

## **Effects of climate change on the yield of major food crops: A case of Madhya Pradesh**

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### **Abstract**

Weather is direct input in the most of the agricultural sector. Therefore it has great importance in the productivity of most of the crop. Over the years climatic conditions are changing drastically, which in-turn is effecting the agricultural sector? The frequency and severity of risks in agriculture particularly in last few decades has increased on account of climate variability and change. The principal evidence of climatic change has been rising temperatures, erratic rainfall pattern, and increase in the severity of droughts, floods and cyclones which have caused huge losses in agricultural production and the livestock population. India has developed response mechanisms for primary (crop failures) and to some extent secondary (livestock deaths) consequences of climate variability. It is more effective in central south Indian states. Madhya Pradesh being in the zone of semi-arid region has major implications of climate variability. Therefore present study aims to analyze major effects of climate change over the years in this region.

**Keywords:** weather, variability, frequency, temperature, rainfall

### **1. Introduction**

Agriculture is the basic activity by which humans live and survive on the earth. Assessing the impacts of climate change on agriculture is a vital task. In both developed and developing countries, the influence of climate on crops and livestock persists despite better irrigation facilities, improved plant, animal hybrids and the growing use of chemical fertilizers. The continued dependence of agricultural production on light, heat, water and other climatic factors, the dependence of much of the world's population on agricultural activities, and the significant magnitude and rapid rates of possible climate changes all combine to create the need for a comprehensive consideration of the potential impacts of climate on global agriculture.

Agricultural production is also severely limited in many humid tropical regions by the wide range of weeds, pests, and diseases that flourish in consistently warm and moist climates. The growth of some crops and varieties, which require long hours of daylight to reach maturity, is also limited by the invariable day lengths of the tropics. Solar radiation, which is critical to plant growth, and whose intensity is controlled by the angle of the sun, day-length, and cloudiness, is lower in winter and higher in summer in temperate zones. In the tropics, solar radiation is often limited by cloudiness during the rainy seasons.

In temperate zone, plant breeding and fertilizer use dramatically increased the yield of many crops early in the twentieth century. Similar increases occurred more recently in tropical regions for crops such as wheat, maize and rice, which benefited from the technological package or improved seeds, fertilizer, mechanization and pesticides known as the Green Revolution.

In both temperate and tropical regions, irrigation has been developed in areas where dry seasons exist and adequate water can be reserved from other seasons or brought in from adjacent regions. Irrigation is an important buffer against climate variability and climate change. About 20% of the world's

cropland is irrigated, mostly in Asia, producing about 40% of the annual crop production.

Numerous studies have examined the impacts of past climatic variations on agriculture using case studies, statistical analyses and simulation models (Parry 1978; Thompson 1975; World Meteorological Organization 1979) <sup>[15, 23]</sup>. Such studies have clearly demonstrated the sensitivity of both temperate and tropical agricultural systems and nations to climatic variations and changes. In the temperate regions, the impacts of climate variability, particularly drought, on yields of grains in North America and the Soviet Union have been of particular concern because of their effects on world food security. In the tropics, drought impacts on agriculture and resulting food shortages have been widely studied, especially when associated with the failure of the monsoon in Asia or the rains in Sudano-Sahelian Africa. In the temperate regions, climatic variations are associated with economic disruptions; like, in the tropics, droughts bring famine and widespread social unrest (Pierce 1990) <sup>[17]</sup>.

Madhya Pradesh, a central Indian state, has a subtropical climate. Hot dry summer extends from April to June followed by monsoon from July to September and winter months (November to February) are cool and relatively dry. The average rainfall is about 1,370 mm (53.9 in). It decreases from east to west. The south-eastern districts have the heaviest rainfall, some places receiving as much as 2,150 mm (84.6 in), while the western and north-western districts receive 1,000 mm (39.4 in) or less. Summer mean maximum temperature rises to about 42.5°C in northern Madhya Pradesh and ranges from 40°C to 42.5°C. The days in the month of May are usually hotter than those of June. The average temperature during winters is as low as 10°C in the north, while in the south it varies from 10°C to 15°C. Therefore keep in view the above analysis; the present study aims to analyze the future trends in climate in Madhya Pradesh and its impact on some major crops.

**Objectives**

1. To assess the climate change trends over a long period of time in the region.
2. To examine the long range effects of climate change on agriculture in the region.

