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SOCIO-ECONOMICS OF CLIMATE CHANGE
(*Impact on Agriculture Land Use Changes in India*)

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~ No one attains perfection by merely giving up work. ~ Bhagavad Gita

1 Introduction

Actuality of Research Topic

Several scientific research evidences made scientists more confident that greenhouse gases may lead to future climate change. Research on measuring the socio-economic impacts of climate change might cause has proceeded world-wide, *but most of the empirical research has focused on the developed countries* [PRASADA RAO ET AL. 2008]. It has been commonly believed that developing countries are more vulnerable to climate change because of their reliance on low-capital agriculture. It has been assumed, but never tested, that low capital agriculture would have more difficulty adapting to climate changes. Even though the ability to project regional differences in impact is still emerging the consequences of climate change impact on agriculture land use are projected to be *more drastic* in the tropical region like India.

The populations of the developing world are more vulnerable as they are not prepared to withstand a deleterious impact. The global economic impacts are likely to be negative for many developing countries for even the lowest global mean temperature increase. The impact of climate change will fall disproportionately upon developing countries and the poor populations within the countries, and thereby exacerbate inequities health status and access to adequate food, clean water and other resources. In addition, poverty and absence of institutions create conditions of low adaptive capacity in these countries. Most developing countries e.g. India, lack the necessary infrastructure to deal with such exigent situations as they are preoccupied with more pressing concerns such as malnutrition, drinking water supply, primary education, a rapidly growing young population and urbanization, lack of infrastructure, import dependence and the difficulties in maintaining a stable macro economy. Their environmental concerns are dominated by the problem of lack of access to technology and investment.

Recently, United Nations Climate Change Conference, commonly known as the Copenhagen Summit, was held at the Bella Center in Copenhagen, Denmark, between 7 December and 18 December. The conference included the 15th Conference of the Parties (COP 15) to the United Nations Framework Convention on Climate Change and the 5th Meeting of the Parties (MOP) (COP/MOP 5) to the Kyoto Protocol. According to the Bali Road Map, a framework for climate change mitigation beyond 2012 was to be agreed there.

The Copenhagen Accord is the document that delegates at the United Nations Climate Change Conference (UNCCC) agreed to "take note of" at the final plenary session of the Conference on 18 December 2009 (COP-15). It is a draft COP decision and, when approved, is operational immediately. After days of frantic negotiations between heads of state, it was announced that a "meaningful agreement" had been reached between the United States, China, India, South Africa, and Brazil called Copenhagen Accord, which is not legally binding and does not commit countries to agree to a binding successor to the Kyoto Protocol, whose present round ends in 2012.

The main key outcomes of the Copenhagen accord are as follows:

1. A commitment "to reduce global emissions so as to hold the increase in global temperature below 2^{o}C" and to achieve "the peaking of global and national emissions as soon as possible".
2. Developed countries must make commitments to reduce greenhouse gas emission on the other hand developing countries must report their plans to curb greenhouse gas emissions to the UN by 31 January 2010.
3. New and additional resources "approaching $30bn" will be channeled to poorer nations over the period 2010-12, with an annual sum of $100bn envisaged by 2020.
4. A Copenhagen Green Climate Fund will be established under the UN convention on climate change, to direct some of this money to climate-related projects in developing countries.
5. Projects to reduce greenhouse gas emissions in developing countries will be subject to international monitoring if they are internationally funded.
6. Programmes to provide developing countries with financial incentives to preserve forests REDD[1] and REDD PLUS - will be established immediately.

I preferred this topic of research because as an Indian, I wanted to investigate the socio-economic issues of climate change and its impact on agriculture land use changes in India. India is second most populated country in the world, where majority of *rural population still is dependent on agriculture for their livelihood and over 600 million farmers involved in agriculture* related activities. *Agriculture and allied activities contribute about 30% to the gross domestic product of India*. *India has 52% of cultivable land and varied climates*. With arable land area at 168 million hectares, India ranks second only to the U.S. in size of agriculture. India, a developing nation is quite vulnerable to climate change, can also cause tremendous impact on world food demand [MANGALA RAI, 2007].

Aim

The determination of targets has to be based on a profound analysis of several factors. The cardinal elements, which can demonstrate the *vulnerability* in accordance with socio-economic of climate change impact on agriculture land use changes in Indian context, can be summarized the following way.

1. How *agricultural production and growth rate of yield varies according to the different climatic zones in India* and also how the socio-economic factors of climate change affect on it?

2. To analyze the *indicators of factor inputs on variation of key agricultural sector productivity and performance, incremental marginal impact of factor inputs of irrigation on agriculture land use changes in India*.

3. To analyze the relationship between the India's biggest socio-economic problem, *rural poverty and its relation with agricultural performance* also which are the other socio-economic and climatic factors are influencing it.

[1] The United Nations Collaborative Programme on Reducing Emissions from Deforestation and Forest Degradation in Developing Countries. The UN-REDD Programme is aimed at tipping the economic balance in favour of sustainable management of forests so that their formidable economic, environmental and social goods and services benefit countries, communities and forest users while also contributing to important reductions in greenhouse gas emissions. [UN, 2010]

4. To analyze also the *socio-economic and climate induced vulnerability index in the different part of India* and to find out the most vulnerable regions, there adaptation and mitigation issues.

Hypothesis

India, the second largest populated and one of the fastest growing economy in the world, having several socio-economic issues, which cannot cope with the pace of economic growth. There is a commonly saying in India that "India lives in villages" and it is true that approximately 70% of the population are residing in rural areas and the tremendous growth in economy is does not truly benefits the rural people. The most important challenges India is facing today is poverty, reduction in agriculture production (mainly destruction of agricultural land due to urbanization, industrialization and other climatic effect) and frequent disasters because of climate change and vulnerability issues.

The hypothesis behind this research investigation is to determine, how the different major socio-economic indicators are varying according to climate change in India and also to find out the vulnerability index to determine the impact assessment. At the same time, comparative variations in production, yield, growth rates and other agricultural dimensions need to be investigated. Measuring the agricultural land use changes and effect of climate change, can provide detail idea about how the socio-economic of climate change phenomenon affect the agriculture land use change in India.

Summary of my most important hypothesis are given below:

1. Severity of climatic effect (most vulnerable regions or states) in particular regions in India caused drastic reduction in agriculture production and growth rate of yield.
2. Less dependency on modern irrigation technologies in the rural part of India caused severe impact on irrigation pattern in different states of India caused by socio-economic impacts of climate change.
3. Rural poverty (most important socio-economic factor for India) is not only related to agricultural performance of particular region or state but also greatly influenced by the other socio-economic and climatic factors.
4. Climate change vulnerability in different parts of India is directly related to the socio-economic status of the states e.g. less economic growth, infrastructure index, migratory situation, destruction of coastal agricultural land etc.

2 Literature Overview

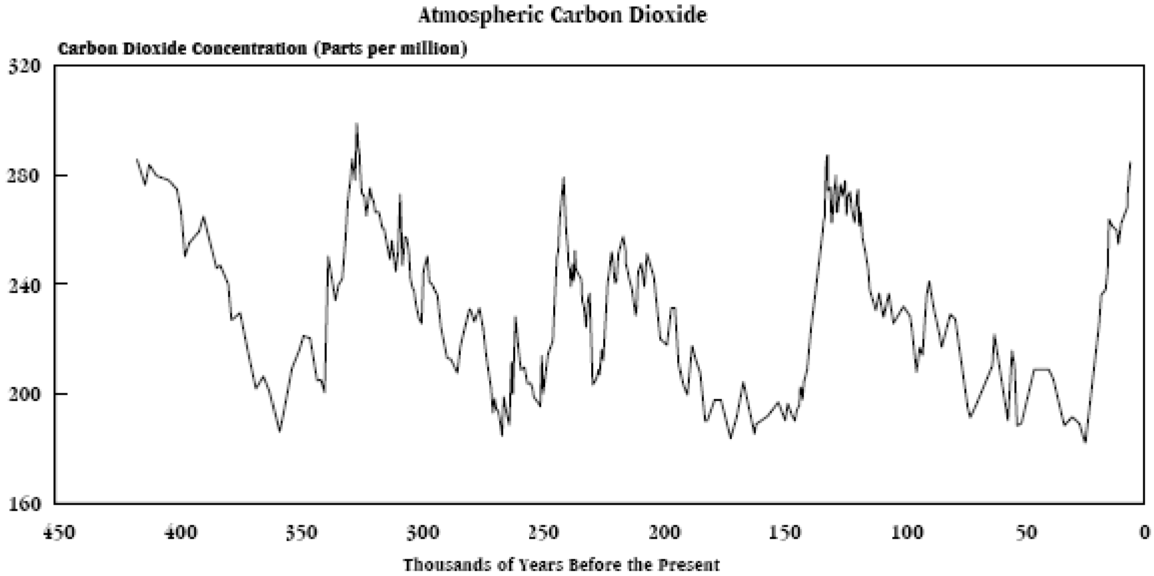
2.1 Climate Change: Global problem

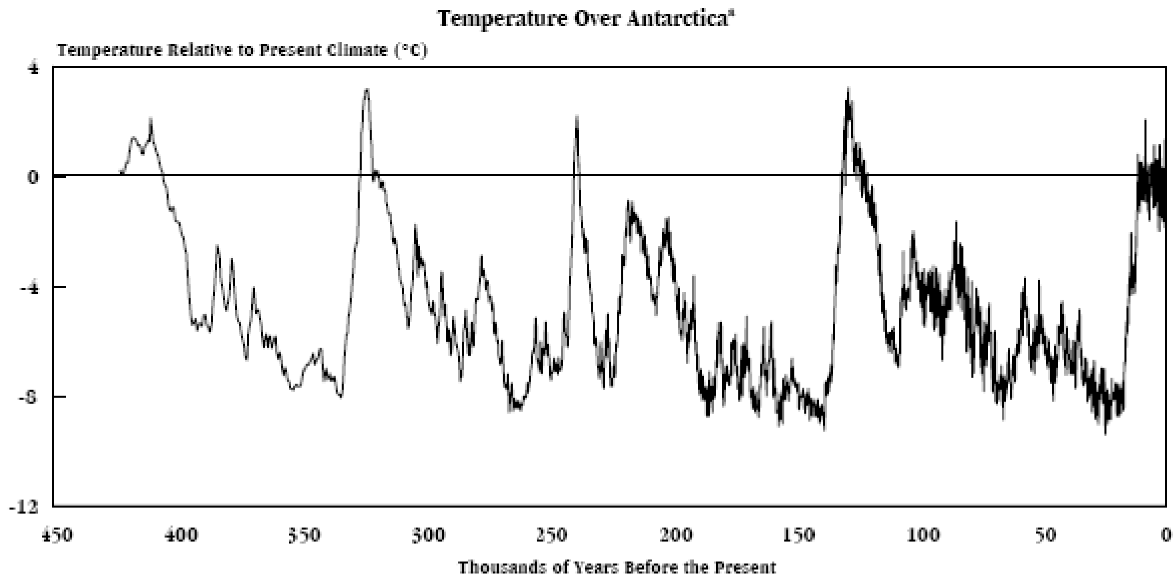
Over the past 150 years, the global mean surface temperature has increased 0.76°C, according to the Intergovernmental Panel on Climate Change [IPCC, 2007]. **Global warming has caused greater climatic volatility—such as changes in precipitation patterns and increased frequency and intensity of extreme weather events**—and has led to a rise in mean global sea levels. It is widely believed that climate change is largely the result of anthropogenic greenhouse gas (GHG) emissions and, if no action is taken, it is likely to intensify in the years to come. Under a high emissions scenario developed by [IPCC, 2001], by the end of this century, the global mean temperature increase—from the 1980–1999 levels—could reach 4°C, with a range from 2.4°C to 6.4°C (Figure 2.1). This would have serious consequences for the world's growth and development. Climate change is a global problem and requires a global solution. In recent years, addressing climate change has been high on the international policy agenda. There is now a consensus that to prevent global warming from reaching dangerous levels, action is needed to control and mitigate GHG emissions and stabilize their atmospheric concentration within a range of 450–550 parts per million (ppm) [IPCC, 2007]. The lower bound is widely considered a desirable target and the upper bound a minimum necessary level of mitigation [STERN, 2007].

The international community is now working toward an international climate regime under the United Nations Framework Convention on Climate Change (UNFCCC) that aims to stabilize GHG atmospheric concentration and provide a long-term solution to the climate change problem through international cooperation based on the principle of common but differentiated responsibility. While the responses of the major current and future GHG-emitting economies under the UNFCCC hold the key, a successful global solution requires the participation of all countries, developed and developing. While GHG mitigation is essential to preventing global warming from reaching dangerous levels, climate change adaptation is critical to reducing and minimizing the costs, often localized, caused by the unavoidable impacts of GHG emissions already locked into the climate system. *Adaptation is particularly important for developing countries and their poverty reduction efforts because the poor—with limited adaptive capacity due to low income and poor access to infrastructure, services, and education—are often most vulnerable to climate change. They generally live in geographically vulnerable areas prone to natural hazards, and are often employed in climate-sensitive sectors, particularly agriculture, forestry, and fisheries, with virtually no chance of switching to alternative sources of income* [MANGALA RAI, 2007].

Thus climate change adaptation, by building adaptive capacity, **taking specific adaptation actions in key climate-sensitive sectors, and assisting the poor to cope with climate change impacts, should be a critical part of the development and poverty reduction strategies of every developing country**.

