mm in 2006.
- All the decadal years since 1990 showed above mean decadal rainfall, indicating increasing trend of annual rainfall since 1980s.

9.4.1.2 Temperature

- Mean decadal Tmax increased by 0.5^{0}C from 32.1 ^{0}C in 1978 to 32.8^{0}C in 2006 with Standard Deviation (SD) of 0.13^{0}C
- The difference between decadal Tamx and Tmin is continuously increasing from 9.8 ^{0}C in 1978 to 10.7 ^{0}C in 2006, indicating about 0.9 ^{0}C increase in 39 years with SD of 0.25^{0}C (Fig. 9.1).

- The mean decadal mean temperature (average of Tmax and Tmin) increased by 0.3^{0}C from 27.2^{0}C in 1978 to 27.5^{0}C in 2006 with SD of 0.15^{0}C. During the 1980s as both Tmax and Tmin remained higher and again increasing in the recent years.

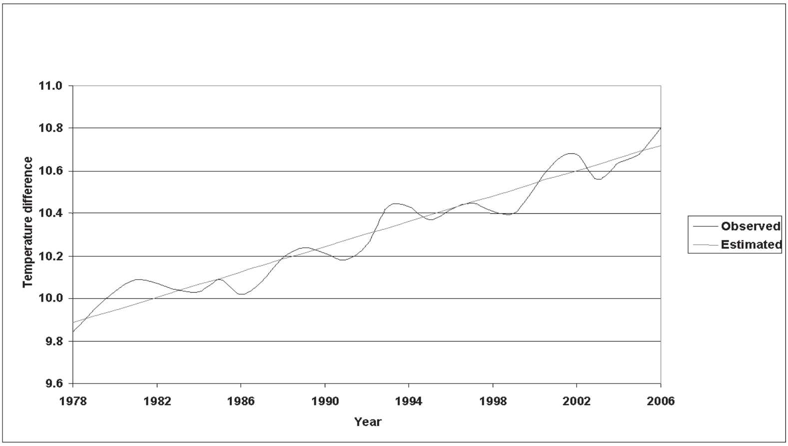

Fig. 9.1 Mean decadal maximum-minimum temperature difference at Bhubaneswar (1978 - 2006)

- The mean decadal Tmin decreased by only 0.2^{0}C from 22.3^{0}C in 1978 to 22.1^{0}C in 2006 and the difference is not significant as the SD value is higher (0.23^{0}C, Fig. 9.2).

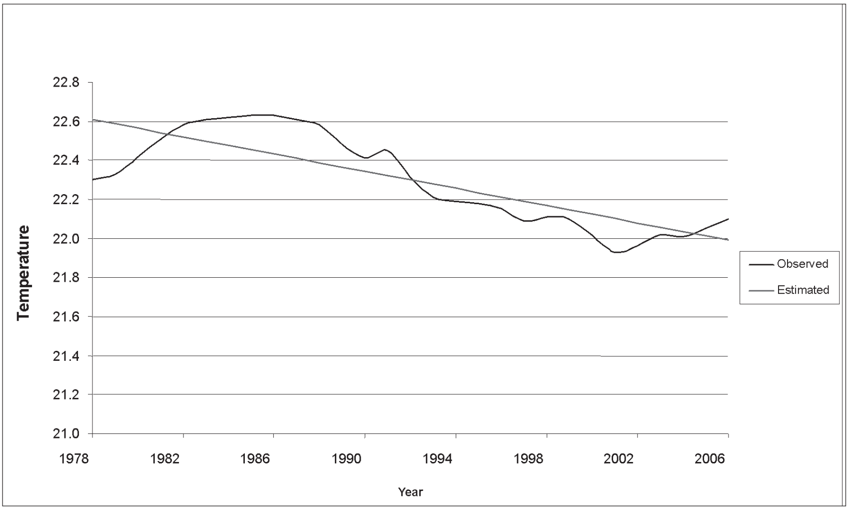

Fig. 9.2 Mean decadal minimum temperature (^{0}C) at Bhubaneswar (1978 - 2006)

9.4.1.3 Weather extremes

- Rainfall: Last decade recorded the maximum rainfall of 400.3 mm in one day as against the preceding record of 256.4 mm between 1969-78. Inter-annual variation within the decade also has increased. Number of days with very heavy rainfall (>125 mm) has also increased.

- Tmax : Record daily Tmax is gradually increasing with 46.3^{0}C in 2005. Number of hot days with >45^{0}C is also increasing with such 3 days in 2005, while it was absent in 1970s and 1980s except for 1972.

- Tmin : No variation was significant. However, the number of cold days with <10^{0}C has increased in the recent years with 3 such days in 2003.

9.5 Future climate

9.5.1 Climate scenario

The General Circulation model HadleyCM3 output was used for climate change scenario in the State. The model has 96 x 73 grid points with 2.5 x 3.75 degrees latitude x longitude resolution. The B2a scenario for 2020 was studied. The district map of Orissa was superimposed with the Grid # 2615 and 2711 and the scenario for rainfall, Tmax and Tmin were obtained. The grid # 2615 roughly coincided with the north Orissa, while the other grid coincided with the south Orissa. The base data used by the original model was corrected for the actual mean data of 1951 to 1990 by taking the ratio. The results were presented for north Orissa districts.

9.5.1.1 Rainfall

The north Orissa is expected to have 98.6 mm more annual rainfall (Table 9.2). The maximum increase of 86.6 mm shall be in summer followed by 19.1 mm in monsoon. Both post monsoon and winter shall be drier. It shall decrease in February, June and October and increase in rest of the months. Balasore shall have maximum increase of 150.2 mm annual rainfall and Jharsuguda the minimum of 59.7 mm.

Table 9.2 Expected change in rainfall (mm) in north Orissa districts in 2020 over 1990

Month	Winter	Summer	Monsoon	Post Monsoon	Annual
Angul	-1.3	72.6	14.6	-5.8	**80.1**
Balasore	-1.0	148.2	15.3	-12.3	**150.2**
Bargarh	1.2	41.1	32.0	-3.8	**70.5**
Baodh	0.7	52.3	33.1	-6.1	**79.9**
Bhadrak	-1.7	126.0	14.2	-9.4	**129.1**
Cuttack	-2.4	91.8	14.9	-6.4	**98.0**
Deogarh	-0.7	57.7	29.8	-7.3	**79.5**
Dhenkanal	-1.1	98.7	9.4	-5.4	**101.5**
Jagatsinghpur	2.2	99.6	16.7	-4.0	**114.5**
Jajpur	-0.5	123.9	11.8	-8.4	**126.8**
Jharsuguda	0.6	39.9	23.7	-4.4	**59.7**
Kendrapara	-2.2	119.9	17.8	-9.1	**126.5**
Keonjhar	-2.3	124.1	5.9	-7.3	**120.4**
Moyurbhanj	-1.1	137.5	3.0	-8.4	**131.0**
Sambalpur	0.5	45.1	34.8	-3.7	**76.7**
Sonepur	1.1	40.9	30.2	-4.4	**67.8**
Sundargarh	0.4	52.6	17.0	-5.6	**64.5**
North Orissa (mm)	-0.4	86.6	19.1	-6.6	**98.6**
North Orissa (%)	114.0	102.2	129.7	150.7	**106.6**

The North Orissa is expected to have 0.72^{0}C more mean annual Tmax (Table 9. 3).

Table 9.3 Expected change in mean seasonal Tmax (^{0}C) in north Orissa districts in 2020 over 1990

Districts	Winter	Summer	Monsoon	Post Monsoon	Annual
Angul	3.28	1.41	0.85	2.66	1.90
Balasore	3.30	1.43	0.89	2.83	1.95
Mayurbhanj	3.00	1.41	0.89	2.80	1.87
Chandabali	3.25	1.42	0.87	2.84	1.93
Cuttack	3.63	1.48	0.88	2.96	2.07
Jharsuguda	2.87	1.40	0.87	2.56	1.79
Keonjhar	2.81	1.32	0.82	2.47	1.72
Paradeep	3.68	1.49	0.90	3.07	2.10
Sambalpur	2.97	1.38	0.88	2.65	1.82
North Orissa	**1.90**	**3.20**	**1.42**	**0.87**	**2.76**

9.5.1.2 Maximum temperature

The maximum increase of 1.36^{0}C shall be in post monsoon followed by 0.87^{0}C in summer and 0.58^{0}C in winter and no change during monsoon. It shall decrease only in July and increase in the rest of 11 months. Maximum increase (1.6^{0}C) shall be in June. Paradeep shall have minimum increase of 0.68^{0}C in mean annual maximum temperature and Jharsuguda the maximum of 0.75^{0}C.

9.5.1.3 Minimum temperature

The North Orissa is expected to have 1.90^{0}C more mean annual Tmin (Table 9.4). The maximum increase of 3.20^{0}C shall be in winter followed by 2.76^{0}C in post monsoon and 1.42^{0}C in summer and minimum of 0.87^{0}C during monsoon. It shall increase in all the 12 months. Maximum increase (3.61^{0}C) shall be in December and minimum of 0.17^{0}C in July. Paradeep shall have maximum increase of 2.18 mean annual minimum temperature and Keonjhar the minimum of 1.72.

Table 9.4 Expected change in mean seasonal Tmin(^{0}C) in north Orissa districts in 2020 over 1990

Districts	Winter	Summer	Monsoon	Post Monsoon	Annual
Angul	0.58	0.91	0.00	1.35	0.74
Balasore	0.57	0.84	0.00	1.36	0.71
Mayurbhanj	0.58	0.89	0.00	1.37	0.73
Chandabali	0.58	0.85	0.00	1.36	0.71
Cuttack	0.61	0.89	0.00	1.41	0.74
Jharsuguda	0.59	0.93	0.01	1.38	0.75
Keonjhar	0.55	0.86	0.00	1.28	0.70
Paradeep	0.57	0.76	0.01	1.37	0.68
Sambalpur	0.58	0.91	0.01	1.36	0.74
North Orissa	**0.58**	**0.87**	**0.00**	**1.36**	**0.72**

9.6 Future crop production scenario

The simulation studies on rice was done with two weather data sets : 2006 Bhubaneswar data and mean projected for 2020 (Annual Report, 2006). LAI of simulated rice crop in 2020 weather was more than that of 2006 weather up to 80 DAS with LAI of 4.05 and 4.45 at 80 DAS (Table 9.5). However, after 80 DAS, LAI decreased faster in the 2020 weather, reaching 0.35 at 120 DAS compared to 0.65 in 2006 weather. Total dry matter of rice crop was higher under 2020 weather scenario up to 100 DAS and thereafter, its rate of accumulation decreased, reaching 10408 kg/ha compared to 10652 kg/ha under 2006 weather. The grain yield under 2020 weather scenario (3928 kg/ha) was less than under

Table 9.5 Simulation impact of climate change on LAI and total dry matter in kharif rice (var Lalat) at Bhubaneswar in 2020 as compared to 2006.

DAS	LAI		Total Dry matter, kg/ha	
	2006	2020	2006	2020
30	0.11	0.12	82	87
40	0.54	0.62	137	149
50	1.24	1.41	306	333
60	2.48	2.75	914	1052
70	3.72	3.98	2050	2260
80	4.36	4.75	4202	4586
90	4.05	4.45	6727	7632
100	2.72	2.02	8414	8934
110	1.65	1.20	9860	9801
120	0.65	0.35	10652	10408

2006 weather (4348 kg/ha) which was 9.7% less (Table 9.6). This was mainly due to less number of filled grains under 2020 weather than 2006 weather. Individual grain weight did not differ between two weather sets. The number of days taken to maturity under 2020

Table 9.6 Simulated input of climate change on yield, yield components and development of kharif rice (var Lalat) at Bhubaneswar in 2020 as compared to 2006.

Sl.No.	Parameters	Unit	2006	2020
1	Total dry meter	Kg/ha	10652	10408
		%	100	97.7
2	No. of grains	No/m^2	20010	18247
		%	100	91.2
3	Single grain Wt	mg	21.72	21.62
		%	100	99.5
4	Grain yield	Kg/ha	4348	3928
		%	100.0	90.3
5	Days to anthesis		72	70
6	Days to maturity		125	118

weather scenario (120 days) was 5 days less than under 2006 weather (125 days). Days taken to anthesis did not differ much between the two weather sets, difference being only 2 days less under 2020 scenario. Most of the simulation studies done elsewhere have shown a shorter duration of field crops with higher temperatures (Agarwal and Sinha, 1993). The present results are in line with the other studies in rice that temperature increase above 30^0C, which is considered critical temperature, reduces grain yield. The reduced yield was attributed to higher spikelet sterility (Yosida and Parao, 1976), decreased growth duration, particularly, grainfilling period (Swaminathan, 1984) and lower dry matter production due to higher respiratory loss without change in photosynthetic rate (Sato and Kim, 1980).

9.6.1 Other general impact

Delayed onset of monsoon and decreased rainfall in June lead to more crop loss under the direct sown than the transplanted rice, thus forcing the farmers to adopt the transplanting for more assured yield (Pasupalak, 2007). The situation is similar to the national scenario with delayed onset of monsoon in India. It has a direct effect on the sowing of rainfed crops with more chances of soil moisture stress (Hundal and Kaur, 2004). Shorter and warm winter will make the existing varieties of winter crops less productive. Water requirement of the crops will be more due to increased evaporation rate. Command area of the water reservoirs may decrease by nearly 10 % in 2020. Incidence of pests in rice and other crops is likely to be more. Increasing infestation of rice crop by swarming caterpillar, hispa bacterial leaf blight and widespread infestation of coconut plants by Eriophyd mite (*Aceria guerroronis*) across the state during the last decade are very unlikely due to natural variability of the climate, but show the evidences of man made climate change

Increased frequency of heavy rainfall events will augment flood risk, which would damage standing crops, increase soil erosion and make productive lands waterlogged. The coastal ecosystem is likely to be adversely affected in this century by climate change bringing in flooding, threatening of biodiversity of mangroves and so on. Coastal agriculture will be at increased risks due to coastal erosion, salinisation, flooding and severe storms. The climate change will place severe pressure on the forest's ability to adapt and survive hydro-thermal stress, which together with the higher CO_2 levels is likely to lead to changes in species composition and distribution of forest. The warmer sea surface temperature will have serious impact on distribution and production of particular fish species and timing of their catch, which would seriously affect the aquaculture and sea fishing, which are now important economic activities in the State.

9.7 Agricultural technology to adopt and mitigate climate change

Several adoption measures are available to reduce vulnerability to climate change by enhancing adaptive capacity and increasing resilience. Some of the potential adoption technologies generated by the Orissa University of Agriculture and Technology (OUAT) are developing new cultivars with high yield potential, altered sowing time to match changes in growing season, improved rice cultivation techniques and efficient use of fertilizer and irrigation water. Agricultural practices having mitigation potential are also available which collectively can make a significant contribution to increasing soil carbon sinks, reducing greenhouse gases emissions reductions and by contributing biomass feedstock for energy use. The technologies having mitigation potential developed at OUAT include improved land management technologies to increase soil carbon storage, restoration of waste and degraded lands, composting and manure management to reduce CH_4 emissions, improved nitrogenous fertilizer management techniques to reduce N_2O loss, integrated nutrient management to reduce the nitrogen fertilizer requirement and identification and propagation of plants for bio-diesel production. A large number of technologies developed for sustainable agriculture have strong mitigation potential and low vulnerability to climate change. But the efficacy of available adoption measures is likely to diminish with increasing climate change. Interestingly, most of the technologies are less costly compared to non-agricultural measures.

In the forestry front, it is required to go for reforestation and better management of existing forests and afforestation in new areas including marginal lands and waste lands through agroforestry, social forestry, urban forestry, coastal forestry and 'green belts'. The University has identified fast-growing tree species and management technology that increase CO_2 sinks at low costs besides having substantial benefits in terms of employment, income generation, biodiversity and watershed conservation, renewable energy supply and poverty alleviation. However, for ensuring food security of the nation, the wide adoption of energy plantation or agroforestry, using available wasteland is necessary.

9.8 Conclusions

The climate change has definitely began, although the projected extent of change and its effect in the State have not been conclusively studied. Trend analysis studies clearly showed increased occurrence of extreme weather events, increased rainfall and increased diurnal range in temperature. There was discernible indication of mean annual temperature increase in Orissa. Climatic model studies clearly project temperature rise in all the months of a year except July and more so in the winter season. Model studies do not indicate any adverse effect on rainfed kharif rice yield. However, impact assessment studies of climate change on agriculture of Orissa are quite limited to arrive at some conclusion. Based on the principles of crop science, it is apprehended that winter crops will be affected most due to warming. The kharif cultivation timing may be delayed, soil moisture stress may increase and the chances of damage due to extreme rainfall events are high. The policy implications are wide reaching, as changes in agriculture could affect food security, trade, livelihood activities and water use issues. It is, therefore, highly suggested that the emerging conditions need to be studied well in totality as climate change influances from land preparation to post harvest technologies.

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CHAPTER 10

Impact of Climate Change on Agriculture over Gujarat

Vyas Pandey and H. R. Patel

The Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report released in February 2007 has confirmed that warming of climate system is unequivocal, as is evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice and rising global mean sea level. At continental, regional, and ocean basin scales, numerous long-term changes in climate have been observed. These include changes in Arctic temperatures and ice, widespread changes in precipitation amounts, ocean salinity, wind patterns and aspects of extreme weather including droughts, heavy precipitation, heat waves and the intensity of tropical cyclones. The report has pointed out with high level of confidence that the warming is due to human activities. Global atmospheric concentrations of carbon dioxide, methane and nitrous oxide have increased markedly as a result of human activities since 1750 and now far exceed pre-industrial values determined from ice cores spanning many thousands of years. The global increases in carbon dioxide concentration are primarily due to fossil fuel use and land-use change, while those of methane and nitrous oxide are primarily due to agriculture.

It seems obvious that any significant change in climate on a global scale should impact local agriculture, and therefore affect the world's food supply. Considerable study has gone into questions of just how farming might be affected in different regions, and by how much; and whether the net result may be harmful or beneficial, and to whom. Several uncertainties limit the accuracy of current projections. One relates to the degree of temperature increase and its geographic distribution. Another pertains to the concomitant changes likely to occur in the precipitation patterns that determine the water supply to crops, and to the evaporative demand imposed on crops by the warmer climate. There is a further uncertainty regarding the physiological response of crops to enriched carbon dioxide in the atmosphere. The problem of predicting the future course of agriculture in a changing world is compounded by the fundamental complexity of natural agricultural systems, and of the socioeconomic systems governing world food supply and demand.

Modeled studies of the sensitivity of world agriculture to potential climate change have suggested that the overall effect of moderate climate change on world food production may be small, as reduced production in some areas is balanced by gains in others. The same studies find, however, that vulnerability to climate change is systematically greater in developing countries like India-which are mostly located in lower and warmer latitudes. In these regions, cereal grain yields are projected to decline under climate change scenarios across the full range of expected warming.

In view of the various uncertainties, climatic data of different stations of Gujarat have been analysed to ascertain the climatic change/variability in the State and its likely impact on agriculture using crop models.

10.1 Biophysical resources

Gujarat is the western-most state of India (Fig. 10.1a). It has a long (1600 km) sea coast on the Arabian Sea. The Gulf of Cambay separates the western peninsula (Saurashatra) from the arid district of Kutch. The hill ranges of Aravalli in the northeast, Saputara in east and Sahyadri in the southeast run along the eastern boundary of the State from the northern district of Banaskantha to its southern end. Topographically, Gujarat state is characterized by a large central alluvial plain and a peninsula, separated by the Gulf of Cambay. Kutch, the largest district, lies north of the peninsula, and on its northern border is the large *rann* (desert) of Kutch. Of the numerous rivers that flow westward across the plain, the most prominent, the Tapi, Narmada and Mahi, have perennial flow. With the exception of the northern-most part, the plain has assured rainfall. Furthermore, the existence of dependable aquifers, which are exploited for irrigation, makes the Gujarat plains the most agriculturally productive and densely populated part of the State. The state's area of 19.60 million ha accounts for about 6.0% of the total area of India. Its net sown area is 9.58 million ha, which is 6.75% of that of the Country. Barren and uncultivated land (2.61 million ha) represents about 13.31% of the landmass of the State.

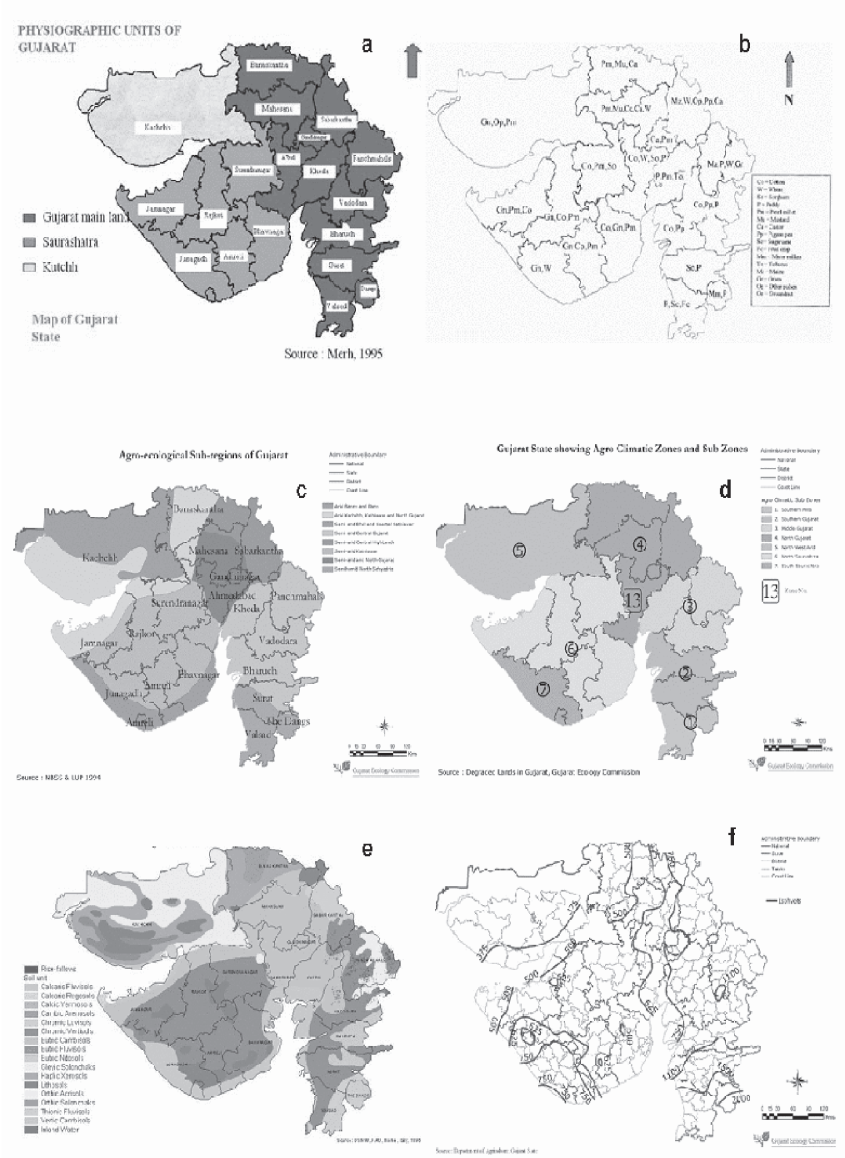


Fig. 10.1 Maps of (a) major physiographic units, (b) dominant crops, (c) climatic regions, (d) agroecological zones, (e) major soils (FAO classification), and (f) annual rainfall isohyets for Gujarat (Hansen et al 2004)

The distribution of cropping systems (Fig. 10.1b) is determined largely by the climatic gradient and distribution of soils. Three types of tropical climate prevail across the State (Fig. 10.1c). An arid climate is seen in the extreme north and northwest, comprising Kutch, western portions of Banaskantha, Patan and Jamnagar. The Surat, Narmada, Navsari, Valsad and Dang districts in the extreme south have a sub-humid climate with good vegetative cover. The remaining parts of the State fall under the semi -arid climate, relatively sparse vegetative cover, frequent droughts and susceptibility to soil erosion. The India Meteorological Department has divided the State into two meteorological subdivisions: the Gujarat region in the East and Saurashtra and Kutch in the West. Gujarat state can be further divided into eight agro-climatic zones, based on several criteria (Fig. 10.1d). The soils of Gujarat can be broadly classified into nine major groups: black soils, mixed red and black, residual sandy, alluvial, saline/ alkali, lateritic hilly, desert and forest soils. Figure 1e gives their equivalent FAO classification.

Water availability is the most serious problem for Gujarat's agricultural production. The potential for irrigation through surface water is assessed at 3.94 million ha, including 1.79 million ha through the Narmada project. An estimated 2.55 million ha can be irrigated by groundwater. Currently, 1161 minor irrigation schemes operate in Gujarat. A large number of check dams (3,669) and percolation tanks (3,138) contribute indirectly through groundwater recharge. Gujarat's agriculture depends critically on precipitation from the southwest monsoon during the monsoon months, as the rest of the year is dry and cannot support rainfed cultivation.