**Review of Related Literature**

Analysis of data for the period 1901-2009 suggests that annual mean temperature for the country as a whole has risen by 0.56°C over the period (IMD, 2010) [8]. While Warming trend over globe of the order of 0.74°C has been reported by I.P.C.C (2007) [9]. The contribution of July rainfall is decreasing in central and west peninsular India (significantly in South interior Karnataka (95%), East M.P. (90%) Vidarbha (90%), Madhya Maharashtra (90%), Marathwada (90%), Konkan & Goa (90%), and North interior Karnataka (90%)), but has increased significantly in the northeastern parts of the country (Guhathakurta, P. and Rajeevan, 2008) Significant increasing trend was observed in the frequency of heavy rainfall events over the west coast (Sinha Ray & Srivastava, 2000) [21]. Rao *et al* (2010) [18] have assessed the role of Southern Tropical Indian Ocean warming on unusual central Indian drought of summer monsoon-2008.

Onyeji & Fischer (1993) [14] observed that climate change has decreased the agricultural productivity, raised food prices and declined consumer incomes. Gbetibouo and Hassan (2005) study identify that agriculture is a more vulnerable sector, physically and economically due to climate change compared to other sectors of the economy. Deressa *et al.* (2005) [2] applied a Ricardian cross section regression model and found that sugarcane production is highly sensitive to climate change. It has a negative impact on sugar production in South Africa. Masters *et al.* (2010) [12] mentioned that climate change has a significant negative effect on agriculture production that occupies around 40% of the land globally. Study by Nandhini *et al.* (2006) [13] observed that cultivable land of rice is lead to decrease due to the scarcity of inputs and low rainfall in Tamil Nadu. Hundal & Prabhjyot (2007) [6] employed a simulation model and mentioned that the increase in temperature by 1°C lead to decrease rice and wheat yield by 3% and 10% respectively in Punjab

Climatic conditions affect the survival, growth, and spread of pathogens, as well as the resistance of hosts. Friedrich (1994) summarizes the observed relationship between climatic conditions and important plant diseases. Among these, mild winters have been associated with more rapid and stronger outbreaks of powdery mildew (*Erysiphe graminis*), brown leaf rust of barley (*Puccinia hordei*), and strip rust of cereals (*Puccinia striiformis*) (Meier, 1985). Mild winters combined with very warm weather conditions provide optimal growth conditions for cercosporia leaf spot disease (*Cercosporia beticola*), powdery mildew (*Erysiphe betae*), and rhizomania disease (*Rizomania*) (Treharne, 1989). Warm, humid conditions lead to earlier and stronger outbreaks of late potato blight (*Phytophthora infestans*) (Lopmeier, 1990; Parry *et al.*, 1990) [16]. Dry and hot summers generally reduce infestations of most fungal diseases because plant resistance is increased. Therefore it is clear from the above analysis that climate change is greatly affecting the agriculture and moreover it is behaving differently with different crop. Thus it is important to examine the effects of this change on various crops separately.

**Methodology**

The present study is based on empirical and quantitative analysis of the problem. In this study we used secondary source of data for the analysis of different indicators of climate change and crop production. To analysis the changes in the climate over a long period of time in the region, we used the previous studies carried out in this regard, particularly we used government of Madhya Pradesh estimates of future climate in the region. To calculate the affects of future climate events on agriculture, we used correlation and regression models to evaluate the spatial effects on production of crop with the changing climate.

**Data and Summary Statics**

To calculate and evaluate the spatial effects of climate change we first taken into account the climate changes in the region during last century and analysis the expected future changes. Let’s see the changes in the climatic variables in the region. Before we present climate change scenarios and its relationship with the crop productivity in the region, let’s see the optimal conditions required for the better growth of different crops. This will help us to understand the correlation between crop productivity and climate.

**Crop phenology of some important crops in the region**

**Table 1.0:** Crop phenology of some important crops in the region

Crop	Base temperature °c	Optimal temperature °c	Emergence to pre-anthesis (degree day)	Emergence to post anthesis (degree days)	Optimal rainfall (mm)
Rice	8	25-31	700-1300	450-850	1000-1500
Wheat	0	20-25	750-1300	450-1050	150-200
Maize	7	17-23	900-1300	700-110	400-500
Soyabean	0	25-35	Highly variable	450-750	
Sugarcane	5	25-30	450-900	600-950	150-180
Potato	0	20-25	400-650	450-700	500-600

**Source:** Adapted from Acock and Acock, 1993.

**Notes:** Base Temp. = minimum temperature for growth; Max. Devel. = optimum temperature for crop development; Emergence to Pre-Anthesis = cumulative degree days needed from crop emergence to pre-anthesis (flowering); Post-Anthesis to Maturity = cumulative degree days required (after flowering) to reach maturity

Water is present in the atmosphere in the form of invisible water vapour, normally known as humidity. Relative humidity is ratio between the amounts of moisture present in the air to the saturation capacity of the air at a particular temperature. Relative humidity of 40-60% is suitable for most of the crop plants. While as very few crops can perform well when relative humidity is 80% and above. If relative humidity is high there is chance for the outbreak of pest and disease.

