Working Paper 277

Climate Change, Agriculture, Poverty and Livelihoods: A Status Report

K N Ninan

Satyasiba Bedamatta

ISBN 978-81-7791-133-6

Institute for Social and Economic Change (ISEC) is engaged in interdisciplinary research in analytical and applied areas of the social sciences, encompassing diverse aspects of development. ISEC works with central, state and local governments as well as international agencies by undertaking systematic studies of resource potential, identifying factors influencing growth and examining measures for reducing poverty. The thrust areas of research include state and local economic policies, issues relating to sociological and demographic transition, environmental issues and fiscal, administrative and political decentralization and governance. It pursues fruitful contacts with other institutions and scholars devoted to social science research through collaborative research programmes, seminars, etc.

The Working Paper Series provides an opportunity for ISEC faculty, visiting fellows and PhD scholars to discuss their ideas and research work before publication and to get feedback from their peer group. Papers selected for publication in the series present empirical analyses and generally deal with wider issues of public policy at a sectoral, regional or national level. These working papers undergo review but typically do not present final research results, and constitute works in progress.

CLIMATE CHANGE, AGRICULTURE, POVERTY AND LIVELIHOODS: A STATUS REPORT

K N Ninan[1] and Satyasiba Bedamatta[2]

Abstract

This paper assesses the impact of climate change on Indian agriculture covering a cross section of crops, seasons and regions based on existing literature. The study notes that the impact of climate change will vary across crops, regions and climate change scenarios. The evidences indicate a decrease in production of crops in different parts of India with an increase in temperature. A number of studies indicate a probability of 10 % to 40% loss in crop production in India with increases in temperature by 2080-2100. In areas located above 27° N latitude yields of irrigated and rainfed wheat are projected to rise in response to climate change whereas in all other locations yields are projected to decline by -2.3% to -23.9 %. Temperature rises of between 2° C to 3.5 ° C is projected to lead to a loss of 3-26 % in net agricultural revenues. Increasing climate sensitivity of Indian agriculture will lead to greater instability of India's food production which will also impact on poverty and livelihoods. How quickly Indian farmers are able to adjust their farming practices to adapt to climate change, and what policies or technologies will enable rapid adaptation to climate change are issues that merit attention.

Introduction

Climate change will have a profound impact on human and eco-systems during the coming decades through variations in global average temperature and rainfall according to the Fourth Assessment Report (FAR) of the Intergovernmental Panel on Climate Change (IPCC). Agriculture and allied sectors are highly sensitive to climate change. It will also affect livelihoods and human well-being. Consequently, the interaction between agricultural performance and weather, which has been an important area of research since the last few decades, has gained momentum due to the awareness of the adverse effects of climate change on agriculture and livelihood. In the context of developing nations such as India, where agriculture continues to support the livelihoods of more than two-thirds of the population, a study of the nature and impact of climate change on agriculture and people's livelihoods assumes importance.

Climate Variability: Indian Context

India is a large country with 15 agro-climatic zones, diverse seasons, crops and farming systems. For a majority of the people in India, agriculture is the main source of livelihood. Agriculture is also most vulnerable to climate change because it is inherently sensitive to climate variability. Climate change will have an impact on Indian agriculture in various direct and indirect ways besides affecting the lives and livelihood of millions of Indians.

Agriculture and allied activities, such as livestock and fisheries, constitute an important component of India's Gross Domestic Product (GDP) contributing nearly 25 per cent of the GDP and

[1] Professor & Head, Centre for Ecological Economics and Natural Resources, Institute for Social and Economic Change, Bangalore – 560 072. E-mail: ninan@isec.ac.in.

[2] Assistant Professor (Temp), Centre for Ecological Economics and Natural Resources, Institute for Social and Economic Change, Bangalore – 560 072. E-mail: satyasiba@isec.ac.in

providing employment opportunities to two-thirds of the population. The South-west monsoon, which brings most of the region's precipitation dominates Indian climate and is critical for the availability of irrigation for agriculture. Agricultural productivity is sensitive to two broad classes of climate-induced effects — (1) direct effects from changes in temperature, precipitation, and carbon dioxide concentrations (2) indirect effects through changes in soil moisture and the distribution and frequency of infestation by pests and diseases.

Box-1

Opinion of Opinion Makers

Climate change may initially have small positive effects on a few rich countries in high latitudes but is likely to be very damaging when temperature increases by mid- to late-century under Business as Usual (BAU) scenarios. (Stern Review, 2007)

A wide array of adaptation options is available but more extensive adaptation than is currently occurring is required to reduce vulnerability to future climate change. There are barriers, limits and costs, but these are not fully understood. (IPCC, 2007)

The idea that developing countries like India and China must share the blame for heating up the earth and destabilising its climate, as espoused in a recent study published in the United States by the World Resources Institute in collaboration with the United Nations, is an excellent example of environmental colonialism. (Global Warming In an Unequal world, CSE, 1992)

The manner in which the global warming debate is being carried out is only sharpening and deepening the North-South divide. Given this newfound interest in the so-called Our Common Future and Future Generations, it is time for the Third World to ask the West, "Whose future generations are we seeking to protect, the Western World's or the Third World's"? (CSE, 1992)

Poverty reduction and sustainable development remain core global priorities. Yet climate change must urgently be addressed. Economic growth alone is unlikely to be fast or equitable enough to counter threats from climate change, particularly if it remains carbon-intensive and accelerates global warming. A climate-smart world is within our reach if we act now, together and differently than we have in the past. (World Development Report, 2010)

Furthermore, agriculture will be adversely affected not only by an increase or decrease in the overall amount of rainfall, but also by shifts in the timing of the rainfall. For instance, over the last few years, the Chattisgarh region 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 paddy cultivation. 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 rise in temperature by 2° C was estimated to reduce production of pearl millet by 10-15 per cent. Madhya Pradesh, where soyabean is grown on 77 per cent of all agricultural land, could ironically benefit from an increase in carbon dioxide in the atmosphere. For example, a study by Lal *et al* (1999) shows that, soyabean 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 soyabean yields could actually decrease. If the maximum and minimum temperatures go up by 1°C and 1.5°C respectively, the gain in yield comes down to 35 per cent. If maximum and minimum temperatures rise by 3°C and 3.5°C respectively, then soyabean yields will decrease. Changes in the soil, pests and weeds brought about 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, run-off and evaporation. Scientists predict that because of global warming, this already erratic 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 10 to 20 per cent in winter rainfall by the 2050s (Rupakumar *et al*, 1992).

Kavi Kumar and Parikh (1998) showed that the economic impact would be significant even after accounting for farm-level adaptation. The loss in net revenue at the farm level is estimated to be between 9 and 25 per cent for a 2^0C to 3.5^0C rise in temperature. Sanghi, Mendelsohn and Dinar (1998) also attempted to incorporate adaptation options while estimating the agricultural impact. They calculated that a 2° C rise in mean temperature and a 7 per cent increase in mean precipitation would reduce net revenues by 12.3 per cent for the entire country. 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 foodgrain 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.

Objectives

From the above discussion we see that there multiple problems are associated with climate change and agriculture would be worst affected, which in turn, will affect the livelihood of the communities depending on agriculture.

Keeping in view the above, the objectives of the study are as follows:

Broad objective:

- To analyse the implications of climate change on Indian agriculture, poverty and livelihood

Specific Objectives:

1. To review the effects of climate change on Indian agricultural across crops, seasons, and regions
2. To review the effects of climate change on irrigated and non-irrigated agriculture
3. To assess the vulnerability of the Indian agricultural sector to climate change and its impact on livelihood and poverty.

Approach

The study analyses the available secondary information and literature on climate variability and its effects on the Indian agricultural sector and the livelihood of the people. Keeping in view the diverse effects of climate change, the present study reviews the literature across geographical locations, crops and seasons.

Understanding Climate Change

The increase in economic activities and change in lifestyle patterns has caused lot of environmental damage to the earth. It is observed that 'climate change' is the most serious environmental issue that the modern world is going to face in the 21st century. The earth's climate is frequently changing and leading to degradation of biodiversity, water and soil resources, desertification, coastal erosion, decrease in agricultural productivity etc. As per the IPCC, climate change refers to any change in climate over time, either due to natural variability or as a result of human activity (IPCC 2007b). The UN Framework Convention on Climate Change (UNFCCC) refers to climate change as a change that is attributable directly or indirectly to human activity that alters the composition of the global atmosphere in addition to the natural climate variability observed over comparable periods of time (IPCC 2007b). Climate change mainly refers to a statistically significant variation in either the mean state of the climate persisting for an extended period, usually decades, or in its variability (GOI, 2008). Climate change occurs due to natural internal processes, external forces, persistent anthropogenic changes in the composition of the atmosphere or in land use (GOI, 2008). The world community faces many risks from climate change.

The concept of 'climate change' is becoming an important area of research not only in the natural sciences but also in the social sciences. The scientific evidence, including the Fourth Assessment Report (AR4) of the Inter-governmental Panel on Climate Change (IPCC) 2007, has asserted that it poses unprecedented challenges to human society and eco-systems in the 21st Century, particularly in the developing nations (i.e. global south – geographically situated at the tropical region; e.g. see McCarthy *et al.*, 2001; Parry *et al.*, 2009). The research, however, has been dominated by scientific discourse, especially by a group of climate scientists, since the early 19th Century (Box 2). It is, in general, based on the 'dose-response model and sensitivity analyses', and thereby focused on potential physical impact with respect to the spatio-temporal scale. Despite these noteworthy efforts in the scientific discourse, it is still not able to justify the issues related to climate policy. For example, what should be done to mitigate it? Whether to mitigate it or adapt? What is the trade-off between both with respect to economic and environmental sustainability? More importantly, the persistent 'uncertainty' over the emission of greenhouse gases (GHGs), the sinking capacity of the oceans, waste lands, forests, melting of ice in Greenland and the Himalayas (though there is a protracted debate over this) and the physical impact have restrained the scientific communities and policy makers from taking decisions in this context (Goulder and Pizer, 2006). Furthermore, since most of the dominant scientific predictions are macro perspectives (e.g. global as well as region-specific) and considering climate change as the only stress on society, it seems very difficult for a small nation, especially local stakeholders, to tackle a wide range of risks including that of climate change.

The impact of climate change will persist. It is estimated that climate change will affect the basic elements of life around the world like access to water, food production, healthcare and the environment. Millions of people could suffer from hunger, water shortage and coastal flooding, as the world gets warmer. The overall costs and risks of climate change are expected to be equivalent to losing at least 5 per cent of global GDP each year, if we do not act now. If a wider range of risks is taken into account, the estimated damage could rise to 20 per cent of GDP or more (Stern, 2007). There are certain regions, sectors, ecosystems and social groups, which will be, affected the most by climate change and the consequences of economic globalisation. Managing the impact of climate change, therefore, poses a challenge to governments and societies.

Kavi Kumar (2007) provides an overview of the available evidence of climate change on Indian agriculture covering impact, vulnerability and adaptation assessments. Kumar and Parikh (2001a) used an integrated modeling framework to assess the socio-economic impact of climate change on Indian agriculture. The changes in crop yield under various climate-change scenarios are incorporated into an applied general equilibrium model of the Indian economy to assess the effect on welfare. Kumar and Parikh (2001b) estimated the relationship between farm level net revenue and climate variables in India using district level data. The study also explores the influence of annual weather and crop prices on the climate response function.

Sathaye *et al.*, (2006) argue that from the perspective of a developing country like India, a sustainable development agenda will be the prudent way to address the concerns over climate change. Aggarwal (1990) analyses the coping capacity of the rural people, especially women, to the seasonal downturns in the agricultural production cycle and calamities such as drought and famine. It also discusses the effectiveness of the coping mechanisms adopted, the intra-household sharing of the burden of coping and the appropriate state and non-state interventions to strengthen the survival mechanisms adopted by the families.

Global warming and climate change are often interchangeably used and understood. However, these terms are not identical. Climate change includes both warming and cooling conditions while global warming pertains only to climatic changes related to increase in temperature (Grover, 2004). The climatic system is a complex interactive system consisting of the atmosphere, land surface, snow and ice, oceans and other bodies of water and living things. The atmospheric component of the climatic system most obviously characterises climate. It is often defined as ‘average weather’. Climate is usually described in terms of the mean and variability of temperature, precipitation and wind over a period of time ranging from months to millions of years (IPCC, 2007a).