The monsoon normally sets in mid-June, initiating intense agricultural operations with a spurt in farm employment, which goes through a lean phase every year during the dry season. The monsoon season lasts only about 90-100 days, making the economy critically dependent on the water received during this short period until the next monsoon nine months away. The annual average rainfall of the State is 821 mm which is not reliable neither representative. Average annual rainfall ranges from as high as 1900 mm in the sub-humid southeast to as low as 320 mm in the arid north (Fig. 10.1 a-f). The distribution of rainfall, particularly wet and dry spell characteristics, has largely determined the traditional evolution of cropping patterns and agricultural practices.

Much of the southern portion of the State experiences excess rainfall frequently. The northern and northwestern parts of Gujarat receive less precipitation and experience frequent failures of monsoon. Because the economy of Gujarat is highly dependent on agriculture and related industries, impacts of climatic variations are felt throughout the state's economy. Gujarat is primarily a rainfed state and will remain rainfed state for years to come in spite of commencing of Narmada Irrigation Project. The agricultural production is highly variable and is dependent largely on variability in monsoon rainfall.

10.2 Climate change/variability

10.2.1 Rainfall variability

Gujarat state receives about 95% of its annual rainfall through the influence of SW monsoon during June to September period. The subdivision-wise rainfall analysis (Fig.10.2) revealed that Saurashtra and Kutch subdivision have mean annual rainfall of 428 mm with coefficient of variation of 44% and decreasing trend of-5% per 100 years while Gujarat sub division has mean annual rainfall of 863 mm with coefficient of variation of 32% and decreasing trend of –5% per 100 years. However, the recent continuous drought / low rainfall for four years (1999, 2000, 2001 and 2002) followed by five years of heavy rainfall (2003, 2004, 2005, 2006 and 2007) have posed great challenge to planners and managers of water resources, therefore need critical analysis on lower spatial and temporal scales.

Temporal and spatial variability of rainfall analysis suggested occurrence of floods and droughts side-by-side. Kutch having less rainfall (350 mm) had highest annual rainfall variability (57%) while the Dangs having highest rainfall (1792 mm) had lowest rainfall variability (29%). On monthly basis, the coefficient of variability is still higher, being >100% in Kutch even in monsoon months. Among four months of monsoon, July contributes 35-45% of annual rainfall. Kutch is having 80% chances of getting low rainfall (<500 mm), the Dang and Valsad have 70% chances of getting higher rainfall (>1500 mm). Kutch district and parts of Banaskantha, Patan, Surendranagar, Rajkot and Jamnagar districts were found prone to experience moderate to severe droughts in more than 30 % of the years (Pandey *et al.,* 2007).

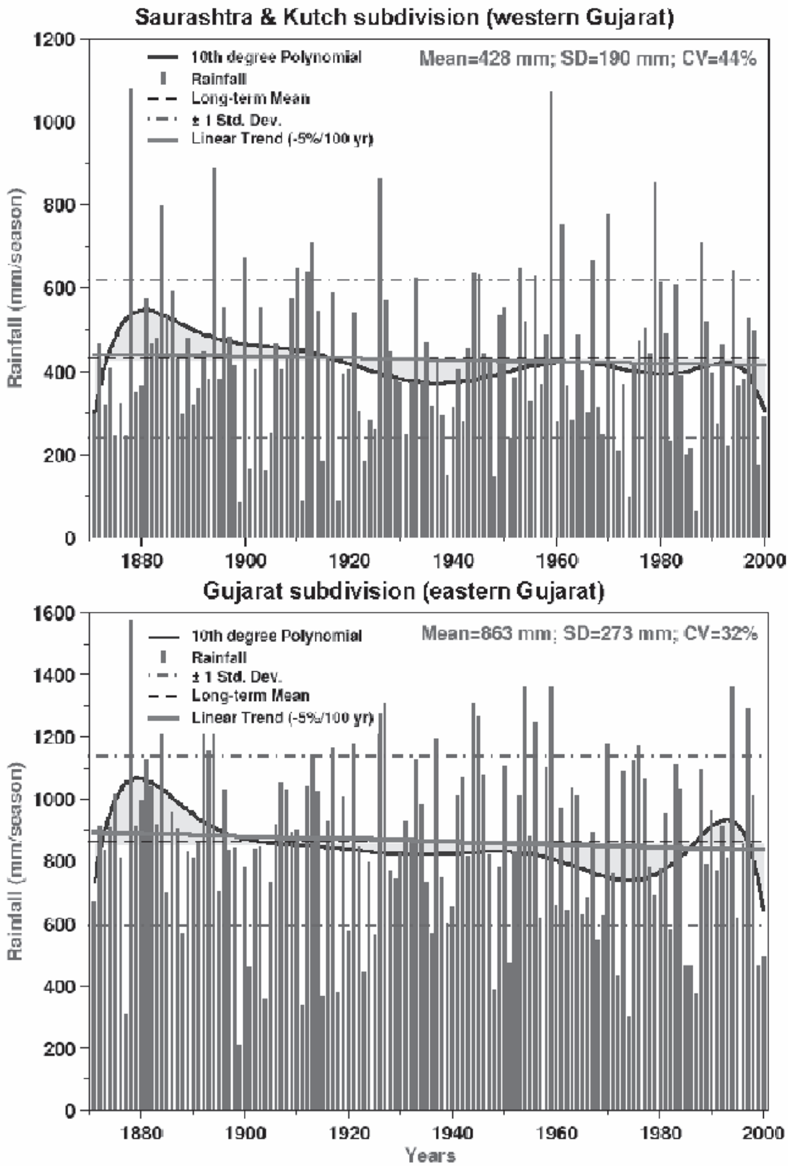


Fig. 10.2 Summer monsoon rainfall variability in meteorological subdivisions in Gujarat (Hansen et al 2004)

The annual rainfall analysis at three locations revealed that Anand and SK Nagar showed slight increase in annual rainfall by 2.86 and 2.16 mm, respectively while Junagadh showed decreasing trend during 1988 to 2002 (Fig. 10.3). The discrepancies may slightly be contributed to non-uniformity in data series at three locations. Although, July and August receive high rainfall, the analysis at Anand showed that June and September receive high rainfall than that of

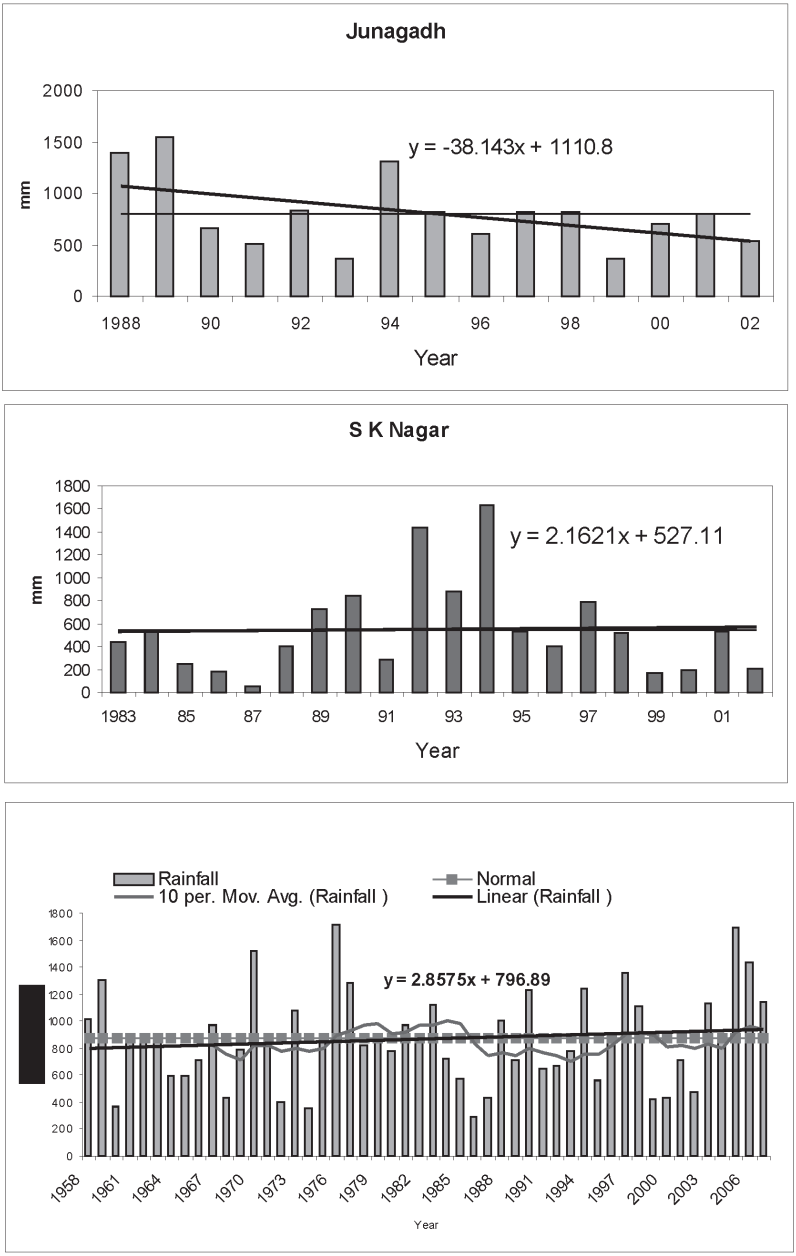


Fig. 10.3 Annual rainfall variability and trend at Anand, Junagadh and SK Nagar (Gujarat)

July and August (Fig.10.4). The rainfall intensity in terms of daily maximum rainfall also showed increasing trend at Anand (Fig.10.5).

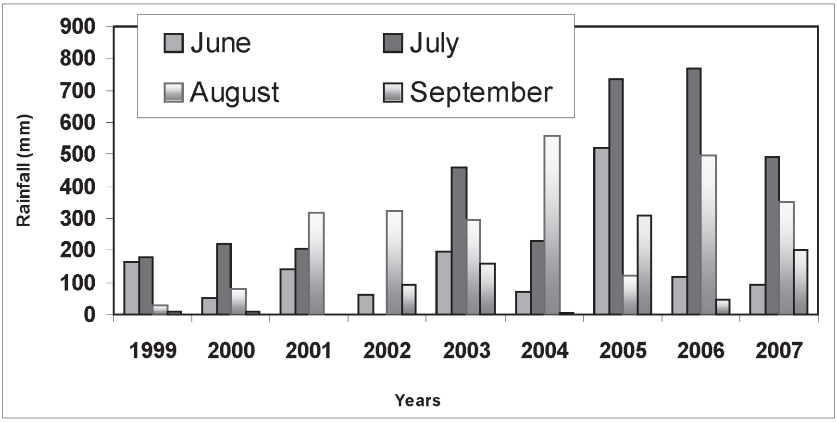


Fig. 10.4 Monthly rainfall distribution at Anand during recent past years

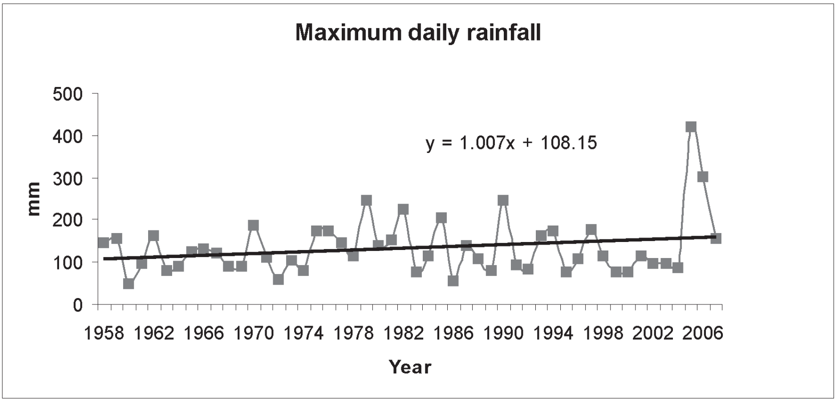
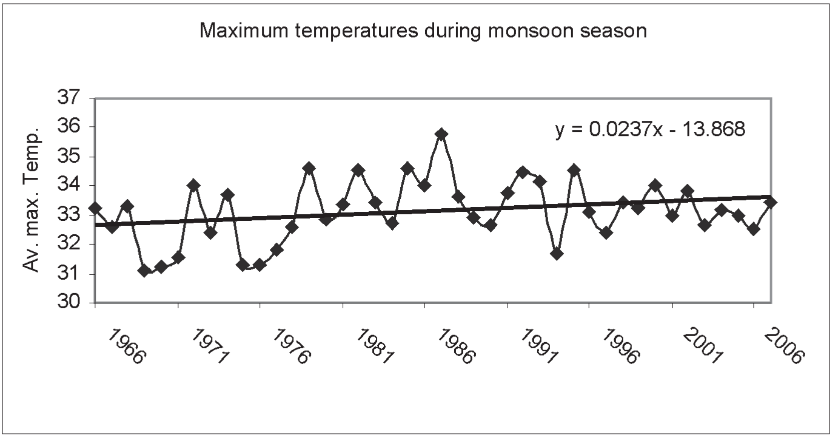
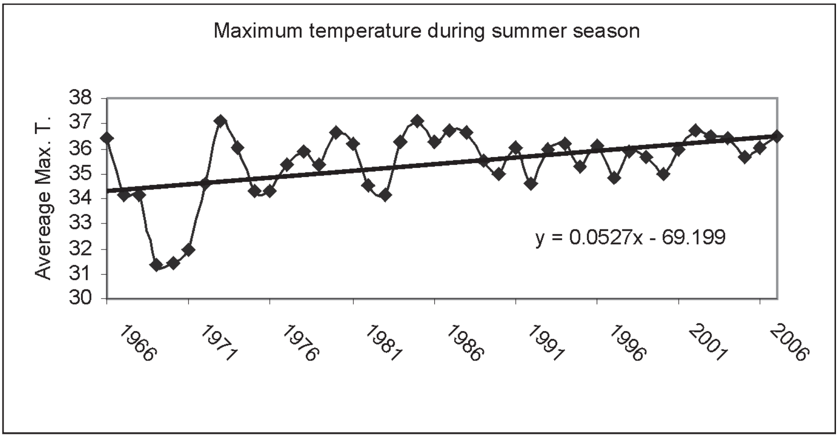


Fig. 10.5 Daily maximum rainfall received at Anand

10.2.2 Temperature

The maximum temperature at Anand was found to increase in three seasons (Summer, monsoon and winter). The rate of increase was between 0.2 to 0.5 ^{0}C per decade, maximum being in summer season (Fig.10.6). Similarly, the minimum temperature was found to increase but with slightly lower rate of 0.2 to 0.3 ^{0}C per decade in different seasons (Fig.10.7). In Saurashtra region (Jungadh) and in north Gujarat (SK Nagar) maximum and minimum temperature during winter season were also found to increase (Figs. 10.8 and 10.9), the rate of increase being highest (0.9 ^{0}C per decade) for minimum temperature in Jungadh (Parmar *et al.*, 2005). Thus Saurashtra region may experience warmer nights in times to come.





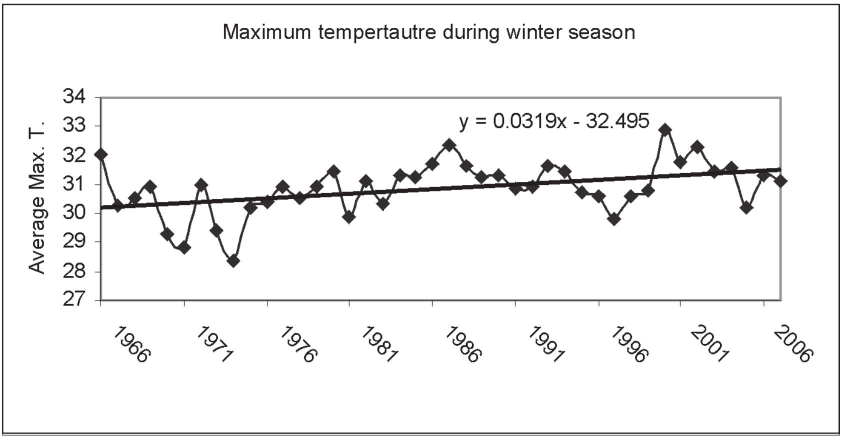
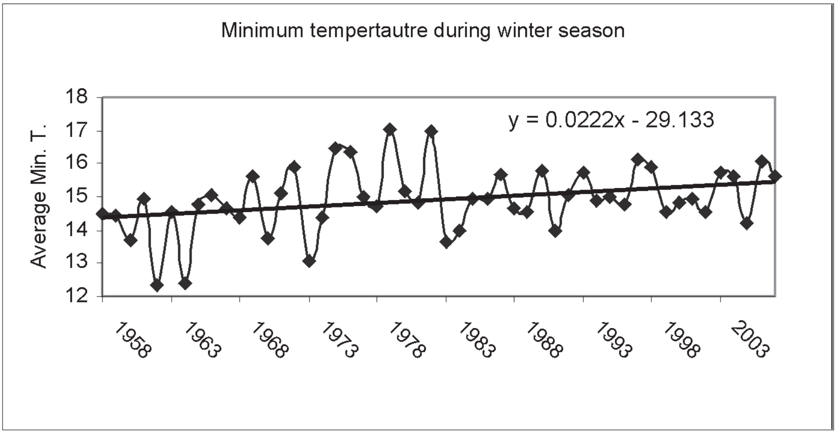
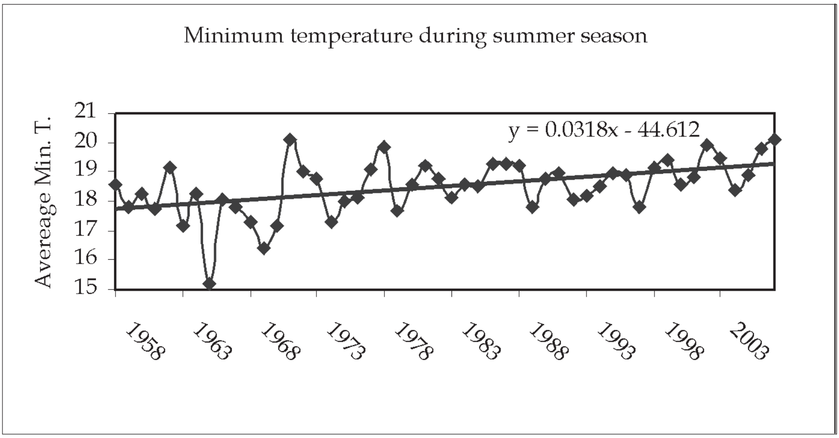


Fig. 10.6 Trends of maximum temperature during different seasons at Anand





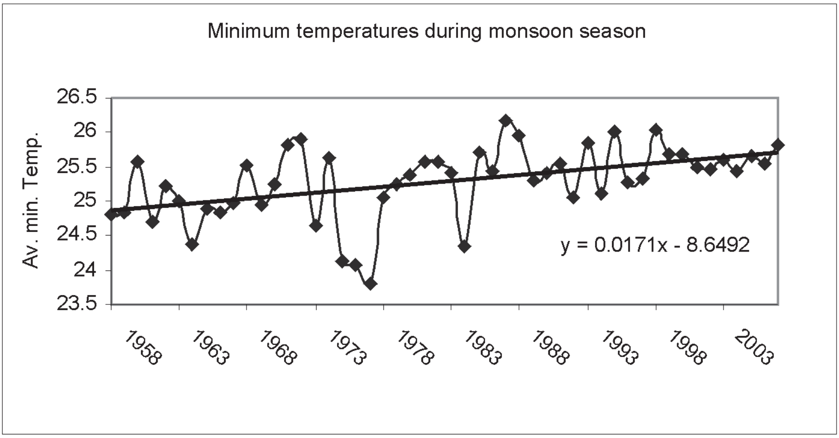


Fig. 10.7 Trends of minimum temperature during different seasons at Anand

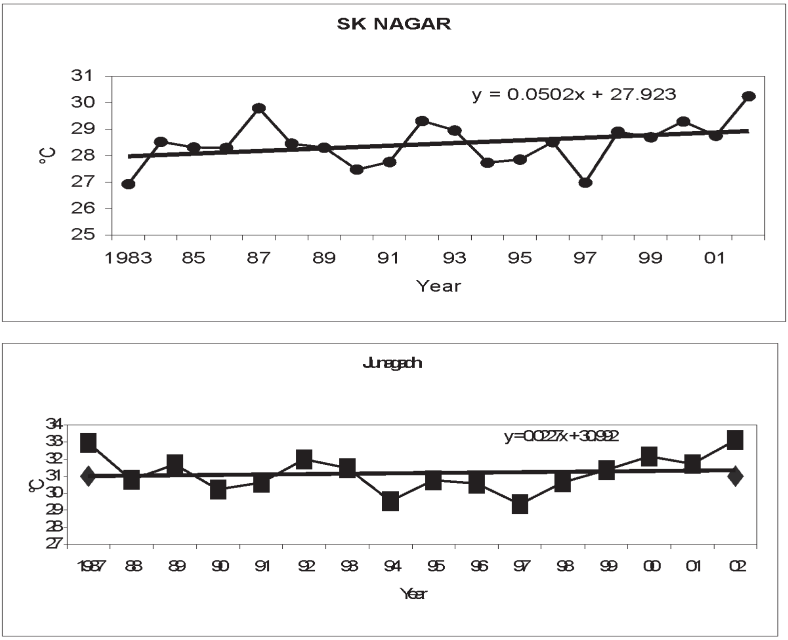


Fig. 10.8 Trends of maximum temperature during winter season at Junagadh and SK Nagar

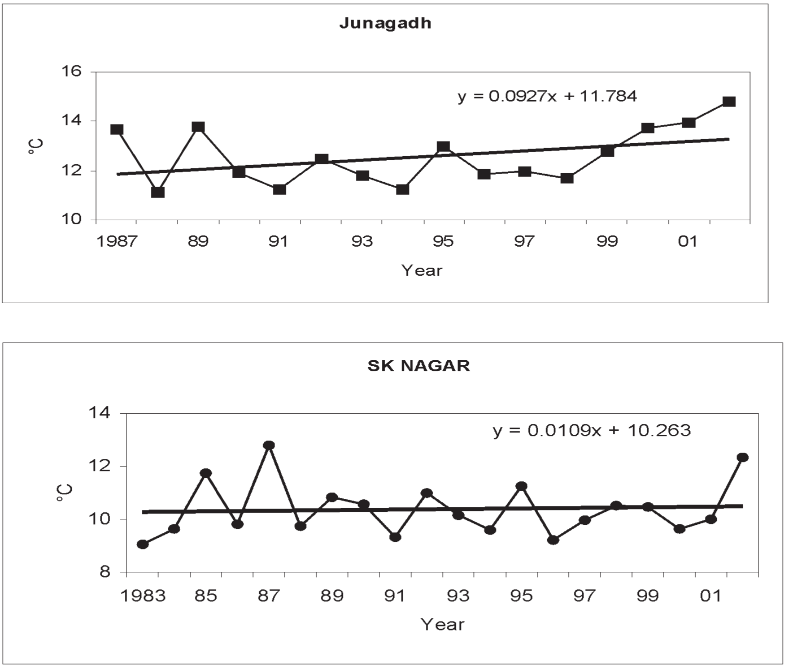


Fig. 10.9 Trends of minimum temperature during winter season at Junagadh and SK Nagar

10.3 Impact analysis

10.3.1 Impact on wheat yield

The impact analysis of climate change on wheat yield was assessed using CERES-wheat model, which was calibrated and validated by Patel (2004) and Patel et al (2007). Model has further been used to analyse the yield gap in different districts (Patel et al 2007). CERES-wheat model was subjected to simulate the wheat yield under hypothetical weather condition that may be arising due to climate change. The climate scenario simulated for temperatures (± 1 to ± 3^{0}C), radiation (± 1 to ± 3 MJm-2 day-1) and CO_2 (440, 550 and 660 ppm against present concentration of 330 ppm) were well within the range of projected climate scenario by IPCC (Anon., 1995). Looking to the complexity in climatic pattern the yield was simulated due to change in individual parameters as well as in combination with other one or two. The analysis has been worked out also for all possible combinations under limited irrigation conditions (Pandey et al 2007).

10.3.2 Effects of temperature, solar radiation and CO_2 concentration

Results on effects of minimum and maximum temperatures, solar radiation and CO_2 concentration on simulated grain yield of wheat under optimal and sub-optimal conditions and its comparison with the base yield are presented in Table 10.1.