2.1. Figure: Atmospheric carbon dioxide concentration (ppmv) and temperature change (°C)





Note: Observed during the past 160 thousand years and predicted during the next 10 thousand years. Historical carbon dioxide data was collected from Antarctic ice cores; temperature changes through time are relative to the present temperature. Graph adapted from the Whitehouse Initiative on Global Climate Change.
Source: IPCC, 2007

2.2 Effects of Climate Change

2.2.1 Effects on Economy

Understanding the scientific evidence for the human influence on climate is an essential starting point for the economics, both for establishing that there is indeed a problem to be tackled and for comprehending its risk and scale. It is the science that dictates the type of economics and where the analyses should focus, for example, on the economics of risk, the nature of public goods or how to deal with externalities, growth and development and intra- and inter-generational equity [STERN, 2007].

Climate change is a result of the externality associated with greenhouse-gas emissions – it entails costs that are not paid for by those who create the emissions. It has a number of features that together distinguish it from other externalities:

- *It is global in its causes and consequences;*
- *The impacts of climate change are long-term and persistent;*
- *Uncertainties and risks in the economic impacts are pervasive.*
- *There is a serious risk of major, irreversible change with non-marginal economic effects.*

These features shape the economic analysis:

- It must be global, deal with long time horizons, have the economics of risk and uncertainty at its core, and examine the possibility of major, non-marginal changes.
- The impacts of climate change are very broad ranging and interact with other market failures and economic dynamics, giving rise to many complex policy problems. Ideas and techniques from most of the important areas of economics, including many recent advances, have to be deployed to analyse them. The breadth, magnitude and nature of impacts imply that several ethical perspectives, such as those focusing on welfare, equity and justice, freedoms and rights, are relevant. Most of these perspectives imply that the outcomes of climate-change policy are to be understood in terms of impacts on consumption, health, education and the environment over time but different ethical perspectives may point to different policy recommendations.
- Questions of intra- and inter-generational equity are central. Climate change will have serious impacts within the lifetime of most of those alive today. Future generations will be even more strongly affected, yet they lack representation in present-day decisions.
- Standard externality and cost-benefit approaches have their usefulness for analysing climate change, but, as they are methods focused on evaluating marginal changes, and generally abstract from dynamics and risk, they can only be starting points for further work.
- Standard treatments of discounting are valuable for analysing marginal projects but are inappropriate for non-marginal comparisons of paths; the approach to discounting must meet the challenge of assessing and comparing paths that have very different trajectories and involve very long-term and large inter-generational impacts.

The severity of the likely consequences and the application of the above analytical approaches form the basis of powerful arguments; develop in this thesis, in favour of strong and urgent global action to reduce greenhouse-gas emissions, and of major action to adapt to the consequences that now cannot be avoided.

The prospect of global climate change has emerged as a major scientific and public policy issue. Scientific studies indicate that accumulated carbon dioxide (CO_2) emitted from the burning of fossil fuels, along with contributions from other human-induced greenhouse gas emissions, is leading to warmer surface temperatures. Possible current-century consequences of this temperature increase include increased frequency of extreme temperature events (such as heat waves), heightened storm intensity, altered precipitation patterns, sea-level rise, and reversal of ocean currents. These changes, in turn, can have significant effects on the functioning of ecosystems, the viability of wildlife, and the well-being of humans.

There is considerable disagreement within and among nations as to what policies, if any, should be introduced to mitigate and perhaps prevent climate change and its various impacts. Despite the disagreements, in recent years we have witnessed the gradual emergence of a range of *international and domestic climate change policies, including emissions trading programs, emissions taxes, performance standards, and technology promoting programs*.

As noted, the potential consequences of climate change include increased average temperatures, greater frequency of extreme temperature events, altered precipitation patterns, and sea level rise. These biophysical changes affect human welfare. While the distinction is imperfect, economists divide the (often negative) welfare impacts into two main categories: market and non-market damages.

Market damages. As the name suggests, market damages are the welfare impacts stemming from changes in prices or quantities of marketed goods. Changes in productivity typically underlie these impacts. Often researchers have employed climate-dependent production functions to model these changes, specifying wheat production, for example, as a function of climate variables such as temperature and precipitation. In addition to agriculture, this approach has been applied in other industries, including forestry, energy services, water utilities, and coastal flooding from sea level rise [MANSUR, MENDELSSOHN AND MORRISON, 2005].

The production function approach tends to ignore possibilities for substitution across products, which motivates an alternative, hedonic approach [MENDELSOHN, NORDHAUS AND SHAW, 1994; SCHLENKER, FISHER AND HANEMANN, 2005]. Applied to agriculture, the hedonic approach aims to embrace a wider range of substitution options, employing cross-section data to examine how geographical, physical, and climate variables are related to the prices of agricultural land. On the assumption that crops are chosen to maximize rents, that rents reflect the productivity of a given plot of land relative to that of marginal land, and that land prices are the present value of land rents, the impact of climate variables on land prices is an indicator of their impact on productivity after crop-substitution is allowed for.

Non-market damages. Non-market damages include the direct utility loss stemming from a less hospitable climate, as well as welfare costs attributable to lost ecosystem services or lost biodiversity. For these damages, revealed-preference methods face major challenges because non-market impacts may not leave a "behavioural trail" of induced changes in prices or quantities that can be used to determine welfare changes. The loss of biodiversity, for example, does not have any obvious connection with price changes or observable demands. Partly because of the difficulties of revealed-preference approaches in this context, researchers often employ stated-preference or interview techniques—most notably the contingent valuation method—to assess the willingness to pay to avoid non-market damages [SMITH, 2004].

2.2.2 Cost Assessment

The costs of avoiding emissions of carbon dioxide, the principal greenhouse gas, depend on substitution possibilities on several margins: *the ability to substitute across different fuels* (which release different amounts of carbon dioxide per unit of energy); *to substitute away from energy in general in production*; and *to shift away from energy-intensive goods*. The greater the potential for substitution, the lower the costs of meeting a given emissions-reduction target.

Applied models have taken two main approaches to assessing substitution options and costs. One approach employs "bottom-up" energy technology models with considerable detail on the technologies of specific energy processes or products. These models tend to concentrate on one sector or a small group of sectors and offer less information on abilities to substitute from energy in general or on how changes in the prices of energy-intensive goods affect intermediate and final demands for those goods.

The other approach employs "top down," economy-wide models, which include, but are not limited to, computable general equilibrium models [CONRAD, 2002]. An attraction of these models is their ability to trace relationships between fuel costs, production methods, and consumer choices throughout the economy in an internally consistent way. However, they tend to include much less detail on specific energy processes or products. Substitution across fuels generally is captured through smooth production functions rather than through explicit attention to alternative discrete processes. In recent years, attempts have been made to reduce the gap between the two types of models. Bottom-up models have gained scope, and top-down models have incorporated greater detail [MCFARLAND, REILLY AND HERZOG, 2004].

Because climate depends on the atmospheric stock of greenhouse gases and because for most gases the residence times in the atmosphere are hundreds (and in some cases, thousands) of years, climate change is an inherently long-term problem and assumptions about technological change are particularly important. The modelling of technological change has advanced significantly beyond the early tradition that treated technological change as exogenous. Several recent models allow the rate or direction of technological progress to respond endogenously to policy interventions. Some models focus on R&D-based technological change, incorporating connections between policy interventions, incentives to research and development, and advances in knowledge [POPP, 2004]. Others emphasize learning-by-doing-based technological change, where production costs fall with cumulative output in keeping with the idea that cumulative output is associated with learning [MANNE AND RICHELS, 2004]. Allowing for policy-induced technological change tends to yield lower (and sometimes significantly lower) assessments of the costs of reaching given emissions-reduction targets than do models in which technological change is exogenous.

2.2.3 Uncertainty and the Stringency of Climate Policy

Increasingly sophisticated numerical models have attempted to deal explicitly with these substantial uncertainties regarding costs and benefits. Some provide an uncertainty analysis using Monte Carlo simulation, in which the model is solved repeatedly, each time using a different set of parameter values that are randomly drawn from pre-assigned probability distributions. This approach produces a probability distribution for policy outcomes that sheds light on appropriate policy design in the face of uncertainty. Other models incorporate uncertainty more directly by explicitly optimizing over uncertain outcomes. These models typically call for a more aggressive climate policy than would emerge from a deterministic analysis. [NORDHAUS, 1994] employs an integrated climate–economy model to compare the optimal carbon tax in a framework with uncertain parameter values with the optimal tax when parameters are set at their central values. In this application, an uncertainty premium arises: the optimal tax is more than twice as high in the former case as in the latter, and the optimal amount of abatement is correspondingly much greater. The higher optimal tax could in principle be due to uncertainty about any parameter whose relationship with damages is convex, thus yielding large downside risks relative to upside risks. In the Nordhaus model, the higher optimal tax stems primarily from uncertainty about the discount rate.

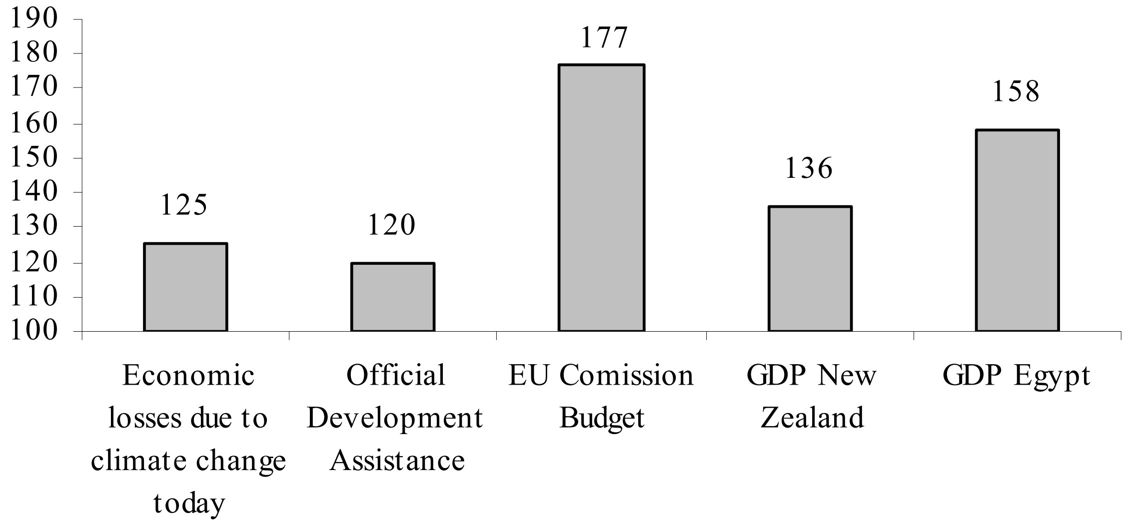
Climate change economics has produced new methods for evaluating environmental benefits, for determining costs in the presence of various market distortions or imperfections, for making policy choices under uncertainty, and for allowing flexibility in policy responses. Although major uncertainties remain, it has helped generate important guidelines for policy choice that remain valid under a wide range of potential empirical conditions. It also has helped focus empirical work by making clear where better information about key parameters would be most valuable.

Clearly, many theoretical and empirical questions remain unanswered. Scientists suggest (with some subjectivity) that there is a particularly strong need for advances in the integration of emissions policy and technology policy, in defining baselines that determine the extent of offset activities outside a regulated system, and in fostering international cooperation. From 2003 until 2030, the world is poised to invest an estimated $16 trillion in energy infrastructure, with annual carbon dioxide emissions estimated to rise by 60 percent. How well economists answer important remaining questions about climate change could have a profound impact on the nature and consequences of that investment [PETER HOPPE, 2007].

2.2.4 The overall Economic Cost of Climate Change (ECCC)

In 2006, Nicholas Stern published a report, which estimated the long term economic costs of climate change, the initiation of adaptation—steps to reduce the effects of climate change has been delayed until 2010 amid criticism that the Stern model assumed too early investment in adaptation in developing countries. Furthermore, *Nicholas Stern* has acknowledged that the model does not fully capture the effect of weather-related disasters. This is supported by *Professor Ross Garnaut's report*, commissioned by the Australian government, on the impacts of weather-related climate change effects in Australia. Therefore, additional losses from natural disasters caused by climate change have been included in the model. The new results obtained are higher than in the original Stern model and in line with Stern's recent recognition that the Stern review underestimated the degree of damages and the risks of climate change. For equity purposes and based on expert recommendations, the weight on poorer countries have been increased in this report to correct for income differentials, i.e. similar incomes across countries is assumed. To put these economic losses into perspective, $125 billion — the mean value of the calculation — is higher than the individual GDPs of 73 percent of the world's countries, the same as the total annual Official Development Assistance (the amount of humanitarian and development aid that flows from industrialized countries into developing nations), which was at about $120 billion in 2008 and higher than Afro-Asian trade which is expected to reach $100 billion in 2010. These losses are also more than four times higher than the average estimated annual adaptation funding gap for developing nations. The losses include asset values destroyed by weather-related disasters and sea level rise, lost income due to reduced productivity, and the costs of reduced health or injury. Figure 2.2 below shows the economic losses compared to other economic outcomes [PETER HOPPE, 2007].

2.2. Figure: Comparing economic losses with other important economic outcomes
USD billion, economic losses: today/annual average



Source: OECD, 2008b

2.3 Effect on Social and Public life

Climate change leaves over 300,000 people dead, 325 million people seriously affected, and economic losses of US$125 billion. Four billion people are vulnerable, and 500 million people are at extreme risk. These already alarming figures may prove too conservative. Weather-related disasters alone cause significant economic losses. Over the past five years this toll has gone as high as $230 billion, with several years around $100 billion and a single year around $50 billion. Such disasters have increased in frequency and severity over the past 30 years in part due to climate change. Over and above these cost are impacts on health, water supply and other shocks not taken into account. Some would say that the worst years are not representative and they may not be. But scientists expect that years like these will be repeated more often in the near future [IPCC, 2007].