Before moving towards examining the expected changes in climatic conditions in our study area, let’s see how a change climate, particularly in temperature, can offset the productivity trends in some important Crops in the region.

**Table 1.1:** Temperature thresholds: High temperature effects on key development stages of five major arable crops.

Crop	Effects
Wheat	Temperature >30°C for more than 8 hours can reverse vernalization
Rice	Temperature >35°C for more than 1 hour at anthesis causes high percentage spikelet sterility
Maize	Pollen begins to lose viability at temperatures >36°C
Potato	Temperatures >20°C depress tuber Pr initiation and bulking
Soyabean	Great ability to recover from temperature stress; critical period in its development unknown

**Climate Change Scenarios**

The I.P.C.C scenarios provide a mechanism to assess the potential impacts on climate change. Global emission scenarios were first developed by the I.P.C.C in 1992 and were used in global general circulation models to provide estimates for the full suite of greenhouse gases and the potential impacts on climate change. Since then, there has been greater understanding of possible future greenhouse gas emissions and climate change as well as considerable improvements in the general circulation models. The I.P.C.C, therefore, developed a new set of emissions scenarios, published in the I.P.C.C Special Report on Emission Scenarios (I.P.C.C S.R.E.S November 2000). These scenarios refer to the predictions made for future conditions mainly related to precipitation, sea level rise and temperature changes MADHYA PRADESH based on ‘storylines’ of the alternate greenhouse gas emissions. There are four storylines (A1,) identifying alternate states of future economic and technological development that takes place over the next few decades as summarized in Table

**Table 1.2:** Temperature for IPCC SRES baseline and A1B scenario as simulated by PRECIS for Madhya Pradesh Mean Daily Maximum Temperature (°C)

	Year	JF	MAM	JJAS	OND	Annual
Madhya Pradesh	1970s	29.3	39.9	29	29	31.8
Madhya Pradesh	2050s	31.3	41.9	30.3	31.1	33.6
Madhya Pradesh	2080s	32.5	43.4	32.4	32.8	35.3

Where; J.F =January and February, M.A.M=March, April and May, J.J.A.S=June, July, August and September, and O.N.D=Oct ember, November, and December

**Mean Daily Minimum Temperature (°C):-**

	Year	JF	MAM	JJAS	OND	Annual
Madhya Pradesh	1970s	14.7	24.5	23.4	16.9	19.9
Madhya Pradesh	2050s	17.1	26.5	25	19.6	22.2
Madhya Pradesh	2080s	19.6	29.5	27	22.2	24.6

Source: IPCC 4th Assessment Report (2007)

Lets now compare the Temperature for I.P.C.C S.R.E.S baseline and A1B scenario as simulated by P.R.E.C.I.S for Madhya Pradesh

**Comparison of projected changes in temperatures for I.P.C.C S.R.E.S scenario with respect to baseline for Madhya Pradesh \*\***

**Table 1.3:** Change in Mean Daily Maximum Temperature (°C)

	JF	MAM	JJAS	OND	Annual
Change from Baseline to Mid Century	2	1.7	1.3	2.1	1.8
Change from Baseline to End Century	3.2	3.5	3.4	2.8	3.5

**Change in Mean Daily Minimum Temperature (°C)**

	JF	MAM	JJAS	OND	Annual
Change from Baseline to Mid Century	2.4	2.4	1.6	2.7	2.3
Change from Baseline to End Centu	4.9	5	3.6	5.3	4.7

Source: IPCC 4th Assessment Report (2007) \*\* Positive change indicates increase in future and negative change indicates decrease in future

A1  
 World: Market Oriented Economy: Rapid economic growth.  
 Population: Peaks in 2050 and then gradually declines.  
 Governance: A convergent world - income and way of life converge between regions. Extensive social and cultural interactions worldwide.  
 Technology: There are three subsets to the A1 family  
 A1FI - fossil-fuels intensive.  
 A1B - balanced on all energy sources.

**P.R.E.C.I.S Precipitation:-**

Madhya Pradesh receives most of its rain during the monsoon season, which starts in late June. The mean seasonal precipitation amounts simulated by P.R.E.C.I.S are as shown in Table 1.3. Data are presented for four seasonal periods: Under the A1B scenario, rainfall is projected to increase. Mean annual rainfall increases by about 126 mm (12%) by mid-century and by about 326 mm (30%) by end-century under the A1B scenario. Most of the increases occur in the monsoon period. There is a slight decline in JF rainfall towards mid-century under the A1B scenario. Mean monsoon rainfall increases by 122 mm by mid-century and by 259 mm by end century.