Box-2

Scientific Discourse

In the early 19th Century, the French mathematician Jean Baptiste Fourier (1827) floated the theory of the 'hothouse effect' of climate regulation by establishing atmosphere as a key determinant of global temperature (Spash, 2002: 12). John Tyndall (1861) and Svante Arrhenius (1896) – founder of the 'greenhouse effect' – made an attempt to take forward the research on climate change with their corresponding observations: CO_2 and water are radiative absorbers affecting climate and double the CO_2 leads to increase in the temperature by 5 to 6 degree Celsius (Cited in Spash, 2002: 12). In the early 20th Century, G S Callendar (1938) solved a set of equations linked to GHGs and climate change. He observed that the doubling of atmospheric concentration of CO_2 resulted in an increase of the mean global temperature by 2 degree Celsius with considerably more warming at the poles (c.f. Le Treut *et al.*, 2007: 105). Furthermore, in the latter half of the 20th Century, a substantial number of research institutes – especially in the US and EU and particularly with the initiation of the IPCC in 1988 (i.e. under the auspices of WMO and UNEP) – emerged in order to understand the scientific roots of climate change. Substantial scientific literature exists but the science is uncertain with regard to the prediction of the emission of GHGs and observation on the physical impact not only in macro but also in the micro-perspective, which confuses scientists as well as policy makers regarding response strategy to be adopted in future.

The atmosphere surrounding the earth is made up of nitrogen (78%), oxygen (21%) and the rest is made up of trace gases (so called because they are present in very small quantities) that include carbon dioxide, methane and nitrous oxide. These gases, also called greenhouse gases, act as a blanket, trap heat radiating from the earth and make the atmosphere warm. Beginning with the industrial revolution and natural causes the global atmospheric concentrations of these greenhouse gases have increased. The global increases in the concentration of carbon dioxide are due primarily to the use of fossil fuel and changes in land-use while those of methane and nitrous oxide are primarily due to agriculture. As a result, we are witnessing global warming.

The increasing GHGs resulted in global warming by 0.74°C over the past 100 years and 11 of the 12 warmest years were recorded between 1995 and 2006 (IPCC, 2007b). The IPCC projections on temperature predict an increase of 1.8 to 4.0°C by the end of this century (IPCC, 2007b). Some changes will have an impact on agriculture by affecting crops, soil, livestock, fisheries and pests directly and indirectly. Tropical countries are likely to be affected more than the countries in the temperate regions. The brunt of environmental changes on India is expected to be very high due to greater dependence on agriculture, limited natural resources, alarming increase in human and livestock population, changing patterns in land use and socio-economic factors that pose a great threat in meeting the growing food, fibre, fuel and fodder requirements. Global warming due to the greenhouse effect is expected to affect the hydrological cycle viz., precipitation, evapo-transpiration, soil moisture etc., which will pose new challenges for agriculture.

Global Scenario of Climate Change

1. Current Scenario

The global atmospheric concentration of carbon dioxide, a GHG largely responsible for global warming, increased from the pre-industrial value of about 280 ppm (particles per million) to 379 ppm in 2005. Similarly, the global atmospheric concentration of methane, nitrous oxides and other GHGs has also increased considerably. The increase in GHGs was 70 per cent between 1970 and 2004. Eleven of the last twelve years rank as the 12 warmest years since 1850. The mean temperature of the earth changed by 0.74°C between 1906 and 2005. Most of the observed increase in global average temperatures since the mid-20th century has been due to the observed increase in anthropogenic concentrations of GHGs. During the last 50 years, cold days and nights, and frost have become less frequent, while hot days and nights, and heat waves have become more frequent. The frequency of heavy precipitation events has increased over most land areas. Global sea level rose at an average rate of 1.8 mm per year between 1961 and 2003. This rate was faster between 1993 and 2003 about 3.1 mm per year. Mendelsohn and Dinar (1999) focused on the impact of climate change on the agricultural sector in developing nations such as India and Brazil. This study compared and contrasted results using three broad approaches: agronomic, agro-economic and Ricardian models.

2. Future Projections

The projected temperature increase by the end of this century is likely to be in the range of 2 to 4.5°C with a best estimate of about 3°C and is very unlikely to be less than 1.5°C. Values substantially higher than 4.5°C cannot be excluded. It is likely that future tropical cyclones will become more intense with larger peak wind speeds and heavier precipitation. For the next two decades, a 0.2°C increase in warming per decade is projected. Even if all emissions were stopped now, a further warming of about 0.1°C per decade would be expected. Himalayan glaciers and snow covers are projected to contract. It is very likely that hot extremes, heat waves and heavy precipitation events will continue to become more frequent. Increase in precipitation is very likely in high-latitudes while decrease is likely in most subtropical land regions going by recent trends. The projected rise in sea level by the end of this century is likely to be 0.18 to 0.59 meters. The average global surface ocean pH is projected to reduce between 0.14 and 0.35 units during the 21st Century.

Indian Scenario of Climate Change

1. Current Scenario

Analyses done by the Indian Meteorology Department and the Indian Institute of Tropical Meteorology, Pune, generally show temperature, heat waves, droughts and floods, and sea level increasing while glaciers decrease. It is similar to indications of the Intergovernmental Panel on Climate Change (IPCC) of the United Nations. The magnitude of the change varies in some cases. Across India, no trend was observed in monsoon rainfall during the last 100 years. However, some regional patterns were noted. Areas along the West coast, North Andhra Pradesh and North-west India reported an increase in monsoon rainfall. Some places across east Madhya Pradesh and adjoining areas, North-east India and parts of Gujarat and Kerala (-6 to -8% of normal over 100 years) recorded a decreasing trend. Surface air temperature for the period 1901 – 2000 indicates a significant warming of 0.4°C over 100 years. The spatial distribution of changes in temperature indicated a significant warming trend along the West coast, Central India, interior Peninsula and Northeast India. However, a cooling trend was observed in the northwest and some parts of Southern India. Instrumental records over the past 130 years do not show any significant long-term trend in the frequency of large-scale droughts or floods in the summer monsoon season. The total frequency of cyclonic storms that form over the Bay of Bengal has remained almost constant over the period 1887 – 1997. There is evidence that the glaciers in the Himalayas are receding at a rapid pace.

2. Future Projections

It is projected that by the end of the 21st Century rainfall will increase by 15 – 31 per cent and the mean annual temperature will increase by 3° C to 6° C. The warming is more pronounced over land areas, with the maximum increase in Northern India. The warming is also projected to be relatively greater in the winter and post-monsoon seasons. The present study extensively reviewed the projections for the future and the impact of climate change on India's agriculture.

Impacts of Climate Change on Agriculture

- Although an increase in carbon dioxide is likely to be beneficial to several crops, associated increase in temperature and increased variability in rainfall would considerably affect food production. The recent IPCC report (IPCC 2007) and a few other global studies (Cf: Parry *et al*, 1994; Dinar *et al*, 1998) indicate a probability of 10 to 40% loss in crop production in India with increase in temperature by 2080 – 2100.
- A few Indian studies on this theme generally confirm an agricultural decline with climate change (Cf: Aggarwal and Kalra, 1994; Dinar *et al*, 1998; Kavi Kumar and Parikh, 2001a, 2001b: Kavi Kumar 2009). Recent studies done at the Indian Agricultural Research Institute indicate the possibility of a loss of 4 to 5 million tons in wheat production in future with every 1^{o}C rise in temperature during the growing period (but no adaptation benefits) (Kalra *et al*, 2007). It also assumes that irrigation would be available in future at today's levels. Losses for other crops are still uncertain but they are expected to be relatively smaller, especially for *kharif* crops.
- It is, however, possible for farmers and other stakeholders to adapt to a limited extent and reduce the losses (possible adaptation options are described later in this document). Simple adaptations such as change in planting dates and crop varieties could help reduce the adverse effects of climate change to some extent. For example, the Indian Agricultural Research Institute study cited above indicates that loss in wheat production in future could be reduced from 4 – 5 million tons to 1 – 2 million tons if farmers adopted timely planting habits and changed to better adapted wheat varieties. This change of planting, however, would have to be examined from the cropping systems perspective.
- Increasing climatic variability associated with global warming, nevertheless, will result in considerable seasonal/annual fluctuations in food production (Mall *et al*, 2006). All agricultural

commodities even today are sensitive to such variability. Droughts, floods, tropical cyclones, heavy precipitation events, hot extremes and heat waves are known to impact agricultural production and farmers' livelihood negatively. The projected increase in these events will result in greater instability in food production and threaten the livelihood of the farmers.

- Increasing glacier melt in the Himalayas will affect availability of irrigation especially in the Indo-Gangetic plains, which, in turn, has large consequences on our food production.
- Global warming in the short-term is likely to favour agricultural production in the temperate regions (largely northern Europe, North America) and negatively impact crop production in tropical areas (South Asia, Africa). This will affect food prices and trade and, consequently, our food security.
- Small changes in temperature and rainfall could have a significant effect on the quality of cereals, fruits, aromatic and medicinal plants and result in changes in prices and trade patterns.
- Pathogens and insect populations are strongly dependent upon temperature and humidity. Increases in these parametres will change their population density resulting in loss in yield.
- Global warming could increase water, shelter and energy requirements of livestock to meet the projected increase in demand for milk. Climate change is likely to aggravate the heat stress in dairy animals and adversely affect their productive and reproductive capabilities. A preliminary estimate indicates that global warming is likely to lead to a loss of 1.6 million tonnes in milk production in India by 2020.
- Increasing sea and river water temperature is likely to affect fish breeding, migration and harvest. A rise in temperature as low as 1°C could have an important and rapid effect on the mortality rate and the geographical distribution of fish. The oil sardine fishery did not exist before 1976 in the northern latitudes and along the east coast as the resource was not available since the sea surface temperature (SST) was not congenial for it. With warming of sea surface, oil sardine is able to find the temperature in the northern latitudes and eastern longitudes suitable for survival and breeding, thereby extending the boundaries to larger coastal areas.

In India, various studies observed an increasing trend in temperature (Table 1). Table 1 gives the detail of studies that reveal that there is no significant trend in rainfall across India. However, some studies note regional variations in rainfall (Rupa Kumar *et al,* 1992; Kripalani *et al,* 1996; Singh *et al,* 2001 etc).

Table 1: Observed Climate Change during the 20th Century in India

Region	Study	Temperature	Rainfall
All India	Hingane *et al.*, 1985	Increase in 0.4^0 C/100 years in the mean annual temp.	-
All India	Rupa Kumar *et al.*, 1994	Increase in Max. temp. (0.60 C/100 years Min. temp. trend less. General increase in the diurnal range of temp	-
Western Himalayas	Pant *et al.*, 1999	Winter season, Srinagar, Mussoorie and Mukteswar show increasing trend (0.5^0 C/100 yrs) Monsoon season, Srinagar, which is beyond the monsoon regime, shows significant increasing trend, whereas Mussoorie and Dehradun at the foothills of Himalaya show decreasing trend	No increasing or decreasing trend for last 100 yrs
Indo-Gangetic Plain Region (IGPR)	Singh and Sontakke, 2002	Annual surface air temperature of the IGPR showed rising trend (0.53^0 C/100 yrs, during 1875-1958) Decreasing trend (-0.93^0 C/100 yrs during 1958-1997)	Summer monsoon rainfall over western IGPR shows increasing trend (170 mm/100 yrs) from 1900 while over Central IGPR it shows decreasing trend (5 mm/100 yrs) from 1939 and over eastern IGPR (50 mm/100 yrs) during 1900-1984 and increasing trend (480 mm/100 yrs) during 1984-1999. Westward shift in rainfall activities over the IGPR
All India	Mooley and Parthasarathy 1984; Thapliyal and Kulshrestha, 1991		Monsoon rainfall is trend-less and is mainly random in nature over a long period
NE Peninsula, NE India, NW Peninsula, West coast and Central peninsula	Rupa Kumar *et al.*, 1992		NE peninsula, NE India and NW peninsula show decreasing trend in the Indian summer monsoon rainfall (-6 to 8 % of normal/100 yrs) while increasing trend was noticed along the west coast and over central

			peninsula (+10 to 12 % of normal/100 yrs)
Western and Eastern Himalayas	Kripalani *et al*., 1996		Western Himalayas get more snowfall than the Eastern Himalayas during winter. More rainfall in the Eastern Himalayas than in the Western Himalayas during the monsoon season
Rajasthan Desert	Pant and Hingne, 1998 (cited in Mall *et al*., 2006)		Slight increase in monsoon rainfall; in spite of large inter annual variation
Luni River basin (Arid West Rajasthan	Singh *et al*., 2001	Rising trend at Barmer, Jodhpur, Ajmer and Pali Decreasing trend at Udaipur and Jwaibandh	Annual rainfall indicates increasing tendency at 19 stations (around Ajmer in upper part of the Luni basin Decreasing trend at the remaining 9 stations in lower Luni basin (Barmer)

Source: Mall *et al*. (2007)

Table 2 gives the details of the studies on projected climate changes over India during the later part of the 21st Century. Most of the studies suggest changing pattern in rainfall and an increase in temperature during the different crop seasons or on annual basis.