Climate change already has a severe human impact today, but it is a silent crisis — it is a neglected area of research as the climate change debate has been heavily focused on physical effects in the long-term. The human impact issues: climate change, therefore, breaks new ground. It focuses on human impact rather than physical consequences. It looks at the increasingly negative consequences that people around the world face as a result of a changing climate. Rather than focusing on environmental events in 50-100 years, the issues takes a unique social angle. It seeks to highlight the magnitude of the crisis at hand in the hope to steer the debate towards urgent action to overcome this challenge and reduce the suffering it causes. The human impact of climate change is happening right now — it requires urgent attention. Events like weather-related disasters, desertification and rising sea levels, exacerbated by climate change, affect individuals and communities around the world. They bring hunger, disease, poverty, and lost livelihoods — reducing economic growth and posing a threat to social and, even, political stability. Many people are not resilient to extreme weather patterns and climate variability. They are unable to protect their families, livelihoods and food supply from negative impacts of seasonal rainfall leading to floods or water scarcity during extended droughts. Climate change is multiplying these risks.

Today, we are at a critical juncture – just months prior to the Copenhagen summit where negotiations for a post-2012 climate agreement must be finalized. Negotiators cannot afford to ignore the current impact of climate change on human society. The responsibility of nations in Copenhagen is not only to contain a serious future threat, but also to address a major contemporary crisis. The urgency is all the more apparent since experts are constantly correcting their own predictions about climate change, with the result that climate change is now considered to be occurring more rapidly than even the most aggressive models recently suggested. The unsettling anatomy of the human impact of climate change cannot be ignored at the negotiating tables.

2.3.1 The human impact of climate change

Climate change affects human health, livelihoods, safety, and society. To assess the human impact of climate change, this overview looks at people hit by weather-related disasters such as floods, droughts and heat waves as well as those seriously affected by gradual environmental degradation such as desertification and sea level rise. The human impact is still difficult to assess with great accuracy because it results from a complex interplay of factors. It is challenging to isolate the human impact of climate change definitively from other factors such as natural variability, population growth, land use and governance. *In several areas, the base of scientific evidence is still not sufficient to make definitive estimates with great precision on the human impacts of climate change*. However, data and models do exist which form a robust starting point for making estimates and projections that can inform public debate, policy-making and future research.

Intensified research on the human impact of climate change is imperative

The need to continue to press for increased precision in estimates presents a rallying cry for investment in research on the social implications of climate change. There are particularly three areas requiring more research:

- The attribution of weather-related disasters to climate change, as no consensus estimate of the global attribution has yet been made;
- Estimate of economic losses today, as the current models are forward looking;
- Regional analysis, as the understanding of the human impact at regional level is often very limited but also crucial to guide effective adaptation interventions.

The true human impact is likely to be far more severe than estimated which are very conservative for four main reasons:

1. The climate change models used as the basis for these estimates are considered credible, but are based on IPCC climate scenarios which have proven to be too conservative. Recent evidence suggests that important changes in climate are likely to occur more rapidly and be more severe than the IPCC assessments made nearly two years ago. In many key areas, the climate system is already moving beyond its traditional patterns. The estimates may also be considered conservative as potential large scale tipping point events, such as the rapid melting of the Greenland ice sheet and the shutdown of the Gulf Stream, which would have dire consequences have not been included in the estimation, they are unlikely to happen within the next 20 years. However, it is important to note that critical tipping points have already been crossed [IPCC, 2007], including the loss of the Arctic summer ice in 2007 and the devastating forest fires in Borneo, which may be a combined effect of deforestation and climate change.

2. The most powerful consequences of climate change arise when a chain reaction magnifies the effects of rising temperatures. Think of a region suffering from water scarcity. That scarcity reduces the amount of arable land and thereby aggravates food security.
3. The reduced crop production results in loss of income for farmers and may bring malnutrition. Health issues arise that could further diminish economic activity as family members become too weak to work. With time, worsening environmental conditions combined with financial instability may force populations to migrate. Migration can then become a catalyst for social unrest if increased population density in the place of refuge causes resource scarcity. Population growth exacerbates the impact of climate change by increasing human exposure to environmental stresses. For example, as population grows, more people are expected to live near the coast and the amount of resources such as food available per person declines.
4. Climate change aggravates existing problems. Many people today are not resilient to current weather patterns and climate variability, which is to say that they are unable to protect their families, livelihoods and food supply from the negative impacts of seasonal rainfall leading to floods or water scarcity during extended droughts. Climate change will multiply these risks. For example, as the international community struggles to reduce hunger-related deaths, a warmer, less predictable climate threatens to further compromise agricultural production in the least developed countries, thereby increasing the risk of malnutrition and hunger.

Global data on climate change has many gaps and uncertainties. As a result estimates may not capture the full range of potential indirect impacts and chain reactions. Scientists will often be inclined or forced to make conservative estimates when confronted with such uncertainties. The definition of “being seriously affected” by climate change includes someone in need of immediate assistance in the context of a weather-related disaster or whose livelihood is significantly compromised. This condition can be temporary, where people have lost their homes or been injured in weather-related disasters, or permanent, where people are living with severe water scarcity, are hungry or suffering from diseases such as diarrhoea and malaria. A couple of examples can illustrate the significance of this number. The impact of climate change today affects 13 times the number injured in traffic accidents globally every year and more people than the number of people who contract malaria annually, which it incidentally is also suggested to increase. An estimated 325 million people are seriously affected by climate change every year. This estimate is derived by attributing a 40 percent proportion of the increase in the number of weather-related disasters from 1980 to current to climate change and a 4 percent proportion of the total seriously affected by environmental degradation based on negative health outcomes [IPCC, 2007].

2.3.2 The social cost of climate change (SCCC)

Carbon dioxide resides over hundreds if not thousands of years in the atmosphere. In fact recent studies show that after 100 years almost 30 percent of the original CO_2 still remains in the atmosphere, after 1000 years about 20 percent. Therefore, the carbon emitted today has long lasting implications and the social cost will be far higher than the impact felt today. The USD 1 trillion social cost of climate change is conservative as it is based on the assumption that the CO_2 emitted today will only reside 100 years in the atmosphere. The Social Cost of Carbon Dioxide ($SCCO_2$) is a monetary indicator of the global damage done over time by the emission of one extra ton of carbon today, discounted to present value. In cost-benefit analyses of projects to control greenhouse gas emissions, the $SCCO_2$ is employed to measure the financial value of the damages avoided, and therefore the benefit of the mitigation project.

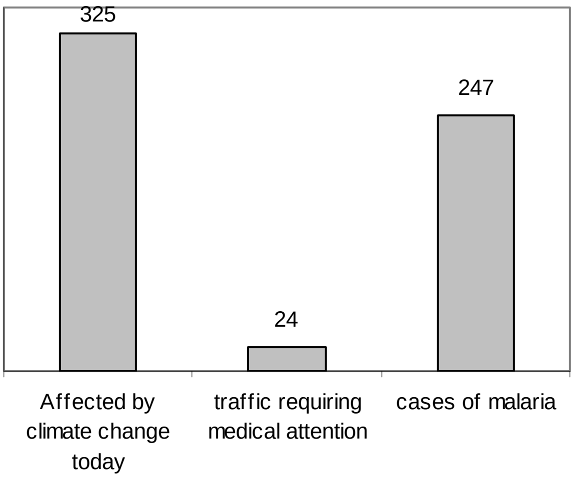
The larger the $SCCO_2$, the more attractive is investment in greenhouse gas emissions reductions. The carbon dioxide emitted globally in 2004, for example, carries a social cost of over $1300 billion, a figure greater than 2 percent of global GDP in 2008 [OECD, 2008a].

Through a complex set of effects, climate change impacts human health, livelihoods, safety, and society:

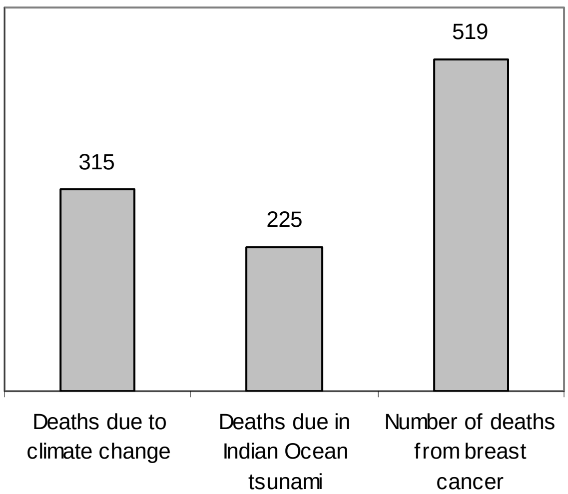
- *Food security*: More poor people, especially children, suffer from hunger due to reduced agricultural yield, livestock and fish supply as a result of environmental degradation.
- *Health*: Health threats like diarrhoea, malaria, asthma and stroke affect more people when temperatures rise.
- *Poverty*: Livelihoods are destroyed when income from agriculture, livestock, tourism and fishing is lost due to weather-related disasters and desertification.
- *Water*: Increased water scarcity results from a decline in the overall supply of clean water and more frequent and severe floods and droughts.
- *Displacement*: More climate-displaced people are expected due to sea level rise, desertification and floods.
- *Security*: More people live under the continuous threat of potential conflict and institutional break down due to migration, weather-related disaster and water scarcity.

2.3. Figure: Comparing human impact of climate change today with other global challenges

Number of People affected by climate change
Million, today/annual average, 2004-08