Table 10.1 Simulated wheat yield due to varying temperature, solar radiation and CO_2 concentration under optimal and sub optimal conditions

Parameters	Simulated grain yield (kgha^{-1})		% Change from base optimal (3837 kgha^{-1}) and sub optimal (3112 kg ha^{-1}) yield	
MaxT (°C)	Optimal	Sub-optimal	Optimal	Sub-optimal
3	2646	2398	-31	-23
2	3091	2668	-19	-14
1	3546	2841	-8	-9
-1	4206	3190	10	3
-2	4485	3358	17	8
-3	4817	3641	26	17
MinT (°C)				
3	3288	2874	-14	-8
2	3460	2948	-10	-5
1	3692	3039	-4	-2
-1	4118	3140	7	1
-2	4226	3195	10	3
-3	4581	3234	19	4
Solar radiation (MJ m^{-2}day^{-1})				
3	5387	2454	40	-21
2	5111	2709	33	-13
1	4523	3085	18	-1
-1	3156	2985	-18	-4
-2	2503	2503	-35	-20
-3	1903	1903	-50	-39
CO_2 concentration (Base value 330 ppm)				
440	4630	3695	21	19
550	5687	4327	48	39
660	6465	4876	68	57

The simulated grain yield of wheat by CERES-wheat model under incremental units of maximum temperature (1 to 3^0C) showed gradual decrease in yield ranging from 3546 to 2646 kg ha^{-1} (8 to 31%) under optimal conditions. Similarly, under sub-optimal conditions, yield reduction was recorded to the extent of 2841 to 2398 $kgha^{-1}$ (9 to 23 %). In general, increase in maximum temperature from 1 to 3^0C significantly reduced the wheat yield. The reduction in yield was mainly due to reduction in duration of anthesis and grain filling with rise in ambient temperature and vice versa. Similarly in case of gradual down scale of maximum temperature in the range of -1 to -3^0C, totally reverse trend was observed. Similar trend was also noticed in case of increase and decrease in minimum temperature under optimal and sub-optimal conditions. However, the magnitude of effect was quite less (-14 to +19 %) than those due to maximum temperature (-31 to +26 %). Under limited irrigation condition (sub optimal) the effect was less than that under optimal condition. This showed that wheat yield was found to be highly sensitive to change in temperature under irrigated as well as under limited irrigation conditions.

The increase in solar radiation from 1 to 3 MJm^{-2} day^{-1} resulted in increase in yield of wheat from 18 to 40 per cent while reduction in solar radiation by –1 to –3 MJm^{-2} day^{-1} caused decrease in wheat yield to the tune of –18 to –50 per cent. However, under sub-optimal conditions, the yield was found to decrease both under elevated as well as reduced solar radiation. This showed that under limited irrigation condition (sub-optimal), high solar radiation may adversely effect through heating and thereby reduction in yield. It may be noted that under low solar radiation regime, the yields under optimal and sub-optimal conditions are same. The overall response of varying radiation to grain yield of wheat showed that the model was more sensitive to radiation than it was to temperature.

10.3.3 Combined effect of temperature and solar radiation

Under optimal condition, the effect of increase in temperatures was found to be nullified by similar increase in solar radiation (MJm^{-2} day^{-1}), as it is evident from the effect on yield (+2 to -4 %), while decreasing temperature and radiation had negative effect (-3 to -25 %) on grain yield (Table 10.2). This showed that the favourable effect of lower temperature was suppressed by negative effect of lower solar radiation regimes. Under sub-optimal condition, the decrease in yield up to 33 per cent was observed due to increase in both temperature and radiation by 3 units, while lowering of temperature and radiation had marginal effect (+6 to -7 %) on wheat yield. It can further be revealed that due to lowering of temperature and radiation by 3 units the wheat yields under optimal condition was same as that of under sub-optimal condition.

Table 10.2 Simulated wheat yield due to combined effect of temperature and solar radiation under optimal and sub optimal conditions

Temperatures (°C) and SAR (MJ $m^{-2}day^{-1}$)	Simulated grain yield ($kgha^{-1}$)		% Change from base optimal (3837 $kgha^{-1}$) and sub optimal (3112 kg ha^{-1}) yield	
	Optimal	Sub-optimal	Optimal	Sub-optimal
3	3670	2083	-4	-33
2	3790	2486	-1	-20
1	3917	2799	2	-10
-1	3738	3292	-3	6
-2	3453	3273	-10	5
-3	2892	2892	-25	-7

10.3.4 Combined effect of temperature, solar radiation and CO_2 concentration

Model simulation was also carried out for combined effect of temperature, solar radiation and different levels of CO_2 concentration (440, 550 and 660 ppm) under optimal and sub optimal condition (Table 10.3). The results revealed that at CO_2 concentration of 440 ppm, the wheat yield was found to generally increase (-2 to 23 %) with either increase or decrease of temperature and radiation up to 3 units under optimal condition. Under sub-optimal condition, however, the favourable effects were observed only under down scaling of the temperature and radiation regimes, the total effect being -23 to 26 per cent. At higher CO_2 concentration of 550 ppm, the net effect on yield was favourable (23 to 51 %) irrespective of whether temperature and radiation increased or decreased under optimal condition, while under sub-optimal condition, the negative effect (-12 %) was observed at higher temperature and radiation (+ 3 units) regimes. Under doubling of CO_2 concentration (660 ppm) scenario, increase in yield levels are quite high (42 to 70 % under optimal condition and -3 to +75 % under sub-optimal condition) due to changes in both temperature and radiation by + 3 units.

Under gradual increase in CO_2 concentration from 440 to 660 ppm, the yield levels increased to the tune of 21 to 68 per cent under optimal condition, whereas, under sub-optimal condition similar response was observed with slightly lower magnitude (19 to 57 %). This shows that under climate change scenario, CO_2 enhancement proved beneficial for higher productivity. The increase in yield under increase in concentration in CO_2, may be due to many plants growing in experimental environments with increased levels of atmospheric CO_2, exhibit increased rates of net photosynthesis and reduced stomatal opening. Partial stomatal closure leads to reduced transpiration per unit leaf area and, combined with enhanced photosynthesis, often improves water-use efficiency.

Table 10.3 Simulated wheat yield due to interaction effect of temperature, solar radiation and CO_2 concentration under optimal and sub optimal conditions

Temperatures (°C) and SAR (MJ $m^{-2}day^{-1}$) and CO_2 (Base value 330 ppm)	**Simulated grain yield ($kgha^{-1}$)**		**% Change from base optimal (3837 $kgha^{-1}$) and sub optimal (3112 kg ha^{-1}) yield**	
440 ppm	Optimal	Sub-optimal	Optimal	Sub-optimal
3	4369	2410	14	-23
2	4699	2896	22	-7
1	4726	3287	23	6
-1	4550	3920	19	26
-2	4255	3929	11	26
-3	3776	3776	-2	21
550 ppm				
3	5125	2730	34	-12
2	5593	3307	46	6
1	5778	3784	51	22
-1	5452	4602	42	48
-2	5161	4642	35	49
-3	4707	4695	23	51
660 ppm				
3	5781	3015	51	-3
2	6332	3476	65	12
1	6541	4226	70	36
-1	6229	5201	62	67
-2	5950	5262	55	69
-3	5537	5439	44	75

The interaction effect of temperature, radiation and CO_2 concentration revealed that the response under optimal condition was quite different than that under sub-optimal condition. Under optimal condition the highest benefits are obtained at higher level of CO_2 concentration combined with one unit increase in temperature and radiation. The percentage change in yield decreased both ways, that is either increasing or decreasing the parameters from the mean values. The percentage change in yield under sub-optimal condition was found to have increasing trend with decreasing (+3 to -3 units) temperature and radiation at higher levels of CO_2 concentration.

10.3.5 Impact on maize yield

CERES-maize model was used to study the impact of climate change on maize production for two cultivars (Ganga Safed-2 and GM-3) commonly grown in the State.

10.3.5.1 Effects of temperatures, solar radiation and CO_2 concentration

Results on effects of minimum and maximum temperatures, solar radiation and CO_2 concentration on simulated grain yield of maize (Cv. Ganga Safed-2 and GM-3) and its comparison with base yield and its per cent change are presented in Table 10.4 - 10.6. Results indicated that as the maximum temperature increases the yield decrease and vise versa. In case of increase or decrease of minimum temperature yield was found to increase, however, there is drastic decrease in yield if minimum temperature falls by more than 3^0C. Thus minimum and maximum temperatures influence the maize crop differently. Higher solar radiation receipt was found to increase the yield of maize while lower radiation may have adverse effect. Higher CO_2 concentration was found to have favourable effect on maize yield. Doubling of CO_2 may increase its yield by 8-9%.

10.3.5.2 Combined effect of temperature and radiation

The combined effect of minimum and maximum temperatures revealed that if both temperatures are increased or decreased by more than 1^0C, maize yield was found to decrease. If the increase in temperature is accompanied by increase in solar radiation the favourable effect was noticed only up to two units of increment in the parameters. Otherwise, the negative effect was observed either by increasing the parameters by more than two units or decreasing them.

Table 10.4 Effect of maximum and minimum temperature, solar radiation and CO_2 concentration for maize cultivars

Parameters	Simulated grain yield (kgha^{-1})		% Change from base yield	
MaxT (°C)	**Ganga Safed-2**	**GM-3**	**Ganga Safed-2 (3675 kgha^{-1})**	**GM-3 (3598 kgha^{-1})**
3	3518	3444	-4.3	-4.3
2	3658	3499	-0.5	-2.8
1	3717	3552	1.1	-1.3
-1	3776	3697	2.7	2.8
-2	3868	3708	5.3	3.1
-3	3927	3773	6.9	4.9
MinT (°C)				
3	3785	3615	3.0	0.5
2	3856	3687	4.9	2.5
1	3999	3631	8.8	0.9
-1	3767	3688	2.5	2.5
-2	3697	3620	0.6	0.6
-3	3537	3418	-3.8	-5.0
Solar radiation (MJ m^{-2}day^{-1})				
3	3862	3778	5.1	5.0
2	3794	3714	3.2	3.2
1	3977	3892	8.2	8.2
-1	3510	3373	-4.5	-6.3
-2	3284	3217	-10.6	-10.6
-3	3013	2954	-18.0	-17.9
CO_2 concentration (Base value 330 ppm)				
440	3781	3701	2.9	2.9
550	3873	3790	5.4	5.3
660	3993	3907	8.7	8.6

Table 10.5 Combined effect of maximum and minimum temperature for maize cultivars

Maximum and minimum temperatures (°C)	Simulated grain yield (kgha^{-1})		% Change from base yield	
	Ganga Safed-2	GM-3	Ganga Safed-2	GM-3
3	3528	3369	-4.0	-6.4
2	3665	3587	-0.3	-0.3
1	3677	3604	0.1	0.2
-1	3798	3661	3.3	1.8
-2	3529	3454	-4.0	-4.0
-3	3351	3279	-8.8	-8.9

Table 10.6 Combined effect of temperature and solar radiation maize cultivars

Mean maximum and minimum temperatures (°C) and SAR (MJ $m^{-2}day^{-1}$)	Simulated grain yield ($kgha^{-1}$)		% Change from base yield	
	Ganga Safed-2	GM-3	Ganga Safed-2	GM-3
3	3630	3552	-1.2	-1.3
2	3903	3725	6.2	3.5
1	3908	3832	6.3	6.5
-1	3600	3578	-2.0	-0.6
-2	3420	3349	-6.9	-6.9
-3	3243	3136	-11.8	-12.8

10.4 Conclusions

Gujarat, being western-most State of India and having long sea coast, has high variability in terms of biophysical parameters. Extreme arid climate to sub-humid climates are experienced in the state. Rainfall in the State varies from less than 300 mm to more than 2000 mm. The soils of Gujarat can be broadly classified into nine major groups: black soils, mixed red and black, residual sandy, alluvial, saline/alkali, lateritic hilly, desert and forest soils. The distribution of cropping systems is determined largely by the climatic gradient and distribution of soils. The temporal variability in rainfall indicates variable trend in different regions of the State. In middle Gujarat, increasing trend is observed in rainfall as well as maximum and minimum temperatures during different seasons. Increase in temperature significantly reduced the wheat yield while decrease in temperature increased the yield. The effect of maximum temperature on yield was more than that of minimum temperature. The higher radiation receipt and lower radiation receipt caused decrease in yield under optimal condition whereas, negative effect was seen under sub-optimal condition due to either increase or decreasing radiation. The combined effect of temperature and solar radiation was very marginal at the lower side of yield. More or less similar effects with less magnitude were observed for maize crop also.

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CHAPTER 11

Impact of Climate Change on Rainfed Agro-ecosystem over Madhya Pradesh

K. K. Agrawal, S. D. Upadhyay and A. P. Upadhyay

"Every beginning biology student knows photosynthesis will increase if you give a plant a 'squirt' of CO_2 given enough light, nutrients, and water, and a suitable temperature. Logic tells us that if this is so, then more CO_2 in the atmosphere should mean more photosynthesis. This in turn, should mean more yield or accumulated carbon in plants. This logic is fine for beginning biology; unfortunately, nature is not that simple' (Lemon, 1983)"

The ever-pervasive arduous task of producing adequate food, fibre and feed to meet ever growing demand has now become even more challenging to sustain the agricultural productivity with dwindling natural resources and ecological constraints. In future, agricultural production may be severely constrained by other emerging threats to agricultural production like increasing climatic variability and number of abiotic factors due to climate change which is mainly caused by human activities. United Nations Framework Convention on Climate Change (UNFCCC) makes a distinction between "Climate Change" attributable to human activities altering the atmospheric composition, and "Climate Variability" attributable to natural causes. Recent report by Intergovernmental Panel on Climate Change (IPCC, 2007) presents a concluding evidence for climate change to be largely attributable to human activities. Now it is beyond any doubt that the planet is warming and given the fact that during the last 150 years eleven of the twelve hottest years have been recorded after 1990, the magnitude of warming and risks associated with it may be even greater than predicted before. Increased concentration of greenhouse gases like CO_2 and warming will have serious consequences like rise in sea level, increased evaporation, increased frequency of extreme events like floods, droughts and heat waves. All these events will have profound impact on crop yields and farm profits particularly in tropical and sub-tropical regions where abiotic stresses like high temperature and water stress are already serious constraints to crop production (Reddy and Hodges, 2000; IPCC, 2007).

There are three aspects of climate change that are important from agriculture point of view; (i) increase in greenhouse gas concentration particularly CO_2 levels (ii) rise in temperature and, (iii) increased climatic variability. Increase in CO_2 concentration *per se* is generally beneficial for biomass production and can even mitigate for other abiotic stresses to some extent. However, its net impact on crop productivity is not always positive. Rise in temperature is beneficial for cooler regions. It will have detrimental effect on crop productivity in warmer regions (Wheeler *et al*., 2000). Crop specific assessments for some of the important Indian crops also support these observations; e.g. Soybean (Lal *et al*., 1999), rice (Aggarwal and Mall, 2002) & wheat (Aggarwal and Sinha, 1993). But the net impact of climate change and the vulnerability of a particular agricultural system or agro-ecosystem will ultimately depend on its sensitivity and adaptability to climate change. And because of inherent characteristics, rainfed productions systems are particularly vulnerable where climatic variability seriously affects food security through its influence on investment, adoption of agricultural technology, aggregate production, market prices and ultimately economic development. Therefore, in future, climate change will have serious repercussions for the rainfed agriculture impacting the livelihood of millions of farmers.

11.1 Biophysical resources

11.1.1 Agriculture in Madhya Pradesh

State agriculture is characterised by its predominantly rainfed agriculture and that underlines the State of its agricultural development. Rainfed agriculture of the State differs fundamentally from that of irrigated agriculture in terms of cropping systems, inherent climatic risk, resource base, flexibility to adopt, productivity and farm profits. The irrigated system has high productivity, better adaptability and low climatic risk but can be vulnerable to other risks like pest and diseases and market forces because of monoculture and higher investment. This system aims at profit maximization whereas in rainfed system the emphasis is on risk aversion with moderate gains in productivity. It is not surprising therefore, that despite sustained research and development efforts the agricultural development in Madhya Pradesh has remained conservative in terms of growth and productivity. However, given its numerous limitations imposed by cohorts of biotic, abiotic and socio-economic factors, the State's agriculture has shown remarkable dynamism and resilience. The State has remained in the forefront of pulse and oil seed production (Table 11.1), two major commodities where rest of

Table 11.1 Comparative position of Madhya Pradesh Agriculture

CROP GROUP/ CROP	FIRST POSITION		SECOND POSITION		THIRD POSITION		POSITION OF M.P.IF NOT IN FIRST THREE	
	STATE	[%] SHARE	STATE	[%] SHARE	STATE	[%] SHARE	POSITION	[%] SHARE
TOTAL CEREALS	RAJASTHAN	25.37	MAHARASHTRA	13.56	ANDHRA PRADESH	9.18	FIFTH	8.7
TOTAL PULSES	MADHYA PRADESH	21.38	UTTAR PRADESH	19.77	MAHARASHTRA	18.51	-	-
TOTAL FOOD GRAINS	UTTAR PRADESH	20.73	PUNJAB	11.59	RAJASTHAN	8.43	FIFTH	7.43
TOTAL OILSEEDS	GUJARAT	22.42	MADHYA PRADESH	22.10	RAJASTHAN	15.82	-	-
RICE	WEST BENGAL	16.61	UTTAR PRADESH	14.75	PUNJAB	10.94	FOURTEENTH	1.90
JOWAR	MAHARASHTRA	46.09	MADHYA PRADESH	14.11	KARNATAK	11.03	-	-
MAIZE	ANDHRA PRADESH	16.61	RAJASTHAN	13.86	MADHYA PRADESH	12.39 -		-
BAJRA	RAJASTHAN	54.87	GUJARAT	13.20	UTTAR PRADESH	9.24	SIXTH	2.15
WHEAT	UTTAR PRADESH	35.46	PUNJAB	20.09	HARYANA	12.66	FOURTH	10.04
ARHAR	MAHARASHTRA	29.11	UTTAR PRADESH	17.30	MADHYA PRADESH	11.39 -		-
GRAM	MADHYA PRADESH	40.33	UTTAR PRADESH	18.40	MAHARASHTRA	10.61	-	-
MASOOR	UTTAR PRADESH	48.54	MADHYA PRADESH	23.30	BIHAR	15.53	-	-
GROUNDNUT	GUJARAT	54.8	ANDHRA PRADESH	12.10	TAMILNADU	11.25	SEVENTH	3.18
SOYABEAN	MADHYA PRADESH	59.92	MAHARASHTRA	28.14	RAJASTHAN	8.78	-	-
RAPE/MUSTARD	RAJASTHAN	44.19	HARYANAs	15.48	UTTAR PRADESH	12.74	FOURTH	7.74
COTTON	GUJARAT	29.06	MAHARASHTRA	22.21	ANDHRA PRADESH	13.65	SEVENTH	4.76
SUGARCANE	UTTAR PRADESH	47.51	MAHARASHTRA	11.37	TAMILNADU	8.31	ELEVENTH	0.92

India has legged behind leaving a wide gap between demand and supply. State agriculture has in its credit a major success story in the Indian agriculture after green revolution i.e. soybean success story.

11.1.2 Agroclimatic zone

Madhya Pradesh has remarkable agrarian diversity in terms of resource base; having a wide range of climatic backcloth within and between different crop seasons, variety of soil types ranging from light textured alfisols to very heavy rich in clay vertisols, each with their own inherent problems, and cropping patterns. The State is divided into ten agro-climatic zones (Fig.11.1), each zone has its unique set of natural resources and constraints. The eastern part of the State is characterised by its rice based cropping systems, light alfisols which have low water holding capacity and are prone to erosion mainly water erosion because of higher and often high intensity rainfall. Rainfall in this part of the State is about 1500 mm mainly received during south-west monsoon season. The central and western parts of the state has soybean based cropping systems where pulses and oilseeds occupy an important place.

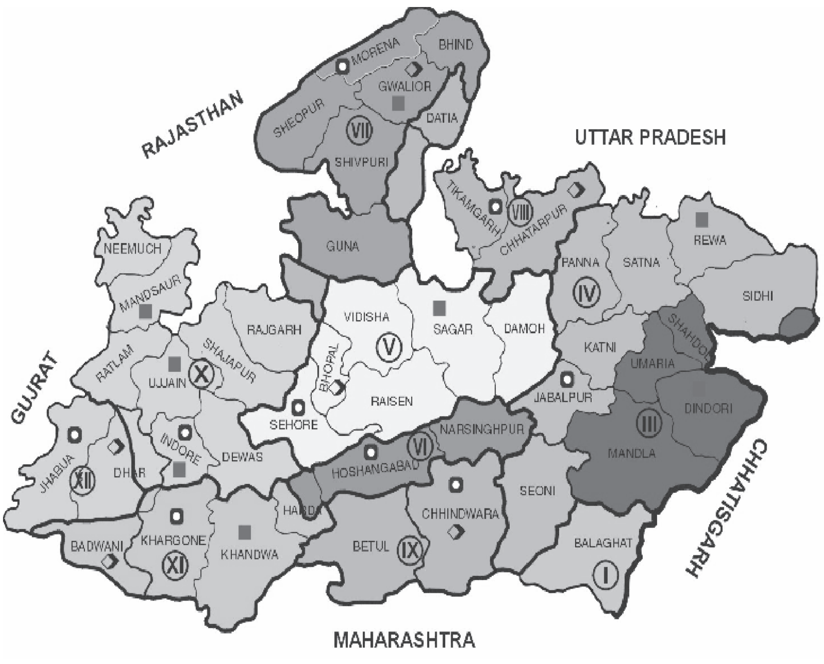

Fig. 11.1 Agroclimatic Zones of Madhya Pradesh

11.1.3 Spatial distribution of rainfall

In rainfed agriculture of the State, monsoon rainfall is the life line and success of agriculture depends on the quantum and distribution of the Southwest monsoon rainfall. Farming has remained a hazardous occupation because of vagaries of monsoon rainfall. Rainfall increases from West to East and decreases towards North. It varies from about 700 mm in northern part of the State to about 1500 mm in eastern part (Fig. 11.2). The latitudinal decline in rainfall and its longitudinal increase decide the cropping system that are grown across the State. The cropping pattern in the State changes with rainfall like rice is a major crop in the East whereas short duration, drought tolerant crops like pearl millet are grown in the northern part.

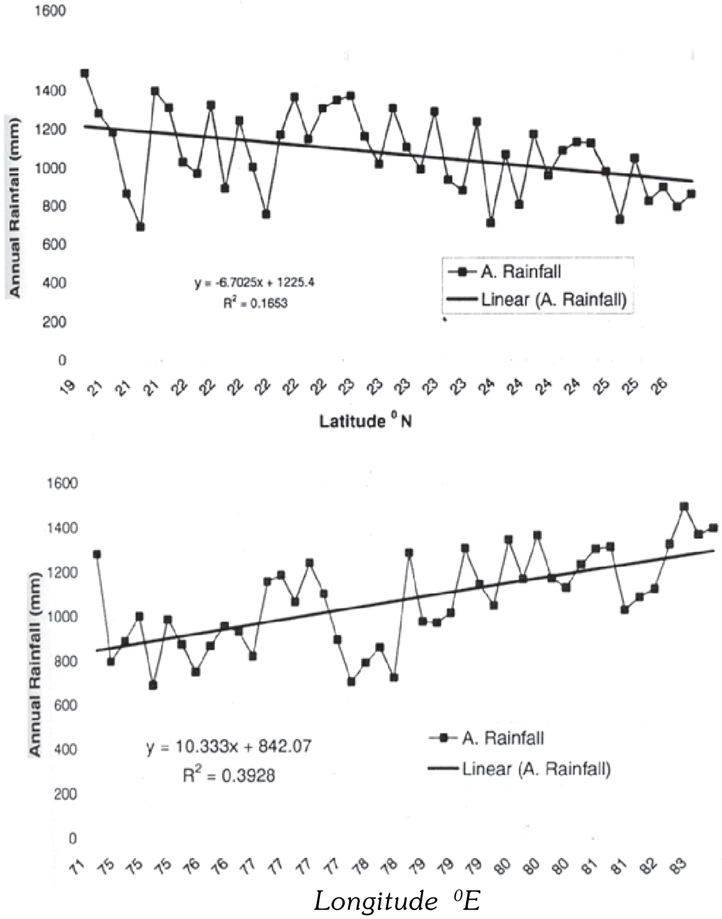

Fig. 11.2 Rainfall Pattern in Madhya Pradesh

11.1.4 Long-term trends

The long-term trends in maximum and minimum temperatures and rainfall were remarkably different for different locations and for different cropping seasons. For example, changes in temperature, particularly minimum temperatures, are very different for Gwalior, Indore and Jabalpur. There is generally a cooling trend at Gwalior whereas at Indore temperatures show a warming trends. At Jabalpur there is a decreasing trend for minimum temperatures during rabi crop season which can have real serious repercussion for rabi crops. It has been generally observed that low night temperature during grain filling period improve crop productivity, particularly for late-planted crops. As almost 90% of the total annual rainfall is received during kharif season, rainfall trends during that season are important. Changes in rainfall pattern are evident at three locations; at Jabalpur rainfall shows an increasing trend whereas the other two locations display a decreasing trend. Jabalpur is in high rainfall zone whereas Gwalior and Indore are at low rainfall zones. Thus further reduction in rainfall at these locations would seriously limit the production potential of crops.