Table 2: Projected Climate Variation Scenarios in India

Author/Study Indian Context	Temperature	CO_2	Precipitation/ Monsoon	Specificity/Effect
co2now.org Aug 2009		**398.42** ppm Jun 2009		Original data file created by NOAA on Wed. June 10, 2009 (10:30:02)
IPCC, 2001	**1.4^0-3^0** C (LES) **2.5^0-5.8^0** C (HES)			1990 levels by 2100
Bhaskaran 1995	**1-4^0** C in winter/*Rabi* crop season	**Increase** in CO_2	**20%** increase	Predicted more heavy rainfall days during summer monsoon or Kharif period and increased inter-annual variability
Lonergan 1998 (in IPCC)	**2.33^0** C- **4.78^0** C	**Doubling** of CO_2	Increase in the frequency of heavy rainfall	India's climate could become warmer under condition of atmospheric CO_2

Lal *et. al*. 1995	Increase in annual mean Max. and Min. surface air temperatures of **0.7^0** and **1.0^0** C over land		Will decline	In the 2040s with respect to the 1980s
Lal *et. al*. 2001	Projected between **$1\text{-}1.4^0$** C and **$2.23\text{-}2.87^0$** C area-averaged annual mean warming by 2020-50	Increase to **397-416** ppm by 2010s and to **605-755 ppm** by 2070,		In 2001, CO_2 was 371 ppm Extreme rainfall events in a warmer atmosphere
Rupa Kumar and Asriti 2001	**1.3^0** C-**1.7^0** C increase		Increase of 13 %	
Rupa Kumar, 2002	Increase		Enhanced rainfall towards 2050	GHG increase scenario Decrease in rainfall in J and K, HP, Bihar, Gujarat and Rajasthan
May, 2002			Intensification of rainfall	Due to intensification of the atmospheric moisture
Stephenson *et al.,* 2001			Weakening of the large scale aspect of the Indian summer monsoon	
Rupa Kumar *et al.,* 2003	-Increase more after 1940s -South of 25^0 N (cities like Udaipur, Khajuraho and Varanasi) max. temperature will increase by **$2\text{-}4^0$** during 2050 -In Northern region the increase in Max. temp. by more than 4^0 C - India min. temperature up to **4^0** C		Increase more after 1940s	Temp. more than **4^0** C in southern peninsula, northeast India, and some parts of Punjab, Haryana and Bihar - overall decrease in rainy days - western and central India >15 days - north-east, Himalaya region, 5-10 days increase

LES- Lower Emission Scenario; HES- Higher Emission Scenario.

Source: Various Studies cited in the table.

Most of the simulation studies have explained a decrease in duration and production of crops as temperature increased in different parts of India (Table 3). However, such reduction was generally offset by rise in CO_2. The magnitude of these varied across crops, regions and climate changes.

Table 3: Vulnerability of Crop Production

Author/Study Indian Context	Crops/ Regions	Temperature Scenario	CO_2 Scenario	Specificity
Saini and Nanda, 1986	Wheat	With every **1⁰** C increase in mean temperature above 17-17.7⁰ during the terminal spikelet initiation to anthesis		**Decline** of 600-650 grains m^{-2}
Sinha and Swaminathan, 1991	Rice Wheat Northern India and coastal regions	Tested With **0.5-2⁰** C increase in temperature		-a **2⁰** C increase in mean temperature could **decrease** rice yield by about 0.75 ton/ha in high yield areas and 0.06 ton/ha in the low yield coastal regions -a 0.5⁰ C increase in winter temperature would **reduce** wheat crop duration by seven days and reduce yield by 0.45 ton/ha, and 10% **reduction** in wheat production in the high yield states of Northern India
Achanta, 1993	Rice- irrigated yield -Uttarakhand	With **increased** temperature	With **Doubled** CO_2	Pantnagar-Uttarakhand-rice production would be **positive** in the absence of nutrient and water limitation
Aggarwal and Sinha, 1993	Wheat at three levels of production (potential, irrigated and rain fed) - Northern India	Tested no rise in temperature to **2⁰** C temp. rise	**425 ppm**	Wheat yield at all three levels of production (potential, irrigated and rain fed) **increased** significantly -Northern India, a **1⁰** C rise in mean temperature had no significant effect on potential yield but irrigated and rainfed yields **increased** in most places -an increase of **2⁰** C, **reduces** potential wheat yields at most places -the effect on irrigated and rainfed productivity **varied** with location -Evapotranspiration reduced in irrigated as well as rainfed environments
Gangadhar Rao and Sinha, 1994	Wheat	Increase		Wheat yield **decreased** due to the **adverse effect of temperature** during filling and maturity stages of the growth
Aggarwal and Kalra, 1994	Wheat at three levels (potential, irrigated and rainfed) - Northern India, Central India, High latitudes, lower latitude, tropical, sub-tropical	Temperature of **0, 1** and **2⁰** C assumed	**425 ppm CO_2** assumed	-at **425** ppm CO_2 and no rise in temperature, grain yield at all levels of production **increased significantly** at all places -**1⁰** C rise in mean temperature, **no significant effect** on potential yields, Irrigated yields **increased** in most places where current yields were greater than 3.5 t/ha. **Significant** Rainfed yields -**2⁰** C rise, **reduced** potential yield at most places. **Less magnitude** at places with low potential productivity -**sub-tropical** region (above 23⁰ N), **decrease** of 1.5 to 5.8%) but in **tropical** locations the **decrease** was 17-18% -**High latitudes** (above 27⁰ N)-slightly increased -**lower latitude**-High decreased -**No significant effect** of climate change in Northern India but yields were **reduced** in **Central** India by 10-15%

Gangadhar Rao *et al.*, 1995	Sorghum (Jowar) in three diverse Sorghum growing regions, i.e., Hyderabad, Akola and Solapur	Used 3 scenario of climate change	Rise of CO_2	In Hyderabad and Akola, yield **declined** in rainy season Sorghum -post rainy season sorghum at Solapur on stored soil water showed a marginal **increase** in yield -the positive effects of CO_2 were **neutralised** by adverse effects of increase in temperature resulting in shortened crop growing season -the study analyses the effects of climate change depending upon the **season** in which it is grown
Mohandass *et al.*, 1995	Rice	High temperature	increased CO_2	-predicted **increase** in rice production under the GCM (Global Circulation Model) scenario -this is due to increase in yield of **main season** crops where the fertilizing effect of the increased CO_2 is able to compensate the crop for any detrimental effects of increased temperature -however large decreases were predicted for **second season** crops due to high temperature but overall impact on rice production is **low** as relatively low proportion of total rice produced in this season
Uprety *et al.*, 1996	Brassica crop (an oilseed crop), in the Northern belt of the Indian subcontinent	Variation in temperature	Variation in CO_2	The production of **Brassica** crop is likely to **increase** and is likely to **extend** to some more relatively **drier regions** than where it is grown presently.
Hundal and Kaur, 1996	Wheat, rice, maize and groundnut in Punjab using crop simulation model	Assumed temperature increase of 1, 2 and 3^0 C from present day condition, keeping all other climate variables constant	increased CO_2	**Reduce** grain yield of studied crops (increase of **1, 2 and 3^0 C**) -**Wheat**: **reduction** by 8.1, 18.7 and 25.7% respectively -**Rice**: **reduction** by 5.4, 7.4 and 25.1% respectively -**Maize**: **reduction** by 10.4, 14.6 and 21.4 respectively -**Groundnut** seed yield: **reduction** by 8.7, 23.2 and 36.2% respectively -the result suggests increase in temperature and decrease in radiation level have negative impacts on growth and yield of cereals and oil seeds crop. The study also mentioned that **increased CO_2** will favour growth and **increase crop production**, hence, **minimizing the adverse effects** of temperature rise in future
Lal *et. al.*, 1998	Vulnerability of wheat and rice crops -Northwest India -through sensitivity experiments	Rise in 2-3^0 C temperature	Rise in CO_2	-Northwest India -**Doubling CO_2**: Rice and Wheat- yield of rice and wheat **increased** significantly (15% and 28% respectively) -however 3^0 C temp. for wheat and 2^0 C temp. for rice **cancelled out the positive effects** of increased CO_2
Auffhammer *et al.*, 2006	Rice, India		Atmospheric Brown clouds (ABC)	Impact: 3.94% during 1966-84 and 10.6% during 1985-98 Reduction of ABC and GHG, increase in rice-6.18% and 14.4%
Chatterjee, 1998	Sorghum	Rise in 1 to 2^0 C temperature	Assumed 50 ppm to 700 ppm CO_2	Observed **increased** temperature would **decrease** the Sorghum yields in present day condition -increase in temperature by 1 and 2^0 C, **Sorghum** yields **decrease** by 7 to

				12% -further temp. increase, drastically reduced the yields by 18 to 24% -there is **no large interaction** effect between yearly **climatic variation** and **increase in temperature** as the decline of production was proportional to the increase in temperature in most years. -increase in 50 ppm CO_2—only 0.5% increase in yield, but **this was nullified** when the temp. increased only by 0.08^0 C. -the beneficial effect of 700 ppm CO_2 was nullified by an **increase of only 0.9^0 C temp**.
Mandal, 1998	Chickpea Pigeonpea	Up to 2^0 C increase	- the study tested 350-700 ppm CO_2	**Chickpea** Observed temp. increase of up to 2^0 C did not influence potential yield of chickpea. Pre-anthesis and total crop duration reduced by 10-12 days with 2^0 C rise of temp. -**irrigated** yield **increased** with temp. rise up to 2^0 C -crop duration reduced by only 4 days - Nitrogen uptake and total water use (as evapo-transpiration) were not significantly different up to 2^0 C temp - **rainfed** crop yield was much **lower** but the effect of temperature rise on crop growth processes and yield were same as observed in irrigated crop -**increase in CO_2**-increased yield under potential, irrigated and rainfed conditions - the study tested 350-700 ppm CO_2 and found increase in production in three levels **Pigeonpea** 1^0 C increase in temp has **great impact** on Pigeonpea production
Lal *et. al.*, 1999	Soybean Central India	3^0 C temperature 10% decline in rainfall	Doubling of CO_2	Doubling of CO_2 will lead to 50% **increase** in Soybean yield in **central India** while 3^0 C temp almost **wipes out the positive** effect of doubling of CO_2 by reducing the duration of crop and inducing **early flowering** and **shortening the grain fill** period -decline in daily rainfall amount by 10% **restricts** the grain yield to about 32% -therefore, in future, in spite of elevated CO_2, acute **water shortage** due to **dry spell** in monsoon could be a **critical** factor for the Soybean productivity

Sahoo, 1999	Maize Irrigated and rainfed	Temperature rise of up to 4^0 C	CO_2 350 to 700 ppm	Rise in temperature **decreased the maize yield** in both **irrigated** and **rainfed** conditions -CO_2 350 ppm, yield decrease continuously with temp. rise till 4^0 C where the yield decreased by about 30% over the present day condition -at CO_2 700 ppm, maize yield **increase** by about 9% over the present day condition **but rise in temp. decreases the yield** (8% yield decrease per rise of 1^0 C in temp -The **effect** of elevated CO_2 is lower in the case of Maize as compared to wheat, chickpea and mustard crop -the beneficial effect of 700 ppm CO_2 was **cancelled out** by rise of only 0.6^0 C temp. -**IPCC** scenario, (rise of 1.8^0C temp for India and 425 ppm CO_2 by the year 2030), potential maize yield would be severely affected by about 18%
Saseenddran *et. al*., 2000	Rice Kerala Sensitivity experiment	Up to 5^0 C temperature rise	CO_2 425 ppm	Rise in CO_2 leads to **increase in rice** production in **Kerala** due to fertilisation effect and also enhances water use efficiency -tested up to 5^0 C temp, there is a **continuous decline** in rice yield -for 1^0 C temp increase there is decline in production of about 6% -in another experiment it was noticed that the physiological effect of ambient CO_2 at 425 ppm **compensated for the yield losses due to increase in temperature** up to 2^0 C
Kumar and Parikh, 2001	Farm level net revenue	2^0 C temperature and 7% increase in precipitation		To understand the climatic sensitivity of Indian agriculture, the study estimated the functional relationship between farm level net revenue and climate variable -Increase in 2^0 C temp. and 7% increase in precipitation are **negative** and about 8.4% of the **total farm level net-revenue** for India -Northern State like **Haryana**, **Punjab**, Western **UP** where wheat is dominant crop in winter experience most **negative** effects along with coastal districts of **Tamil Nadu** -However, the Eastern district of **West Bengal** and part of **Bihar** seem to **benefit** from the changes in future