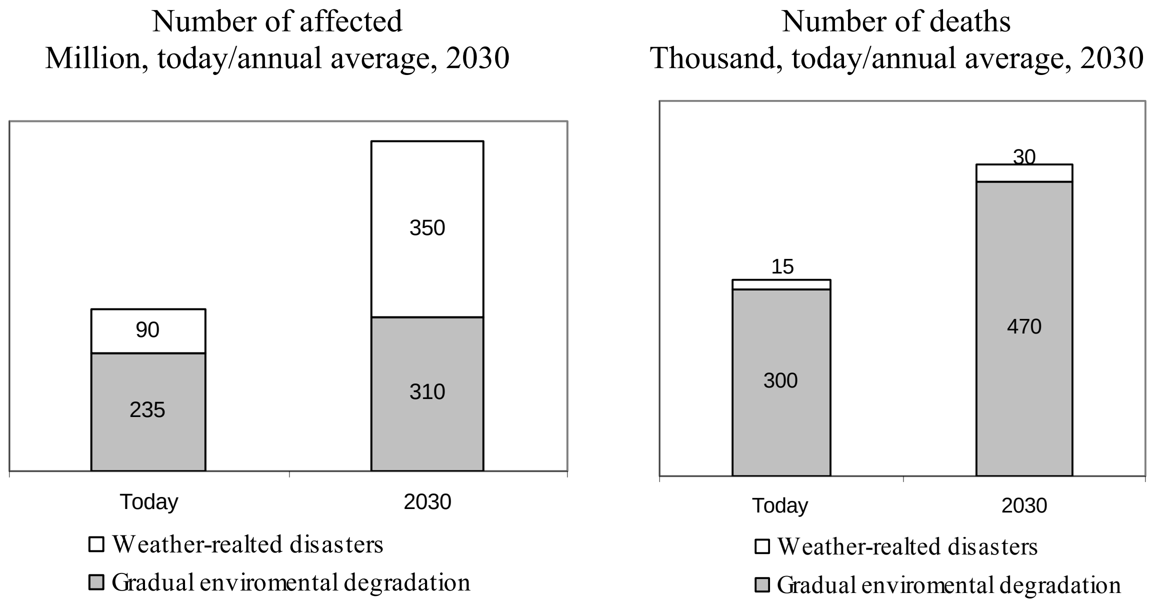


Number of death due to climate change
Thousand today/annual average, 2004-08



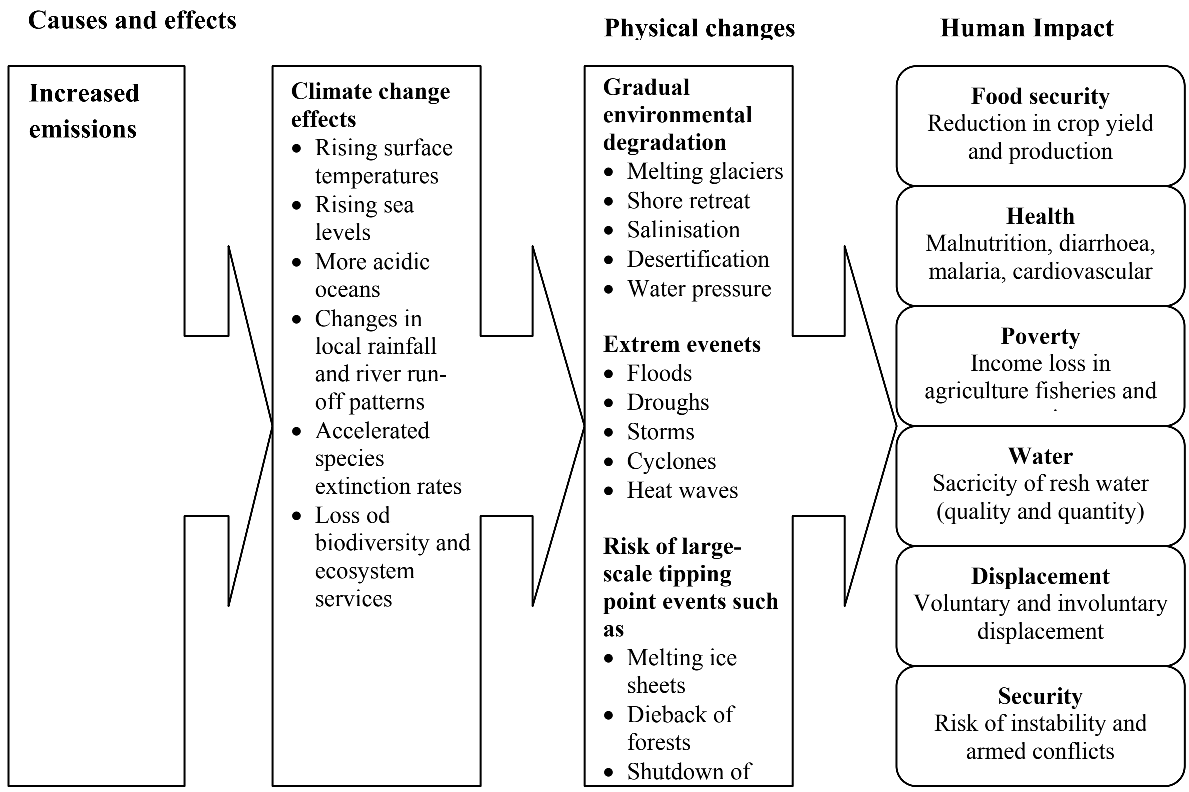
Source: OECD, 2008b

2.4. Figure: The impact of climate change is accelerating over the next 20 years



Source: OECD, 2008b

2.5. Figure: The links from increased emissions to human impact



Source: OECD, 2008b

2.4 Effect on Ecosystem Services

Searches have revealed a disappointingly small set of attempts to measure and value these services. The first chronologically is the quantification of global ecosystem services by [CONSTANZA ET AL, 1997]. Estimates were extracted from the literature of values based on willingness to pay for a hectare's worth of each of the services. These were all expressed in 1994 US$ per hectare, there was some attempt to adjust these values across regions by purchasing power. The results were that central estimate of the total value of annual global flows of ecosystem services in the mid 1990s was $33 trillion (i.e. 10^{12}) the range was thought to be US$ 16 – 54 trillion. To put their figure into some kind of context, their central estimate was 1.8 times bigger than global Gross Domestic Product (GDP) at that time. We should take the figures only as the roughest of approximations – indeed the authors warn of the huge uncertainties involved in making calculations of this kind.

Another study, "Millennium Ecosystem Assessment" (MA), found that over the second half of the 20th Century human capacity to exploit ecosystems has increased dramatically to meet rapidly growing demands for food, fresh water, timber, fiber and fuel, which has resulted in a substantial and largely irreversible loss in biodiversity of life on Earth. The benefits of these developments have been unevenly distributed and they are causing uncomfortable tradeoffs amongst the services provided by ecosystems [UNITED NATIONS, 2003].

The findings of "The ecosystems and human well-being – biodiversity synthesis" have established the importance of biodiversity in associated environmental or ecosystem services to human-wellbeing [Reid, et al., 2005]. The report is based on the findings of the Millennium Ecosystem Assessment (MA) and supports the goals of improving the management of the world's ecosystems, improving the information used by policy makers, and building human and institutional capacity to conduct integrated assessments. The challenge of sustainably managing ecosystems for human well-being needs to be met through institutions at multiple scales – there is no single critical scale. Local, national, regional and international institutions have a unique role to play in understanding and managing ecosystems for people. Ecosystems provide many tangible benefits or "ecosystem services" to people around the world.

The "Stern Review" parallels the TEEB (see later) study into the economics of climate change [STERN, 2006]. Climate change could have very serious impacts on growth and development. The costs of stabilizing the climate are significant but manageable; delay would be dangerous and much more costly. The review estimates that if we don't act, the overall costs and risks of climate change will be equivalent to losing at least 5% of global GDP each year, now and forever. In contrast, the costs of action – reducing greenhouse gas emissions to avoid the worst impacts of climate change – can be limited to around 1% of global GDP each year. Key to understanding the conclusions is that as forests decline, nature stops providing services which it used to provide essentially for free. So the human economy either has to provide them instead, perhaps through building reservoirs, building facilities to sequester carbon dioxide, or farming foods that were once naturally available.

"World Wildlife Fund's Living Planet Report" demonstrates that mankind is living way beyond the capacity of the environment to supply us with services and to absorb our waste [WWF, 2008]. They express this using the concepts of ecological footprints and biocapacity, each expressed per hectare per person[2]. Humanity's footprint first exceeded global biocapacity in 1980 and the overshoot has been increasing ever since. In 2005 they calculated

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[2] The Ecological Footprint "measures the amount of biologically productive land and water area required to produce the resources an individual, population or activity consumes and to absorb the waste it generates, given prevailing technology and resource management." [WWF, 2008]

the global footprint on average across the world was 2.7 global hectares (gha) per person[3] compared to a biocapacity they calculated as 2.1 gha/person, a difference of 30%. That is each person on earth, on average is consuming 30% more resources and waste absorption capacity than the world can provide. We are therefore destroying the earth's capacity and compromising future generations.

The study on "The Economics of Ecosystems and Biodiversity" (TEEB) is fundamentally about the struggle to find the value of nature. Calculations show that the global economy is losing more money from the disappearance of forests than through the current banking crisis as forest decline could be costing about 7% of global GDP**.** It puts the annual cost of forest loss at between $2 trillion and $5 trillion. The figure comes from adding the value of the various services that forests perform, such as providing clean water and absorbing carbon dioxide. But the cost falls disproportionately on the poor, because a greater part of their livelihood depends directly on the forest, especially in tropical regions. The greatest cost to western nations would initially come through losing a natural absorber of the most important greenhouse gas [EUROPEAN COMMISSION, 2008].

The Global Canopy Programme's report concludes: "If we lose forests, we lose the fight against climate change". International demand has driven intensive agriculture, logging and ranching leading to deforestation. Standing forest was not included in the original Kyoto protocols and stands outside the carbon markets. The inclusion of standing forests in internationally regulated carbon markets could provide cash incentives to halt this disastrous process. Marketing these ecosystem services could provide the added value forests need and help dampen the effects of industrial emissions. Those countries wise enough to have kept their forests could find themselves the owners of a new billion-dollar industry [PARKER ET AL., 2008].

Currently, there are two paradigms for generating ecosystem service assessments that are meant to influence policy decisions. Under the first paradigm, researchers use broad-scale assessments of multiple services to extrapolate a few estimates of values, based on habitat types, to entire regions or the entire planet [COSTANZA ET AL. 1997]. This "benefits transfer" approach incorrectly assumes that every hectare of a given habitat type is of equal value – regardless of its quality, rarity, spatial configuration, size, proximity to population center's, or the prevailing social practices and values. Furthermore, this approach does not allow for analyses of service provision and changes in value under new conditions. In contrast, under the second paradigm for generating policy-relevant ecosystem service assessments, researchers carefully model the production of a single service in a small area with an "ecological production function" – how provision of that service depends on local ecological variables [KAISER AND ROUMASSET 2002; RICKETTS ET AL. 2004]. These methods lack both the scope (number of services) and scale (geographic and temporal) to be relevant for most policy questions [NELSON, ET AL., 2009]

Spatially explicit values of services across landscapes that might inform land-use and management decisions are still lacking. Quantifying ecosystem services in a spatially explicit manner, and analyzing tradeoffs between them, can help to make natural resource decisions more effective, efficient, and defensible [NELSON, AT AL., 2009]. Both the costs and the benefits of biodiversity-enhancing land-use measures are subject to spatial variation, and the criterion of cost-effectiveness calls for spatially heterogeneous compensation payments [DRECHSLER AND WAETZOLD, 2005]. Cost-effectiveness may also be achieved by paying compensation for results rather than measures. We have to ensure that all the

[3] A global hectare is a hectare with a global average ability to produce resources and absorb wastes

possibilities to create markets to provide environmental services are fully exploited to minimize the public costs (and the extent of government bureaucracy etc).

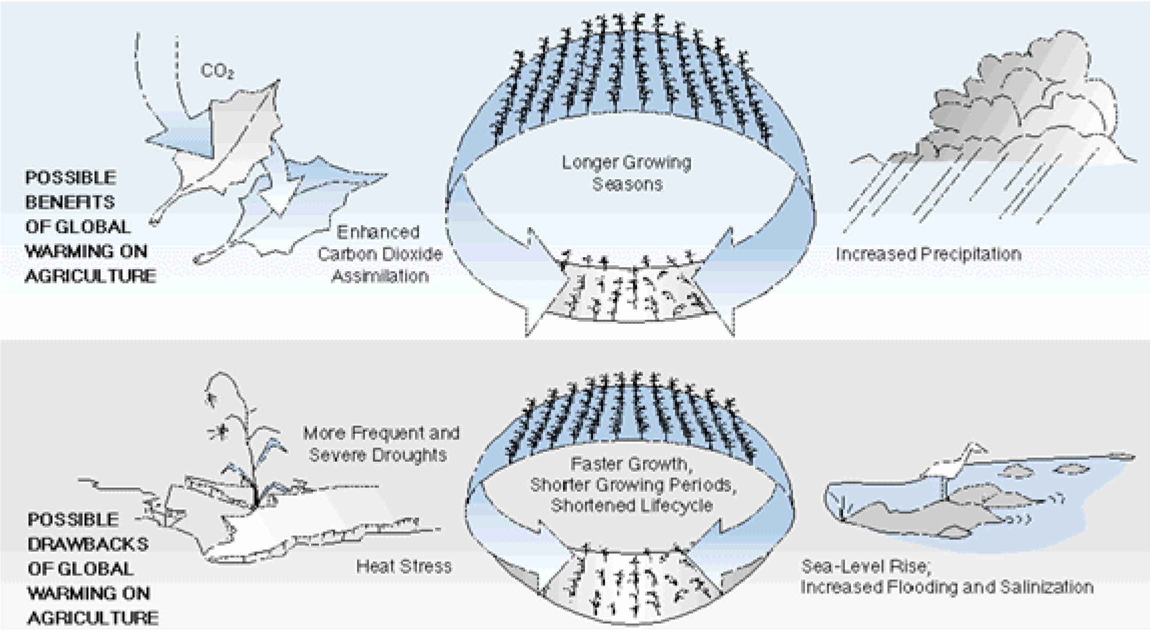
2.5 Effect on Agriculture

It seems obvious that any significant change in climate on a global scale should impact local agriculture, and therefore affect the world's food supply. Considerable study has gone into questions of just how farming might be affected in different regions, and by how much; and whether the net result may be harmful or beneficial, and to whom. Several uncertainties limit the accuracy of current projections. One relates to the degree of temperature increase and its geographic distribution. Another pertains to the concomitant changes likely to occur in the precipitation patterns that determine the water supply to crops, and to the evaporative demand imposed on crops by the warmer climate. There is a further uncertainty regarding the physiological response of crops to enriched carbon dioxide in the atmosphere. The problem of predicting the future course of agriculture in a changing world is compounded by the fundamental complexity of natural agricultural systems, and of the socioeconomic systems governing world food supply and demand [ABILDTRUP ET AL 2006].

What happens to the agricultural economy in a given region, or country, or county, will depend on the interplay of the set of dynamic factors specific to each area. Scientific studies, typically based on computer models, have for some time examined the effects of postulated climate and atmospheric carbon dioxide changes on specific *agroecosystems*-a now common term that defines the interactive unit made up of a crop community, such as a field of wheat or corn, and its biophysical environment. We have more recently gone a step farther by developing methods to study these systems in more integrated regional and global contexts. Both biophysical and socioeconomic processes are taken into account in these integrated studies, since agricultural production is a player in both worlds: it is very much dependent upon environmental variables and is in turn an important agent of environmental change and a determinant of market prices [FARKAS-FEKETE AND SINGH, 2008].

Climate change presents crop production with prospects for both benefits and drawbacks, some of which are shown schematically in Figure 2.6. To address any of them more clearly we must first define the main interactions that link a chain of processes together: food is derived from crops (or from animals that consume crops); crops in turn grow in fields, which exist in farms, which are components of farming communities, which are sectors in nation states, and which ultimately take part in the international food trade system. Understanding the potential impacts of global environmental change on this sequence of interlocking elements is a first step in modelling what will happen when any one of them is changed as a result of possible global warming, and a prerequisite for defining appropriate societal responses. In my dissertation, I used the possible methodology to predict these effects statistically in India.

2.6. Figure: Possible benefits and drawbacks of climate change on agriculture, based on an illustration in *Scientific American*, March, 1994.



Source: Abildtrup et al, 2006

2.5.1 Effects of elevated CO_2 on crop growth

Plants grow through the well-known process of *photosynthesis*, utilizing the energy of sunlight to convert water from the soil and carbon dioxide from the air into sugar, starches, and cellulose – the *carbohydrates* that are the foundations of the entire food chain. CO_2 enters a plant through its leaves. Greater atmospheric concentrations tend to increase the difference in partial pressure between the air outside and inside the plant leaves, and as a result more CO_2 is absorbed and converted to carbohydrates. Crop species vary in their response to CO_2. Wheat, rice, and soybeans belong to a physiological class (called *C3 plants*) that respond readily to increased CO_2 levels. Corn, sorghum, sugarcane, and millet are *C4 plants* that follow a different pathway. The latter, though more efficient photosynthetically than C3 crops at present levels of CO_2, tend to be less responsive to enriched concentrations. Thus far, these effects have been demonstrated mainly in controlled environments such as growth chambers, greenhouses, and plastic enclosures. Experimental studies of the long-term effects of CO_2 in more realistic field settings have not yet been done on a comprehensive scale [SINGH AND DOBO, 2007].