11.1.5 Long-term Trend Analysis of Soybean Productivity in Madhya Pradesh

Soybean yield trends in three selected districts of Madhya Pradesh were examined in relation to rainfall of that district. Jabalpur is in high rainfall zone where normal rainfall during monsoon season is more than 1250 mm whereas Indore is in low rainfall zone with a normal rainfall of about 850 mm and Chhindwara is in between these two in terms of rainfall. The long term productivity trend in these districts have been different; at Jabalpur and Indore there was an increasing trends in productivity until mid-nineties and thereafter it started declining whereas in Chhindwara productivity shows a downward trend. But normalized yields at chhindwara show no change in yield levels. However, a plot of normalized yields with normalized rainfall of three districts shows that there is an increase in yield levels with increased rainfall at Indore and Chhindwara, but yields decline with increased rainfall at Jabalpur . This shows the negative effect of high rainfall on soybean productivity at Jabalpur. This explains, atleast partly, why there has been a drastic reduction in soybean area in Jabalpur district in the last few years and farmers have been looking for an alternative crop to soybean.

11.1.6 Effect of temperature on chickpea

Inter and intra-seasonal temperatures also vary considerably in different parts of the State ranging from as high as 45 °C during summer and less than 4 °C during winter. Unfavourable thermal regimes take a heavy toll on crop productivity albeit, it does not get as much attention as drought or moisture stress. Severe winter temperatures pose a major threat to pulses causing wide spread frost damage to some of the sensitive crops like pigeonpea, fieldpea and chickpea on the one hand whereas crops like wheat and chickpea suffer from higher temperatures particularly during grain filling on the other. Studies on the effect of temperature on grain yield of wheat and chickpea have shown that sub-optimal temperature is one of the major causes of low yields of chickpea and wheat (Fig. 11.3).

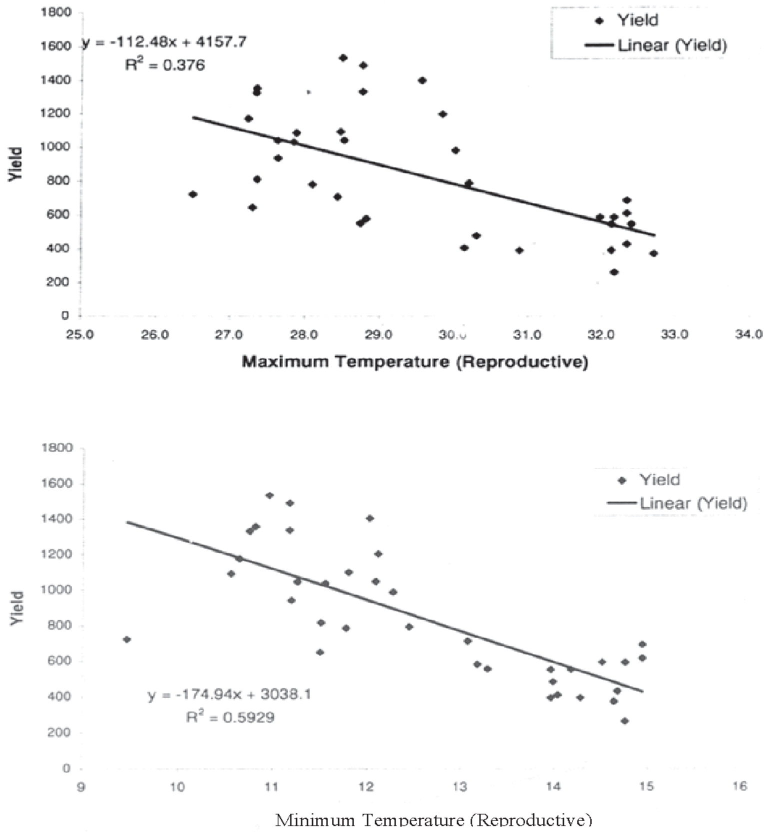

Fig. 11.3 Effect of Maximum & Minimum Temperature on the Productivity of Chickpea

Abiotic stresses imposed by unfavourable climatic conditions have remained major constrain in maximising crop productivity. In future these stresses are most likely to become much more intense and frequent due to climate change related increases in climatic variability. It is therefore, important that steps are taken to minimise climate change related impact on agriculture. The exercise can be very useful in developing adaptation strategies and appropriate government policies to insulate state agriculture from climate change. Although improving irrigation facilities has been suggested as one of the main adaptation options to offset climate change impact on agriculture production, water resources may be limited for future food production particularly in dry regions (Döll, 2002). Also given the economic and environmental implications, potential for further expansion of irrigated system in countries like India is limited. Green revolution in India had its major impact in irrigated production system but as now becoming clear from the experiences of rice-wheat irrigated system in Punjab that it may not be sustainable. Therefore, Indian agriculture has to rely more on rainfed system for large proportion of its future food supplies (Paroda, 1998).

11.2 Climate variability

11.2.1 Long-term trends in temperature and rainfall

Changes in temperature and precipitation patterns together with occurrence of extreme events are major threat to future food security due to climate change. After collection of long term data for more locations of Madhya Pradesh, climatic characterization was done for long-term trends and occurrence of extreme events for precipitation and temperature in relation to crop growth phases as climate change related occurrence of these extreme events can have serious consequences for agricultural production. A comparison of these trends for different places reveals important trends that can be useful for making future changes in cropping patterns. For example, long term trends in weekly temperatures for Jabalpur and Gwalior reveal a very different trend; whereas in Gwalior there is a cooling trends for most part of crop growth period but Jabalpur has a warming trends during kharif and cooling trends during rabi season (Fig. 11.4). These places also vary remarkably in terms of occurrence of extreme events of precipitation and temperature (Fig. 11.5).

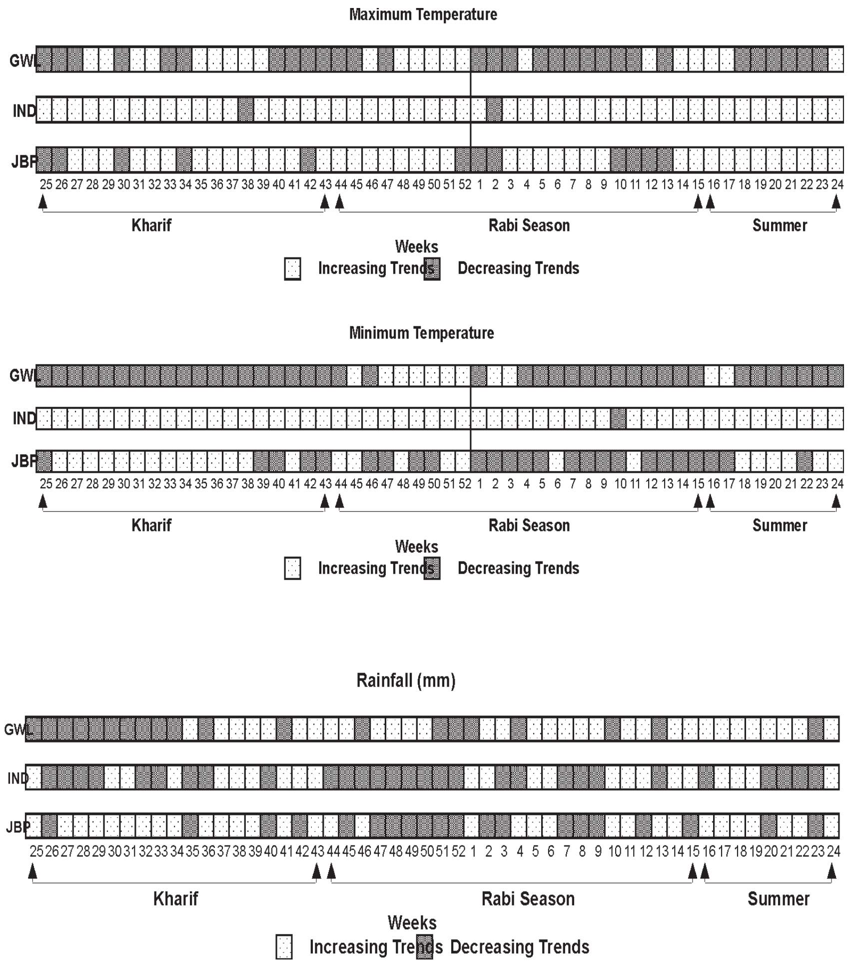

Fig. 11.4 Weekly Trends in Maximum and Minimum Temperature and Rainfall in Relation to Cropping Season

11.2.2 Trend analysis for crop productivity

Trend analysis for major crops of the State was done in relation to temperature and precipitation. The normalized yields were compared with normalized rainfall and temperature to assess the sensitivity of crop productivity with changes in these important weather variables. In soybean for example, productivity at Jabalpur is negatively associated with increasing rainfall whereas at Indore there is an increase in yield with increased precipitation. Thus, in future with increased precipitation soybean may not be a viable option for places like Jabalpur that are in high rainfall zone (Fig. 11.6 - 11.14).

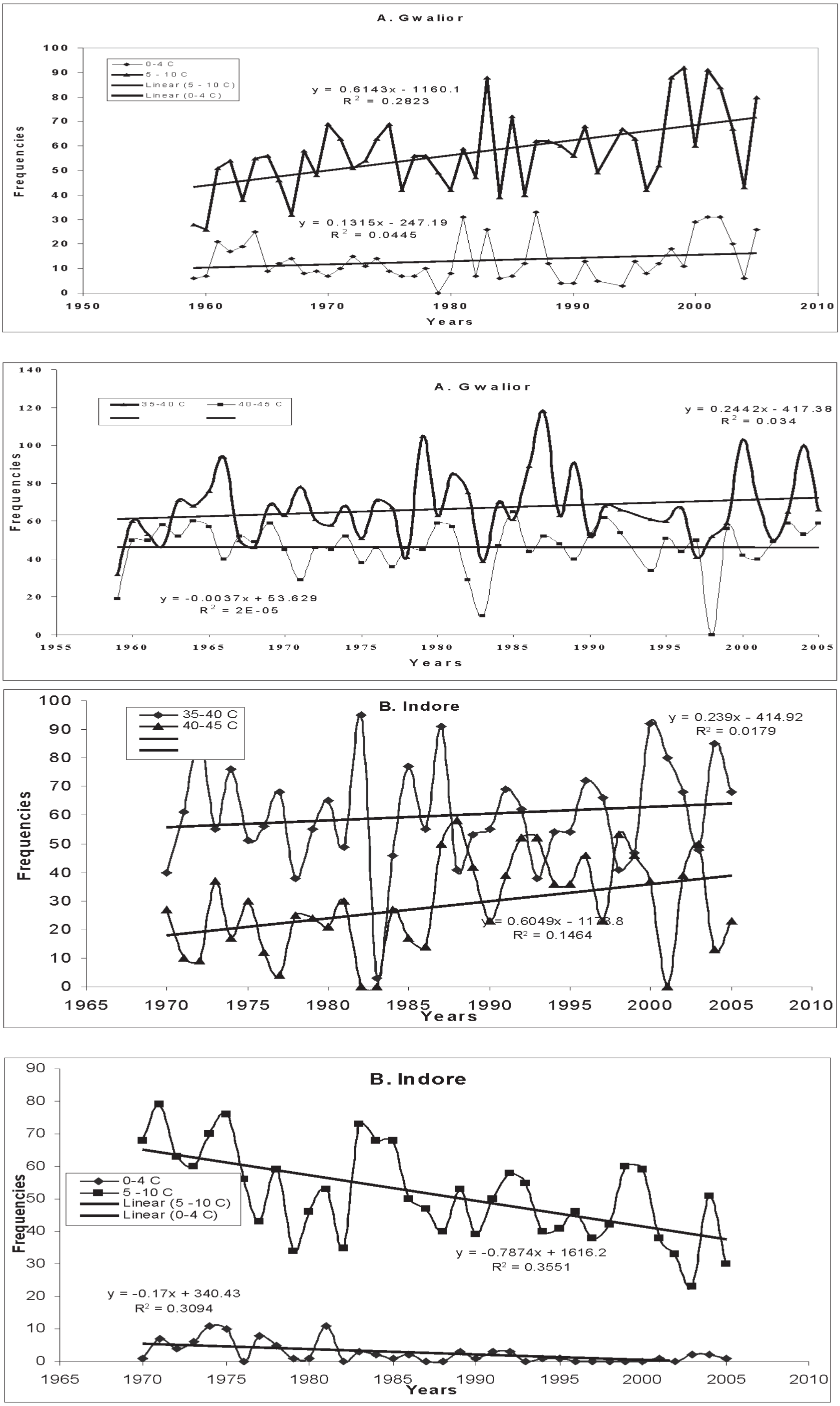

Fig. 11.5 Occurrence of extreme temperatures at (A) Gwalior and (B) Indore

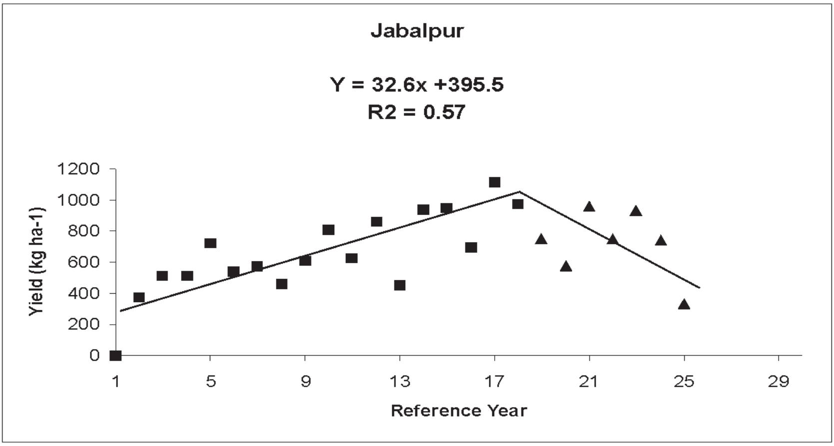

Fig. 11.6 Long-term trends in soybean productivity in Jabalpur District

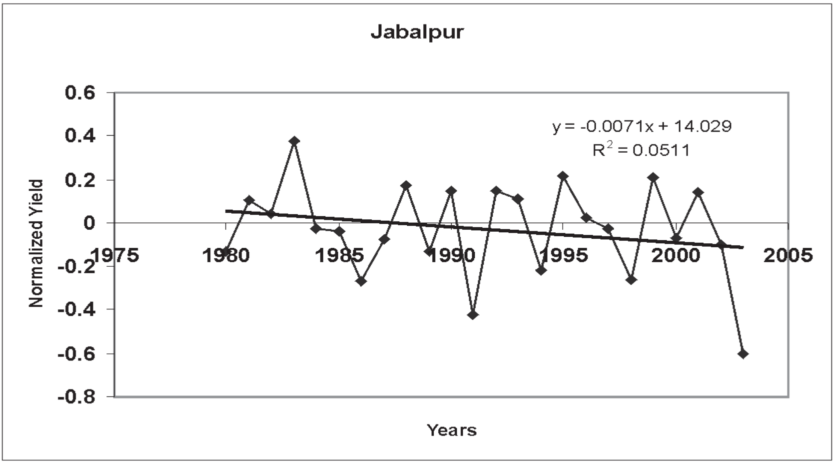

Fig. 11.7 Normalized productivity of soybean at Jabalpur

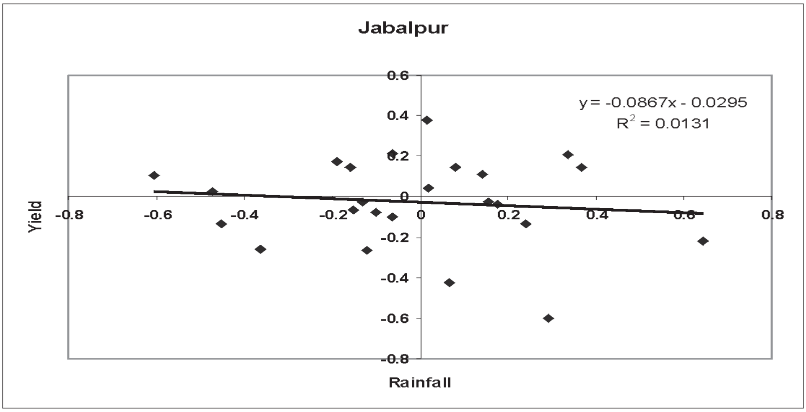

Fig. 11.8 Normalized soybean yield in relation to normalized rainfall at Jabalpur

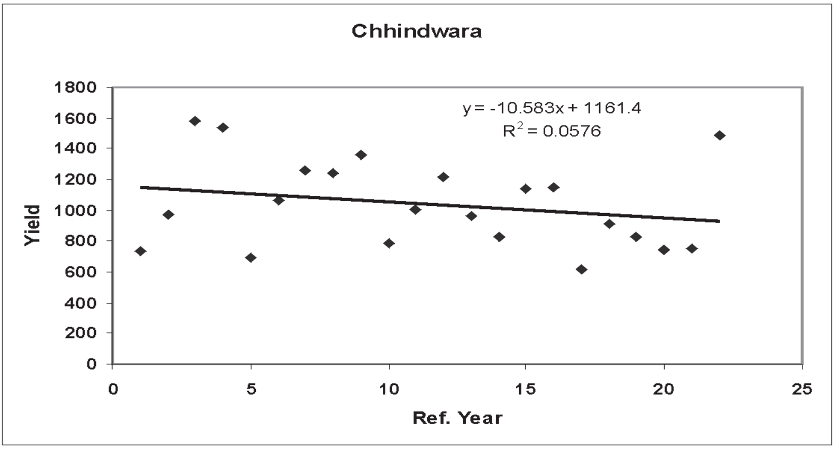

Fig. 11.9 Long-term trends in soybean productivity in Chhindwara District

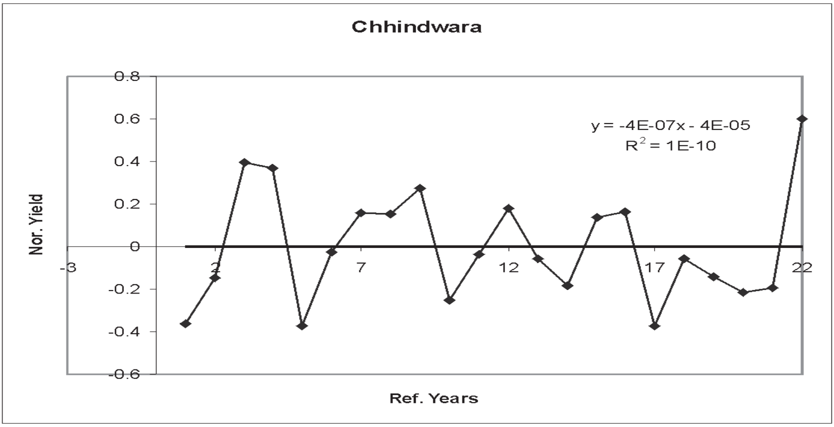

Fig. 11.10 Normalized productivity of soybean at Chhindwara

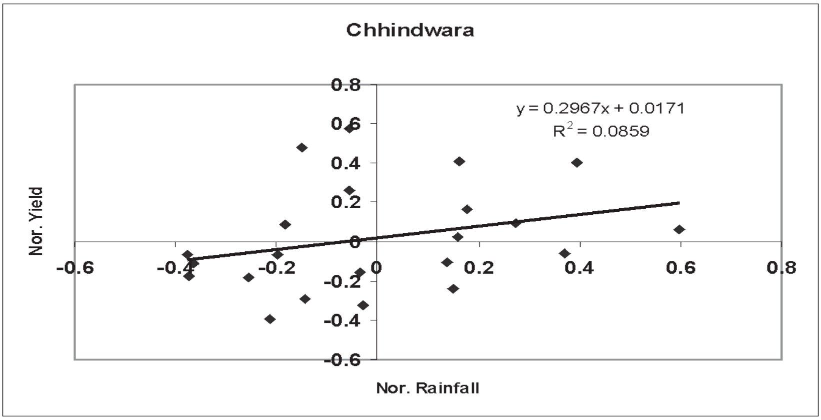

Fig. 11.11 Normalized soybean yield in relation to normalized rainfall at Chhindwara.

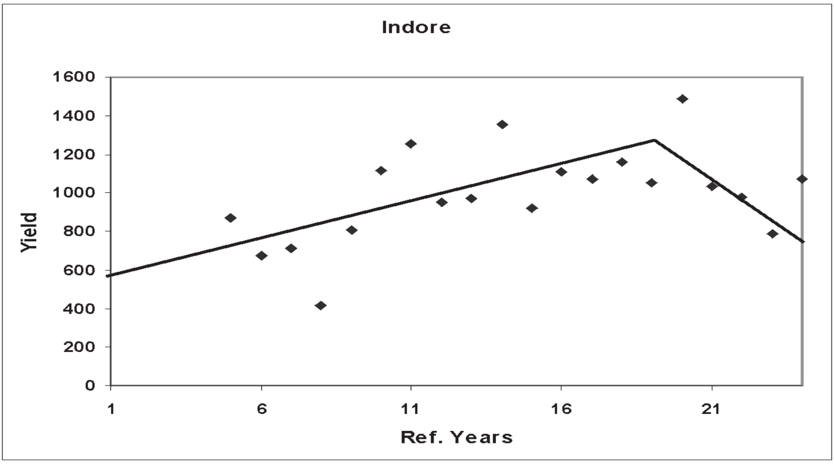

Fig. 11.12 Long-term trends in soybean productivity at Indore.

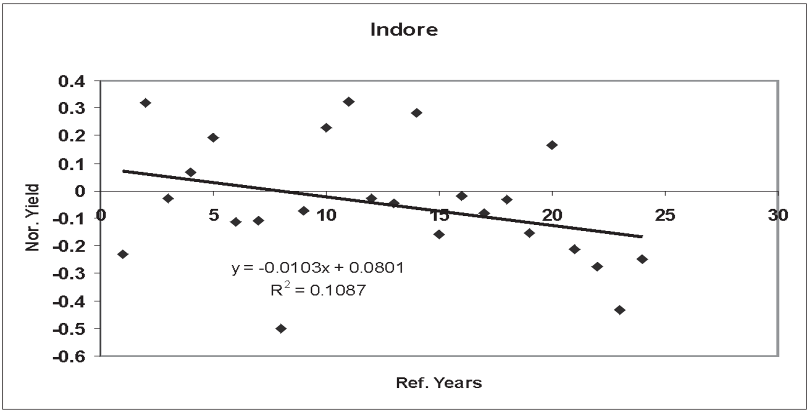

Fig. 11.13 Normalized productivity of soybean at Indore

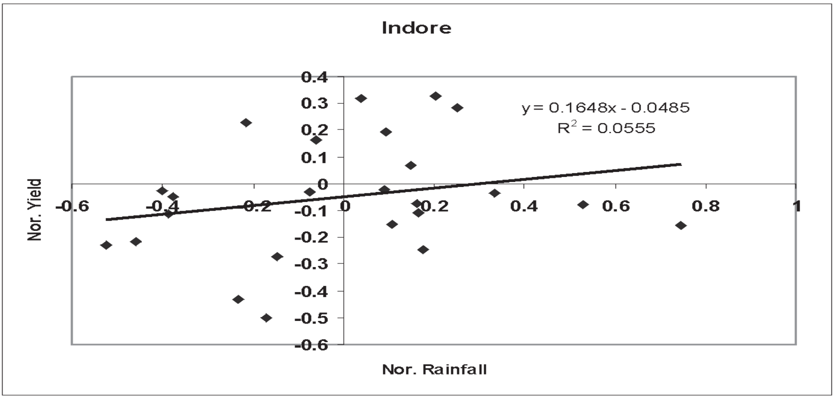

Fig. 11.14 Normalized soybean yield in relation to normalized rainfall at Indore.

11.2.3 Biological indicators for climate change

11.2.3.1 Changes in phenology

Other than long term trends in temperature and rainfall, there are some other biological indicators suggesting for changes and/or shift from normal climatic conditions. Such changes are best displayed by trees and behaviour of other living beings. One remarkable indicator that has been recorded for the last more than 10 years is flowering in mango in this region. During last decade early flowering in mango has been a common feature which has been recorded in the university farm. It is believed to be triggered by generally warmer winters. There are other such examples too which indicate towards a climate change and particularly, towards warmer temperatures.

11.2.4 Altitudinal shifts in species diversity

Species diversity evaluation (*in-situ)* under altitudinal gradient at Pachmarhi Biosphere Reserve (PBR) has revealed an upward shift in certain plant communities. Although there are no systematic long term records of altitudinal distribution of medicinal plant species, however, a survey conducted in the Pachmarhi Biosphere Reserve and an interaction with locals has revealed that many species have disappeared from lower altitudes and now only found at higher elevations. Many other factors, like over exploitation and population pressure may have also contributed to this upward shift but it is plausible to suggest that rising temperature is also a major factor in this shift.

11.3 Altitudinal distribution of Pachmarhi Biosphere Reserve

The minimum and maximum temperatures vary with altitude. Three communities have been formed corresponding to different altitudes based upon the densities. Density of rare and endangered medicinal plants viz., *Andrographis paniculata* (Kalmegh), *Evolvulus alsinoidis* (Sankhpuspi) and *Gymnena sylvestre* (Gudmar) were observed to increases as altitude increases.