**Table 1.4:** Rainfall Statistics for Madhya Pradesh IPCC SRES baseline and A1B scenario as simulated by PRECIS for Madhya Pradesh (Rainfall mm)

	Year	JF	MAM	JJAS	OND	Annual
Madhya Pradesh	1970s	37	50.8	914.9	83.5	1086.2
Madhya Pradesh	2050s	27.8	57	1037	90.7	1212
Madhya Pradesh	2080s	44.6	72.8	1173.6	121.3	1412.3

Comparison of projected changes in seasonal and annual rainfall (mm) for IPCC SRES scenario with respect to baseline for Madhya Pradesh \*\*

**Change in rainfall (%)**

	JF	MAM	JJAS	OND	Annual
Change from Baseline to Mid Century	-24.9	12.2	13.3	8.6	11.6
Change from Baseline to Mid Century	20.5	43.3	28.3	45.3	30.0

Source: IPCC 4th Assessment Report (2007) \*\* Positive change indicates increase in future and negative change indicates decrease in future

**The Above Analysis Summarizes as**

Mid-century- Annual maximum temperature to increase by 1.8°C and annual minimum Temperature by 2.3°C

End century-Annual maximum temperature to increase by 3.5°C and annual minimum

Temperature by 4.7°C

Precipitation - Increase is projected for average annual rainfall by 11.6% and 30.0% respectively for mid and end century scenarios

From the above analysis it is clear that the climate changes are taking place in the region. There is no doubt that these changes climate will affect the productivity of different crops over a long period of time in the state. But how and to what extend these changes will affect the crop production in the state is matter of consideration of our research. For this purposes, we built the index of climate conditions (variables) required for the production of different crops. The index of climatic conditions was utilized to examine the minimum and maximum temperature and water required for the optimal production of different crops.

The anticipated increase in temperatures with global warming can lead to spikelet sterility in rice, loss of pollen viability in maize, reversal of vernalization in wheat, and reduced formation of tubers and tuber bulking in potatoes for areas near critical thresholds (Table 1.1). Yield losses can be severe in these cases, if temperatures exceed critical limits for periods as short as 1 hour during anthesis (flowering).

Environmental changes will interact with changes in climate variables and elevated CO<sub>2</sub> to affect crop yields. Consistent moisture availability throughout the crop growth period is critical. Overall, the hydrological cycle is expected to intensify with higher evaporation, air humidity, and precipitation. Higher temperatures would, at the same time, increase crop water demand. Changes in large-scale atmospheric patterns such as the El Niño and tropical monsoons could cause significant shifts in rainfall patterns, with consequent effects on agricultural Production, among these are exposure to O<sub>3</sub>-tropospheric (surface) concentrations

Abundant precipitation can affect mortality, for example, through drowning of soil-dwelling insects (Watt and Leather, 1986) [25] but is more likely to affect insects indirectly through climatic effects on insect pathogens, predators, and parasites. In addition to this Analyses suggest that warming in the region during warm months would likely impact livestock reproduction and production negatively (e.g., reduced animal weight gain, dairy production, and feed conversion efficiency

**Wheat:** - An assessment of the impact of climate change on wheat production states that the country's annual wheat output could plunge by 6 million tonnes with every 1°C rise in temperature. Madhya Pradesh is among major wheat producing state in the country. In fact that temperature of the state could rise up to 4°C till the end of century could adversely effect the wheat production in the state.

**Rice:** - Research conducted by Indian Council Agricultural Research (I.C.A.R., 2009) has shown that the grain yield of rice is not impacted by a temperature increase less than 1°C. However from an increase of 1-4°C the grain yield reduced on average by 10% for each degree the temperature increased. Thus from the fact the rice season temperature could rise from up to 3-5°C in 2080s, will have a major effects on future production of rice in the region. Further rainfall pattern is a

very important limiting factor for rain-fed rice production. Higher variability in distribution and a likely decrease in precipitation will adversely impact rice production and complete crop failure is possible if severe drought takes place during the reproductive stages. In upland fields, if the rice crop receives up to 200 mm of precipitation in 1 day and then receives no rainfall for the next 20 days, the moisture stress will severely damage final yields. This shift is of particular concern to the state because lower rice production will immediately create a hunger situation on a large scale if adaptive measures are not taken to minimize the effects of climate variations.