Higher levels of atmospheric CO_2 also induce plants to close the small leaf openings known as *stomates* through which CO_2 is absorbed and water vapour is released. Thus, under CO_2 enrichment crops may use less water even while they produce more carbohydrates. This dual effect will likely improve water-use efficiency, which is the ratio between crop biomass and the amount of water consumed. At the same time, associated climatic effects, such as higher temperatures, changes in rainfall and soil moisture, and increased frequencies of extreme meteorological events, could either enhance or negate potentially beneficial effects of enhanced atmospheric CO_2 on crop physiology [DOBO ET AL, 2008].

2.5.2 Effects of higher temperature

In middle and higher latitudes, global warming will extend the length of the potential growing season, allowing earlier planting of crops in the spring, earlier maturation and harvesting, and the possibility of completing two or more cropping cycles during the same season. Crop-producing areas may expand pole ward in countries such as Canada and Russia, although yields in higher latitudes will likely be lower due to the less fertile soils that lie there. Many crops have become adapted to the growing-season day lengths of the middle and lower latitudes and may not respond well to the much longer days of the high latitude summers. In warmer, lower latitude regions, increased temperatures may accelerate the rate at which plants release CO_2 in the process of *respiration*, resulting in less than optimal conditions for net growth. When temperatures exceed the optimal for biological processes, crops often respond negatively with a steep drop in net growth and yield. If night-time temperature minima rise more than do daytime maxima – as is expected from greenhouse warming projections – heat stress during the day may be less severe than otherwise, but increased night-time respiration may also reduce potential yields. Another important effect of high temperature is accelerated physiological development, resulting in hastened maturation and reduced yield [VILLANYI ET AL, 2008].

2.5.3 Available water

Agriculture of any kind is strongly influenced by the availability of water. Climate change will modify rainfall, evaporation, runoff, and soil moisture storage. Changes in total seasonal precipitation or in its pattern of variability are both important. The occurrence of moisture stress during flowering, pollination, and grain-filling is harmful to most crops and particularly so to corn, soybeans, and wheat. Increased evaporation from the soil and accelerated transpiration in the plants themselves will cause moisture stress; as a result there will be a need to develop crop varieties with greater drought tolerance.

The demand for water for irrigation is projected to rise in a warmer climate, bringing increased competition between agriculture – already the largest consumer of water resources in semiarid regions – and urban as well as industrial users. Falling water tables and the resulting increase in the energy needed to pump water will make the practice of irrigation more expensive, particularly when with drier conditions more water will be required per acre. Some land – such as the region of the U.S. supplied by the Ogallala aquifer (including parts of Nebraska, Oklahoma, Texas, Colorado, and New Mexico) – may be taken out of irrigation, following a trend that has already begun, with loss of considerable prior investment. Peak irrigation demands are also predicted to rise due to more severe heat waves. Additional investment for dams, reservoirs, canals, wells, pumps, and piping may be needed to develop irrigation networks in new locations. Finally, intensified evaporation will increase the hazard of salt accumulation in the soil [IPCC, 2007].

Extreme meteorological events, such as spells of high temperature, heavy storms, or droughts, disrupt crop production. Recent studies have considered possible changes in the variability as well as in the mean values of climatic variables. Where certain varieties of crops are grown near their limits of maximum temperature tolerance, such as rice in Southern Asia, heat spells can be particularly detrimental. Similarly, frequent droughts not only reduce water supplies but also increase the amount of water needed for plant transpiration [SINGH ET AL, 2008].

2.5.4 Soil fertility and Erosion

Higher air temperatures will also be felt in the soil, where warmer conditions are likely to speed the natural decomposition of organic matter and to increase the rates of other soil processes that affect fertility. Additional application of fertilizer may be needed to counteract these processes and to take advantage of the potential for enhanced crop growth that can result from increased atmospheric CO_2. This can come at the cost of environmental risk, for additional use of chemicals may impact water and air quality. The continual cycling of plant *nutrients* – carbon, nitrogen, phosphorus, potassium, and sulfur – in the soil-plant-atmosphere system is also likely to accelerate in warmer conditions, enhancing CO_2 and N_2O greenhouse gas emissions [SINGH ET AL, 2007].

Nitrogen is made available to plants in a biologically usable form through the action of bacteria in the soil. This process of *nitrogen fixation*, associated with greater root development, is also predicted to increase in warmer conditions and with higher CO_2, if soil moisture is not limiting. Where they occur, drier soil conditions will suppress both root growth and decomposition of organic matter, and will increase vulnerability to wind erosion, especially if winds intensify. An expected increase in convective rainfall – caused by stronger gradients of temperature and pressure and more atmospheric moisture – may result in heavier rainfall when and where it does occur. Such "extreme precipitation events" can cause increased soil erosion.

2.5.5 Pest and diseases

Conditions are more favorable for the proliferation of insect pests in warmer climates. Longer growing seasons will enable insects such as grasshoppers to complete a greater number of reproductive cycles during the spring, summer, and autumn. Warmer winter temperatures may also allow larvae to winter-over in areas where they are now limited by cold, thus causing greater infestation during the following crop season. Altered wind patterns may change the spread of both wind-borne pests and of the bacteria and fungi that are the agents of crop disease. Crop-pest interactions may shift as the timing of development stages in both hosts and pests is altered. Livestock diseases may be similarly affected. The possible increases in pest infestations may bring about greater use of chemical pesticides to control them, a situation that will require the further development and application of integrated pest management techniques.

2.5.6 Adaptation

A wide variety of adaptive actions may be taken to lessen or overcome adverse effects of climate change on agriculture. At the level of farms, adjustments may include the introduction of later- maturing crop varieties or species, switching cropping sequences, sowing earlier, adjusting timing of field operations, conserving soil moisture through appropriate tillage methods, and improving irrigation efficiency. Some options such as switching crop varieties may be inexpensive while others, such as introducing irrigation (especially high-efficiency, water-conserving technologies), involve major investments. Economic adjustments include shifts in regional production centres and adjustments of capital, labour, and land allocations. For example, trade adjustments should help to shift commodity production to regions where comparative advantage improves; in areas where comparative advantage declines, labour and capital may move out of agriculture into more productive sectors. Studies combining biophysical and economic impacts show that, in general, market adjustments can indeed moderate the impacts of reduced yields [DOBO ET AL, 2007].

A major adaptive response will be the breeding of heat- and drought-resistant crop varieties by utilizing genetic resources that may be better adapted to new climatic and atmospheric conditions. Collections of such genetic resources are maintained in germ-plasm banks; these may be screened to find sources of resistance to changing diseases and insects, as well as tolerances to heat and water stress and better compatibility to new agricultural technologies. Crop varieties with a higher *harvest index* (the fraction of total plant matter that is marketable) will help to keep irrigated production efficient under conditions of reduced water supplies or enhanced demands. Genetic manipulation may also help to exploit the beneficial effects of CO_2 enhancement on crop growth and water use [PERCZE ET AL, 2007].

Recent studies by the National Research Council and other organizations have emphasized the ability of U.S. farming to adapt to changing conditions, since in the past technological improvements have indeed been developed and put into use when needed. The U.S. has substantial agricultural research capabilities and a wide range of adaptation options is currently available to farmers in this country. Hence, insofar as the U.S. is concerned, prospects for agricultural adaptation to climate change appear favourable, assuming water is available. Considerable investments may be needed, however, to utilize soil and water resources more efficiently in a changed climate. Other countries, particularly in the tropics and semi-tropics, are not so well provisioned with respect to both the research base and the availability of investment capital [ABILDTRUP ET AL, 2006].

The potential for adaptation should not lead to complacency. Agricultural adaptation to climatic variation is not now and may never be perfect, and changes in how farmers operate or in what they produce may cause significant disruption for people in rural regions. Indeed, some adaptive measures may have detrimental impacts of their own. For example, were major shifts in crops to be made, as from grain to fruit and vegetable production, farmers may find themselves more exposed to marketing problems and credit crises brought on by higher capital and operating costs. The considerable social and economic costs that can result from large- scale climatic extremes was exemplified by the consequences of the Mississippi River flood of 1993 [ABILDTRUP ET AL, 2006].

While changes in planting schedules or in crop varieties may be readily adopted, modifying the types of crops grown does not ensure equal levels of either food production or nutritional quality. Nor can it guarantee equal profits for farmers. Expanded irrigation may lead to groundwater depletion, soil salinization, and water logging. Increased demand for water by competing sectors may limit the viability of irrigation as an adaptation to climate change. Expansion of irrigation as a response to climate change will be difficult and costly even under the best circumstances. Mounting societal pressures to reduce environmental damage from agriculture will likely foster an increase in protective regulatory policies that can further complicate the process of adaptation [SINGH ET AL, 2007].

Present agricultural institutions and policies in the Europe tend to discourage farm management adaptation strategies, such as altering the mix of crops that are grown. At the policy level, obstacles to change are created by supporting prices of crops that are not well suited to a changing climate, by providing disaster payments when crops fail, and by restricting competition through import quotas. Programs could be modified to expand the flexibility allowed in crop mixes, to remove institutional barriers to the development of water markets, and to improve the basis for crop disaster payments [FEKETE-FARKAS ET AL, 2006].

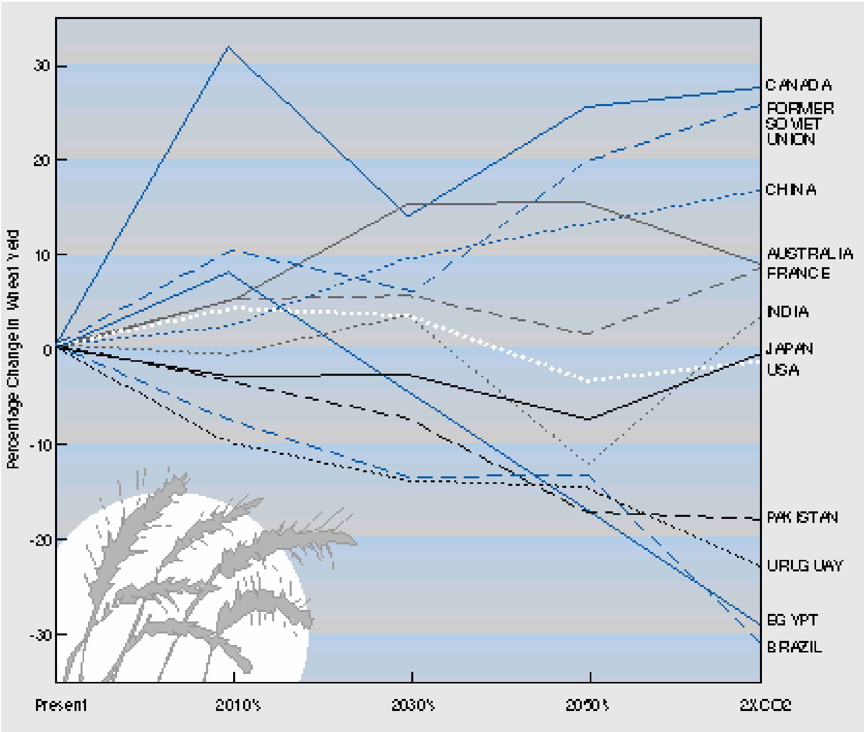
Adaptation cannot be taken for granted: improvements in agriculture have always depended upon on the investment that is made in agricultural research and infrastructure. It would help to identify, through research, the specific ways that farmers now adapt to present variations in climate. Do farmers attempt to compensate for a less favourable climate by applying more fertilizer, more machinery, or more labour? Information of this nature is needed to assess potentialities for coping with more drastic climate change. Success in adapting to possible future climate change will depend on a better definition of what changes will occur where, and on prudent investments, made in timely fashion, in adaptation strategies [SINGH ET AL, 2007].

2.5.7 Regional and Global Assessments

In studying the impacts of climate change, attempts are made to link state-of-the-art models developed by researchers in disparate disciplines – including climatology, agronomy, and economics – in order to project future food supplies. Present global circulation models, or GCMs, calculate the temporal and spatial transports and exchanges of heat and moisture throughout the Earth's surface and atmosphere. These models are used to predict changes in temperature, precipitation, radiation, and other climate variables caused by increases in greenhouse gases in the atmosphere. They are used as well to develop "practice climates" or climate change scenarios for use in impact studies. Crop models then predict the response of specific crops to alternative sets of climate and CO_2 conditions. Results in terms of changed crop yields and water use are then subjected to an economic analysis based on a linked model system of international food trade. Such comprehensive, interdisciplinary research is needed to improve our understanding of the interactive biophysical and socioeconomic effects that may result from global environmental change. At the same time, however, the superposition of model upon model, each with its own range of inaccuracy, amplifies the overall range of uncertainty in the final result.

The GCM-based assessment of the IPCC contemplates a change in global surface temperature of 1.5 to 4.5°C by the year 2050, as a result of enhanced greenhouse gases. While global agricultural production may increase at the lower limit of the predicted range or decrease at the higher limit, global effects measured with current economic valuation techniques are generally predicted to be moderate. The reason is that the world economic system has been generally effective in fostering adaptation to current biophysical constraints on crop production and in realizing opportunities for improving crop production. This macroeconomic perspective, however, speaks only to the averaged global effect and not to specific regional and social impacts. Model studies done to date concur that there will be significant changes in regional agricultural patterns as a result of climate change. All regions are likely to be affected, but some regions will be impacted more adversely than others. The timing of regional effects – which gains or losses when and for how long – will also be complex, as is illustrated in Figure 2.7 in terms of modelled changes in country-by-country wheat yield [AGGARWAL ET AL, 1994,; IPCC, 2007].