Phytosociological parameters *viz.* frequency, density, abundance, relative frequency, relative density, relative abundance, importance Value Index, Similarity and Diversity Index have been computed. According to Champion and Seth (1968), the major forest type of Pachmarhi Biosphere Reserve is 3B-south Indian Moist Deciduous Forest. Analytical characters of woody and non woody vegetation of three altitudes are discussed here to evaluate the impact of climate change on biodiversity.

In woody and non woody vegetation of top altitude (Pachmarhi), a total of 37 trees and 37 herbaceous flora are recorded. The Minimum and Maximum Importance Value Index of woody and non-woody vegetation ranges from 7.73 - 46.56 and 2.24 - 16.26, respectively. *Shorea robusta* and *Terminalia tomentosa* exhibited the highest density of 114 and 35 tree per ha respectively. Hence, the community can be named as *Shorea robusta- Terminalia tomentosa community.*

In woody and non woody vegetation of middle altitude (Chhindwara), a total of 37 trees and 43 herbaceous flora are recorded. The Minimum and Maximum Importance Value Index of woody and non- woody vegetation ranges from 2.94 - 18.18 and 1.83 - 13.42, respectively. *Terminalia tomentosa* and *Terminalia belerica* exhibited the highest density of 61 and 51 trees per ha, respectively. Hence, the community can be named as *Terminalia tomentosa- Terminalia belerica community.*

In woody and non woody vegetation of lower altitude (Pawarkheda), a total of 33 trees and 47 herbaceous floras are recorded. The Minimum and Maximum Importance Value Index of woody and non- woody vegetation ranges from 24.37 - 24.93 and 4.93 - 22.63, respectively. *Tectona grandis* and *Madhuc latifolia* exhibited the highest density of 63 and 50 tree per ha, respectively. Hence, the community can be named as *Tectona grandis - Madhuc latifolia community (Fig. 11.15).*

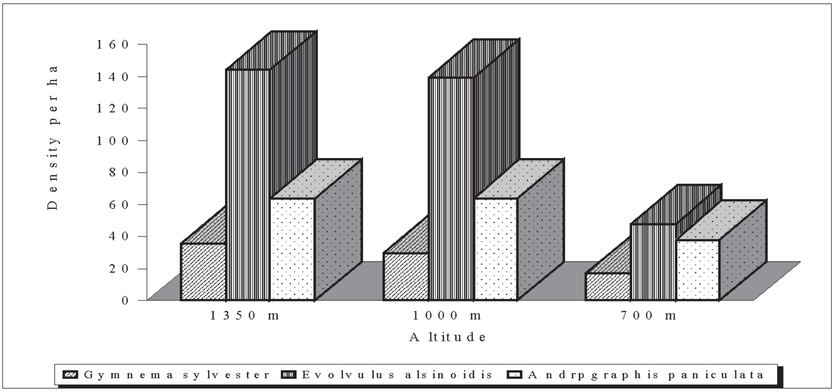

Fig. 11.15 Altitude wise distribution of Medicinal Plants in Pachmarhi Biosphere Reserve

The species richness for woody vegetation was found maximum at middle altitude (4.91) and minimum at top altitude (3.47). For non woody vegetation maximum species richness was observed at top altitude (5.32) and minimum for lower altitude (2.32). Maximum similarity has been found between community of top altitude and middle altitude.

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CHAPTER 12

Impact of Climate Change on Agriculture over Eastern Uttar Pradesh

Padmakr Tripathi and A. K. Singh

Eastern Uttar Pradesh, consisting of 25 districts, spred in seven revenue divisions (Faizabad, Gorakhpur, Basti, Varanasi, Devipatan, Azamgarh and Mirzapur). It has been divided into three zones, viz., north eastern plain zone, eastern plain zone and vindhyan zone. Rice and wheat are the prominent cereal crops of the Uttar Pradesh. During 2005-06, Uttar Pradesh produced 235.7 lakh metric tonnes of wheat from an area of 91.85 lakh. ha with a productivity level of 2.57 t/ha whereas the crop coverage of rice during 2006 was 59.25 lakh ha with the total production of 150.6 lakh metric tonnes at average productivity level of 2.3 t/ha. There is a wide range in rice and wheat productivity in eastern districts of Uttar Pradesh due to following constraints. Prevalence of harsh climate (low/high temp. and moisture stress) in hilly districts of Vindhyan zones, is common. Small or marginal and scattered land holdings and women centric Agriculture, are also common features in the region. Low adoption of improved technology and high yielding improved varieties due to poor socio-economic condition of the farmers and poor extension network especially in eastern region are the constraints. Due to erratic rainfall and uneven distribution, the frequency of flood in Bihar and drought in E.U.P. is considerably increasing. It affects the crop productivity to a great extent. Rice farming in eastern India, is therefore, most vulnerable and risk prone due to complex ecological situations marked by frequent floods and droughts.

12.1 Zonal climatic features

12.1.1 North Eastern Plain Zone (NEPZ)

The zone is relatively more humid having greater relative humidity as compared to other regions of eastern U.P. The normal annual rainfall of the zone is 1207.2 mm. More than 74% of the total rainfall occurs during Southwest monsoon (June-Sep). Intensity of rainfall of the Zone is high as compared to other zones. 17.0 mm/ day is the annual average intensity of rainfall as compared to 25.84 mm/ day during monsoon period. Total annual evaporating demand of the zone is 1370-1400 mm. Maximum RH varies between 84% (August) to 41.6% (April) in the zone. Average range of mean temperature of the zone is 24-32 °C with average maximum temperature of 39.5 °C and minimum of 8.6 °C which generally occur during May and January, respectively. Average wind speed of the zone is 5 km/ hour but ranges between 2-7 km/ hour with maximum in April. This zone experiences maximum AET in April, June and July whereas PET is maximum in May.

12.1.2 Eastern Plain Zone (EPZ)

Range of mean temperature of this zone is 28-32°C during summer season. January is the coldest month. May is hottest month of the region. Mean maximum temperature of this zone is 30.5^{0}C. Average annual rainfall of this zone is about 1031mm. Out of total, 82.5% rainfall is received during Southwest monsoon period. Post monsoon rainfall (4.0%) is the smallest among the zones. Annual average rainfall intensity of this zone is 16.28 mm/ day. The rainfall intensity during Southwest monsoon period of the zone is 21.47 mm/day, which is lower than the NEPZ (25.8 mm/ day). Mean cloud during monsoon season varies from 4-5 okta in the morning and 3-6 okta in the evening. Ninety per cent of cloud is low level clouds in the region during monsoon season while during withdrawl of monsoon low cloud remains only 30%. Rainfall of the region is very erratic.

12.1.3 Vindhyan Zone (VZ)

Normal annual rainfall and rainfall intensity of this zone are about 1024 mm and 15.88 mm/ day, respectively. As regard to rainfall distribution, a tune of 80.6% of rainfall occur during Southwest monsoon perod (June-Sept), followed by winter monsoon 8.0% (Dec-Feb) and 6.4% in summer season. This rainfall pattern shows that winter vegetable crops may be harvested in this zone, not susceptible to high temperature. The general trend shows that a year of high rainfall is followed by a year of relatively low rainfall and usually deviations are marginal. Rainfall patern shows that the deviations from normal increased greatly. Highest and lowest percentage of variability of rainfall is 66% and 50%, respectively.

12.2 Climate change

The maximum temperature is likely to increase between 0.5^{0}C and 3.0^{0}C in Eastern Uttar Pradesh and Bihar while minimum temperature between 1.0 and 5.0^{0}C during ensuing decades by 2080. A slight increase in rainfall is likely over Bihar and eastern Uttar Pradesh by 2080 (Fig. 12.1)

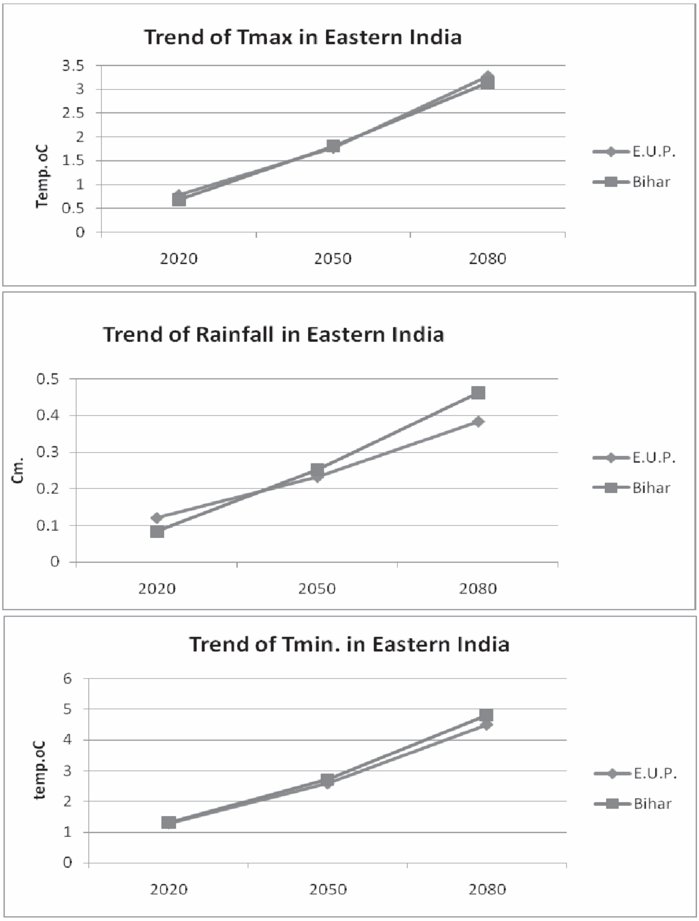

Fig. 12.1 Projected trends in temperature and rainfall over E.U.P and Bihar

12.3 Mitigation strategies

- Hybrid vigour of heat stress in wheat crop and water stress in rice crop need to be exploited as it offers to an increase in yield by 20-25% over best improved varieties under favourable conditions.
- Traditional rice varieties due to their moderate adaptability are still cultivated on larger proportion of rainfed upland areas of eastern U.P. Farmers participatory approach for development of high yielding varieties with improved drought tolerance should be encouraged.
- Integrated crop management need to be emphasized in future besides developing short duration, drought tolerant varieties responsive to low inputs.
- Flood prone rice is more vulnerable than other rice grown in rainfed ecosystem as their yields are low and unstable due to unpredictable droughts, submergence and flash flood.
- Crop intensification is one of the strategies to step up productivity. Development of short duration varieties like Govind, Saket 4 and NDR-97 helped to fit into diverse rice based cropping system of U.P.
- Rice cultivation in upland rainfed involve a lot of risk. Plant-soil-and-water relations reducing potential productivity, are critical constraints accounting for 30% of yield losses in eastern India.

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CHAPTER 13

Impact of Climate Change on Agriculture over West Bengal

Saon Bannerjee and S. A. Khan

Climate change is one of the greatest challenges that the global community has ever faced. During past few decades the climate change issue is the prime focus of almost all sectors including agriculture. Earth's climate is warmed by 0.6^0C to 0.8^0C since industrial revolution. Eleven of the last twelve years (1995-2006) rank among the 12 warmest years since human started keeping record of global surface temperature. The mean temperature in South Asia is projected to increase by 0.1^0C to 0.3^0C in *Kharif* (July to October) and 0.3^0C to 0.7^0C in *Rabi* (November to March) season. The CO_2 and methane concentrations have reached from 280 ppm and 0.7 ppm in the pre-industrial period to 379 ppm and 1.78 ppm at present, respectively (IPCC, 2001). The elevated temperature and CO_2 level by induced climate change are affecting the growth, yield and yield components of crops. Pest and disease incidences are also likely to be affected due to this change. High temperature enhancing evaporation may give rise to higher rainfall which may be different from that of expected. Due to this, the coastal area will be affected most as rise in the sea level is projected. Past observations on the mean sea level along the Indian coast, indicated that a long-term rising trend of about 1.0 mm/year on an annual mean basis. However, recent data suggest a rising trend of 2.5 mm/year in sea level along the Indian coast (Mahapatra, 2006).

Forecasting future climate conditions is challenging and some major processes are yet to be properly understood. However, the methods have vastly improved in recent past to characterize the risks. Due to climate change the poorer countries like India and her people will suffer earliest and most, even though they have contributed little to causing the problem. Moreover, India is already warmer and also suffers from high rainfall variability. As a result, further warming will affect adversely. Again developing countries like India are heavily dependent on agriculture, the most climate sensitive aspect of all economic activities. Therefore, proper care must be taken to assess the possible impact of climate change on agriculture and to find out the economically viable mitigation options.

13.1 Biophysical resources

West Bengal has mostly a tropical climate. The plains are hot except during the short winter season. The mountainous region in the North is cold on account of its altitude. The hot season lasts from mid-March to mid-June, with the day temperature ranging from 38° C to 45°C in different parts of the State. The monsoon arrives by middle of June and variability is a characteristic feature of the monsoon. Winter, which lasts about three months, is mild over the plains. The average minimum temperature seldom falls below 10° C during winter. It experiences cold and dry northern wind, substantially lowering the humidity level. There are six agro-climatic zones in West Bengal (Table 13.1).

Table 13.1 Agro-climatic zones of West Bengal

Name of the Zone	Constraints	Opportunity
Hill Zone	Shallow soil depth, high acidity, high slope (Physiographic constraint)	Opportunity for extension of orange and tea cultivation, orchid export
Terai Zone	Flash flood, sand deposition on the top soil	Fruit processing (Tomato, Pineapple), jute based industry
Old Alluvial Zone	Low to medium soil organic matter	Opportunity for mango, litchi, vegetables, sugarcane
New Alluvial Zone	Poor micronutrient status, groundwater contamination with arsenic and other heavy metals	Opportunity for vegetables and flowers
Red and Laterite Zone	Unfertile uplands , prone to erosion	Seed production. Opportunity for jute, cotton, fruits and medicinal plants
Coastal and Saline Zone	Patches of saline, acid sulphate saline soils	Paira cropping after paddy (in low land) such as lathyrus, land-shaping

There are varied types of soil seen in the State. In Hill Zone, the soil type is brown forest soil having sandy loam texture and strong to moderate acidity. In Terai Zone, alluvial soil is sandy to sandy-loam texture, acidic and deficient in some micro-nutrient. Gangetic alluvial soils and Vindhyan alluvial soils cover major parts of West Bengal. These soils are low to medium in organic matter content. Red and lateritic soils are poor in organic matter content, calcium and nitrogen. In coastal region, the soils are partly saline with sporadic patches of saline alkali, non-saline alkali and degraded alkaline soils.

Depending on land situation, soil texture, rainfall, availability of irrigation, different cropping systems are followed at different zones. The main cropping systems of the State are, rice-rice-mustard, jute/rice-mustard/pulses, jute-wheat, rice-potato, jute-rice-potato, maize-winter vegetables and greengram-mustard.

13.2 Climate change impacts

Like other parts of India, in West Bengal also, the Coastal Saline Zone will face the problem of sea level rise, whereas the Hill Zone and Terai Zone will face the problem of glacier melting. The Red and Lateritic Zone of West Bengal has already started suffering from temperature rise as the water retention capacity of the soil and irrigation facilities are very poor. Even under well irrigated region of old and new Alluvial Zone, rising temperature and abnormal behaviour of monsoon will cause a great set-back of agricultural system. Increased level of CO_2 and SO_2 due to combustion of fossil fuel and formation of NO_2 may lead to increased acid rain which will affect soil, vegetation and water. Deforestation has changed the pattern of rainfall in Darjelling hill with passage of time, bringing about substantial losses of surface soil and nutrient and reduction in tea production.

13.3 Climatic variability

For climatic variability analysis, twenty raingauge stations covering three districts (namely Bankura, Birbhum and Purulia) of Red and Lateritic zone of West Bengal were considered for the rainfall pattern and temperature study. The particular zone is cited here due to inherent problems of water holding capacity of soil. It is very much vulnerable to any change of weather parameters (Milly, 1994; Milly and Dunne, 1994). Daily rainfall for the period of 1970 to

2000 for May to November and yearly rainfall were analysed by Mukherjee and Banerjee (2007). The monthly average of maximum and minimum temperatures were also analysed to determine temperature trends.

13.3.1 Rainfall

An increasing trend of yearly rainfall and shifting pattern of rainfall were observed in the said zone as a whole. The average yearly rainfall of 1990 – 2000 increased to the tune of 81 mm to 837 mm compared to the average of 1970-80 (Table 13.2). Rainfall

Table 13.2 Average annual rainfall (mm) of different stations in Red and Lateritic zone of West Bengal

Stations	Year		
	1970-80	1980-90	1990-2000
Baghmundi	1093.3	1154.0	1333.0
Hathwara	1151.2	1203.6	1314.4
Jhalda	1185.8	1280.9	1449.3
Manbazar	743.6	978.3	1431.1
Hura	1240.6	1260.7	1382.1
Kashipur	571.8	855.4	1364.6
Para	556.1	841.4	1393.1
Dubrjpur	1041.9	1111.8	1332.7
Bolepur	685.9	811.3	1131.0
Illambazar	1062.9	1126.8	1346.7
Labhpur	1144.5	1123.6	1225.6
Md bazar	999.0	1144.2	1354.7
Mollar pur	820.1	1006.8	1351.5
Nalhati	1025.4	1155.4	1335.2
Nanoor	875.1	1038.9	1323.4
Rampurhat	1416.6	1336.0	1357.8
Susunia	991.7	1149.2	1380.4
Bankura	1265.4	1269.8	1400.1
Indus	1009.3	1086.4	1231.4
Joyrambati	1398.7	1315.6	1283.9
Average	1113.9	1112.5	1136.1

during May decreased in most of the selected stations, whereas in October rainfall amount increased in 75 % cases and in November, it increased in 95 % cases (Figs 13.1 and 13.2). By analyzing the rainfall data of Kalyani and Haringhata of Nadia district (data base: 1971 to 2005), it is observed that there is a shift of rainfall and at 41 Standard Meteorological Week (SMW) there is a rainfall peak. Hence in the mid of October, Gangetic West Bengal receives high rainfall (about 100 mm per week). However, during the peak monsoon season, there is less variation of weekly total rainfall (Fig. 13.3).

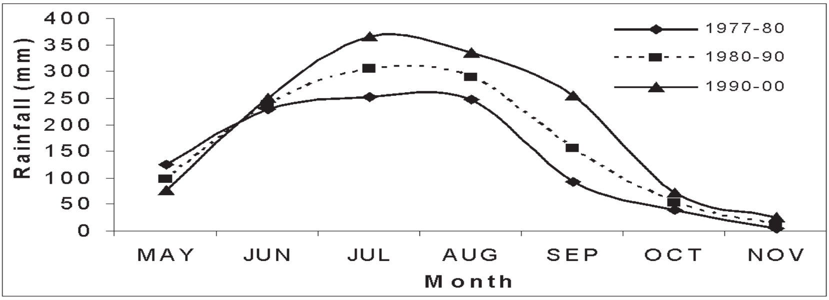

Fig.13.1 Decadal rainfall pattern from May to November at Susunia, Bankura district

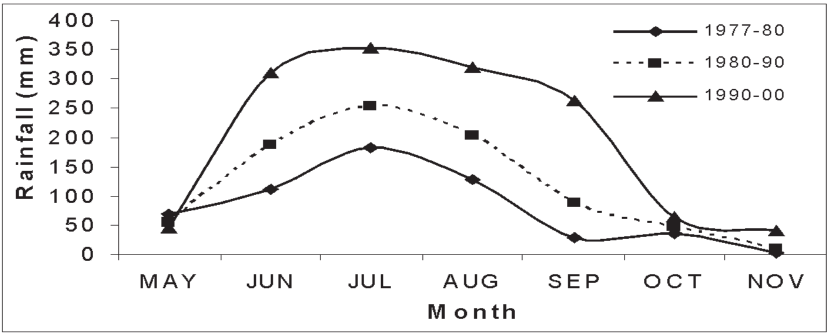

Fig. 13.2 Decadal rainfall pattern from May to November at Para, Purulia district

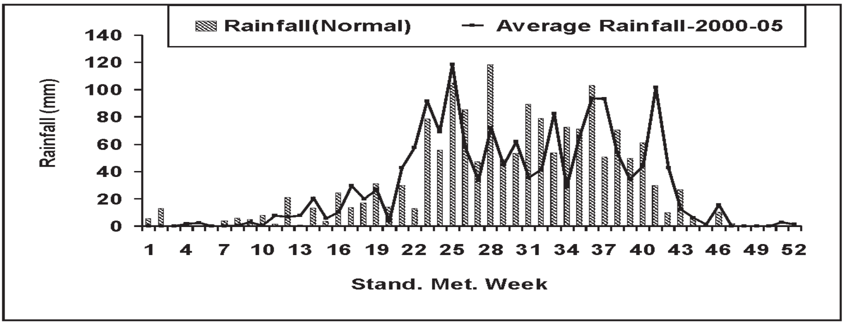

Fig. 13.3 Normal rainfall (mm) at Kalyani and Haringhata, Nadia district

13.3.2 Maximum temperature

Average monthly maximum temperature of summer (April – May) during 1990-2000 decreased marginally compared to that of 1970-80 (Table 13.3). Similar was the trend in almost all months. Only in few stations like Bankura, the maximum temperature increased in June. It may be due to decrease in rainfall. The minimum temperature of the zone, as a whole showd an increasing trend. For example in Bankura monthly minimum temperature in January increased by 1^{O}C and in Asansole by 0.5^{O}C. The monthly mean temperature does not show any changed pattern during the study period.

Table 13.3 Average monthly temperature (^{O}C) of selected stations during the study period

Station	April			May		
	1970-80	1980-90	1990-2000	1970-80	1980-90	1990-2000
Bankura	39.1	37.9	37.1	39.1	38.8	38.8
Purulia	38.4	38.2	38.3	39.0	38.2	37.8
Shantiniketon	37.3	37.3	37.6	37.4	36.6	36.1
Asansole	38.3	37.8	37.6	38.2	37.0	36.3
Burdwan	37.5	36.1	35.1	37.8	36.5	35.6

13.3.4 The projected climate scenario

Das and Lohar (2005) working in West Bengal had developed composite seasonal scenarios (per ^{0}C change in global equilibrium mean) for the period 2010-2039 using five General Circulation Models (GCMs), namely , HadCM2, CSIRO-MK2b, CGCM1, GFDL-R15 and ECHAM4/OPY3. The scenarios indicate a warming of about 0.4 ± 0.2 ^{0}C over Gangetic West Bengal and surrounding region in the eastern part of the Country. There is a warming in the range of 0.3 to 0.7 ^{0}C in the seasons all over the Gangetic West Bengal except for the monsoon season for HadCM2. In the latter case, there is a warming of more than 1 ^{0}C in the NW part of the study area. The spatial distribution shows more change in the eastern and NW part of the said region for both the models. In the pre-monsoon season, changes are between 0.3 to 0.6 ^{0}C with less value over the coastal belt for ECHAM4. HadCM2 indicates a variation of about 0.4 to 0.7 ^{0}C with a maximum over the central part of the area. In the monsoon season, HadCM2 shows a variation of 0.3 to 1.1 ^{0}C with a positive gradient from the sea to inland. ECHAM4 also shows less change in the post monsoon season with a maximum of 0.7 ^{0}C while ECHAM4 shows a similar maximum of 0.7 ^{0}C, though both the models indicate a similar gradient, from a minimum over SW to a maximum over the NW part of the Gangetic plain.

Maximum change in rainfall is seen in the winter season for the models HadCM2 and ECHAM4. The values range from 10 to 25% for HadCM2 and from 5 to 35 % for ECHAM4.The pattern indicates a maximum over the coast of the Bay of Bengal and gradually decreases inland for ECHAM4. In the pre-monsoon season, negative changes in rainfall are seen throughout the study region (-13%), while slightly positive changes are seen for ECHAM4 (1 to 6%). The monsoon season rainfall will change very slightly. The maximum change in rainfall over this part of the Country, according to the scenarios developed, would be 4%. In general, an increase in rainfall is estimated in all the seasons except for the pre-monsoon season. Rainfall scenarios indicate a variation of -5 to +9%, except in the winter where it exceeds 20%. This estimation is also higher than that of the projected changes derived directly from the GCMs.

13.4 Impact of climatic variability

The probable impact of rainfall pattern change in the Red and Lateritic zone of West Bengal may be envisaged on the degree of soil erosion. During the end of monsoon (October-November), when the soil is already been saturated with water, little more rain will accelerate soil erosion. By utilizing November rainfall, crops with low water requirement may be adopted after kharif season. Moreover, as during prior or onset of monsoon the rainfall amount shows a decreasing trend, optimum sowing window based on the changed climatic scenario should be assessed.