Rathore *et. al*. 2001	Rice Central, South and Northwest India	Tested climate change scenarios projected by Lal et. al. 1995 (surface air temperatures of **0.7^0** and **1.0^0** C over land)		-middle of the 21st Century in central and **south** India, **rice** production will **increase** -under climate change, **Northwest rice** production would **decrease** significantly under irrigated condition as a result of **decrease in rainfall** during monsoon season -**reduction** in crop duration may occur at all location in India due to **increase in temp.** associated with the build-up of **GHGs** in the atmosphere
Aggarwal and Mall, 2002	Rice Northern, Southern, Western and Eastern India -Current level of management (150 Kg) N/ha-3 doses and frequent Irrigation	Changes in Temperature 1-4^0 C rise	Changes in CO_2 450 ppm	**without increase in CO_2** and Rise in temperature of 1-2^0 C and, showed a decrease of 3-17 % in rice production in different regions -**Extent of effect of temp rise on Rice production:** Eastern and Western: Less affected Northern: Moderate Southern: Severely affected **With CO_2 increase:** production increased in all regions **Doubling CO_2**: 12-21 % **increase** in production in different regions -Beneficial effect of **450 ppm CO_2 was nullified** by an increase of 1.9-2^0 C in Northern and eastern regions and by 0.9-1^0 C in Southern and Western regions -**Increase of 1-4^0 temp without increase in CO_2:** 5-30 % **decrease** in grain yield in different regions -a 28-35 % **increase** in yields of rice as CO_2 doubled -The beneficial effect of 450 ppm CO_2 was nullified by an increase of 1.2-1.7^0 C in Northern and Eastern regions and by 0.9-1^0 C in Southern and Western regions

Source: Various Studies cited in the table.

Climate Change Projections for India

In the literature, climate change projection has generally been done using the average of prediction of six General Circulation Models including HadCM3, CSIRO-Mk2, CGCM2, GFDL-R30, CCSR/NIES and ECHAM4/OPYC3 (Cline 2007).

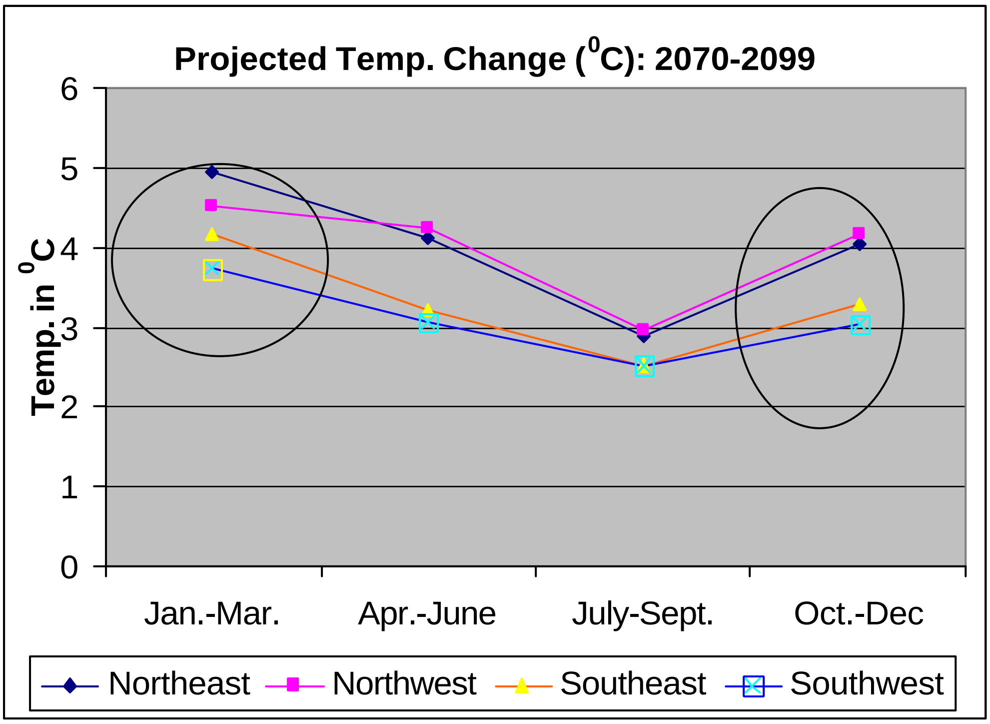
Table 4 gives the detail of temperature and precipitation changes across various regions and seasons for the period of 2070-2099 with reference to the base period 1960-1990. Figures 1 and 2 give the trends of temperature change and rainfall changes across four regions of India over the period 2070-2099.

Table 4: Projected Changes in Climate in India: 2070-2099

	Region	Jan.-Mar.	Apr.-June	July-Sept.	Oct.-Dec
Temp. Change (^{0}C)	Northeast	4.95	4.11	2.88	4.05
	Northwest	4.53	4.25	2.96	4.16
	Southeast	4.16	3.21	2.53	3.29
	Southwest	3.74	3.07	2.52	3.04
Preci. Change (%)	Northeast	-9.30	20.30	21.00	7.50
	Northwest	7.20	7.10	27.20	57.00
	Southeast	-32.90	29.70	10.90	0.70
	Southwest	22.30	32.30	8.80	8.50

Source: Cline (2007), cited in Kavi Kumar (2009)

Figure 1: Projected Temperature Change in India (^{0}C): 2070-2099

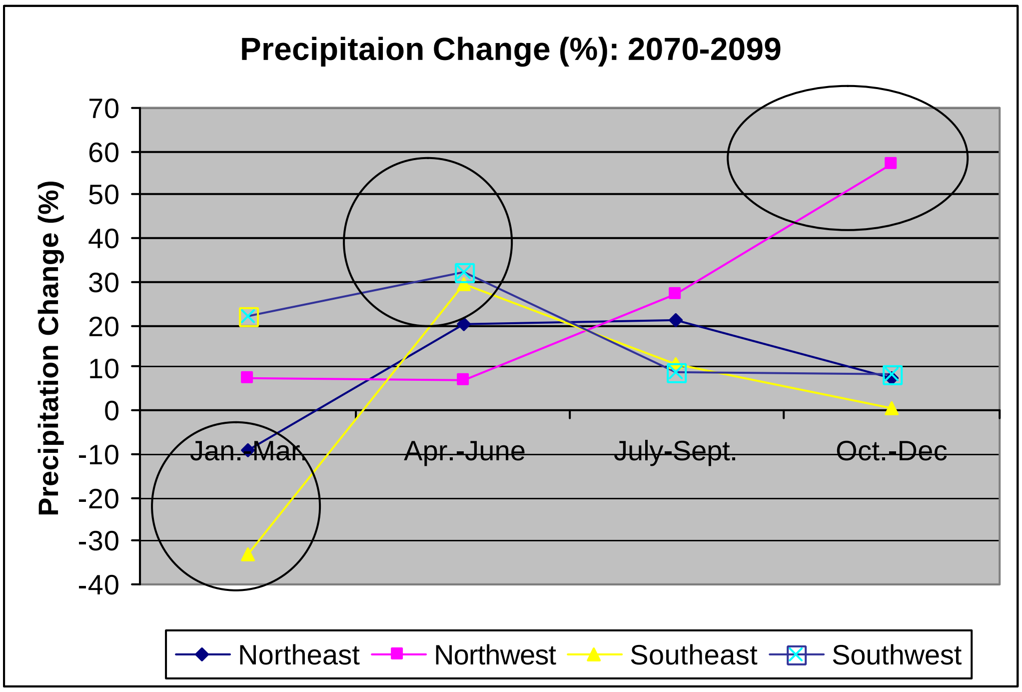


Source: Based on data in: Cline (2007)

It can be observed from Figure 1 that temperature increased (4 to 5^0 C) during January-March across all regions. As far as October-December months are concerned, the temperature also increased (3-4^0 C) across India. The figure also suggests that there are variations in increase in temperature across the regions. Northeast and Northwest temperature will be higher than the other regions though seasonal variability has been predicted. The projected results suggest that in all four regions of India the temperature is going to increase from more than 2^0 to 5^0 C over the years. The precipitation projection indicates wide variations across the regions over the years.

Figure 2 presents the details of the predicted precipitation changes across the regions of India. From figure 2, it is observable that the rate of precipitation will vary significantly from 2070 to 2099. The Southeastern regions of India will have more than -32 per cent decline in precipitation from January to March over the same years. The above figure suggests that during October-December the precipitation is projected to increase in the Northwestern regions of India in 2070-2099 (increase of 57 per cent of average).

Figure 2: Projected Precipitation Change in India (^{0}C): 2070-2099



Source: Based on data in: Cline (2007)

Kumar (2009) estimated the net revenue change due to changes in climate variables (Table 5). The study estimated the impact for each period at the district level and then aggregated to derive the impact at the national level. In the paper three scenarios were used, namely, (1) increase of 2^{0} C of temperature and increase of 7 per cent precipitation (2) increase of 3.5^{0} C of temperature and increase of 14 per cent precipitation and (3) India specific scenario adopted from Cline (2007). The table indicates the all India level of estimation of impacts in each time period as a percentage of 1990 all India net revenue expressed in 1999-2000 prices. It can be observed that in each time period the percentage of net revenue loss has increased (See table 5 and figure 3). The worst result has been observed over the years in the second and third scenarios (over 85 % and 61 % of revenue loss respectively). This finding necessitates further probing to understand the impact of future climate change on India as the agricultural sector is extremely sensitive to climate variability. Kumar (2009) suggests this increasing effect of climate change on agriculture in spite of the possible advances made through technology and overall development of the country. Table 5 also indicates higher impact during the period from the mid-1980s to the late 1990s. During these periods, the overall production of agriculture has been weakening. The India-specific scenario gives a different picture of the impact of climate change, e.g., during 1971-85 the negative impact declined and it increased during 1986-99.

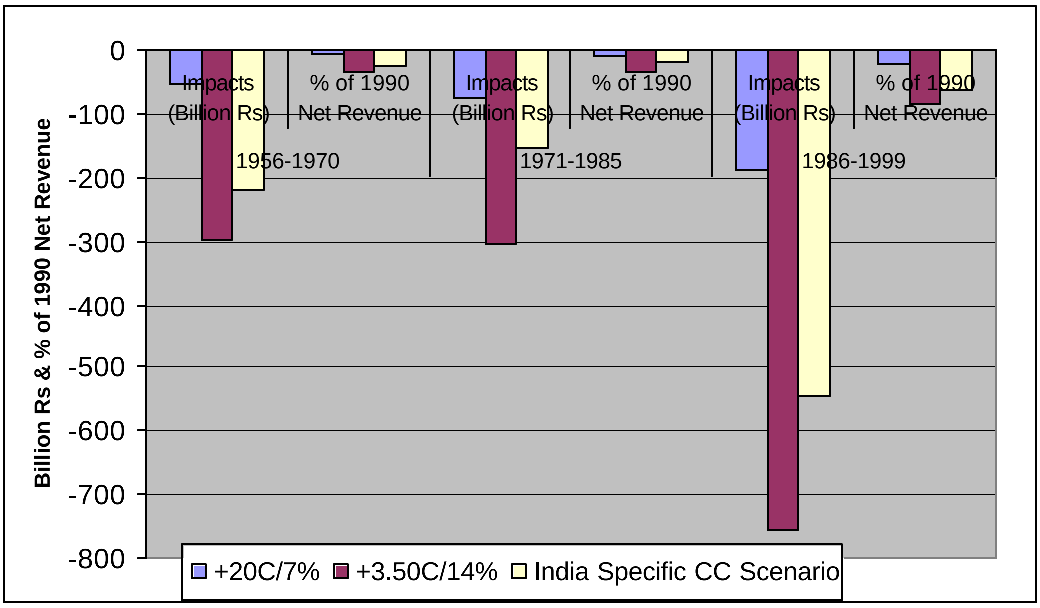
Table 5: Climate Change Impacts Over Time

Scenario	1956-1970		1971-1985		1986-1999	
	Impacts (Billion Rs)	% of 1990 Net Revenue	Impacts (Billion Rs)	% of 1990 Net Revenue	Impacts (Billion Rs)	% of 1990 Net Revenue
$+2^0C/7\%$	-53.70	-6.1	-76.8	-8.7	-188.7	-21.3
$+3.5^0C/14\%$	-297.4	-33.6	-303.4	-34.3	-754.9	-85.3
India Specific CC Scenario	-219.6	-24.8	-153.6	-17.4	-544.4	-61.5

Note: Prices-1999-2000; Net Revenue in India in 1990 was Rs 885 Billion (1990-2000 prices). The first two scenario use hypothetical increase in temperature and precipitation

Source: Kavi Kumar (2009)

Figure 3: Impact of Climate Change on Revenue



Source: Kavi Kumar (2009)

Table 6 gives the details of implications of climate change on India's agricultural sectors covering a cross section of regions. Kumar (2009) suggested that the loss would be over Rs 80 to 195 billion. Kumar and Parikh (1997) found that farm level net revenue would decline by 9 to 25 per cent. Sanghi *et al* (1998) suggested that agricultural net revenue would fall by 12.3 per cent.