2.7. Figure: Calculated change in wheat yield



Note: Yield resulting from a "business as usual" increase in atmospheric CO2 and modelled climate change scenario, as applied to present conditions in the 12 countries shown. Direct effects of CO2 on plant growth and water use are included.
Source: IPCC, 2007

Modelled studies of the sensitivity of world agriculture to potential climate change have suggested that the overall effect of moderate climate change on world food production may be small, as reduced production in some areas is balanced by gains in others. The same studies find, however, that vulnerability to climate change is systematically greater in developing countries – which in most cases are located in lower, warmer latitudes. In those regions, cereal grain yields are projected to decline under climate change scenarios, across the full range of expected warming. Agricultural exporters in middle and high latitudes (such as the U.S., Canada, and Australia) stand to gain, as their national production is predicted to expand, and particularly if grain supplies are restricted and prices rise. Thus, countries with the lowest income may be the hardest hit [AUBINET ET AL, 2000].

Yet, not all impacts in developing countries may be negative. Inland areas located far from sources of precipitation may suffer increased aridity, whereas areas in the path of rain-bearing winds may benefit from increased rainfall. A point that needs to be stressed is that the ability of any country to take advantage of the opportunities and to avoid the drawbacks as climate changes will depend on the availability of adequate resources as well as on the quality of the research base. The presently inadequate capacity of agricultural research systems in the tropics and semi-tropics will need to be rectified, and this task can best be achieved through international cooperation.

2.5.8 Sustainability and Food Security

Agriculture is not a wholly benign actor on the environment, as it causes accelerated soil erosion by water and wind, through cultivation, and often introduces nitrates and other chemicals into water supplies through the application of chemical fertilizers and pesticides. The concept of "sustainable agriculture" endeavours to reduce chemical inputs and energy use in farming systems, in order to minimize environmental damage and to ensure longer-term productivity. Most agricultural assessments of global environmental change made to date have not focused explicitly on sustainability issues, and have neglected the considerable impacts of shifting agricultural zones, alterations in commercial fertilizer and pesticide use, and changes in the demand for water resources [BARRETT, 2003].

Climate change can impact agricultural sustainability in two interrelated ways: first, by diminishing the long-term ability of agro ecosystems to provide food and fibres for the world's population; and second, by inducing shifts in agricultural regions that may encroach upon natural habitats, at the expense of floral and faunal diversity. Global warming may encourage the expansion of agricultural activities into regions now occupied by natural ecosystems such as forests, particularly at mid- and high-latitudes. Forced encroachments of this sort may thwart the processes of natural selection of climatically-adapted native crops and other species. [KRUGMAN, 2009]

While the overall, global impact of climate change on agricultural production may be small, regional vulnerabilities to food deficits may increase, due to problems of distributing and marketing food to specific regions and groups of people. For subsistence farmers and more so for people who now face a shortage of food, lower yields may result not only in measurable economic losses, but also in malnutrition and even famine [DEBROY AND SHAH, 2003].

2.5.9 Agriculture as Greenhouse gas contributor

The role of climate as a determinant of agriculture has long been recognized. It is only in the last decade, however, that the reciprocal effect has come to light: the role of agriculture as a potential contributor to climate change. Clearing forests for fields, burning crop residues, submerging land in rice paddies, raising large herds of cattle and other ruminants and fertilizing with nitrogen, all release greenhouse gases to the atmosphere. The main gases emitted are CO_2, CH_4, and N_2O. From about 1700 to 1900, the clearing of northern hemisphere forests for agriculture was the largest agent of change in the carbon cycle. Emissions from agricultural sources are believed to account for some 15% of today's anthropogenic greenhouse gas emissions. Land use changes, often made for agricultural purposes, contribute another 8% or so to the total. As a result, agriculture ranks third after energy consumption (which is also in part agricultural) and chlorofluorocarbon production as a contributor to the enhanced greenhouse effect [IPCC, 2007].

Emissions of greenhouse gases from agricultural sources are likely to increase in the years ahead, given the necessity to expand food production in order to provide for the world's growing population. This imposes a task upon agricultural researchers to devise ways to continue improving yields while at the same time holding down emissions. Some possible improvements include reducing land- clearing and biomass burning in the tropics; managing rice paddies and livestock so as to reduce methane emissions; and improving fertilizer-use efficiency to reduce the conversion of nitrogen to gaseous N_2O [FISCHER, 2004].

Much research is still needed to understand the processes by which greenhouse gases are emitted from different agricultural practices. Needed as well are efforts to disseminate the knowledge gained in order to apply it on the farm. Reductions in some gases are likely to be more easily achievable than in others, and appropriate strategies will vary by region. The task of reducing emissions will doubtlessly be complicated by accompanying changes in climate variables such as temperature and wind and precipitation, which interact with the processes through which greenhouse gases are, released [GHOSH, 2005].

2.1. Table: Predicted effects of climate change on agriculture over the next 50 years

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

Source: IPCC, 2007

2.6 Effect on Land use Change

Land use and land-use change directly affect the exchange of greenhouse gases between terrestrial ecosystems and the atmosphere. Changes such as the clearing of forests for use in agriculture or as settlements are associated with clear changes in land cover and carbon stocks. Much of the world's land area continues to be managed for food and wood production, human habitation, recreation, and ecosystem preservation without a change in land use. Management of these land uses affects sources and sinks of CO_2, CH_4, and N_2O. Furthermore, the resulting agricultural and wood products contain carbon. The carbon stocks held in these products are eventually released back to the atmosphere, after the products have served their use. [GOSAIN ET AL, 2006].

Different factors and mechanisms drive land use and land cover transformation. In many cases, climate, technology, and economics appear to be determinants of land-use change at different spatial and temporal scales. At the same time, land conversion seems to be an adaptive feedback mechanism that farmers use to smooth the impact of climate variability, especially in extremely dry and humid periods. Land-use change is often associated with a change in land cover and an associated change in carbon stocks. For example, as Figure 2.8 shows, if a forest is cleared, the carbon stocks in aboveground biomass are either removed as products, released by combustion, or decay back to the atmosphere through microbial decomposition. Stocks of carbon in soil will also be affected, although this effect will depend on the subsequent treatment of the land. Following clearing, carbon stocks in aboveground biomass may again increase, depending on the type of land cover associated with the new land use. During the time required for the growth of the new land cover-which can be decades for trees-the aboveground carbon stocks will be smaller than their original value [GOSAIN ET AL, 2003].

Houghton [HOUGHTON, 1991] assessed seven types of land-use change for carbon stock changes: (1) conversion of natural ecosystems to permanent croplands, (2) conversion of natural ecosystems for shifting of cultivation, (3) conversion of natural ecosystems to pasture, (4) abandonment of croplands, (5) abandonment of pastures, (6) harvest of timber, and (7) establishment of tree plantations. I recognize that, depending on the temporal scope of the assessment, classes 6 and 7 may also be considered a land-use practice rather than land-use change.

When forests are cleared for conversion to agriculture or pasture, a very large proportion of the aboveground biomass may be burned, releasing most of its carbon rapidly into the atmosphere. Some of the wood may be used as wood products; these carbon stocks could thereby be preserved for a longer time. Forest clearing also accelerates the decay of dead wood and litter, as well as below-ground organic carbon (Figure 2.8.). Local climate and soil conditions will determine the rates of decay; in tropical moist regions, most of the remaining biomass decomposes in less than 10 years. Some carbon or charcoal accretes to the soil carbon pool. When wetlands are drained for conversion to agriculture or pasture, soils become exposed to oxygen. Carbon stocks, which are resistant to decay under the anaerobic conditions prevalent in wetland soils, can then be lost by aerobic respiration [MINKKINEN AND LAINE, 1998].

Forest clearing for shifting cultivation releases less carbon than permanent forest clearing because the fallow period allows some forest regrowth. On average, the carbon stocks depend on forest type and the length of fallow, which vary across regions. Some soil organic matter is also oxidized to release carbon during shifting cultivation-but less than during continuous cultivation. Under some conditions, shifting cultivation can increase carbon stocks in forests and soils, from one cut-regrowth cycle to another. Because shifting cultivation usually has lower average agricultural productivity than permanent cultivation, however, more land would be required to provide the same products. In addition, shorter rotation periods deplete soil carbon more rapidly.

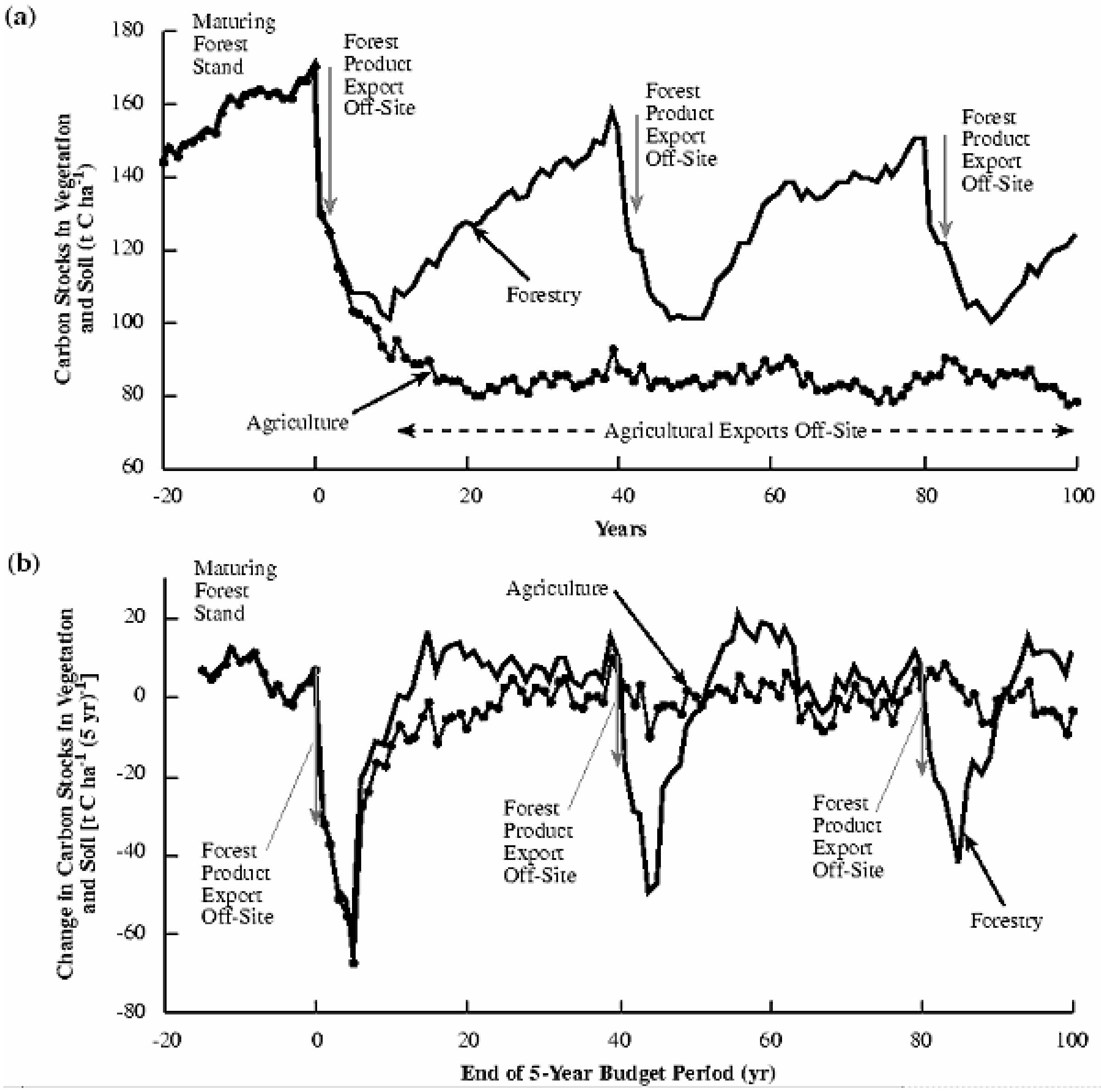
Abandonment of cultivated land and pastures may result in recovery of forest at a rate determined by local conditions [FEARNSIDE AND GUIMARÃES, 1996].

Selective logging often releases carbon to the atmosphere through the indirect effect of damaging or destroying up to a third of the original forest biomass, which then decays as litter and waste in the forest (although there are techniques that may reduce these consequences). The harvested wood decays at rates dependent on their end use; for example, fuel wood decays in 1 year, paper in less than a few years, and construction material in decades. The logged forest may then act as a sink for carbon as it grows at a rate determined by the local soil and climate, and it will gradually compensate for the decay of the waste created during harvest. Clear-cutting of forest can also lead to the release of soil carbon, depending on what happens after harvesting. For example, harvesting followed by cultivation or intensive site preparation for planting trees may result in large decreases in soil carbon-up to 30 to 50 percent in the tropics over a period of up to several decades [FEARNSIDE AND BARBOSA, 1998]. Harvesting followed by reforestation, however, in most cases has a limited effect (±10 percent). This effect is particularly prevalent in the tropics, where recovery to original soil carbon contents after reforestation is quite rapid. There are also some cases in which soil carbon increases significantly, probably because of the additions of slash and its decomposition and incorporation into the mineral soil.