In the Gangetic plains of West Bengal, generally July and August receive the maximum rainfall. But recent trend is that the basin receives maximum rainfall during September and October. As soil moisture status changes continuously depending on precipitation and at the end of September, the stored soil moisture is very high, a little increase of rainfall causes runoff. The chance of flood is also increased due to recent rainfall pattern scenario.

13.4.1 Assessing impact of climate change

Considering the pattern of changing climatic scenario, the production potential of different crops in different location under probable climatic situation must be assessed. To predict the yield and yield potential of a locality under a given climatic condition/ changed climatic condition, crop growth model (CGM) can be used successfully. Banerjee *et al.,* (2007) assessed the impact of climate change on popular rice cultivar grown in the New Alluvial Zone of West Bengal using WOFOST (WOrld FOod STudies) model. WOFOST was originally developed as a crop growth simulation model for the assessment of the yield potential of various annual crops in tropical countries (Boogaard *et al*., 1998).

It was observed that the yield decrease of *Kharif* rice due to temperature increase by 1^{0}C (both maximum and minimum) is in the tune of 300 kg/ha. If temperature is increased by 2^{0}C, the potential yield may be reduced to about 800 kg/ha (Table 13.4). In

Table 13.4 Effect of climate change on crop duration and yield of rice

Climatic scenario	Duration of pre-anthesis phase (Days)	Maturity (Days after emergence)	Yield (kg/ha)
Actual	78	122	5613
Predicted under normal temperature condition	74	118	5650
Predicted under 1^{0}C temperature increase	72	114	5315
Predicted under 2^{0}C temperature increase	72	113	4773

the initial period, the above ground biomass is more under increased temperature conditions (Fig. 13.4). Similar results are also observed in the case of dry stem and leaf weight (Figs. 13.5 and 13.6). Due to temperature increase the rate of tillering is more, hence in initial period the predicted biomass and other related parameters are also higher than the normal situation. With the progress of crop growth period, the predicted biomass under normal climatic condition is more. If the mean temperature is 1^{0}C more, the model output shows a decrease of dry matter accumulation @ 6kg/ha/day. Again due to

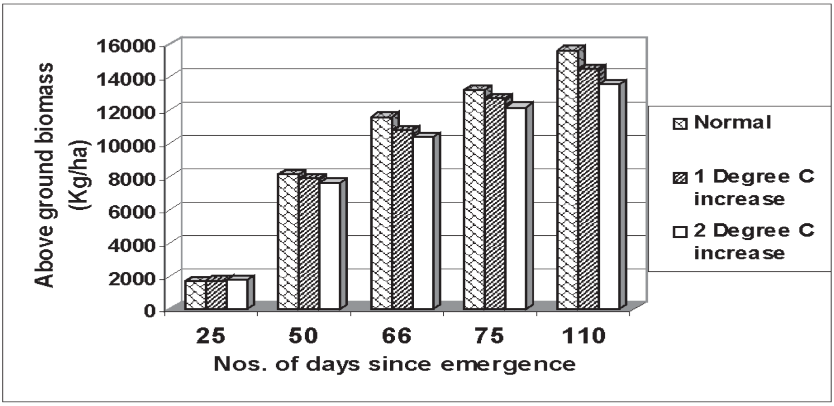

Fig. 13.4 Effect of temperature on biomass at different stations

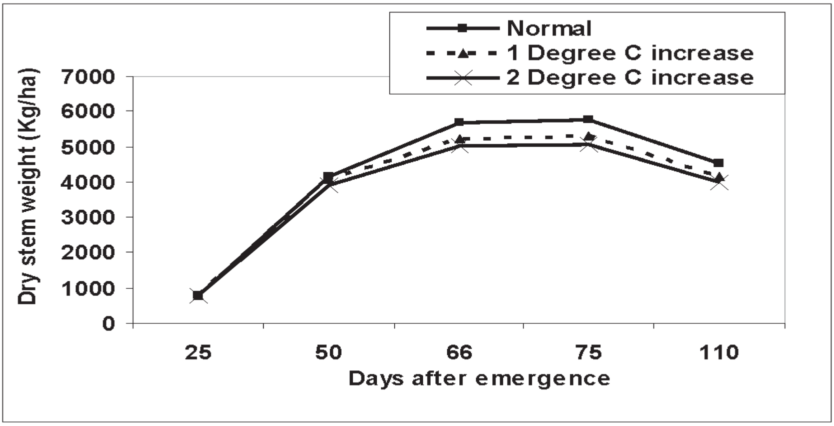

Fig. 13.5 Dry stem weight under changing climatic conditions

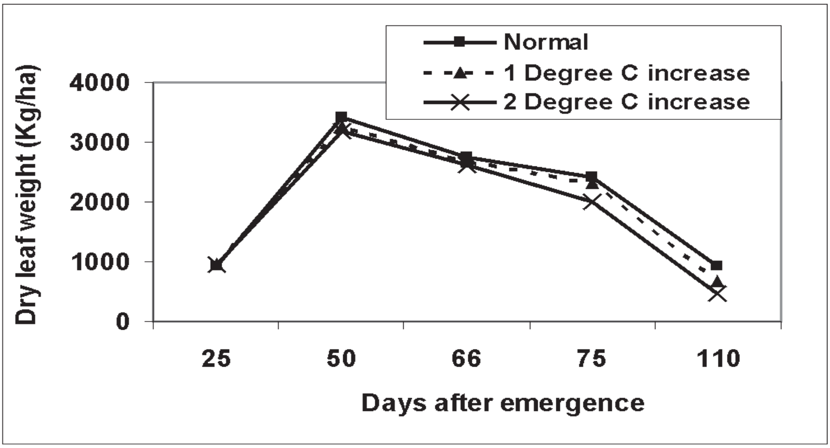

Fig. 13.6 Leaf dry weight under changing climatic condition

increase in temperature, the crop matures earlier, the biomass production declines and ultimately the yield is reduced. The suitable agronomic and other management option must be sorted out and modified accordingly to reduce the yield gap.

It can be stated that as induced by climate change, affecting rhythm of rainfall received in West Bengal, crop and cropping system followed by the farmers have also witnessed a change during the recent years. Pre-monsoon showers and frequency of Nor'wester during April-May decreased and consequently sowing of upland rice and jute grown under rainfed condition has been affected greatly. Further, increased quantum of post-monsoon rainfall has affected sowing of rabi pulses and oil-seeds and planting of potato. Therefore, the package of practices (time of sowing/ planting, selection of crops and varieties of crops) need to be rationalized in tune with the changing climate scenario.

13.5 Weather extremes

Crop production in West Bengal is affected by several weather aberrations like high wind, excessive rain, scanty rain, untimely rain and hail. Both quantum and distribution of rainfall have altered as induced by changes in climate and consequently droughts and floods are occurring in different times in West Bengal. Drought which occurs more frequently in the drier tracts such as Purulia, Bankura and Birbhum is more serious than flood. The effects of the drought lasts longer and make the chances of growing crops following the poor monsoon years uncertain, while the flood years will get bumper rabi crops due to greater amount of stored soil moisture during post-monsoon period. Changes in distribution have also affected crop production. Lower rainfall during pre-monsoon months of April and May delays nowadays the sowing of upland rice and jute. Success of these crops are very much dependent upon pre-monsoon rain which help the crops grow up to tillering and knee-high stage, in rice and jute, respectively before the monsoon set in second week of June in the Gangetic West Bengal. Of late, rainfed jute produces lower yield than before because of change in scenario of rainfall during pre-monsoon months in this zone, as the crop sown late in the season vulnerable to produce low for shorter growing season. But this fact is very difficult to establish because the average yield as estimated by the state agencies include both rainfed and irrigated crops together. To escape the terminal drought, occurring due to early withdrawal of monsoon, choice of suitable short duration varieties maturing in October should be suggested. Usually the rainfall is highest in July which is optimum time for transplanting of kharif rice. Since recent past it is observed that the highest rainfall occurs at the start and end of monsoon months. Further the frequency of high rainfall period has extended to October, causing widespread flood because by the time all the rivers flow in full swing. Due to this flood the standing crop of kharif rice, early vegetables, early rabi crops, livestock and people are affected miserably. Damage to crops and properties accounts for crores of rupees. In West Bengal, there are many basins and low-lying areas which are often flooded due to heavy rainfall. Flood prone areas are parts of Malda, Murshidabad, Burdwan, Hooghly, Howrah, Midnapore and 24-Parganas. To tackle the drought and flood situations, suitable contingent crop planning for different situations will go a long way in mitigating the ill effects of weather extremes on crop production.

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CHAPTER 14

Impact of Climate Change on Agriculture over Haryana

Diwan Singh, Surender Singh and V. U. M. Rao

Agricultural production is for a large part still dependent on weather and climate despite the impressive advances in agricultural technology over the last half a century. Crop growth simulation assessments indicate that yield of some crops in tropical stations would decrease generally with even minimal increase in temperature under dryland/rainfed agriculture. Where there is also a large decrease in rainfall, tropical crop yields would be even more adversely affected. Some studies indicate that climate change would lower incomes of the vulnerable populations and increase the absolute number of people at risk of hunger. Climate change, mainly through increased extremes and temporal/spatial shifts, would worsen food security in some parts of the globe. The Intergovernmental Panel on Climate Change in its recently released 4th Assessment Report (IPCC, 2007) concluded that the warming of the climate is unequivocal and evident from increased global air and ocean temperatures, melting of ice and rising global mean sea level. The major reports include that eleven of the last twelve years (1995-2006) rank among the 12 warmest years in the instrumental record of global surface temperature since 1850. The linear warming trend over the last 50 years (0.13ºC per decade) is nearly twice of that for the last 100 years. The all India mean annual temperature also show similar trends as global viz. faster rise in the last fifty years. Studies on climate change trend have shown that the change is now real for India but its impact on society as well as its social and economic consequences is yet to be fully understood. There seems to be no increasing trend in Indian monsoon in the past 100 years. However, there has been increase in the intensity of extreme events.

Climatic change will have significant interactions with crop growth, development, water use and productivity. The effect of increasing CO_2 concentrations will increase the net primary productivity of plants, but climate change, and the changes in disturbance regimes associated with them, may lead either to increased or decreased net ecosystem productivity. In many tropical and subtropical regions, potential yields are projected to decrease for most projected increases in temperature. Predictions of regional scale climate changes are still on a loose ground, because of the problems faced by the current climate models in realistically simulating the atmospheric and surface processes with a fine resolution and the air-sea interaction. Even if a reasonable regional scenario can be obtained for a specific part of the world, the complexities in the nature's variability themselves make the interpretations highly unstable. Here, an attempt has been made to document and understand the observed climate changes and variability and its implications for sustainable agriculture on a regional scale like Haryana.

14.1 Biophysical resources

The State of Haryana is located in NW India, contributed tremendously to the success of the Green Revolution in India. Haryana is located in a semi-arid, subtropical environment between 27^0 39' and 30^0 55' N latitude and 74^0 7' and 77^0 36' E longitude, occupies an area of 4.42 m ha (Fig. 14.1). Although in broad terms,

Fig. 14.1 Geographical map of Haryana state

Haryana is a plain, yet with variations in geomorphology, soil, climate and irrigation facilities, the diversity in land use is obvious. The physiography of the State shows that major part of Haryana lies within Indo-Gangetic plains which are amongst the fertile tracts of India. Sand dunes of different magnitudes are also found in the Aeolian plains of south-western Haryana. The most of waterlogged and salt-incrusted areas are found in central belt of the state from south of Karnal to south of Rohtak districts. However, some problematic areas are also present in the Ghaggar and Yamuna river basins.

Despite too much emphasis on afforestation, there is hardly any increase in the area under forest since the green revolution campaign. This is a very alarming situation which needs special attention. To maintain ecological balance, the area under forest must be one third of total area whereas it remains around 3-4 per cent. The change in area is negligible *i.e.* – 0.5 per cent during the period 1970-71 to 1995-96 (Ram, 2002). But the change in land put to non-agricultural uses is quite significant *i.e.* 29.4 per cent may be due to decline in the areas under barren and uncultivable lands, permanent pastures and other grazing lands and cultivable waste which are on the verge of obliteration very soon. The agricultural area constitutes 81 per cent of the total area and 47 per cent of the agricultural area is sown more than once in a year. Rice and wheat, usually grown in a double cropping rotation, are the major food crops and their current total production is 11 million tonnes. This may be attributed to the use of high yielding varieties of seeds, fertilizers, creation of irrigation facilities and innovation of suitable agro-technology. The other important features of Haryana agriculture is that fibers (cotton), oilseeds (mustard) and vegetables also occupy an important place in the cropping pattern. There is more or less a continuous decrease in the area under pulses (-61.0 %), sugarcane (-7.7%), chillies (-72.9%), tobacco (-90.0%) and other crops (-23.5%) from 1970-71 to 1995-96. The intensive cultivation of main crops viz., rice-wheat and thereby over exploitation of water resources (tube-wells and canal irrigation) resulted in degradation of soil health, fluctuation in water table (Fig. 14.2). There has been an alarming decrease in the water table in north-eastern and south-eastern parts of the state owing to continuous over-exploitation without any consideration of recharge. On the other hand, the water table having brackish water underneath has increased tremendously in the south-central tract of the state over the period (1974-02).

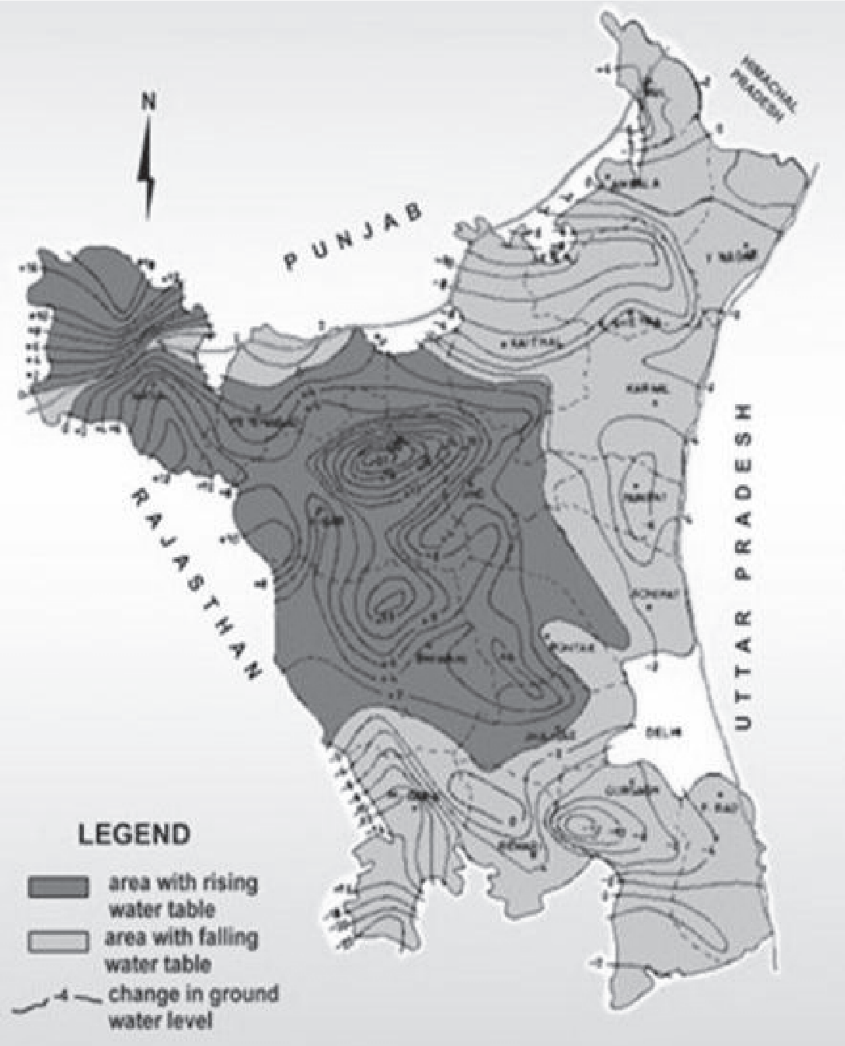

Fig. 14.2 Water table Fluctuations in Haryana

For past fifteen years, there is an alarming stagnation in the productivity levels in the rice-wheat, cotton-wheat cropping systems due to deterioration in soil and water health because of intensive use of inorganic fertilizers and crop protection chemicals. Sudden increase in air temperature during the reproductive phase of *rabi* crop (terminal heat stress) has multiplied the problem of low/ decreasing yields because of ill-effects of intensely debated global warming and climatic variability in recent times.

14.2 Climate variability

Climate is one of the important agricultural resource which has not been exploited to its full for increasing the productivity. Year - to - year variations in climate and sudden departure from normal weather features have deleterious effects on crops and keep the food production highly fluctuating. Scanty rains, excess and untimely rains, heat waves, cold waves, high and hot winds during summer (locally known as '*loo*'), dust storms, fog, frost and hails are important weather abnormalities occurring in the State and adversely affect the crop production. The climate of Haryana is strongly influenced by north-westerly cold and south-westerly monsoon winds. Only tails of summer monsoon depressions are received from July to September.

Normal annual rainfall features depicted in Fig.14.3 shows that amount of annual rainfall in the State ranges between 300 mm

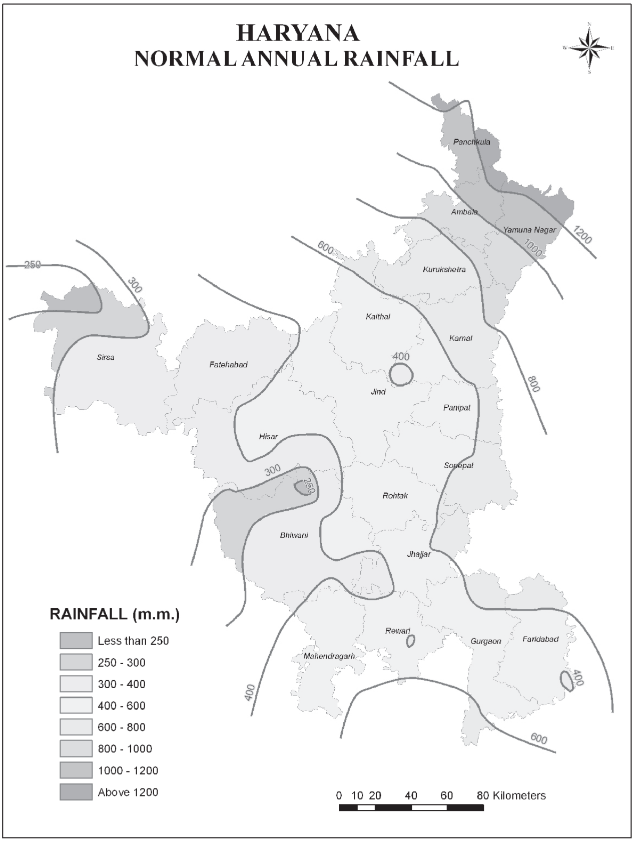

Fig 14.3 Normal annual rainfall in Haryana state

(south-western parts) to 1300 mm (northern parts- Shivalik foothills) with coefficient of variation between 25 to 45 per cent. Above 80 per cent of this rainfall is received during the monsoon season (July to September) which coincides with the growing season of *kharif* crops. On an average around 250 mm of rains are received during this period in the south-western (SW) region and 1000 mm in the northern most region with coefficient of variation ranging between 45 to 55 per cent. Only 10 to 15 per cent of the annual rainfall is received during October to March period coinciding with the growing season of *rabi* crops.

The mean temperature during *Kharif* season in south-west region is around 32^0C and decreases to 29^0C in the northern parts. However, during the *rabi* season the mean temperature of 15^0C in the northern parts with an increase towards the south-western upto 20^0C is observed. Day temperature of 48^0C during summer (May/ June) and night temperature below freezing point during winter (December to February) are not uncommon. Haryana has arid, semi-arid climate in the south-west and dry sub-humid environment in the remaining parts.

14.2.1 Climate change scenario

The 32-year rainfall analysis (1970-2001) in the State indicated an increasing trend for monsoon rainfall (Singh *et al.*, 2007). The districts of Sirsa, Hisar, Bhiwani, Narnaul, Rohtak, Gurgaon, Karnal, Ambala and Chandigarh had increasing trend (Table 14.1). The highest increase (5.8 mm/annum) was recorded at Chandigarh and the lowest increase (0.3 mm/annum) was observed at Sirsa. Such general increasing trends in monsoon rainfall in the region could have been partly because of the increased particulate matter in the atmosphere due to intensely debated warming in recent times.

The annual mean rainfall in the State during the 32 years period varied from a low of 422.8 mm at Sirsa to a high of 1132.6 mm at Chandigarh (Singh *et al.*, 2003). The mean seasonal rainfall during pre-monsoon and monsoon at Sirsa (Table 14.2) was lowest (39.2 and 324.8 mm, respectively) whereas at Chandigarh it was highest (84.7 and 906.1 mm, respectively). However, Hisar observed lowest (14.0 and 31.9 mm) and Chandigarh recorded highest (36.6 and 109.8 mm) mean rainfall in post monsoon and winter seasons, respectively. Rainfall during the monsoon season at various stations

Table 14.1 Annual rate of change of climatic parameters and rainfall relation with SST anomaly at different Stations in Haryana

Stations	Rate of Change of		Year of highest monsoon rainfall	SST anomaly	Year of lowest monsoon rainfall	SST anomaly
	Monsoon rainfall (mm)	Mean Temp (ºC)				
Sirsa	0.3	0.03	1997	El Niño	1987	El Niño
Hisar	1.5	-0.01	1988	La Niña	1987	El Niño
Bhiwani	4.5	-0.01	1993	Neutral	1987	El Niño
Narnaul	2.3	0.02	1996	Neutral	1987	El Niño
Rohtak	3.9	0.01	1995	El Niño	1987	El Niño
Gurgaon	4.2	0.02	1995	El Niño	1987	El Niño
Delhi	1.4	0.02	1988	La Niña	1987	El Niño
Karnal	4.6	-0.02	1988	La Niña	1987	El Niño
Ambala	3.2	-0.01	1988	La Niña	1975	La Niña
Chandigarh	5.8	0.01	1988	La Niña	1987	El Niño
Haryana State	3.3	0.02	1988	La Niña	1987	El Niño

Table 14.2 Features of rainfall (mm) at different stations in Haryana during 1970-2001

Stations	Pre monsoon			Monsoon			Post monsoon			Winter			Annual
	Mean	SEm	CV	Mean	SEm	CV	Mean	SEm	CV	Mean	SEm	CV	Mean
Sirsa	39.2	11.2	104	324.8	21.5	36	23.3	9.6	167	35.4	7.8	85	422.8
Hisar	55.2	20.5	110	359.7	25.5	39	14.0	9.6	183	31.9	6.2	59	461.1
Bhiwani	39.4	9.8	92	387.5	29.5	35	17.7	7.2	173	39.7	7.7	77	484.3
Narnaul	50.2	10.9	80	486.2	41.0	46	34.7	9.2	106	36.9	6.4	72	607.7
Rohtak	61.9	15.1	85	503.0	30.3	33	29.0	7.2	133	50.6	9.9	79	644.8
Gurgaon	55.3	15.4	84	650.4	41.6	45	28.1	8.5	98	45.3	9.9	70	802.9
Delhi	53.4	11.3	76	683.4	32.9	26	29.5	8.7	124	47.8	10.5	71	833.3
Karnal	67.4	19.3	91	608.7	40.8	37	27.1	10.1	125	68.5	13.5	63	773.0
Ambala	72.3	16.4	67	774.5	45.7	32	32.5	12.5	117	88.8	13.5	56	968.1
Chandigarh	84.7	19.3	66	906.1	57.8	35	36.6	9.8	124	109.8	19.4	55	1132.6
Haryana State	58.2	16.2	85	569.8	29.2	32	28.9	7.9	135	57.4	13.0	63	713.0

was quite stable in comparison of other seasons as the CV values were moderate (d" 46 %). The rainfall in the State during the post monsoon season was highly variable as indicated by the higher values of coefficient of variation.

Hisar, Bhiwani, Karnal and Ambala observed decreasing trend in annual mean air temperature @ 0.02^{0}C per annum and remaining other stations recorded increasing trend in annual mean air temperature @ 0.01 to 0.03^{0}C per annum (Table 14.1). However, over the larger area/region, the annual mean air temperature increased @ 0.02^{0}C per annum (Singh *et al.*, 2004). While going through the latest trends of climate change scenarios reported (IPCC, 2007), it is quite interesting to note a cooling trend in mean annual temperature at Hisar during 1998, 1999, 2000, 2002, 2004 and 2006 contrary to otherwise warming trends on All India and global basis. The highest and lowest monsoon rainfall years with their corresponding SST anomalies showed that Sirsa, Rohtak and Gurgaon received their highest rainfall during *El Niño* years. However, Bhiwani and Narnaul received their highest monsoon rainfall in the year of no episodes (neutral year). Similarly, lowest monsoon rainfall at Ambala was observed in the year of La Niña episode. The remaining other stations received their respective lowest monsoon rainfall in the year of El Niño episode. The results advocated the identification of other major non- *El Niño*-Southern Oscillation phenomenon on the SW monsoon, which so far has remained elusive.