Table 6: Climate Change Implications on India's Agricultural Sector

Sector / Parameter	Assumptions	Impact	Source	Region
Aggregate Agriculture	+2^{0}C/ 7% India specific scenario	Decline of Rs. -81.2 to -195.1 billion	Kumar (2009)	India
Aggregate Agriculture	Temperature Rise from 2.7 ^{0}C to 5.4 ^{0}C; Cross Section data used; and Local adaptation included	Loss up to US $ 87 billion	Mendelsohn (2005)	India
Rice and wheat yield	A2, B2 scenario	Decline in yields	Sharma, Roy, Kumar *et al.* (2003)	India
Yields of Soyabean	Increase in temperature. By 2-4 ^{0}C; ± 20% to ± 40 % change	Decline in yield by 18% - 22%	Lal *et al.*, (1998)	India
GDP		Drop of 1.8% -3.4% om GDP	Kumar and Parikh (1998)	India
Agricultural prices relative to non-agricultural prices		Increase in agricultural prices by 7% - 18%	Kumar and Parikh (1998)	India
Farm level net revenue	Temperature Rise by 2–3.5 ^{0}C	Decline in net revenue by 9% - 25%	Kumar and Parikh (1998)	India
Farm level net revenue	Rise in temperature By 2 ^{0}C and an accompanying precipitation change of + 7%, with adaptation by farmers of cropping patterns and inputs	Fall in net revenue by 9%	Kumar and Parikh (1998)	India
Agricultural net revenue	2 ^{0}C rise in mean temperature and a 7% increase in mean precipitation	Drop in net revenue by 12.3 %	Sanghi *et al.* (1998)	Gujarat, Maharashtra and Karnataka
Agriculture in coastal regions		High risk	Sanghi *et al.* (1998)	India
Rice	Rise in temperature 2 ^{0}C	Decline in yield by 0.06-0.075 tonne/ha	Sinha and Swaminathan (1991)	Southern India
Rice	1.5 ^{0}C rise +2 mm rainfall rise + 460 ppm CO_2	Increase in yield by 12%	Saseendran *et al.* (1999)	Southern India
Wheat	2 ^{0}C rise in temperature	Decline in yield by 1.5%- 5.8%	Aggarwal and Kalra (1994)	Subtropical and tropical India in Punjab and Haryana
	425 PPM CO_2	Decline in yield by 17%-18%	Kumar and Parikh (1998)	
	2 ^{0}C rise+ 425 PPM CO_2	Decline in yield by 10%	Kumar and Parikh (1998)	
Maize	2 ^{0}C rise + 425 PPM CO_2	Decline in yield by 7% -12%	Chatterjee (1998)	Northern India
Aggregate	1.5-2.5 ^{0}C	Drop in yield GDP by 2%	Mendelsohn (1996)	India

Source: Various Studies cited in the table

In India, the projected impact of climate change on agriculture varies across regions because India has immense climatic/geographic diversity. In the arid regions, where the agricultural crops face the heat stress, even small changes in temperature (increase) will have a devastating effect (decline) on agricultural production. However, the same rate of increase in temperature in cooler places such as near the Himalayas could have a positive effect on agricultural production (World Bank, 2009). Table 7 gives the details of the results obtained by various scholars using the Ricardian approach. This approach estimates the impact of climate change on agricultural land value. The Ricardian approach could provide valuable information on the economic effect of climate-induced agricultural changes. These studies suggest that an increase in temperature of 2^0 C to 3.5^0 C would result in a 3-26 per cent loss of net agricultural revenue. Table 8 gives the detail of climate change impact on different crops as indicated by various studies. It can be observed that in general an increase of 2^0 C in temperature would have a negative effect on crop production. Further, the World Bank (2009) projected that if rainfall is less, the negative impact is more pronounced. Lal *et al*., (1998) by using one scenario (+2 ^{0} C in temperature and doubling of CO_2) predicted that there will be no change in rice production in Northwestern India. Apart from this, the study used another scenario (+2 ^{0} C, doubling of CO_2, water shortage) and projected that rice production will reduce by 20 per cent in Northwestern India. For wheat crop, the study (Lal *et al*. 1998) used higher scenario (+3^0 C, doubling CO_2) and found that there would not be any change in wheat production in Northwestern India. Lal *et al* (1999) noted that in Madhya Pradesh soybean production would decline by up to 4 per cent with an increase of 3^0 C in temperature, doubling of CO_2 and decline of 10 per cent in daily rainfall. However, in South Indian states such as Kerala, rice production is projected to decline by 6 per cent with 1.5^0 C increase in temperature (Saseendran *et al,* 2000). The above finding is contrary to the finding of the Lal *et al*.(1998) study although it was predicted for the Northwestern parts of India. The study also used a scenario of a doubling of CO_2. Interestingly, Aggarwal and Mall, 2002 (CERES-Rice model) suggest using IPCC scenario (Both optimistic and pessimistic – see table 7), that rice production in many parts of India (in 2010 and 2070) would increase by up to 26 per cent in optimistic and 9 per cent in pessimistic scenario. However, when they apply the ORYZAIN model, rice production increased under both scenarios. Nevertheless, the study by Kalra *et al.* (2007) suggests a decline in rice production of up to 30 per cent with an increase of 4^0 C in temperature. The production of maize and *jowar* also will decline with an increase in temperature (Kalra *et al.,* 2007). The study by the World Bank (2006) suggests an increase in the production of rice, groundnut, *jowar*, sunflower and maize in two climatic change scenarios (see table 8). Nevertheless, in the second scenario where the study followed the same scenario with 10 per cent decline of monsoon precipitation, all the other crops except rice reported an increase in production.

Table 7: Projected Impact of Climate Change on Selected Crops in India (Using Ricardian Model)

Study	Temperature Change	% Change (Net Agricultural Revenue per ha.)
Sanghi, Mendelsohn and Dinar, 1998	2^0C	-3 to -6
Kumar and Parikh, 1998	2^0C	-7 to -9
Kumar and Parikh, 2001	2^0C	-8
Kumar and Parikh, 1998	3.5^0C	-20 to -26
Sanghi, Mendelsohn and Dinar, 1998	3.5^0C	-3 to -8

Source: World Bank (2009)

Auffhammer, Ramanathan and Vincent (2006) suggest that adverse climatic change due to atmospheric brown clouds (ABCs) and GHGs contributed to the decline in rice production. Their study estimated the impact of only ABCs on rice to be 3.94 per cent during 1966-84 and 10.6 per cent during 1985-1998.

Table 8: Agronomic Assessment for Crops in India

Crop	Region	Study	Scenario	Yield Change (%)	Model
Rice	Northwest	Lal et al. 1998	+2 ^{0} C, Doubling CO_2	0	CERES-Rice
Rice	Northwest	Lal et al. 1998	+2 ^{0} C, Doubling CO_2, Water Shortage	-20	CERES-Rice
Wheat	Northwest	Lal et al. 1998	+3^0 C, Doubling CO_2	0	CERES-Wheat
Soybean	Madhya Pradesh	Lal et al. 1999	+3^0 C, Doubling CO_2; -10% daily rainfall	-4 to 0	CROPGRO
Rice	Kerala	Saseendran et al, 2000	+1.5^0 C	-6	CERES-Rice
Rice	Parts of all India	Aggarwal and Mall, 2002*	Optimistic IPCC scenarios; +0.1^0 C, 416 ppm CO_2; +0.4^0 C, 755 ppm CO_2. Both at current crop management level**	+3.5 to +4.3 (2010) +13.8 to 22.3 (2070)	CERES-Rice
Rice	Parts of all India	Aggarwal and Mall, 2002*	Pessimistic IPCC scenarios; +0.3^0 C, 397 ppm CO_2; +0.2^0 C, , 605 ppm CO_2. Both at current crop management level**	+2.3 to +1.9 (2010) +3.6 to +9 (2070)	CERES-Rice
Rice	Parts of all India	Aggarwal and Mall, 2002*	Optimistic IPCC scenario	+5.1 to 7.4 (2010) +16.6 to +25.7 (2070)	ORYZAIN
Rice	Parts of all India	Aggarwal and Mall, 2002*	Pessimistic IPCC scenario	+2.5 to +4.1 (2010) +6.1 to +16.8 (2070)	ORYZAIN
Rice	All India	Kalra et al., 2007: DEFRA Study	+1^0 C; No change in CO_2	-5 to -8	CERES-Rice
Rice	All India	Kalra et al., 2007: DEFRA Study	+2^0 C; No change in CO_2	-10 to -16	CERES-Rice
Rice	All India	Kalra et al., 2007: DEFRA Study	+4^0 C	-21 to -30	CERES-Rice
Maize	All India	Kalra et al., 2007: DEFRA Study	+1^0 C to +4^0 C; 350 ppm CO_2	-10 to -30	CERES- Maize
Jowar	All India	Kalra et al., 2007: DEFRA Study	+1^0 C +2^0 C	-7 -12	CERES-Sorghum
Rice	All India	World Bank, 2006	Max. temp. +2°C; min. temp. +4°C; annual rainy days –5%; 550 ppm CO_2	-9	EPIC
Groundnut	All India	World Bank, 2006	Max. temp. +2°C; min. temp. +4°C; annual rainy days –5%; 550 ppm CO_2	+2	EPIC
Jowar	All India	World Bank, 2006	Max. temp. +2°C; min. temp. +4°C; annual rainy days –5%; 550 ppm CO_2	+3	EPIC
Sunflower	All India	World Bank, 2006	Max. temp. +2°C; min. temp. +4°C; annual rainy days –5%; 550 ppm CO_2	+10	EPIC

Maize	All India	World Bank, 2006	Max. temp. +2°C; min. temp. +4°C; annual rainy days –5%; 550 ppm CO_2	+3	EPIC
Rice	All India	World Bank, 2006	Max. temp. +2°C; min. temp. +4°C; annual rainy days –5%; 550 ppm CO_2; cumulative monsoon rainfall (Jun–Sept) –10%	-8	EPIC
Groundnut	All India	World Bank, 2006	Max. temp. +2°C; min. temp. +4°C; annual rainy days –5%; 550 ppm CO_2; cumulative monsoon rainfall (Jun–Sept) –10%	0	EPIC
Jowar	All India	World Bank, 2006	Max. temp. +2°C; min. temp. +4°C; annual rainy days –5%; 550 ppm CO_2; cumulative monsoon rainfall (Jun–Sept) –10%	0	EPIC
Sunflower	All India	World Bank, 2006	Max. temp. +2°C; min. temp. +4°C; annual rainy days –5%; 550 ppm CO_2; cumulative monsoon rainfall (Jun–Sept) –10%	+9	EPIC
Maize	All India	World Bank, 2006	Max. temp. +2°C; min. temp. +4°C; annual rainy days –5%; 550 ppm CO_2; cumulative monsoon rainfall (Jun–Sept) –10%	0	EPIC

* The margin of error can be as much as 32 per cent, depending on the uncertainty in climate change and other factors. Sensitivity analyses were run for increase in temperature, level of nutrients fed to the crop and variations in CO_2 levels. All this showed that yield would increase if temperature remained unchanged and CO_2 levels increased. However, with increase in temperature, the CO_2 effect is nullified for increase in temperature as low as 0.9^0 C.