If tree plantations are raised on land that has been specifically cleared, initially there would be net carbon emissions from the natural biomass and the soil. The plantations would then begin to fix carbon at rates dependent on site conditions and species grown. To estimate the time scale of carbon uptake in forest plantations, previous work has linked fixation rates to the growth rate over time [NILSSON AND SCHOPFHAUSER, 1995]. Nilsson and Schopfhauser summarize data suggesting the following rates of aboveground carbon accumulation in plantations: 10 t ha^{-1} yr^{-1} for coniferous plantations in Australia and New Zealand, 1.5 to 4.5 t ha^{-1} yr^{-1} in coniferous temperate plantations of Europe and the United States, 0.9 to 1.2 t ha^{-1} yr^{-1} in Canada and the former Soviet Union, and 6.4 to 10.0 t ha^{-1} yr^{-1} in tropical Asia, Africa, and Latin America. Even if soil carbon accumulation is considered, these numbers probably represent maximum rates achieved under intensive management that includes the use of fertilizers. However, tree plantations also go through a rotational pattern of harvest, and the long-term estimates of carbon uptake might therefore be much lower than suggested by the foregoing figures.

Changes in land use of the types listed above have led to an estimated net emission of CO_2 of 121 Gt C from 1850 to 1990 [HOUGHTON ET AL., 1999, 2000], as well as an estimated 60 Gt C prior to 1850. Prior to 1950, high- and mid-latitude Northern Hemisphere regions released substantial amounts of carbon from forest clearing and conversion to agricultural use, but this situation has since reversed as many forests presently seem to be in a stage of regeneration and regrowth. The low-latitude tropical belts, on the other hand, have been experiencing high rates of deforestation in recent decades [HOUGHTON ET AL., 2000]. The wide variation in vegetation carbon density in the low latitudes, however, introduces considerable uncertainty in estimates of carbon stock changes resulting from land-use changes. An estimate of global net emissions of 1.6 ± 1.0 Gt C yr^{-1} from land-use changes from 1980-1989 [Houghton, 1994;] was judged to have been on the high side from newer data from the Brazilian Amazon. More recent analyses, however, have revised this estimate to even higher figures of 1.7 ± 0.8 Gt C yr^{-1} [HOUGHTON ET AL., 1999, 2000], 2.0 ± 0.8 Gt C yr^{-1}, and 2.4 Gt C yr^{-1} [FEARNSIDE, 1998]. Most of the carbon emission in the 1980s was from tropical regions (tropical Asia alone accounted for 50 percent of this flux) where deforestation rates averaged about 15 Mha yr^{-1}. Of the major categories of land-use change, the clearing of forests for use as cropland accounted for the largest fraction of CO_2 emissions from net land-use change; emissions from conversion to pastures, harvest, and shifting cultivation were lower. These estimates, however, do not include sources and sinks of CO_2 caused by land-use management practices not associated with land-use change.

2.8. Figure: The hypothetical time-evolution of annual-average on-site carbon stocks is given (a) for two illustrative cases of land use, land-use change, and forestry. (b) Fluctuates due to both variability and human activities.



Source: Houghton et al, 2000

2.6.1 Land Use Change Management

Management of forests, croplands, and rangelands affects sources and sinks of CO_2, CH_4, and N_2O. On land managed for forestry, harvesting of crops and timber changes land cover and carbon stocks in the short term while maintaining continued land use. Moreover, most agricultural management practices affect soil condition. A forest that is managed in a wholly sustainable manner will encompass stands, patches, or compartments comprising all stages from regeneration through harvest, including areas disturbed by natural events and management operations. Overall, a forest comprising all stages in the stand life cycle operates as a functional system that removes carbon from the atmosphere, utilizing carbon in the stand cycle and exporting carbon as forest products. Forests of such characteristics, if well managed, assure rural development through working opportunities at the beginning and establishment of forest industries in later stages of the development process. In addition, such forests provide other benefits, such as biodiversity, nature conservation, recreation, and amenities for local communities. For historical and economic reasons, however, many forests today depart from this ideal and are fragmented or have strongly skewed stand age distribution that influences their carbon sequestration capability [KEELING AND WHORF, 1999].

Forest soils present opportunities to conserve or sequester carbon. Several long-term experiments demonstrate that carbon can accrete in the soil at rates of 0.5 to 2.0 t ha^{-1} yr^{-1}. Management practices to maintain, restore, and enlarge forest soil carbon pools include fertilizer use; concentration of agriculture and reduction of slash-and-burn practices; preservation of wetlands, peat lands, and old-growth forest; forestation of degraded and non-degraded sites, marginal agricultural lands, and lands subject to severe erosion; minimization of site disturbance during harvest operations to retain organic matter; retention of forest litter and debris after silvicultural activities; and any practice that reduces soil aeration, heating, and drying [HOUGHTON ET AL., 2000].

Cropland soils can lose carbon as a consequence of soil disturbance (e.g., tillage). Tillage increases aeration and soil temperatures [ELLIOTT, 1986], making soil aggregates more susceptible to breakdown and physically protected organic material more available for decomposition [ELLIOTT, 1986]. In addition, erosion can significantly affect soil carbon stocks through the removal or deposition of soil particles and associated organic matter. Erosion and redistribution of soil may not result in a net loss of carbon at the landscape level because carbon may be re-deposited on the landscape instead of being released to the atmosphere [LAL ET AL., 1998]. Although some the displaced organic matter may be re-deposited and buried on the landscape, in general the productivity of the soil that is eroded-and its inherent ability to support carbon fixation and storage-is reduced. Losses through leaching of soluble organic carbon occur in many soils; although this leaching is seldom a dominant carbon flux in soils, it is a contributor to the transport of carbon from the terrestrial environment to the marine environment via runoff. Soil carbon content can be protected and even increased through alteration of tillage practices, crop rotations, residue management, reduction of soil erosion, improvement of irrigation and nutrient management, and other changes in forestland and cropland management.

Livestock grazing on grasslands, converted cropland, savannas, and permanent pastures is the largest areal extent of land use [FAO, 1993]. Grazing alters ground cover and can lead to soil compaction and erosion, as well as alteration of nutrient cycles and runoff. Soil carbon, in turn, is affected by these changes. Avoiding overgrazing can reduce these effects.

Croplands and pastures are the dominant anthropogenic source of CH_4 and N_2O, although estimates of the CH_4 and N_2O budgets remain uncertain. Rice cultivation and livestock (enteric fermentation) have been estimated to be the two primary sources of CH_4. The primary sources of N_2O are denitrification and nitrification processes in soils. Emissions of N_2O are estimated to have increased significantly as a result of changes in fertilizer use and animal waste. Alteration of rice cultivation practices, livestock feed, and fertilizer use are potential management practices that could reduce CH_4 and N_2O sources.

Ecosystem conservation may also influence carbon sinks. Many forests, savannas, and wetlands, if managed as nature reserves or/and recreation areas, can preserve significant stocks of carbon, although these stocks might be affected negatively by climate change. Some wetlands and old-growth forests exhibit particularly high carbon densities; other semi-natural ecosystems (e.g., savannas) may conserve carbon simply because of their large areal extent.

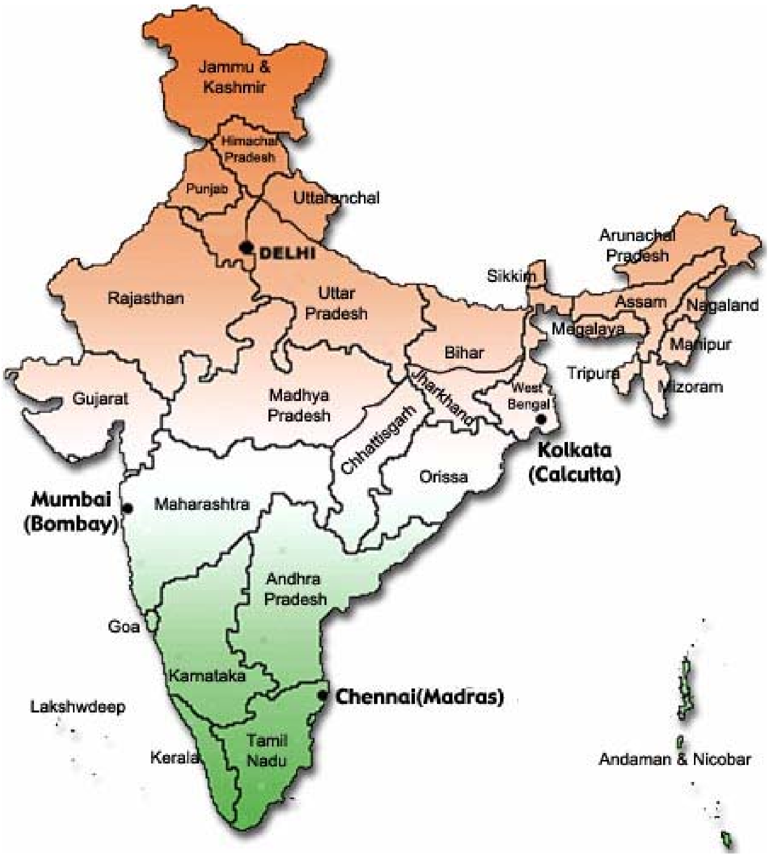
3 India

3.1 Social Issues of India

India is one of the oldest civilizations in the world with a kaleidoscopic variety and rich cultural heritage. It has achieved multifaceted socio-economic progress during the last sixty-two years of its independence. India has become self-sufficient in agricultural production, and is now the tenth most industrialized country in the world and the sixth nation to have gone into outer space. India's population as on 1st March, 2001, was 1,028million (532.1 million males and 496.4 million females). India accounts for a meagre 2.4 per cent of the world surface area of 135.79 million sq. km. Yet, it supports and sustains a whopping 16.7 per cent of the world population. It covers an area of 3,287,263 sq. km., extending from the snow-covered Himalayan heights in the North to the tropical rain forests of the South (Figure 3.1). As the seventh largest country in the world, India stands apart from the rest of Asia, marked off as it is by mountains and the sea, which give the country a distinct geographical entity. Bounded by the Great Himalaya in the North, it stretches southwards and at the Tropic of Cancer, tapers off into the Indian Ocean between the Bay of Bengal in the East and the Arabian Sea in the West. India has a land frontier of about 15,200 km. The total length of the coastline, including the mainland, Lakshadweep Islands, and the Andaman and Nicobar Islands is 7, 517 km.

Countries sharing a common border with India are Afghanistan and Pakistan in the North-West, China, Bhutan and Nepal in the North and Myanmar and Bangladesh in the East. Sri Lanka is separated from India by a narrow channel of sea formed by the Palk Strait and the Gulf of Mannar. The mainland comprises of four regions, namely, the Great Mountain Zone, the Indo-Gangetic Plains, the Desert Region and the Southern Peninsula. The **Himalaya** comprises of three near parallel ranges interspersed with large plateaus and valleys, some of which, like the Kashmir and Kullu valleys, are fertile, extensive and of great scenic beauty. Some of the highest peaks in the world are found in these ranges. In the East, between India and Myanmar, and India and Bangladesh, the hill ranges are much lower. The Garo, Khasi, Jaintia and Naga hills, running almost East-West, join the chain of the Mizo and Arakan hills running North-South. The **Indo-Gangetic Plains**, about 2,400 km long and ranging from 240 to 320 km in width, are formed by the basins of three distinct river systems - the Indus, the Ganga and the Brahmaputra. They are one of the world's greatest stretches of flat alluvium and also one of the most densely populated areas on Earth. The **Desert Region** can be divided into two parts - the great Thar desert and the ‘little desert’. The great Thar desert extends from the edge of the Rann of Kutch beyond the Luni River northwards. The whole of Rajasthan-Sind frontier runs through this. The ‘little desert’ extends from the Luni between Jaisalmer and Jodhpur up to the Northern West. Between the great Thar desert and the little desert, lies a zone of absolutely sterile country, consisting of rocky land cut by limestone ridges. The **Peninsular Plateau** is marked off from the plains of river Ganga and the Indus by a mass of mountain and hill ranges, varying from 460 to 1,220 meters in height. Prominent among these are the Aravali, Vindhya, Satpura, Maikala and Ajanta. The Peninsula is flanked on one side by the Eastern Ghats with an average elevation of about 610 meters, and on the other by the Western Ghats where the average elevation varies between 915 to 1,220 meters, rising in places to over 2,440 meters. The southern point of the plateau, where the Eastern and the Western Ghats meet is formed by the Nilgiri Hills. The Cardamom Hills lying beyond may be regarded as a continuation of the Western Ghats [RAMAKRISHNA ET AL. 2007].