14.3 Weather extremes and economic impact

Monthly and seasonal extreme rainfall amounts (lowest and highest rainfall) in the monsoon season at different stations in the sub-division have been given in Table 14.3. The highest rainfall observed in June ranged between 97.0 mm at Bhiwani (1978) and 419.0 mm at Narnaul (1996). July month's highest rainfall ranged between 265.2 mm at Sirsa (1974) and 602.1 mm at Chandigarh (1994). In August, rainfall varied between 198.0 mm at Sirsa (1976) and 640.0 mm at Gurgaon (1995). In September, the highest rainfall amount ranged between 170.0 mm at Sirsa (1988) and 488.7 mm at Chandigarh (1988). The monsoon season's highest rainfall ranged between 504.1 mm at Sirsa (1997) and 1758.5 mm at Chandigarh (1988). The monsoon rainfall variability based on Monsoon Rainfall Index (MRI) at Hisar, Narnaul, Rohtak, Karnal, Ambala and Chandigarh showed broader range of MRI (>100). The MRI ranges

Table 14.3 Extreme rainfall (mm) and Monsoon Rainfall Index during SW Monsoon season in Haryana (1970-2001)

tations	June		July		August		September		Monsoon season		MRI
	Highest	Lowest	Highest	Lowest	Highest	Lowest	Highest	Lowest	Lowest	Highest	(range)
irsa	182.8	0*	265.2	10.4	170.0	0	504.1	56.1	16.4	198.0	-82.7 to 53.2
	('97)		('74)	('74)	('88)	('74)	('97)	('87)	('82)	('76)	(70.5)
isar	125.8	0	335.4	10.1	313.6	0*	665.6	63.5	0	365.8	-82.3 to 84.0
	('86)	('73)	('78)	('87)	('88)		('88)	('87)	('87)	('76)	(101.7)
hiwani	97.0	0	426.8	5.0	187.6	0*	627.6	98.0	9.0	313.0	-74.7 to 61.9
	('78)	('73)	('93)	('81)	('95)		('95)	('87)	('91)	('76)	(87.2)
arnaul	419.0	0	520.3	61.0	244.0	0*	1229.0	136.4	14.2	420.0	-68.4 to 153.8
	('96)	('73)	('78)	('89)	('96)		('96)	('87)	('77)	('95)	(185.4)
ohtak	143.4	4.2	338.0	16.6	336.0	3.0	1065.0	74.2	27.8	522.0	-85.2 to 111.7
	('81)	('92)	('80)	('87)	('95)	('94)	('95)	('87)	('70)	('95)	(126.5)
urgaon	266.1	14.6	517.0	32.7	336.2	16.8	1030.0	100.1	36.0	640.0	-84.6 to 58.3
	('81)	('87)	('77)	('87)	('78)	('87)	('95)	('87)	('87)	('95)	(73.7)
elhi	221.8	5.6	511.0	63.8	312.9	7.2	1053.8	290.0	70.6	483.5	-57.6 to 54.2
	('81)	('72)	('77)	('87)	('71)	('74)	('88)	('87)	('95)	('88)	(96.6)
arnal	260.9	15.2	487.8	23.4	331.4	4.8	1130.9	215.3	17.0	486.4	-64.6 to 85.8
	('94)	('77)	('80)	('93)	('88)	('87)	('88)	('87)	('86)	('94)	(121.2)
mbala	350.0	21.1	580.8	1.7	347.5	0.2	1315.7	279.9	22.4	582.0	-63.9 to 69.9
	('73)	('82)	('88)	('93)	('90)	('87)	('88)	('87)	('87)	('95)	(106.0)
handigarh	406.2	28.2	602.1	70.9	488.7	12.8	1758.5	275.7	71.5	568.1	-69.6 to 94.1
	('73)	('77)	('94)	('93)	('88)	('81)	('88)	('87)	('91)	('78)	(124.5)
aryana State	177.6	32.3	337.9	61.0	225.8	17.3	914.3	153.9	43.4	394.4	-72.9 to 60.5
	('96)	('87)	('93)	('87)	('88)	('87)	('88)	('87)	('87)	('95)	(87.6)

* No rain was received in June at Sirsa ('73, '81) in September at Hisar('72, '74, '80, '81), at Bhiwani ('72, '80, '81, '82,'91) and at Narnaul ('79, '87).

Values in parentheses are years of extreme rainfall except MRI range

at the other stations were below 100. This may be due to inherent variability existing in weather systems of monsoon season. The comparative narrow range of MRI at some location was linked with lower rainfall variability as compared to the stations mentioned earlier with MRI (>100). The MRI range showed a decrease when it was computed over whole of the State of Haryana.

Similarly, at certain stations (Sirsa, Hisar, Bhiwani and Narnaul), of June and September were completely dry in some years during the period under reference. In July, the lowest rainfall ranged between no rain at Hisar (1987) to 71.5 mm at Chandigarh (1991). In August, the lowest rainfall ranged between 1.7 mm at Ambala (1993) to 70.9 mm at Chandigarh (1993). In September, the lowest rainfall ranged between no rain at Sirsa (1974), Hisar (1972, 1974, 1980 and 1981), Bhiwani (1972, 1980, 1981, 1982 and 1991), Narnaul (1979 and 1987) and 16.8 mm at Gurgaon (1987). It will be pertinent to note here that the stations viz., Rohtak, Gurgaon, Delhi, Karnal, Ambala and Chandigarh received rainfall in all four months during monsoon season. All stations in the State received their lowest rainfall in monsoon season of 1987 which was a drought year and rainfall received ranged between 56.1 mm (Sirsa) to 290.0 mm (Delhi). The highest rainfall at various stations occurred during different years in 1988, 1995, 1996 and 1997.

Simple extremes, such as occurrence of higher maximum land temperatures, intense foggy days and more intense precipitation, are projected to be very likely in the future. The importance of extreme events and regional climate threshold exceedance for various field crops need to be further established. During past decade, the occurrence of exceptionally high temperature during reproductive phase of rabi crops (January to March) have become quite frequent and proved detrimental because of terminal stress. The intermittent higher than the normal temperatures regimes with insufficient rainfall forced crop maturity ahead thereby curtailing final grain yield. Such events in which temperature stress (>3-6^{0}C higher than normal) prevailed during latter growth stages were during 2000-01 (above normal day temp and below normal night temp), 2001-02 (above normal day and night temp), 2003-04 (above normal day and night temp), 2004-05 (above normal day and night temp), 2005-06 (above normal day and night temp) and 2006-07 (above normal day and night temp). More recently, freezing events were recorded during 1-

4 and 21-28 January, 2007 with lowest minimum temperature of -3.2^{0}C (22 Jan, 07); 6-9 January, 2006 with lowest minimum temperature of -3.5^{0}C (8 Jan, 06). An extended period marked by foggy weather prevailed in the winter season of 2003-04 and was characterized by low daytime temperature. Similarly, extreme rainy events also occurred in the Hisar region when 135.0 mm of rainfall occurred over 16-20 June, 07; 130 mm (Feb-Mar, 07), continuous wet spells with heavy rainfall of 160.0 mm (5-8 July & 10-15 Sept, 05); 200.0 mm (16-22 July,03) and 87.0 mm (28-29 May,02).

Fog climatology based on satellite remote sensing using time series data is important because long term knowledge of regional changes in fog frequency and fog properties are of over all important for Global Circulation Model simulations dealing with global climate change (Singh *et al.,* 2001). Interestingly, an increasing trend (@ 1.3 day/season) in occurrence of fog events was noted in Haryana during 1993 to 2003. The intense foggy events during winter season (October to March) reduced photosynthetically active radiation (PAR) availability to wheat crop and thus, reduced the grain yield (Singh *et al.,* 2007). Exceptionally high temperature during reproductive, grain formation and ripening phases (January to March) are understood to be detrimental for wheat production due to terminal stress. The intermittent higher than the normal temperatures regimes with insufficient rainfall caused forced crop maturity in wheat by curtailing the grain development phase which resulted in shriveling of grain with poor grain size affecting the test weight and final seed yield. The reduction in wheat yield (q/ha) was reported around 10-15 % due to the terminal heat stress. While developing multiple regression equations using foggy events and terminal heat stress, about 60 to 70 % variations in wheat productivity may be explained by these two extreme weather events. It may be ascertained that these amplified simple extremes could lead to extreme weather events like sustenance and intense foggy events leading to radiation stress and terminal heat stress causing significant decrease in wheat productivity in the region.

14.4 Impact studies

Climatic variability is basically a micro-regional climatic phenomenon having some direct impacts on people and environment. Extreme events are induced by this variability at micro-regional level. Climate variability poses a serious threat to every part of the world. The agricultural productivity in India is too sensitive not only to temperature increases but also to changes in the nature and characteristics of monsoon rainfall. Experiments reported by Sinha (1994) found that higher temperatures and reduced radiation associated with increased cloudiness caused spikelet sterility and reduced yield to such an extent that any increase in dry-matter production as a result of CO_2 the fertilization proved to be of no advantage in grain productivity. Simulations of the impact of climate change on wheat yields for several stations in India using a dynamic crop growth model, WTGROWS, indicated that productivity depended on the magnitude of temperature change. In north India, a 1^0C rise in the mean temperature had no significant effect on potential yields though an increase of 2^0C reduced potential grain yields at many places (Aggarwal and Sinha, 1993). In a subsequent study, Rao and Sinha (1994) used the CERES-Wheat simulation models and scenarios for three equilibrium GCMs and the transient GISS model to assess the physiological effects of increased CO_2 levels. In all simulations, wheat yields were smaller than those in the current climate, even with the beneficial effects of CO_2 on crop yield; and yield reductions were due to a shortening of the wheat-growing season, resulting from temperature increase scenario. Agriculture will be adversely affected not only by an increase or decrease in the overall amounts of rainfall, but also by shifts in the timing of rainfall. For instance, over the last few years, the Chattisgarh region has received less than its share of pre-monsoon showers in May and June. These showers are important to ensure adequate moisture in fields being prepared for rice crops (Ramakrishna *et al.*, 2002). Likewise, the agriculture will be worst affected in the coastal regions of Gujarat and Maharashtra, where agriculturally fertile areas are vulnerable to inundation and salinisation. Standing crops in these regions are also more likely to be damaged due to cyclonic activity. In Rajasthan, a 2^0C rise in temperature was estimated to reduce production of pearl millet by 10-15 per cent (Ramakrishna *et al.*, 2002). If the maximum and minimum temperatures go up by 1^0C and 1.5^0C respectively, the gain in yield comes down to 35 per cent. If maximum and minimum temperatures rise by 3^0C and 3.5^0C respectively, then soybean yields will decrease by five per cent compared to 1998 (Lal, 1999). Changes in the soil, pests and weeds brought by climate change will also affect agriculture in India (TERI, 2002). For instance, the amount of moisture in the soil will be affected by changes in factors such as precipitation, runoff and evaporation.

14.5 Future climate impacts on crop projections

While simulating the impact of climatic change on agricultural crops, the results have shown a decrease in duration and yield of crops as temperature increased in different parts of India. Such reductions were, however, generally, offset by the increase in CO_2; the magnitude of these varied with crop, region and climate change scenario.

For one of the IPCC scenario (an increase of 1.8°C temperature and 425 ppm CO_2 by the year 2030 for India), potential maize yields would be severely affected by 18 per cent. In north India, irrigated wheat yields decreased as temperature increases, a 2.0 °C increase resulted in 17 per cent decrease in grain yield but beyond that the decrease was very high. These decreases were compensated by increase in CO_2 due to latter's fertilizing effect on crop growth. CO_2 concentration has to rise to 450 ppm to nullify the negative effect of 1.0°C increase in temperature. Studies found that the overall impacts due to the climate change scenario for a 2.0°C rise in temperature and a 7 per cent increase in precipitation are negative for India. On the whole, the negative impacts due to temperature change more than compensate for the small positive impact due to precipitation change.

The northern states of Haryana, Punjab and western Uttar Pradesh, which grow predominantly wheat in the winter season, experience most negative effects. Uprety *et al.,* (1996) concluded that with the type of climate we have in the northern belt of Indian subcontinent, viz, variation in temperatures and CO_2 concentration, the production of *Brassica* crop is likely to increase and shifted in some more relatively drier region. In wheat, decrease in yields was reported over all India basis (Sinha and Swaminathan, 1991; Aggarwal and Sinha, 1993; Gangandhar Rao and Sinha, 1994; Aggarwal, 2000; Aggarwal, 2003) and decrease/increase trend on scenario basis (Lal *et al.*, 1998; Aggarwal and Kalra, 1994; Attri and Rathore; 2003). Similarly, an increase in rice yield was reported (Aggarwal and Mall, 2002), whereas decreasing trend was noticed by Sasendran *et al.*, 1999; Lal *et al.*, 1998; Sinha and Swaminathan, 1991) in India. Similarly decrease in yields have been reported in chickpea (Mandal, 1998); pigeonpea (Mandal, 1998), sorghum

(Chatterjee, 1998). Therefore, it is essential to understand the crop ecosystem responses which are influenced during the crop growing season so as to influence the variation in crop yield due to rise of Co_2 levels or greenhouse gases concentration and global warming. Kalra *et al.* (2003) showed the dependence of yield on seasonal temperature in northern environment for wheat, barley, grain, winter, maize and mustard with a linear decreasing trend of 4.26, 2.77, 0.32, 1.52 and 1.32 q/ha, respectively.

Hundal and Kaur (1996) examined the climate change impact on productivity of wheat, rice and maize crop in Punjab using CERES-wheat (Godwin *et al.*, 1989), CERES-rice (Singh *et al.*, 1993) and CERES-maize (Ritchie *et al.*, 1989) crop simulation models. They concluded that, if all other climate variables were to remain constant, temperature increase of 1.0, 2.0 and 3.0°C from present day condition, would reduce the grain yield of wheat by 8.1, 18.7 and 25.7 per cent, rice by 5.4, 7.4 and 25.1 per cent and maize by 10.4, 14.6 and 21.4 per cent, respectively. The recent trends in abnormal rise in temperature (terminal heat stress) during February onward also adversely affected the productivity of *rabi* field crops more so in case of wheat crop in Haryana (Singh and Singh, 2005). The adverse affect of higher temperature in *brassicas* will be there but likely to be a marginal one and that too only in case of late sown crop otherwise the productivity level in case of October sown mustard may be normal. The moisture and high temp stress during the maturity phase in rainfed gram crop may result in slight fall in productivity. The intermittent higher than the normal temperatures regimes prevailed during reproductive phase had led to forced crop maturity particularly in late sown wheat by curtailing the grain development phase which will result in shriveling of grain causing poor grain size affecting the test weight and final seed yield. The loss is likely to be higher (20-30 %) in areas where the crop could not be irrigated frequently during February-March period.

In vegetables, there may be sudden decrease in fruit set and due to that crop growth will increase and expected yield may likely to reduce by 50 per cent in tomato. In onion and garlic too, the unfavourable weather conditions/sudden temperature rise may reduce the yield up to 25 per cent. There will be severe tip burning, thereby photosynthetic activity will reduce and bulb development may be hampered in garlic. Thus the yield reduction will be around

25 per cent. In seed spices there are increased incidences of powdery mildew disease and forced maturity due to high temperature which will reduce yield up to 30 per cent. In Broccoli seed crop, the forced maturity due to high temperature is going to result into reduced seed yield as well as seed quality. The seed crops of carrot, radish and turnip have also been affected by high temperatures where in later stage due to forced maturity the seed yield is going to be reduced to the tune of 10-15 per cent and similarly the quality of the seed will also be affected in the State of Haryana.

14.6 Sustainability issues

The big change for agricultural research and development is thus to suggest the solutions like protecting the land from deterioration, building and maintaining soil fertility, conserving water for farm use, provision of proper drainage facilities, flood protection and erosion control, which are some of the essential requirements to protect land and soil (Singh *et al.*, 2000). This has, however, not been done in the past which has led to the fast deterioration. With the increasing rate of population at a fast rate, the requirements of food, feed, fodder and fiber have increased tremendously and it has become an ardent recently to use land and soil most carefully to produce more and more from this without deteriorating the same. We have a sacred duty to pass on to the posterity the soil in almost similar condition as we had received from our ancestors if we cannot improve upon it further. Farmers probably already use effective methods to limit damage from weather. We can encourage them to do more damage control, and to adapt and improve their methods. For example, both soil and water degradation is likely to get worse with global warming. So, on farm intervention to conserve soil and water will be particularly useful. While preparing for contingency planning for a region under the threat of environmental degradation, extreme weather events under different climate change scenarios; strategies should be outlined for the benefit of farming community. Remember to disseminate and well explain these strategies to the end users. There are some useful strategies listed here need to be practiced for maintaining the sustainability in agricultural productivity in the region. The growers can:

- Capture and store runoff water.
- Use tillage methods that conserve soil and water, and limit erosion in dry areas.

- Add organic matter to the soil, such as crop residues, compost, and manure.
- Keep the soil covered with vegetation at all times.
- Select and cultivate cover crops and dig planting pits in dry areas.
- Practice agroforestry and plant drought-tolerant crops and crop varieties.
- Choose and experiment with effective and long-term storage techniques.

In most of the regions, farmers will benefit from planting different crops and raising different kinds of livestock, or changing plant varieties and livestock breeds to address the new farming conditions in fragile environment. Under these situations, the farmers may be advised to select new or alternative crops, or crop varieties:

- Grow salt-tolerant crops or varieties if soil becomes contaminated with salt
- Drought proofing by mixed cropping, grow drought- and heat-tolerant crops in areas where drought and heat increase with climate change
- Resource conservation techniques
- Frost management by irrigation
- Heat stress alleviation by frequent irrigation
- Invent short varieties/crops for altering growing season
- Altering fertiliser rates to maintain grain or fruit quality and be more suited to the prevailing climate
- Altering amounts and timing of irrigation
- Conserve soil moisture (e.g. crop residue retention)
- Altering the timing or location of cropping activities

Besides the adaptation measures at growers level, our response to global warming should include both mitigation by reducing greenhouse gas emissions, and adaptation, learning to live with a changed climate. The Kyoto Protocol and further negotiations recently under Bali Roadmap can be seen as useful steps along the path of mitigation. Global action to reduce greenhouse gas emissions could reduce the negative impacts, and local actions will also help. And adaptation, such as new crop varieties, better management of existing water resources, and the ability to respond rapidly to disasters can be seen as necessary in a changing world. Sensitization of the farming community with the environmental concerns has to be given top priority. Balanced and conjunctive use of biomass, organic and inorganic fertilizers and controlled use of agro-chemicals through integrated nutrients and pest management (INM & IPM) will have to be promoted to achieve the sustainable increases in agricultural production. A nation-wide programme for utilization of rural and urban garbage, farm residues and organic waste for organic matter repletion and pollution control has to be worked out.

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CHAPTER 15

Impact of Climate Change on Agriculture over Punjab

Prabhjyot-Kaur and S. S. Hundal

The threat of global climatic change due to anthropogenic modification of the atmosphere, its impact on food production and on global food security is one of the major environmental issues of our times. These climatic changes are the result of changes in atmospheric gaseous constituents, vegetation / crop cover and biodiversity (Fig. 15.1).

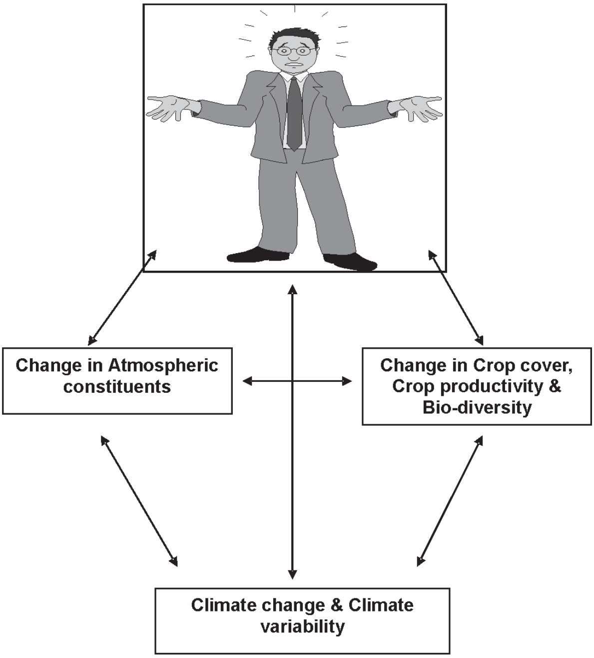

Fig. 15.1 Climate change – as induced by and having effect on man

The Inter-Governmental Panel on Climate Change (IPCC) in its recently released report has reconfirmed that the global atmospheric concentrations of greenhouse gases (GHG's) have increased markedly as a result of human activities. Between 1000 and 1750 AD, the CO_2, methane and nitrous oxide concentrations were 280 ppm, 700 ppb and 270 ppb, respectively. In 2005, these values have increased to 379 ppm, 1774 ppb and 319 ppb, respectively. The global increases in CO_2 concentrations are primarily due to fossil fuel use and land use change, while those of methane and nitrous oxide are primarily due to agriculture.

These increases in GHG's have resulted in warming of the climate system by 0.74^0C between 1906 and 2005. Eleven of the last twelve years (1995-2006) rank amongst the 12 warmest years in the instrumental record of global surface temperature (since 1850). The rate of warming has been much higher in the recent decades and the night time minimum temperature have been increasing at twice the rate of daytime maximum temperature. The quantity of rainfall and its distribution has also become more uncertain. In some places, climatic extremes such as droughts, floods, timing of rainfall and snowmelt have also increased. The sea level has risen by 10-20 cm with regional variations. Similarly, snow cover is also believed to be gradually decreasing.

Such global climatic changes will affect the agriculture through their direct and indirect effects on crops, soils, livestock and pests. One of the direct effect is the increase in temperature which can reduce crop duration, increase crop respiration rates, alter photosynthate partitioning from source to sink, effect the survival and distribution of pest populations thus developing new equilibrium between crops and pests, hasten nutrient mineralisation in soils, decrease fertilizer use efficiencies and increase evaporation. Indirectly, there may be considerable effects on agricultural land use due to snowmelt, availability of irrigation, frequency and intensity of inter- and intra – seasonal droughts and floods, soil organic matter transformations, soil erosion, decline in arable areas (due to submergence of coastal lands) and availability of energy. Considering the crop-pest interactions, for an estimated loss of about 30% of crop production due to biotic interference, 10% loss each is attributed to insect pests, pathogens and weeds. The change in climate may bring about changes in population dynamics, growth and distribution of insect and pests. The occurrence and intensity of different crop diseases depends on the interaction of pathogen, host and the environment. If global climatic changes are likely to be even half as serious as these are being made out to be, the variations in the yield in many countries including India could be much more than 20 %. The brunt of these environmental changes is expected to be considerable in South Asian region which is the home for almost one quarter of the world population and is highly dependent on agricultural production.

15.1 The agents of climate change

Human and industrial activities are primarily responsible for the rise in the concentration of greenhouse gases in the atmosphere. The increasing levels of CO_2, the most abundant greenhouse gas, are mostly because of fossil fuel combustion. Similarly, the industrial processes and products cause CFC emissions. The increased agricultural activities and organic waste management are presumed to be contributing to the build up of methane and nitrous oxides in the atmosphere (Hundal and Abrol, 1991).

15.1.1 Carbon dioxide

There is a large fixation of CO_2 in agriculture but its estimates are generally not available because of continuous consumption of its products by the human beings and other secondary consumers. In India, fixation of CO_2 assumes importance because almost 190 million-hectare land is being used for farming. The estimated dry biomass production from agriculture in India is almost 800 million tons / year. This is equivalent to fixation of 320 Tg of C or 1000 Tg of CO_2 per annum. Only a part of this is retained over time as the body weight of human being and other consumers, while the rest is released back to atmosphere. Improvements in agricultural technology and its enhanced adoption as well as improved infrastructure in the future is expected to raise gross agricultural production which will translate into higher CO_2 fixation and greater losses of nitrous oxides due to higher fertilizer use unless technologies are evolved to restrict them. Alternatively, agricultural residues may be ploughed in to increase soil carbon. Efforts are needed to determine such options for meeting our future food requirements. Information on carbon sequestration especially in fruit trees and agro-forestry needs to be quantified.

15.1.2 Methane

The total annual output of methane into the atmosphere from all sources in the world is estimated to be 535 Tg/year. Although the increase in annual load of methane in the atmosphere is much less than that of CO_2, its higher impaired absorption accounts for major contribution (15-20%) in global warming. India's total contribution to global methane emission from all sources is only 18.5 Tg/year. Agriculture, largely rice paddies and ruminant animal production, is the major (68%) source of this emission. The continuously flooded rice fields emit methane because anaerobic conditions favour methane production. International studies based on very limited measurements from USA and Europe and extrapolated to the whole world indicate that as much as 110 Tg/year were released from rice paddies alone (Houghton *et al*., 1990). Since India and China are the major rice growing nations, US-EPA attributed 38 Tg/year methane to Indian rice paddies. Based on this, international opinion was build that Asia and in particular India and China are having considerable contribution to the global warming. Systematic studies from India later have helped in changing this opinion. Sinha (1995) estimated that global annual methane emission from rice paddies is less than 13Tg/year and the contribution of Indian paddies to this is estimated to be only 4.2 Tg/ year (Bhattacharya and Mitra, 1998).