** it assumes no change in current nutrient application and irrigation

Aggrawal and Kalra (1994) evaluated the mean simulated yield of wheat for current and changed climate (2? C rise and CO_2 level of 425 CO_2 ppm) in different latitudinal ranges (Table 9). Irrigated yields slightly increased for latitudes greater than 27^0 N but reduced at all other places. The decrease in yield was much higher in the lower latitude regions. Several locations, particularly where current rainfed yields were greater than 2 t/ha, showed a very signi?cant increase in rain fed yields with climate change. These locations are mostly above 27^0 N; the mean increase here was 28.6 per cent. In locations between 25^0N and 27^0 N although rainfed yields under current weather conditions were high, there was a signi?cant decrease in yields with change in climate. These results were closely related to the effects of climate change on crop duration. Depending upon the magnitude of increase in temperature, crop duration, particularly in the period up to anthesis, was reduced. In northern India, because of this reduction in the pre-anthesis duration, grain-?lling often shifted to the relatively cooler temperature of February, thus, enabling the crop to maintain reasonable grain-?lling duration in changed climate situation. There was no effect of climate change in Northern India but yields reduced in Central India by 10–15 per cent. This reduction in productivity due to climate change, unless accompanied with suitable research and policy interventions, may reduce wheat production in Central India (Kalra and Aggarwal, 1994; Aggarwal, 2000).

Table 9: Changes in Wheat Production in Response to Climate Change*
in Different Regions of India (t/ha)

Regions	Potential Yield		Irrigated yield		Rainfed yield	
	Current	**% Change**	**Current**	**% Change**	**Current**	**% Change**
> 27^0 N	6.66	-3.9	4.89	3.7	2.95	28.6
25-27^0 N	5.84	-1.5	4.78	-4.4	3.34	-7.2
23-25^0 N	5.86	-5.6	4.18	-10.8	1.17	-19.6
20-23^0 N	4.18	-18.4	2.29	-18.3	0.51	-11.8
<20^0 N	3.69	-17.3	2.43	-21.4	0.97	-23.9

*(425 ppm CO_2, 2^0 C increase in mean temp.)

Source: Aggarwal and Kalra (1994)

Adaptation to Climatic Variability

Adaptation could be possible at various levels, e.g., farmers, economic agents and the macro level. For example, Reilly and Schimmelpfenng (1999) suggest that the relative speed of adoption of various measures (see table 10). Stern (2007) provides two types of adaptation measures for the short and long run, namely, autonomous and policy driven adaptation. Table 11 gives the details of these adaptation practices. Southeast Asian countries such as Indonesia have adopted changing crop combinations and integrated production management like doing pissiculture with rice cultivation and changing rice-rice combinations to rice-millet, rice-vegetable, etc. People are also changing food habits by shifting from rice to rice-wheat/millet combinations that help implement agricultural adaptation strategies.

Jodha (1989), using observations of adoption and technological response in post-independent Indian agriculture, estimated the response time to be 5-15 years for the productive life of farm assets, crop rotation cycles, and recovery from major disasters. **Broad Categories of Responses** - some of which could be beneficial regardless of how or whether climate changes - include:

- Improved training and general education of populations dependent on agriculture.
- Identification of the present vulnerabilities of agricultural systems.
- Agricultural research to develop new crop varieties.
- Food programmes and other social security programmes to provide insurance against supply changes.

- Transportation, distribution and market integration to provide the infrastructure to supply food during crop shortfalls.
- Removal of subsidies, which can, by limiting changes in prices, mask the climate change signal in the marketplace.

Table 10: Relative Speed of Adoption of Various Measures

Adaptation Measure	Adjustment Time (years)
Variety Adoption	3-14
Dams and Irrigation	50-100
Variety Development	8-15
Tillage Systems	10-12
Opening New Lands	3-10
Irrigation Equipment	20-25
Fertilizer Adoption	10

Source: Reilly and Schimmelpfennig (1999)

Table 11: Adaptation in Practice

Response to Climate Change	Autonomous Adaptation	Policy-driven Adaptation
Short-run	-Making short-run adjustment, e.g., changing crop planting dates -Spreading the loss, e.g., pooling risk through insurance	-Developing greater understanding of climate risks, e.g., researching risks and carrying out a vulnerability assessment -Improving emergency response, e.g., early warning systems
Long-run	-Investment in climate resilience if future effects relatively well understood and benefits easy to capture fully, e.g., localized irrigation on farm	-Investing to create or modify major infrastructure, e.g., larger reservoir storage, increased drainage capacity, higher sea walls -Avoiding the impacts, e.g., land use planning to restrict development in flood plains or in areas of increasing aridity

Source: Stern (2007)

Understanding the Implications of Climate Change on Food Security and Livelihoods

Our present knowledge is very little, at least in quantitative terms, to understand the role of climate change on food security and livelihoods. In a country such as India, multiple stressors like economic, political and social conditions in addition to climatic factors influence food security. In spite of this, there has been no systematic methodology to operationalise vulnerability in the context of the multiple stressors.

There is the likelihood of a considerable impact of climatic variability on agricultural land-use and the nation's food security due to snow melt, availability of irrigation, frequency and intensity of inter- and intra- seasonal droughts and floods, soil organic transformation matters, soil erosion and availability of energy as a consequence of global warming. The FAO (2001) defines food security as a "*situation when all people, at all times, have physical, social and economic access to sufficient, safe and nutritious food that meet their dietary requirements and food preferences for an active and healthy life"*. There are four key dimensions that are related to food security, namely, availability, stability, access and utilisation. The FAO study (2002 and 2006) suggests that climate change will affect the four dimensions of food security, namely food availability (i.e., production and trade), access to food, stability of food supplies and food utilisation. The importance of the various dimensions and the overall impact of climate change on food security will differ across regions and over time and, most significantly, will depend on the overall socio-economic status that a county has achieved as the effects of climate change set in (Schmidhuber and Tubiello, 2007). Schmidhuber and Tubiello (2007) assessed that climatic change will adversely affect food security. Climate change may increase the dependency on imports, which in turn, will affect the growth process of the country. One can argue that, within the developing world, the adverse effect of climate change will be profound on the poor. The quantitative assessments (Schmidhuber and Tubiello, 2007) suggest that the socio-economic setting in which climate change is likely to evolve is more important than the impact that can be expected from the biophysical changes of climate variability.

Climatic variability is predicted to reduce net cereal production in South Asian countries by 4 to 10 per cent by the year 2100 under the most pessimistic scenario of the IPCC (Cruz and Harasawa *et al.*, 2007). Various studies have found a negative correlation between agricultural production and poverty rates. Datt and Ravallion (1998) suggest that between 1958 and 1994 increase in yield lowered poverty almost one for one in India. Eswaran *et al* (2008) reported that the increase in agricultural productivity was responsible for at least four-fifths of the 75 per cent growth in real agricultural wage in India. In a recent study Kotwal and Ramaswami *et al* (2009) suggest that agricultural productivity has to increase to improve the living standards of the rural poor in India.

IASC (2009) suggested key messages on food security in a changing climate scenario. They are:

- Climate change will act as a multiplier of existing threats to food security. By 2050, the risk of hunger is projected to increase by 10–20 per cent and child malnutrition is anticipated to be 20 per cent higher compared to a no-climate change scenario.
- The other issue of concern is achieving food security under a changing climate scenario. It requires substantial increase in food production and improved access to adequate and nutritious food on the one hand and the capacity to cope with the risks posed by climate change on the other hand.
- Community-based development processes need to be fostered to enable the poorest and most vulnerable to build sustainable and climate-resilient livelihoods and move out of chronic poverty and food insecurity.
- The humanitarian organisations must be prepared for more extreme weather events and protect the people facing food insecurity by strengthening their crisis response and prevention startegies.

As per the Fourth Assessment Report (FAR) of the IPCC, warming of the climate is now unequivocal and evident from the observations of increases in global average air and ocean temperatures, widespread melting of snow and ice and rising sea levels. Importantly, developing nations are adversely affected in comparison to the developed nations (Mendelsohn *et al.*, 2006; and Stern, 2006). For instance, during the 2000-04 on an average annual basis one in 19 people living in the developing world was affected by climate disasters (HDR, 2007). Flooding alone affected the lives of the 68 million people in East Asia and 40 million people in South Asia (HDR, 2007). In addition, monsoon floods and storms in South Asia during the 2007 season displaced more than 14 million people in India and 7 million people in Bangladesh, and more than 1000 people lost their lives across South Asia (HDR, 2007: 76).

These climatic disasters, therefore, make the livelihood of the people more susceptible, especially in India as they are already vulnerable to the conventional problems like poverty and food insecurity etc. It is argued that India is particularly vulnerable to predicted climate changes because of its high population density, low adaptive capacity, several unique and valuable ecosystems (coral reef, large deltaic region with rich biodiversity) and vast low-altitude agricultural activities (Roy, 2007). India has to maintain the sustainability of its ecosystems to meet the food and non-food needs of a growing population. India is home to the largest number of hungry and deprived people in the world – to be precise 360 million undernourished and 300 million poor people. Sustaining the supply of food itself is emerging as a critical issue. Growth in food grain production has been slow if not decreasing, over the last few decades. During 1996-2008, it increased by just 1.2 per cent per annum: from 199 to 230 million tons, as against an annual rate of growth of 3.5 per cent achieved during the 1980s (Roy, 2007). The net food grain availability declined from 510 grams per day per capita in 1991 to 443 grams in 2007. It affects the poor the most as they have cannot afford the more expensive fruits, vegetables, poultry and meat products. They need food but do not have the purchasing power. This situation is more pronounced in central and eastern India (Roy, 2007)

Another big change observed during the last three decades is the dominant use of groundwater as opposed to surface and sub-soil (through shallow wells). Groundwater has become the main source of irrigation. Surface irrigation systems already created are lying wasted because canals or other systems are hardly maintained. The inefficiency of the large water irrigation systems has forced the people to exploit groundwater. Thus, the bulk of Indian agriculture not only remains rain-fed but also depends on groundwater rather than surface water. This is worrisome in the current context of increasingly variable rainfall.

The existing problems of poor farmers, if not addressed in time, will become more acute due to climate change induced by global warming. The prediction so far suggests an upward trend in mean monthly temperature and average rainfall. However, the prediction indicates a downward trend in the number of wet days in a year. The impact of climate change would be seen in terms of increased sub-regional variations and more extreme rain events. In a country that gets rain for less than 100 hours in a year (a year has 8,760 hours), this would be disastrous. A recent World Bank report (World Bank, 2008) studied two drought prone regions in Andhra Pradesh and Maharashtra and one in Orissa for impact of climate change. It found that climate change could have the following serious impacts: (i) in

Andhra Pradesh dry-land farmers may see their incomes plunge by 20 per cent; (ii) in Maharashtra, sugarcane yields may fall dramatically by 25-30 per cent; and (iii) in Orissa, flooding will rise dramatically leading to a drop in rice yields by as much as 12 per cent in some districts.

Agriculture and allied activities constitute the single largest component of India's economy, contributing nearly 27 per cent of the total GDP while agricultural exports account for 13–18 per cent of the total annual exports of the country. However, given the fact that 62 per cent of the cropped area is still dependent on rainfall, Indian agriculture continues to be fundamentally dependent on the weather. The impact of climate change on agriculture is serious in India. About 75 per cent of the population lives in rural areas and agricultural performance is closely related to the prevalence of poverty. The focus is on the two main cereal crops – rice and wheat – in terms of the effect of climate change on crop yields, overall food production and welfare.

Conclusion

As the scientific consensus that significant climate change, in particular increased temperatures and precipitation, is very likely to occur during the 21st century gathers momentum, economic research has attempted to quantify the possible implications of climate change on society and agriculture. The vulnerability to climate change may be greater in developing countries such as India, where agriculture typically plays a larger economic role. This study reviews the evidence on the impact of climate change on agriculture in India, where poverty and agricultural performance are related. Our review finds that climate change is likely to reduce agricultural yields significantly and the damage could be severe unless the adaptation to higher temperatures is rapid and complete.

The evidence presented in this review paper suggests that the impact of climate change impacts is increasing over time indicating the increasing sensitivity of Indian agriculture. In India, the projected impact of climate change on agriculture varies across the regions because India has immense climatic/geographic diversity. The study argues that understanding the impact of climate change on agriculture in environmentally and economically vulnerable regions of India will require better understanding of the long-term path of innovation, land use and the dynamic behaviour of managed ecosystems. This finding poses an important question for future research, for the welfare of Indian agriculture, how quickly will Indian farmers be able to adjust their farming practices to adapt to the changing climate and what policies or technologies will enable rapid adaptation to climate change.