**Soyabean:** - Climatic change is likely to have substantial impact on soybean production. Increasing CO<sub>2</sub> levels will increase productivity, due to increase in photosynthesis. However, this increase will be offset by increases in temperature, which will significantly reduce the grain yield due to accelerated development and early flowering, and thus decreased time for grain weight accumulation, i.e. reduced grain-fill period. Moisture stress, due to swings in the continuity of monsoons, is likely to continue to adversely affect soybean development and growth at critical life stages. (M. Lal *et al.*, 1999) [11]. Increasing temperature will further offset the productivity trend in future.

**Maize:** - Maize production in arid and semi arid tropical regions is particularly sensitive to weather conditions, especially rain-fed areas. Therefore, variation in the rainfall as well as maximum and minimum temperature during the south-west and north-east monsoon period will negatively impact maize crops. According to the research conducted by Indian Agricultural Research Institute (I.A.R.I) shows maize yield during monsoon could be reduced by up to 35% in most of the Southern Plateau regions and up to 55% in Mid Indo-Gangetic Plains. High temperatures plays a greater role in affecting maize yield as compared to rainfall, which may not have a major impact on winter yields as the crops in the Gangetic belt are well irrigated.

**Vegetables and legumes**

Most vegetables are sensitive to environmental extremes, thus periodic high temperature and soil moisture stress conditions are likely to reduce yield, on average. But research also shows that higher CO<sub>2</sub> concentration could offset the negative effect of higher temperature especially in the case of leafy vegetables that would benefit from increased rates of photosynthesis

**Tomato:** Tomatoes are positively influenced by elevated CO<sub>2</sub> levels (550ppm). Plant length, number of secondary branches and leaf area increase at elevated levels of CO<sub>2</sub>, as compared to ambient levels. At elevated concentrations of CO<sub>2</sub> the fruit yield is higher.

**Conclusion**

Thus it is clear from our analysis that climatic conditions are changing over the time and this change poses substantial threat to the production of most agricultural crops in the region. Madhya Pradesh, being an agricultural state and most of its poor depend on the traditional farming practices, increases the vulnerability to climate changes. There is an urgent call for cost effective opportunities for reducing methane generation, emissions in ruminants by modification of diet and nutrient

management which will help make adaptation measures sustainable. A more sustainable agriculture which improves the asset base can lead to rural livelihood improvements. Coping with the impact of climate change on agriculture will require careful management of resources like soil, water and biodiversity. Making agriculture sustainable is key, and is possible only through production systems that make the most efficient use of environmental goods and services without damaging these assets. If climate change impacts can be incorporated in the design and implementation of development programs right away, it will help to reduce vulnerability, stabilize food production and better secure livelihoods. A large scale climate literacy program is necessary to prepare farmers, who are today bewildered by the rapid fluctuations in weather conditions that affect their agriculture. Their traditional knowledge does not help them to manage these recent anthropogenic changes.

Adaptation to climate change requires solutions that simultaneously address livelihood improvements and environmental sustainability. Proactive measures for adaptation to climate change and change can substantially reduce many of the adverse impacts, and thus contribute to livelihood security of the vulnerable rural population. While climate change will affect the nation's economy as a whole, its impact will be more severely felt by the poor who also have the least adaptive capacity. Recognizing this, the National Action Plan on Climate Change (N.A.P.C.C) clearly outlines its principle as "protecting the poor and vulnerable sections of the society through inclusive and sustainable development strategy, sensitive to climate change.

The effects of climate change on crop production are international concerns, but they are particularly significant for the sustainable agricultural development of Madhya Pradesh. This is a region of variant climatic conditions year-round due to its geographic position and physiographic status.

Historically, farming systems have adapted to changing economic conditions, technology, and resource availabilities and have kept pace with a growing population (Rosenberg, 1992)<sup>[20]</sup>. Evidence exists that agricultural innovation responds to economic incentives such as factor prices and can relocate geographically (Hyami and Ruttan, 1985). A number of studies indicate that adaptation and adjustment will be important to limit losses or to take advantage of improving climatic conditions (e.g Rosenberg, 1992)<sup>[20]</sup>. Cropping practices that maintain a more closed ground cover over longer periods-including crop rotation, planting of cover crops, and reduced or minimum tillage-combined with integrated nutrient management are quite effective in combating or reversing current land degradation and would be similarly effective where climate change had the potential to exacerbate land degradation (Rasmussen and Collins, 1991)<sup>[19]</sup>. Brinkman and Sombroek (1993)<sup>[22]</sup> found that, in most cases, changes in soils by direct human action, whether intentional or unintended, are likely to have a greater impact than climate change.

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