15.1.3 Nitrous oxides

Nitrous oxides, which are present in the atmosphere at a very low concentration (310 ppbv), are increasing at a rate of about 0.25% per year. But inspite of its low concentration and less rapid rise, N_2O is becoming important because of longer lifetime (150 years) and greater global warming potential than CO_2 (about 300 times more than CO_2). Both fertilized and unfertilized soils contribute to the release of this gas. Estimates of total nitrous oxides released from Indian agriculture are low due to generally low native soil fertility of our soils and relatively lower amounts of fertilizer used compared to western countries. Studies are being conducted in India to precisely quantify the magnitude of N_2O emission from different agro-ecosystems.

15.2 Climate change/variability

An analysis of the mean annual surface air temperature over India for the period 1901-1988 based on 73 stations shows a significant warming of about 0.4^0C per 100 years (Hingane *et al*., 1985). This warming trend in general is comparable to the global mean trend of 0.5^0C in last 100 years. Analysis of a representative rainfall series over the past 176 years for India as a whole does not suggest any significant trend (Sontakke, 1990). There is considerable uncertainty in the magnitude of change in rainfall and temperature predicted for India. Relatively, the increase in temperature is projected to be less in *kharif* than in *rabi* while the *rabi* rainfall will have larger uncertainty but *kharif* rainfall is likely to increase by as much as 10%. Since there is a large spatial and temporal variability in weather factors in a region, it is desirable that more detailed scenarios are made available for different agroclimatic zones. Future climate variability in India will lead to more frequent extremes of weather in the form of uncertain onset of monsoon, and frequency and intensity of drought and flooding.

15.2.1 Temperature variability

The variability analysis was carried out by analyzing historical data of maximum and minimum temperature and rainfall for five locations in three agroclimatic zones of the Punjab, i.e., Zone I (Ballowal Saunkhri), Zone III (Amritsar, Ludhiana and Patiala) and Zone IV (Bathinda). The daily temperature and rainfall data of past three decades for Ballowal Saunkhri (1984-2005), Amritsar (1970-2005), Ludhiana (1970-2005), Patiala (1970-2005) and Bathinda (1977-2005) were analyzed for annual, *kharif* (1 May to 31 October) and *rabi* (1 November-30 April) crop growing seasons. The results of the study are discussed below :

The trend line obtained by regressing the five-yearly moving averages against time for annual, *kharif* and *rabi* season maximum and minimum temperatures are shown in Table15.1 and 15.2, respectively for locations of Ballowal Saunkhri, Amritsar, Ludhiana, Patiala and Bathinda. In general, the maximum temperature has decreased from the normal at Ballowal Saunkhri and Bathinda, however, for other locations no trend could be established. The *kharif* maximum temperature decreased at the rate of 0.04 °C/year at Ballowal Saunkhri and Bathinda.

The annual and seasonal minimum temperature has increased at the rate of 0.07 °C/year over the past three decades at Ludhiana. At Patiala the annual and *kharif* minimum temperature has increased

Table 15.1 Time trend equations for maximum temperature (slope of regression = °C/calendar year) over the past three decades at different locations for annual, kharif and rabi seasons in Punjab

Station (Latitude, Longitude & Height a.m.s.l.)	*Annual*	*Kharif*	*Rabi*
Ballowal Saunkhri (31° 60' N, 76° 23' E, 355m)	Y = 0.058X - 86.08 R^2 = 0.46	Y = 0.045X - 56.17 R^2 = 0.46	Y = 0.089X – 152.30 R^2 = 0.56
Amritsar (31° 37' N, 74° 53' E, 231 m)	Y = -0.010X + 50.97 R^2 = 0.13	Y = -0.018X + 73.07 R^2 = 0.32	Y = 0.007X + 10.39 R^2 = 0.05
Ludhiana (30° 56' N 75° 48' E 247 m)	Y = -0.0001X + 30.90 R^2 = 0.00	Y = -0.014X + 62.67 R^2 = 0.21	Y = 0.017X - 98.40 R^2 = 0.15
Patiala (30° 20' N 76° 28' E 251 m)	Y = 0.004X + 21.10 R^2 = 0.04	Y= -0.007X + 50.33 R^2 = 0.17	Y = 0.020X - 16.39 R^2 = 0.26
Bathinda (30° 12' N 74° 57' E 211 m)	Y = -0.023X + 77.42 R^2 = 0.21	Y = -0.040X + 117.00 R^2 = 0.31	Y = -0.001X + 29.41 R^2 = 0.00

Table 15.2 Time trend equations for minimum temperature (slope of regression = °C/calendar year) over the past three decades at different locations for annual, kharif and rabi seasons in Punjab

Station (Latitude, Longitude & Height a.m.s.l.)	*Annual*	*Kharif*	*Rabi*
Ballowal Saunkhri (31° 60' N, 76° 23' E, 355m)	Y = -0.022X + 61.80 R^2 = 0.06	Y = -0.011X + 45.87 R^2 = 0.02	Y = -0.008X + 27.25 R^2 = 0.006
Amritsar (31° 37' N, 74° 53' E, 231 m)	Y = -0.004X + 25.17 R^2 = 0.017	Y = -0.002X + 28.13 R^2 =0.004	Y = -0.006X + 21.01 R^2 = 0.02
Ludhiana (30° 56' N 75° 48' E 247 m)	Y = 0.071X - 125.00 R^2 = 0.92	Y = 0.076X - 129.00 R^2 = 0.94	Y = 0.067X - 125.00 R^2 = 0.86
Patiala (30° 20' N 76° 28' E 251 m)	Y = 0.015X - 13.34 R^2 = 0.43	Y = 0.022X - 20.81 R^2 = 0.59	Y = 0.010X - 9.803 R^2 = 0.15
Bathinda (30° 12' N 74° 57' E 211 m)	Y = 0.038X - 59.57 R^2 = 0.59	Y = 0.025X - 27.30 R^2 = 0.25	Y = 0.053X - 97.18 R^2 = 0.71

at the rate of 0.02 °C/year and at Bathinda the annual, *kharif* and *rabi* minimum temperature has increased at the rate of about 0.03, 0.02 and 0.05 °C/year, respectively. However no trend of change in minimum temperature was observed at Ballowal Saunkhri and Amritsar.

15.2.2 Rainfall variability

The trend lines obtained by regressing the five-yearly moving averages against time for annual, *kharif* and *rabi* season rainfall are shown in Table 15.3 for locations of Ballowal Saunkhri, Amritsar, Ludhiana, Patiala and Bathinda. In general, no significant change was noted for annual and seasonal rainfall at different locations over the past three decades. At Ballowal Saunkhri the annual, *kharif* and *rabi* rainfall has decreased at the rate of 16, 12 and 3 mm/year, respectively. At Bathinda *rabi* season rainfall has decreased at the rate of 2 mm/year over the past three decades.

The earlier study conducted by Hundal and Prabhjyot-Kaur (2002) revealed an overall increase in rainfall over a period of 1970-1998 at different locations. But during the period from 1999 to 2005, below normal rainfall was received at all the five locations during the year 1999, 2002, 2004 and 2005. During the year 2000 below normal rainfall was recorded at Ludhiana and Patiala and during 2001 below normal rainfall was recorded at all four locations except Ludhiana. This resulted in arresting the increasing trend of rainfall at different locations in the State. Hence, no significant trend in increase / decrease of rainfall was observed at all the locations except Ballowal, Saunkhri where a significant decreasing trend was observed.

15.3 Impact of climatic change on crop productivity

Rise in temperature and carbon dioxide and uncertainties in rainfall associated with global climate change may have serious direct and indirect consequences on crop production and hence food security (Sinha and Swaminathan, 1991). It is, therefore, important to have an assessment of the direct and indirect consequences of global warming on different crops contributing to our food security. Future agricultural planning, thus has to formulate a holistic approach on productivity, stability, sustainability, profitability and equity in Indian agriculture in coming decades.

Table 15.3 Time trend equations for rainfall (slope of regression = mm/calendar year) over the past three decades at different locations for annual, kharif and rabi seasons in Punjab

Station (Latitude, Longitude & Height above m.s.l.)	*Annual*	*Kharif*	*Rabi*
Ballowal Saunkhri (31° 60' N, 76° 23' E, 355m)	$Y = -16.11X + 3314$ $R^2 = 0.39$	$Y = -12.50X + 25948$ $R^2 = 0.34$	$Y = -3.26X + 6675$ $R^2 = 0.36$
Amritsar (31° 37' N, 74° 53' E, 231 m)	$Y = -1.94X + 4579$ $R^2 = 0.06$	$Y = -1.32X + 3210$ $R^2 = 0.04$	$Y = -1.18X + 2493$ $R^2 = 0.06$
Ludhiana (30° 56' N 75° 48' E 247 m)	$Y = 3.193X – 5602$ $R^2 = 0.12$	$Y = 3.26X - 5860$ $R^2 = 0.13$	$Y = -0.476X + 1077$ $R^2 = 0.02$
Patiala (30° 20' N 76° 28' E 251 m)	$Y = 1.08X – 1358$ $R^2 = 0.007$	$Y = 2.25X - 3824$ $R^2 = 0.038$	$Y = -1.462X + 3044$ $R^2 = 0.054$
Bathinda (30° 12' N 74° 57' E 211 m)	$Y = -3.015X + 6562$ $R^2 = 0.034$	$Y = -0.276X + 1009$ $R^2 = 0.00$	$Y = -2.976X + 6025$ $R^2 = 0.54$

The effects of changes in temperature, precipitaion and CO_2 concentrations on crop productivity have been studied extensively using crop simulation models (Parry *et al*, 2004). The combined effects of climate change have been found to have implications for dryland and irrigated crop yields (Rosenzweig and Iglesias, 1994). However, the effect on production is expected to vary by crop and location, as well as by the magnitude of warming, the direction and magnitude of precipitation change (Adams *et al.*, 1998).

15.3.1 Effect of elevated concentration of CO_2 and climate change on crop growth

CO_2 is vital for photosynthesis and hence for plant growth. An increase in atmospheric CO_2 concentration affects agricultural production by climate change and changes in photosynthesis and transpiration rate. The rise in atmospheric CO_2 concentration from pre-industrial level of about 280 ìmol/mol to about 377 ìmol/mol currently is well documented (Keeling and Whorf, 2005). It is therefore important to assess the combined effects of elevated atmospheric concentration and climate change on the productivity of a region's dominant crops (Haskett *et al.*, 1997). The direct effects of increased concentrations of CO_2 are generally beneficial to vegetation (Farquhar, 1997), especially for C_3 plants, as elevated levels lead to higher assimilation rates and to an increase in stomatal resistance resulting in a decline in transpiration and improved water use efficiency of crops.

Simulation studies have been conducted for predicting the plausible effects of elevated levels of CO_2 on yield of crops (Tubeillo and Ewert, 2002). Lal *et al.,* (1998) through sensitivity experiments found that under elevated CO_2 levels, yields of rice and wheat increased by 15% and 28%, respectively for a doubling of CO_2 in NW India. Hundal and Prabhjyot-Kaur (1996) reported that compared to base level of 330 ppm CO_2 , grain yield of rice would increase by 1.5, 6.6 and 8.7% with enhanced CO_2 concentrations of 400, 500 and 600 ppm, respectively. Soybean yields have been reported to increase by nearly 50% for a doubling of atmospheric CO_2 from its current level of 330ppmv by Lal *et al.,* (1999) and Mall *et al.,* (2004).

The interaction effects of CO_2, rainfall and temperature can best be studied through the use of crop growth simulation models.

A large number of crop models have been developed in recent years. Models are now available for most major crops such as wheat, rice, maize, sorghum, millet, groundnut, potato, sugarcane etc.

Several impact assessment studies in the developed countries have utilized simulation models and also evaluated the impact of global climatic changes on agriculture. Few such modelling studies have been done in India to assess the impact of climate change on crop production in different parts of India (Hundal and Prabhjyot-Kaur, 1996; Aggarwal and Sinha, 1993; Rao and Sinha, 1994, Saseendran *et al.,* 2000, Mall *et al.,* 2004). In these studies, the sensitivity of different crops to independent as well as simultaneous changes in temperature, radiation, carbon dioxide etc. has been studied.

The magnitude of response varies with the crop, region and climate change scenarios. However, positive effects of increase in CO_2 concentrations on growth and yield of crops are nullified by simultaneous increase in temperature. Such results have been reported in field crops by Hundal and Prabhjyot-Kaur (1996 & 2007) and soybean by Mall *et al.,* (2004). In some cases, the integrated impact of a rise in temperature and CO_2 concentration on the yield of wheat and rice may be negative (Sinha and Swaminathan, 1991).

Simulated yields of both wheat and rice decreased as temperature increased. A 2^0C increase resulted in 15-17% decrease in grain yield of both crops but beyond that the decrease was very high in wheat (Hundal and Prabhjyot-Kaur, 2007). These decreases were compensated by increase in CO_2 due to latter's fertilizing effect on crop growth. CO_2 concentration has to rise to 450 ppm to nullify the negative effect of 1^0C increase in temperature, and to 550 ppm to nullify 2^0C increase in temperature. Super-imposing different climate change scenarios on these isolines can guide us on the magnitude of the potential impact of change on crop productivity.

The indirect effects on crops indicate that changes in pest scenario, soil moisture storage, irrigation water availability, mineralization of nutrients, and socio-economic changes may have large effects on agricultural production. Considering the crop-pest interactions, for an estimated loss of about 30% of crop production due to biotic interference, 10% loss each is attributed to insect pests, pathogens and weeds. The change in climate may bring about changes in population dynamics, growth and distribution of insect and pests. The occurrence and intensity of different crop diseases depends on the interaction of pathogen, host and the environment. Aphid is one of the very few major pests of wheat and its occurrence is highly influenced by weather conditions. Cloudy weather with enough relative humidity favours the occurrence of aphids in the field. Regional weather changes may, therefore, influence the occurrence of particular species of aphids during the cropping season.

15.3.2 Simulation effect of intra-seasonal temperature rise on wheat yield

Wheat is a major winter cereal crop in northern India and it requires cool climate during its early growth stages for potential productivity. Any abrupt changes in weather parameters, especially an increase in maximum/ minimum temperature from normal at any growth stage of crop adversely affects the growth and ultimately the potential yield of wheat. A simulation study was conducted using CERES-Wheat model to assess the effect of intra-seasonal increase of temperature from normal on yield of wheat sown on different dates (Prabhjyot-Kaur *et al.*, 2007). The study was carried out with the assumption that weather remained normal in rest of the crop growth period, crop remained free of water and nutrient stress and pest infestation. The simulation results revealed that in general, an increase in temperature from mid February to mid March severely affected the yield of early, normal and late sown wheat (Table 15.4). A further scrutiny revealed that the temperature increase mostly affected the early (October) sown crop during 4th week of January, February and up to 1st fortnight of March; the timely (November) sown crop during February and March; the late (4th week of November) sown crop during March; and very late (December) sown crop during March and 1st week of April.

The analysis revealed that an increase of temperature from normal decreased grain yield of wheat (Table15.5) at the following rates:

- Temperature increase in 4th week of January decreased the grain yield by 0.99, 0.66 and 0.70 percent per degree Celsius for wheat sown in 4th week of October, 1st week of November, and 2nd week of November, respectively.

Table 15.4 Effect of temperature increase (maximum & minimum) from normal during January to March on grain yield (% deviation from normal) of wheat sown on different dates.

Month	Time period	Temperature increase from normal					
		+1.0°C	+2.0°C	+3.0°C	+4.0°C	+5.0°C	+6.0°C
Early sown (28th October)							
January	Last week	-3.0	-3.1	-3.1	-6.3	-6.8	-7.1
February	1st fortnight	-3.4	-3.7	-7.6	-11.5	-13.0	-17.2
	2nd fortnight	-2.4	-2.8	-5.2	-8.1	-10.9	-13.8
March	1st fortnight	-2.3	-4.6	-6.8	-13.8	-8.2	-10.4
Normal sown (8th November)							
January	Last week	+1.9	+0.1	+0.4	-1.5	-2.0	-1.1
February	1st fortnight	+1.7	-1.6	-1.8	-3.9	-7.7	-7.3
	2nd fortnight	-0.4	-4.1	-5.1	-9.9	-14.2	-16.4
March	1st fortnight	-2.7	-3.3	-6.0	-9.5	-9.5	-13.0
	2nd fortnight	+1.1	-1.5	-0.5	-0.1	-1.9	-1.5
Normal sown (15th November)							
January	Last week	+1.8	+1.7	+1.4	+0.5	-0.2	-1.8
February	1st fortnight	-0.5	-2.7	-1.5	-2.0	-1.3	-1.9
	2nd fortnight	-2.0	-5.8	-6.0	-8.7	-9.7	-14.2
March	1st fortnight	-4.8	-9.3	-10.1	-14.2	-16.0	-20.8
	2nd fortnight	-2.5	-1.6	-4.3	-6.9	-5.9	-8.1
Late sown (25th November)							
January	Last week	+0.1	+3.7	+3.5	+3.4	+3.4	+7.2
February	1st fortnight	+0.5	+2.4	+2.8	+4.7	+4.9	+7.0
	2nd fortnight	+2.5	+1.1	+3.4	-0.6	-2.6	-3.3
March	1st fortnight	-0.5	-5.4	-6.7	-3.3	-16.0	-19.4
	2nd fortnight	-0.1	-4.7	-5.6	-9.2	-10.1	-11.2
Late sown (2nd December)							
January	Last week	0.0	+0.6	+0.6	+0.5	+0.6	+3.4
February	1st fortnight	+0.7	+0.6	+0.6	+3.4	+3.6	+3.7
	2nd fortnight	-0.5	-0.4	-1.7	-2.3	-3.1	-3.6
March	1st fortnight	-2.3	-1.6	-6.8	-7.6	-12.5	-17.7
	2nd fortnight	-5.5	-6.6	-12.3	-14.5	-19.1	-21.4
April	1st week	-1.4	-1.8	-2.6	-2.2	-3.5	-3.1

- Temperature increase in 1st fortnight of February decreased the grain yield by 2.88 and 1.87 percent per degree Celsius for wheat sown in 4th week of October, and 1st week of November, respectively.
- Temperature increase in 2nd fortnight of February decreased the grain yield by 2.40, 3.30, 2.15, 1.26 and 0.69 percent

Table 15.5 Rate of change (increase / decrease from normal) in grain yield of wheat sown on different dates due to intra-season temperature increase

Temperature increase (Time period)	Date of sowing	Rate of change in grain yield (Percent / °C)
4th week of January	Early sown (28th October)	-0.99
	Normal sown (8th November)	-0.66
	Normal sown (15th November)	-0.70
	Late sown (25th November)	+0.98
	Late sown (2nd December)	+0.48
1st fortnight of February	Early sown (28th October)	-2.88
	Normal sown (8th November)	-1.87
	Normal sown (15th November)	-
	Late sown (25th November)	+1.19
	Late sown (2nd December)	+0.76
2nd fortnight of February	Early sown (28th October)	-2.40
	Normal sown (8th November)	-3.30
	Normal sown (15th November)	-2.15
	Late sown (25th November)	-1.26
	Late sown (2nd December)	-0.69
1st fortnight of March	Early sown (28th October)	-2.40
	Normal sown (8th November)	-2.10
	Normal sown (15th November)	-2.98
	Late sown (25th November)	-3.51
	Late sown (2nd December)	-3.15
2nd fortnight of March	Normal sown (15th November)	-1.24
	Late sown (25th November)	-2.15
	Late sown (2nd December)	-3.40
1st week of April	Late sown (2nd December)	-0.38

per degree Celsius for wheat sown in 4th week of October, 1st week, 2nd week, 4th week of November, and 1st week of December, respectively.

- Temperature increase in 1st fortnight of March decreased the grain yield by 2.40, 2.10, 2.98, 3.51 and 3.15 percent per degree Celsius for wheat sown in 4th week of October, 1st week, 2nd week, 4th week of November, and 1st week of December, respectively.
- Temperature increase in 2nd fortnight of March decreased the grain yield by 1.24, 2.15 and 3.40 percent per degree Celsius for wheat sown in 2nd week, 4th week of November, and 1st week of December, respectively.

15.4 Mitigation and adaptation strategies

To cope up with anticipated climate change impacts, mitigation and adaptation strategies may be chalked out. These include :

- Evolve suitable crop management practices
- Breeding of short duration, temperature resistant and low water requirement varieties
- Improvement in irrigation efficiency of crop plants
- Creation and strengthening of C sinks in the soil
- Stabilizing atmospheric concentration of greenhouse gases
- Increase productivity of existing farmed area and reduce deforestation and paddy plantation which contribute to CH_4 emission
- Production of biofuels to replace fossil fuels
- Manipulation of crop microclimate by means such as use of windbreaks, tunnels or greenhouses to reduce the effects of climate change

15.5 Conclusions

The long term assessment of climate change focusing on average effects over time and space suggest worldwide enhanced thermal stress due to global warming. But at regional and local scales, the effects of climate change could be more adversely felt particularly in developing countries like India which shares only 2% of geographical area but supports around 18% of world's population and over 15%

of world's livestock. Climatic changes leading to snowmelt and retreating glaciers will also influence water availability for agriculture in the long run. Apart from monsoon rains, India depends on Himalayan rivers for water resources development. Temperature increase associated with global warming may increase snowmelt and consequently snow cover will decrease. In short term, this may increase water flow in many rivers which, in turn, may lead to increased frequency of floods. In the long run, however, receding snow line would result in reduced water flow in rivers. Under climate change scenarios, the onset of summer monsoon over India may be delayed and become more uncertain. This will have a direct effect not only on the rainfed crops, but also water storage will be affected putting stress on irrigation water availability. Since availability of water for agriculture would have to face tremendous competition for domestic and other uses of water, agriculture in future could come under greater strain with respect to water availability for crop production.

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CLIMATE CHANGE EVENTS

1877 – All-India drought year

1891 – El Nino year

1899 – All-India drought year

1925 – El Nino year

1929 – The commission for climatology was instituted by IMO

1950 – The First Convention of the World Meteorological Organization (Formerly known as International Meteorological Organization – IMO)

1950 – The World Meteorological Day came into force on 23rd March

1950s – Radars, Satellites and computers contributed to high quality research in atmospheric processes, led to technological achievements

Late1960s and early 1970s – The unprecedented drought in the Sahel and the evidence of a period of prolonged cooling raised concern about the future climate

1972 – El Nino year

1976 – The first authoritative statement by the WMO on the potential impact of an increasing accumulation of greenhouse gases in the atmosphere on our future climate

1979 – All-India drought year

1979 – The first World Climate Conference, led to the establishment of World Climate Programme (WCP); Collaboration of WMO with United Nations Environment Programme (UNEP) and the International Council for Science (ICSU) in research

1982-83 – Severe El Nino year – Caused $13 billion in damages worldwide

1983 – Worst drought year during summer over Kerala – Plantation crops production suffered to a large extent in the same year and subsequent years depending upon the type of crop

1987 – All-India drought – Indian foodgrains production declined

1988 – Established Intergovernmental Panel on Climate change (IPCC)

1990 – The First Assessment Report of IPCC, led to UNCED

1990-91– Mild El Nino year

1992 – Framework Convention on Climate Change was signed in Rio during the United Nations Conference on Environment and Development (UNCED)

1995 – The Second Assessment Report of IPCC contributed to the negotiation of the Kyoto Protocol to the United Nations Framework Convention on Climate Change (UNFCCC)

1997 – El Nino year

1998 – The second warmest year. Declared as the weather related disaster year

1999 – The sixth warmest year. Super cyclone hit Orissa coast on 27th October

2001 – The Third Assessment Report of IPCC– New and stronger evidence that warming over 50 years is attributable to human activities – The third warmest year

2001-02– El Nino year

2002 – All-India drought – Indian foodgrains production declined

2003 – Worst heat wave in Europe since last 130 years

2004 – Worst drought year during summer over Kerala. Tsunami disaster, 26th December over Southeast Asian Countries.

2005 – The warmest year ever recorded. Declared as the year of hurricanes. Mumbai recorded more than 940 mm on 26th July (The highest one day rainfall event). The costliest and deadliest cyclones viz., Katrina(August 31) and Rita (September 24) hit New Orleans and Texas & Lousiana in U.S. and caused $10.5 billion and $11.3 billion damage, respectively.

2006 – The severe cyclone 'Ogni' hit AP coast in October and devastated rice crop. Typhoon "Durian" hit the Tabaco Albay Province, South Manila on November 30 and caused heavy damage

2007 Flood year in India.

2007 – Scheduled the Fourth Assessment Report of IPCC. The second warmest year.

UNFCCC at Bali, Indonesia during December 3-14, 2007.

SUBJECT INDEX