References

Achanta, A N (1993). An Assessment of the Potential Impact of Global Warming on Indian Rice Production. In Achanta A N (ed), *The Climate Change Agenda: An Indian Perspective*. New Delhi: TERI.

Agarwal, B (1990). Social Security and the Family in Rural India: Coping with Seasonality and Calamity. *Journal of Peasant Studies*, 17: 341-412.

Aggarwal, P K (2003). Impact of Climate Change on Indian Agriculture. *J Plant Biology*, 30 (2): 189-98.

———— (2000). Application of Systems Simulation for Understanding and Increasing Yield Potential of Wheat and Rice. *Ph.D. thesis*. Wageningen University, The Netherlands, pp. 176.

Aggarwal, P K and N Kalra (1994). *Simulating the Effect of Climatic Factors, Genotype and Management on Productivity of Wheat in India*. New Delhi: Indian Agricultural Research Institute Publication. Pp. 156.

Aggarwal, P K, P K Joshi, J S I Ingram and R K Gupta (2004). Adapting Food Systems of the Indo-Gangetic Plains to Global Environmental Change: Key Information Needs to Improve Policy Formulation. *Environmental Science & Policy*, 7: 487-98.

Aggarwal, P K and R K Mall (2002). Climate Change and Rice Yields in Diverse Agro-environments of India. II. Effect of uncertainties in scenarios and crop models on impact assessment. *Climatic Change*, 52 (3): 331-43.

Aggarwal, P K and S K Sinha (1993). Effect of probable increase in carbon dioxide and temperature on productivity of wheat in India. *Jr. of Agric. Meteorology,* 48 (5): 811-14.

Auffhammer, M, V Ramanathan and J R Vincent (2006). Integrated Model Shows that Atmospheric Brown Cloud and GHGs have Reduced Rice Harvests in India. *PNAS*, 103 (52).

Bhaskaran, B, J F B Mitchell, J R Lavery, and M Lal (1995). Climatic Response of Indian Subcontinent to Doubled CO_2 Concentrations. *International Journal Climatology*, 15: 873-92.

Chatterjee, A (1998). Simulating the Impact of Increase in Temperature and CO_2 on Growth and Yield of Maize and Sorghum. *M.Sc. Thesis* (Unpublished). New Delhi: Indian Agricultural Research Institute.

Christy, J R, R W Spencer, and Braswell (2000). MSU Tropospheric Temperatures: Dataset Construction and Radiosonde Comparisons. *Journal of Atmospheric and Oceanic Research,* 17: 1153-70.

Cruz, R V, H Harasawa *et al* (2007). Asia. Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the IPCC, M L Parry, O F Canziani, J P Palutikof, *et al*, Cambridge: Cambridge University Press. 469-506.

Datt, G and M Ravallion (1998). Farm Productivity and Rural Poverty in India. *Journal of Development Studies*, 34 (4): 62-85.

Dinar, A, R Mendelsohn, R Evenson, J Parikh, A Sanghi, K Kumar, J McKinsey and S Lonergan (eds) (1998). Measuring the Impact of Climate Change on Indian Agriculture. *World Bank Technical Paper No. 402.* Washington, DC.

Eswaran, M, A Kotwal *et al* (2008). How Does Poverty Decline? Suggestive Evidence from India, 1983-1999. *Bread policy papers*.

Food and Agriculture Organization (2002). *The State of Food Insecurity in the World 2001*. Rome: FAO.

———— (2006). *The State of Food Insecurity in the World 2006*. Rome: FAO.

Gangadhar Rao, D and S K Sinha (1994). Impact of Climate Change on Simulated Wheat Production in India. In C Rosenzweig and I Iglesias (ed), Implications of Climate Change for International Agriculture: Crop Modelling Study. *USEPA230-B-94-003*. Washigton, D.C.: USEPA. Pp. 1-17.

Gangadhar Rao, D, J C Katyal, S K Sinha, and K Srinivas (1995). Impacts of Climate Change on Sorghum Productivity in India: Simulation Study, American Society of Agronomy, 677 S. Segoe Rd., Madison, WI 53711, USA, Climate Change and Agriculture: Analysis of Potential International Impacts. ASA Special Publ. No. 59. Pp. 325–337.

GOI (2008). *Climate Change, Ministry of Environment and Forests*. New Delhi: Government of India. Retrieved October 2008, from http://envfor.nic.in/cc/what.htm

Goulder, Lawrence H and, William A Pizer (2006). The Economics of Climate Change. *Discussion Paper 06*, Washington, D.C.: Resources for the Future (RFF).

Grover, Velma I (eds) (2004). *Climate Change: Five years after Kyoto*. Enfield, USA: Science Publishers, Inc.

Hingane, L S, K Rupa Kumar and B H V Ramana Murthy (1985). Long-term trends of Surface air Temperature in India. *J Climatol*, 5: 521-28.

Hundal, S and P Kaur (1996). Crop Productivity in the Punjab, India. In Y P Gadgil and G B Pant (eds), *Climate Variability and Agriculture*. New Delhi: Abrol.

IASC (2009). *Climate Change, Food Insecurity and Hunger, Technical Paper for IASC Task Force on Climate Change*. Submitted by WFP, FAO, IFRC, OXFAM.

IPCC (2007a). Climate Change 2007: *Climate Impacts, Adaptation and Vulnerability*. Working Group II to the Intergovernmental Panel on Climate Change Fourth Assessment Report, DRAFT technical summary 2006, Geneva: Intergovernmental Panel on Climate Change.

———— (2007b). Climate Change 2007: The Physical Science Basis: Summary for Policymakers' Working Group I to the Intergovernmental Panel on Climate Change Fourth Assessment Report. Geneva: Intergovernmental Panel on Climate Change.

———— (2001a). *Climate Change 2001: The Scientific Basis*. Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge: Cambridge University Press. http://www.ipcc.ch/ipccreports-/tar/wg1/index.htm

———— (2001b). *Climate Change 2001: Impacts, Adaptation and Vulnerability*. Contribution of Working Group II to the Third Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge: Cambridge University Press. http://www.ipcc.ch/ipccreports/tar/wg2/index.htm

———— (2001). Climate Change 2001: Impacts, Adaptation, and Vulnerability. Cambridge: Cambridge University Press.

Jodha, N S (1989). Potential Strategies for Adapting to Greenhouse Warming: Perspectives from the Developing World. In Rosenberg, N J, W E Easterling, P R Crosson and J Darmstadter (eds), *Greenhouse Warming: Abatement and Adaptation*. Washington D.C.: Resources for the Future.

Kalra, N, D Chakraborty, P R Ramesh, M Jolly, and P K Sharma (2007). *Impacts of Climate Change in India: Agricultural Impacts*. Final Report, Joint Indo-UK Programme of Ministry of Environment and Forests, India, and Department for Environment, Food and Rural Affairs (DEFRA), United Kingdom. New Delhi: Indian Agricultural Research Institute, Unit of Simulation and Informatics.

Kavi Kumar, K S (2009). Climate Sensitivity of Indian Agriculture. *Madras School of Economics, Working Paper No. 43.*

———— (2007). Climate Change Studies in Indian Agriculture. *Economic and Political Weekly*, 42 (45): 13-18.

Kavi Kumar, K S and Jyoti Parikh (1998). Climate Change Impacts on Indian Agriculture: The Ricardian Approach. In Dinar *et al* (eds), Measuring the Impacts of Climate Change on Indian Agriculture. *World Bank Technical Paper No. 402*. Washington, DC.

———— (2001). Socio-economic Impacts of Climate Change on Indian Agriculture. *International Review for Environmental Strategies*, 2 (2): 277-93.

———— (2001b). Indian Agriculture and Climate Sensitivity. *Global Environmental Change*, 11: 147-54.

Kotwal, A, B Ramaswami *et al* (2009). *Economic Liberalization and Indian Economic growth: What's the Evidence?*. Delhi: Indian statistical Institute.

Kripalani, R H, S R Inamdar and N A Sontakke (1996). Rainfall Variability over Bangladesh and Nepal: Comparison and Connection with Features Over India. *International Journal of Climatology,* 16: 689-703.

Lal, M, K K Singh, G Srinivasan, L S Rathore and A S Saseendran (1998), 'Vulnerability of rice and wheat yields in NW-India to future change in climate', *Agric. Forest Meteorology* 89, 101–114.

Lal, M, S K Singh, G Srinivasan, L S Rathore, D Naidu, and C N Tripathi (1999). Growth and Yield Response of Soybean in Madhya Pradesh, India to Climate Variability and Change. *Agricultural and Forest Meteorology* 93, 53–70.

Lal, M, T Nozawa, S Emori, H Harasawa, K Takahashi, M Kimoto, A Abe-Ouchi, T Nakajima, T Takemura and A Numaguti (2001). Future Climate Change: Implications for Indian Summer Monsoon and Its Variability. *Current Science*, 81: 1196-207.

Lal, M, U Cubasch, R Voss and J Waszkewitz (1995). Effect of Transient Increases in Greenhouse Gases and Sulphate Aerosols on Monsoon Climate. *Current Science*, 69 (9): 752-63.

Lonergan, S (1998). Climate Warming and India. In A Dinar *et al* (ed), *Measuring the Impact of Climate Change on Indian Agriculture*. Washington DC: World Bank. [World Bank Technical Paper No. 402].

Mall, R K, R Singh, A Gupta, G Srinivasan, L S Rathore (2006). Impact of Climate Change on Indian Agriculture: A Review. *Climatic Change*, 78: 445-78

———— (2007). Impact of Climate Change on Indian Agriculture: A Review. Erratum, *Climatic Change*, 82: 225-31.

Mandal, N (1998). Simulating the Impact of Climatic Variability and Climate Change on Growth and Yield of Chickpea and Pigenon Pea Crops. *M.Sc. Thesis* (Unpublished). New Delhi: Indian Agricultural Research Institute.

May, W (2002). Simulated Changes of the Indian Summer Monsoon under Enhanced Greenhouse Gas Conditions in a Global Time-slice Experiment. *Geophysical Research Letters,* 29 (7): 22.1–22.4.

McCarthy, James J, Osvaldo F Canziani, Neil A Leary, David J Dokken and Kasey S White (eds) (2001). *WG II: Climate Change 2001: Impacts, Adaptation & Vulnerability.* Cambridge: Cambridge University Press.

Mendelsohn, R and A Dinar (2003). Climate, Water, and Agriculture. *Land Economics*, 79: 328-41.

Mendelsohn, R and W Nordhaus (1999). The impact of Global Warming on Agriculture: Reply to Quiggin and Horowitz. *The American Economic Review*, 89: 1046-48.

———— (1999b). The Impact of Global Warming on Agriculture, A Ricardian Analysis: Reply to Darwin. *The American Economic Review*, 89: 1053-55.

Mendelsohn, R, A Dinar (1999), Climate change, agriculture, and developing countries: does adaptation matter? *The World Bank Research Observer* ,14 (2), Pp. 277–293.

Mendelsohn, R, A Dinar and L Williams (2006). The Distributional Impacts of Climate Change on Rich and Poor Countries. *Environment and Development Economics*, 11: 159-78.

Mendelsohn, R, W Morrison, M Schlesinger and N Adronova (2000). Country Specific Market Impacts from Climate Change. *Climatic Change*, 45: 553-69.

Mendelsohn, R, W Nordhaus, D G Shaw (1994). The Impact of Global Warming on Agriculture: A Ricardian Analysis. *American Economic Review*, 84 (4): 753-71.

Mendelsohn, Robert and William D Nordhaus (1996). The Impact of Global Warming on Agriculture: Reply to Cline. *The American Economic Review*, 86 (5): 1312-15.

Mendelsohn, Robert, A Dinar and A Sanghi (2001). The Effect of Development on the Climate Sensitivity of Agriculture. *Environment and Development Economics*, 6 (1): 85-101.

Mohandass, S, A A Kareem, T B Ranganathan and S Jeyaraman (1995). Rice Production in India under Current and Future Climates. In Matthews R B, Kropff M J, Bachelet D and Laar van H H (eds), *Modeling the Impact of Climate Change on Rice Production in Asia*. U.K.: CAB International.

Mooley, D A and B Parthasarathy (1984). Fluctuations of All India Summer Monsoon Rainfall during 1871-1978. *Climatic Change,* 6: 287-301.

O'Brien K L, R M Leichenko, U Kelkar, H Venema, G Aandahl, H Tompkins, A Javed, S Bhadwal, S Barg, L Nygaard and J West (2004b). Mapping Vulnerability to Multiple Stressors: Climate Change and Globalisation in India. *Global Environmental Change*, 14 (4): 303-13.

O'Brien, K, S Eriksen, A Schjolden and L Nygaard (2004a). What's in a Word? Conflicting Interpretations of Vulnerability in Climate Change Research. *Working Paper, 2004:04*. Norway: Centre for International Climate and Environmental Research Oslo, University of Oslo.

Pant, G B, Rupa Kumar and K Borgaonkar H P (1999). Climate and Its Long-term Variability over the Western Himalaya during the past two Centuries. In S K Dash and J Bahadur (eds), *The Himalayan Environment*. New Delhi: New Age International (P) Limited, Publishers.

Parry M L, C Rosenzweig and M Livermore (2005). Climate Change, Global Food Supply and Risk of Hunger. *Philosophical Transactions of the Royal Society,* 360: 2125-36.

Parry M L, C Rosenzweig, A Iglesias *et al* (2004). Effects of Climate Change on Global Food Production under SRES Emissions and Socio-economic Scenarios. *Global Environmental Change*, 14: 53-67.

Parry, M (1990). *Climate Change and World Agriculture*. London: Earthscan.

Parry, M L, M Blantran, A L deRozari, S Chong and S Panich (1992). The Potential Socio-economic Effects of Climate Change in South East Asia. Nairobi: United Nations Environment Programme.

Pathak, H, Ladha, P K Aggarwal, S Peng, S Das, Y Singh, B Singh, S K Kamra, B Mishra, A S R A S Sastri, H P Aggarwal, D K Das, and R K Gupta (2003). Trends of Climatic Potential and On-farm Yields of Rice and Wheat in the Indo-Gangetic Plains. *Field Crops Research,* 80: 223-34.

Rathore, L S, K K Singh, S A Saseendran and A K Baxla (2001). Modelling the Impact of Climate Change on Rice Production in India. *Mausam*, 52 (1).

Reilly, J M and D Schimmelpfennig (1999). Agricultural Impact Assessment, Vulnerability, and the Scope for Adaptation. *Climatic Change*, 43: 745-88.

Reilly, John (1999). What Does Climate Change Mean for Agriculture in Developing Countries? A Comment on Mendelsohn and Dinar. *The World Bank Research Observer*, 14 (2): 295-305.

Roy, J (2007). Climate Change in the South Asian Context with a Special Focus on India: A Review. *AEI Newsletter*, 3 (April 2007).

Rupakumar, K (2002). *Regional Climate Scenarios*. TERI Workshop on Climate Change: Policy Options for India, New Delhi, September, 5-6, 2002.

Rupakumar, K, G B Pant, B Parthasarathy and N A Sontakke (1992). Spatial and Sub-seasonal Patterns of the Long-term Trends of Indian Summer Monsoon Rainfall. *International Journal of Climatology*, 12: 257-68.

Rupakumar, K, K Krishna Kumar and G B Pant (1994). Diurnal Asymmetry of Surface Temperature Trends Over India. *Geophysical Research Letters,* 21: 677-80.

Rupakumar, K, K Kumar, V Prasanna, K Kamala, N R Desphnade, S K Patwardhan and G B Pant (2003). Future Climate Scenario. In *Climate Change and Indian Vulnerability Assessment and Adaptation*. Hyderabad: Universities Press (India) Pvt Ltd.

Rupakumar, K and R G Ashrit (2001). Regional Aspects of Global Climate Change Simulations: Validation and Assessment of Climate Response over Indian Monsoon Region to Transient Increase of Greenhouse Gases and Sulphate Aerosoles. *Mausam,* 52 (1): 229-44.

Sahoo, S K (1999). Simulating Growth and Yield of Maize in Different Agro-climatic Regions. *M.Sc. Thesis* (Unpublished). New Delhi: Indian Agricultural Research Institute.

Saini, A D and R Nanda (1986). Relationship between Incident Radiation, Leaf Area and Dry Matter Yield in Wheat. *Indian Journal of Agricultural Sciences,* 56: 512-19.

Sanghi, A (1997). *The Climate Sensitivity of Brazilian Agriculture: Estimates from the Ricardian Model*. Paper presented at the workshop: Measuring the Impacts of Climate Change on Indian and Brazilian Agriculture. World Bank, Washington.

Sanghi, A, R Mendelsohn, and A Dinar (1998). The Climate Sensitivity of Indian Agriculture. In A Dinar, R Mendelsohn, R Evenson, J Parikh, A Sanghi, K Kumar, J McKinsey, and S Lonergon (eds), Measuring the Impact of Climatic Change on Indian Agriculture. *World Bank Technical Report No. 409*. Washington, DC: World Bank.

Saseendran, A S, K, K K Singh, L S Rathore, S V Singh and S K Sinha (2000). Effects of Climate Change on Rice Production in the Tropical Humid Climate of Kerala, India. *Climatic Change*, 44: 495-514.

Sathaye, Jayant P R Shukla and N H Ravindranath (2006). Climate Change, Sustainable Development and India: Global and National Concerns. *Current Science*, 90 (3): 314-25.

Schmidhuber, J, F N Tubiello (2007). Global Food Security Under Climate Change. *PNAS*, 104 (50).

Singh, N and N A Sontakke (2002). On Climatic Fluctuations and Environmental Changes of the Indo-Gangetic Plains, India. *Climatic Change*, 52: 287-313.

Singh, R S, P Narain and K D Sharma (2001). Climate Changes in Luni River Basin of Arid Western Rajasthan (India). *Vayu Mandal,* 31 (1-4): 103-6.

Sinha, S K and M S Swaminathan (1991). Deforestation, Climate Change and Sustainable Nutrients Security. *Climatic Change*, 16: 33-45.

Sinha, S K, G B Singh Rai, M (1998). *Decline in crop productivity in Haryana and Punjab: Myth or Reality?*. New Delhi: Indian Council of Agricultural Research.

Spash, Clive L (2002). Greenhouse Economics: Value and Ethics. London: Routledge Publication.

Srivastava, H N, B N Dewan, S K Dikshit, G S P Rao, S S Singh and R Rao (1992). Decadal trends in Climate over India. *Mausam*, 43: 7-20.

Stephenson B David, Herve Douville and K Rupakumar (2001). Searching for a Fingerprint of Global Warming in the Asian Summer Monsoon. *Mausam*, 52 (1): 213-20.

Stern, N (2006). Stern Review on the Economics of Climate Change. London: Her Majesty's Treasury and the Cabinet Office. available from http://www.hmtreasury.gov.uk/independent_reviews/stern_review_economics_climate_ change/sternreview_index.cfm.

Stern, N (2007). *The Economics of Climate Change: The Stern Review*. Cambridge, UK: Cambridge University Press.

Thapliyal, V and S M Kulshrestha (1991). Climate Change and Trends over India. *Mausam,* 42: 333-38.

UNDP (2007). *Central Asia: Background Paper on Climate Change*. Human Development Report, 2007/11.

Uprety, D C, N V K Chakravarty, R K Katiyal and Y P Abroal (1996). Climate Variability and Brassica. In Abrol, Y P, Sulochana Gadgil, Pant, G B (eds), *Climate Variability and Agriculture*. New Delhi: Narosa Publishing House.

World Bank (2006). *The Little Green Data Book*. Washington, D.C.: The World Bank.

———— (2008). Climate Change Impacts in Drought and Flood Affected Areas: Case Studies in India. South Asia Region India Country Management Unit, Sustainable Development Department, Social, Environment and Water Resources Management Unit.

———— (2009). *South Asia: Shared Views on Development and Climate Change*. Washington DC 20433, U.S.A.

World Bank, EU, UNDP and DFID (2002). *Linking Poverty Reduction and Environmental Management: Policy Challenges and Opportunities*. Joint WSSD submission.

Recent Working Papers

217 Fisheries and Livelihoods in Tungabhadra Basin, India: Current Status and Future Possibilities
Manasi S, Latha N and K V Raju

218 Economics of Shrimp Farming: A Comparative Study of Traditional Vs. Scientific Shrimp Farming in West Bengal
Poulomi Bhattacharya

219 Output and Input Efficiency of Manufacturing Firms in India: A Case of the Indian Pharmaceutical Sector
Mainak Mazumdar, Meenakshi Rajeev and Subhash C Ray

220 Panchayats, Hariyali Guidelines and Watershed Development: Lessons from Karnataka
N Sivanna

221 Gender Differential in Disease Burden: It's Role to Explain Gender Differential in Mortality
Biplab Dhak and Mutharayappa R

222 Sanitation Strategies in Karnataka: A Review
Veerashekharappa and Shashanka Bhide

223 A Comparative Analysis of Efficiency and productivity of the Indian Pharmaceutical Firms: A Malmquist-Meta-Frontier Approach
Mainak Mazumdar and Meenakshi Rajeev

224 Local Governance, Patronage and Accountability in Karnataka and Kerala
Anand Inbanathan

225 Downward Dividends of Groundwater Irrigation in Hard Rock Areas of Southern Peninsular India
Anantha K H

226 Trends and Patterns of Private Investment in India
Jagannath Mallick

227 Environmental Efficiency of the Indian Cement Industry: An Interstate Analysis
Sabuj Kumar Mandal and S Madheswaran

228 Determinants of Living Arrangements of Elderly in Orissa: An Analysis
Akshaya Kumar Panigrahi

229 Fiscal Empowerment of Panchayats in India: Real or Rhetoric?
M Devendra Babu

230 Energy Use Efficiency in Indian Cement Industry: Application of Data Envelopment Analysis and Directional Distance Function
Sabuj Kumar Mandaland S Madheswaran

231 Ethnicity, Caste and Community in a Disaster Prone Area of Orissa
Priya Gupta

232 Koodankulam Anti-Nuclear Movement: A Struggle for Alternative Development?
Patibandla Srikant

233 History Revisited: Narratives on Political and Constitutional Changes in Kashmir (1947-1990)
Khalid Wasim Hassan

234 Spatial Heterogeneity and Population Mobility in India
Jajati Keshari Parida and S Madheswaran

235 Measuring Energy Use Efficiency in Presence of Undesirable Output: An Application of Data Envelopment Analysis (DEA) to Indian Cement Industry
Sabuj Kumar Mandaland S Madheswaran

236 Increasing trend in Caesarean Section Delivery in India: Role of Medicalisation of Maternal Health
Sancheetha Ghosh

237 Migration of Kashmiri Pandits: Kashmiriyat Challenged?
Khalid Wasim Hassan

238 Causality Between Energy Consumption and Output Growth in Indian Cement Industry: An Application of Panel Vector Error Correction Model
Sabuj Kumar Mandaland S Madheswaran

239 Conflict Over Worship:A Study of the Sri Guru Dattatreya Swami Bababudhan Dargah in South India
Sudha Sitharaman

240 Living Arrangement Preferences of the Elderly in Orissa, India
Akshaya Kumar Panigrahi

241 Challenges and Pospects in the Measurement of Trade in Services
Krushna Mohan Pattanaik

242 Dalit Movement and Emergence of the Bahujan Samaj Party in Uttar Pradesh: Politics and Priorities
Shyam Singh

243 Globalisation, Democratic Decentralisation and Social Secutiry in India
S N Sangita and T K Jyothi

244 Health, Labour Supply and Wages: A Critical Review of Literature
Amrita Ghatak

245 Is Young Maternal Age A Risk Factor for Sexually Transmitted Diseases and Anemia in India? An Examination in Urban and Rural Areas
Kavitha N

246 Patterns and Determinants of Female Migration in India: Insights from Census
Sandhya Rani Mahapatro

247 Spillover Effects from Multinational Corporations: Evidence From West Bengal Engineering Industries
Rajdeep Singha and K Gayithri

248 Effectiveness of SEZs Over EPZs Structure: The Performance at Aggregate Level
Malini L Tantri

249 Income, Income Inequality and Mortality An empirical investigation of the relationship in India, 1971-2003
K S James and T S Syamala

250 Institutions and their Interactions: An Economic Analysis of Irrigation Institutions in the Malaprabha Dam Project Area, Karnataka, India
Durba Biswas and L Venkatachalam

Price: Rs. 30.00

ISBN 978-81-7791-133-6

INSTITUTE FOR SOCIAL AND ECONOMIC CHANGE
Dr V K R V Rao Road, Nagarabhavi P.O., Bangalore - 560 072, India
Phone: 0091-80-23215468, 23215519, 23215592; Fax: 0091-80-23217008
E-mail: lekha@isec.ac.in; Web: www.isec.ac.in