3.1. Figure: Administrative Map of India



Source: Government of India, Ministry of Environment

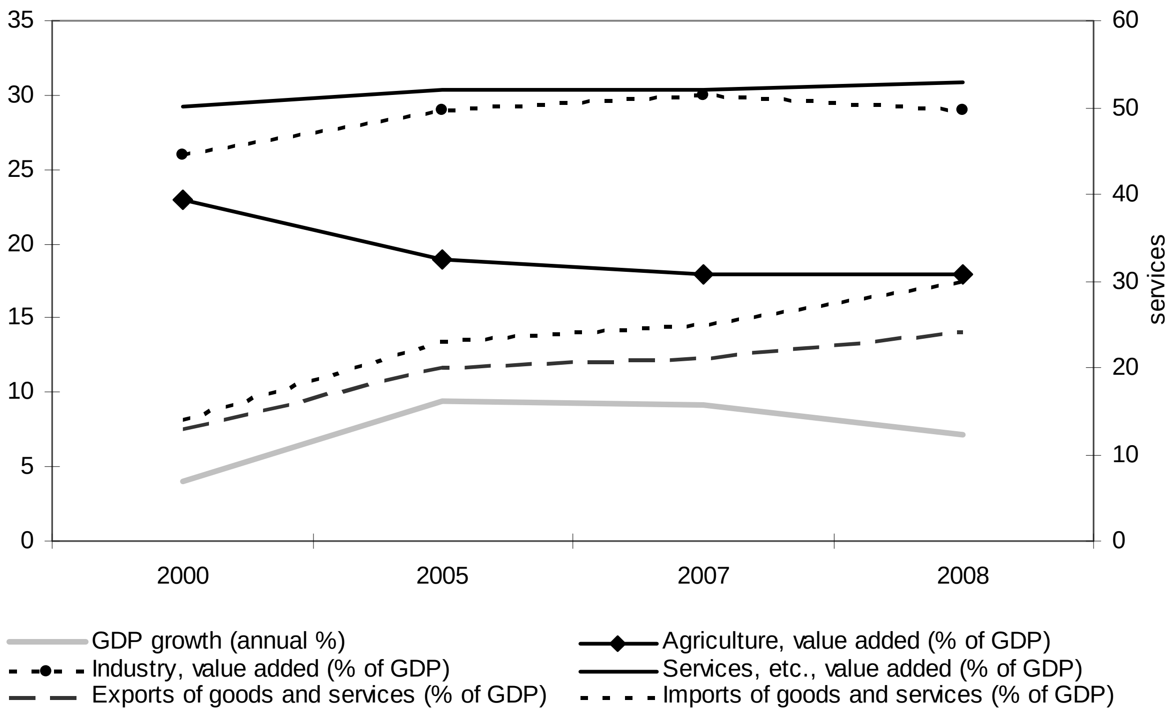
3.2 Economic Issues of India

India's diverse economy encompasses traditional village farming, modern agriculture, fisheries, handicrafts, a wide range of modern industries, and a multitude of services. The structure of the Indian economy has undergone considerable change in the last decade. These include increasing importance of external trade and of external capital flows. The services sector has become a major contributor to the economy with GDP share of over 50 per cent and the country becoming an important hub for exporting IT services. The share of merchandise trade to GDP increased to over 35 per cent in 2007-08 from 23.7 per cent in 2003-04. If the trade in services is included, the trade ratio is 47 per cent of GDP for 2007-08 [RAMAKRISHNA ET AL. 2007].

The overall growth of GDP at factor cost at constant prices in 2008-09, as per revised estimates released by the Central Statistical Organization (CSO) (2009) was 6.7 per cent. This represented a decline of 2.1 per cent from the average growth rate of 8.8 per cent in the previous five years (2003-04 to 2007-08) (Figure 3.2).

The growth of GDP at factor cost (at constant 1999-2000 prices) at 6.7 per cent in 2008-09 nevertheless represents a deceleration from high growth of 9.0 per cent and 9.7 per cent in 2007-08 and 2006-07 respectively. The deceleration of growth in 2008-09 was spread across all sectors except mining & quarrying and community, social and personal services. The growth in agriculture and allied activities decelerated from 4.9 per cent in 2007-08 to 1.6 per cent in 2008- 09, mainly on account of the high base effect of 2007- 08 and due to a fall in the production of non-food crops including oilseeds, cotton, sugarcane and jute. The production of wheat was also marginally lower than in 2007-08. The performance of the agricultural sector influences the growth of the Indian economy. Agriculture (including allied activities) accounted for 17.8 per cent of the GDP in 2007-08 as compared to 21.7 per cent in 2003-04. Notwithstanding the fact that the share of the agricultural sector in GDP (figure 3.3) has been declining over the years, its role remains critical as it accounts for about 52 per cent of the employment in the country. Apart from being the provider of food and fodder, its importance also stems from the raw materials that it provides to industry. The prosperity of the rural economy is also closely linked to agriculture and allied activities. Agricultural sector contributed 12.2 per cent of national exports in 2007-08 [PRASADA RAO ET AL. 2008].

3.2. Figure: Main economic trends in India during 2001-2008.



Source: Own calculation based on Ministry of Finance, India

3.3 Agriculture in India

India's record of progress in agriculture over the past four decades has been quite impressive. The agriculture sector has been successful in keeping pace with rising demand for food. The contribution of increased land area under agricultural production has declined over time and increases in production in the past two decades have been almost entirely due to increased productivity. Contribution of agricultural growth to overall progress has been widespread. Increased productivity has helped to feed the poor, enhanced farm income and provided opportunities for both direct and indirect employment. The success of India's agriculture is attributed to a series of steps that led to availability of farm technologies which brought about dramatic increases in productivity in 70s and 80s often described as the Green Revolution era. The major sources of agricultural growth during this period were the spread of modern crop varieties, intensification of input use and investments leading to expansion in the irrigated area. In areas where 'Green Revolution' technologies had major impact, growth has now slowed. New technologies are needed to push out yield frontiers, utilize inputs more efficiently and diversify to more sustainable and higher value cropping patterns. At the same time there is urgency to better exploit potential of rainfed and other less endowed areas if we are to meet targets of agricultural growth and poverty alleviation. Given the wide range of agroecological setting and producers, Indian agriculture is faced with a great diversity of needs, opportunities and prospects. Future growth needs to be more rapid, more widely distributed and better targeted. These challenges have profound implications for the way farmers' problems are conceived, researched and transferred to the farmers. On the one hand agricultural research will increasingly be required to address location specific problems facing the communities on the other the systems will have to position themselves in an increasingly competitive environment to generate and adopt cutting edge technologies to bear upon the solutions facing a vast majority of resource poor farmers [KHESHGI ET AL, 1999, PRASADA RAO ET AL. 2008]

In the past agriculture has played and will continue to play a dominant role in the growth of Indian economy in the foreseeable future. It represents the largest sector producing around 28 percent of the GDP, is the largest employer providing more than 60 percent of the jobs and is the prime arbiter of living standards for seventy percent of India's population living in the rural areas. These factors together with a strong determination to achieve self-sufficiency in food grains production have ensured a high priority for agriculture sector in the successive development plans of the country.

An important facet of progress in agriculture is its success in eradication of its critical dependence on imported food grains. In the 1950's nearly 5 percent of the total food grains available in the country were imported. This dependence worsened during the 1960's when two severe drought years led to a sharp increase in import of food grains. During 1966 India had to import more than 10 million tonnes of food grains as against a domestic production of 72 million tonnes. In the following year again, nearly twelve million tonnes had to be imported. On the average well over seven percent of the total availability of food grains during the 1960s had to be imported [KUMAR ET AL, 1998].

Indian agriculture has progressed a long way from an era of frequent droughts and vulnerability to food shortages to becoming a significant exporter of agricultural commodities. This has been possible due to persistent efforts at harnessing the potential of land and water resources for agricultural purposes. Indian agriculture, which grew at the rate of about 1 percent per annum during the fifty years before independence, has grown at the rate of about 3 percent per annum in the post independence era [RAO, 2007].

Agriculture – sub-sectors

Indian agriculture broadly consists of four sub-sectors. Agriculture proper including all food-crops oilseeds, fiber, plantation crops, fruits and vegetables is the largest accounting for nearly 70 percent of the agriculture sector as a whole. The rapid growth in this sub-sector through exploitation of wastelands and fallows spread of irrigation and adoption of production enhancing technologies was critical in transforming India from a country vulnerable to food shortages to one of exportable surplus. Although this sub-sector has made impressive progress its share in the sector as a whole has declined from 78 percent in 1960-61 to less than 70 percent by early 90s [KUMAR ET AL, 2001].

Correspondingly the share of livestock sector has increased considerably. The livestock industry has grown from Rs. 15 billion in early 1960s to Rs. 100 billion by 1980-81 and Rs. 972 billion by 2005-06. In nominal terms the sector grew at almost 15 percent per annum during 1980s. Milk production, which was almost stagnant for two decades ending 1970, grew by over 5 percent per annum in the 80s. Similarly, production of eggs increased at the rate of about 6.5 percent during the same period. As a result the share of livestock increased from about 17 percent till early 80s to 35 percent by 2005-06 [RAO, 2007].

Though it plays relatively a minor role within the sector as a whole, fishing sub-sector activities have been on the rise. The sub-sector has grown from only Rs. 3 billion in 1970-71 to nearly Rs. 190 billion in 2005-06. The growth was particularly rapid in 70s and 80s. Value added increased at over 5 percent per annum during this period [RATHORE ET AL, 2007].

In real terms forestry and logging activities have been on the decline since mid seventies. As of 2005-06, the size of the industry in terms of value of output was 173 billion.

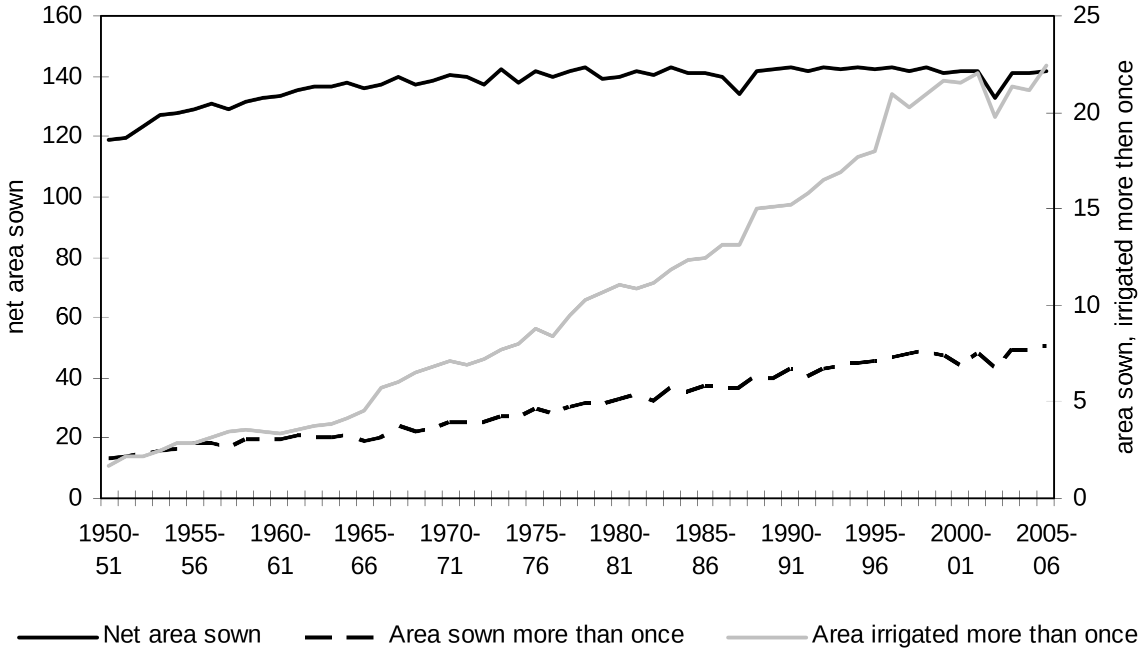
Over the past three decades, the country has successfully transformed itself from a food deficit economy to one which is essentially self sufficient in availability of foodgrains and other essential commodities, albeit only at the prevailing level of effective demand. Annual aggregate foodgrains production, which averaged about 82 million tonnes in 1960-61 increased to 123.7 and 172.5 million tonnes for the trienniums ending 1980-81 and 1990-91 respectively. Current production level is 265 million tonnes and the country has been able to accumulate substantial, (35 million tonnes) stocks of foodgrains to cope up with any sudden difficulties arising from drought or a similar situation in any part of the country [KUMAR ET AL, 2001].

Increased outputs have been achieved chiefly by adopting, since mid sixties, a strategy aimed at increasing foodgrains production by concentrating public sector efforts and resources in regions with a high potential for quick and substantial productivity gains through increased cropping intensity and average yields. These were the areas favoured by agroclimatic resource conditions and where irrigation facilities already existed or could be developed relatively rapidly. The main elements of this strategy were: (i) expansion of irrigation coverage, (ii) increased provision and utilization of key inputs – mainly high yielding varieties (HYVs) of crops, mainly of wheat and rice and chemical fertilizers and plant protection chemicals, (iii) expansion and improvement of institutional support services such as research and extension and (iv) price policies favourable to producers of major foodgrains [MITRA, 2004].

The success of this strategy was made possible by development and availability of replicable production technology packages, so called 'Green Revolution' technologies. Irrigation facilitated double cropping and widespread adoption of HYVs. The HYVs performed particularly well under irrigated conditions, were highly responsive to fertilizers and their short duration permitted increases in cropping intensities.

Irrigation development was the cornerstone of the strategy. Undivided India was amongst the largest irrigated areas in the world. With partition nearly one-third of the irrigated area went to Pakistan. At the time of independence the net irrigated area was 20.9 million ha (gross irrigated area 22.6 million ha). Recognizing large-scale development of irrigation facilities as critical to rapid agricultural growth, the country has spent about Rs. 45,000 crores on irrigation development in the first four decades after independence. During the period 1950-51 to 1965-66 development of irrigation through government canals grew from 7.2 million ha to 9.8 million ha – a growth rate of 2.1 percent per annum. During 1970s this pace dropped slightly to 1.9 percent. In 1980s the rate of increase dropped significantly to 1.1 percent per annum. The growth of tube-well irrigation, however, increased rapidly from 4.5 million ha in 1970-71 to 9.5 million ha in 1980-81 and then to 14.3 million ha by 1990-91. The net irrigated area increased from 31 million ha in 1970-71 to 53.5 million ha in 1995-96 which corresponds to 22 percent of the net sown area in 1970-71 and 43.63 percent in 2005-06. With improvements in irrigation efficiency the gross irrigated areas has increased to 71.51 million ha. The percentage of gross cropped area service by irrigation increased from 18.3 percent in 1960-61 to 23.0 percent in 1970-71 and to over 38 percent at present (see Figure. 3.4.) [MITRA, 2004, PALANISAMI ET AL. 2007].

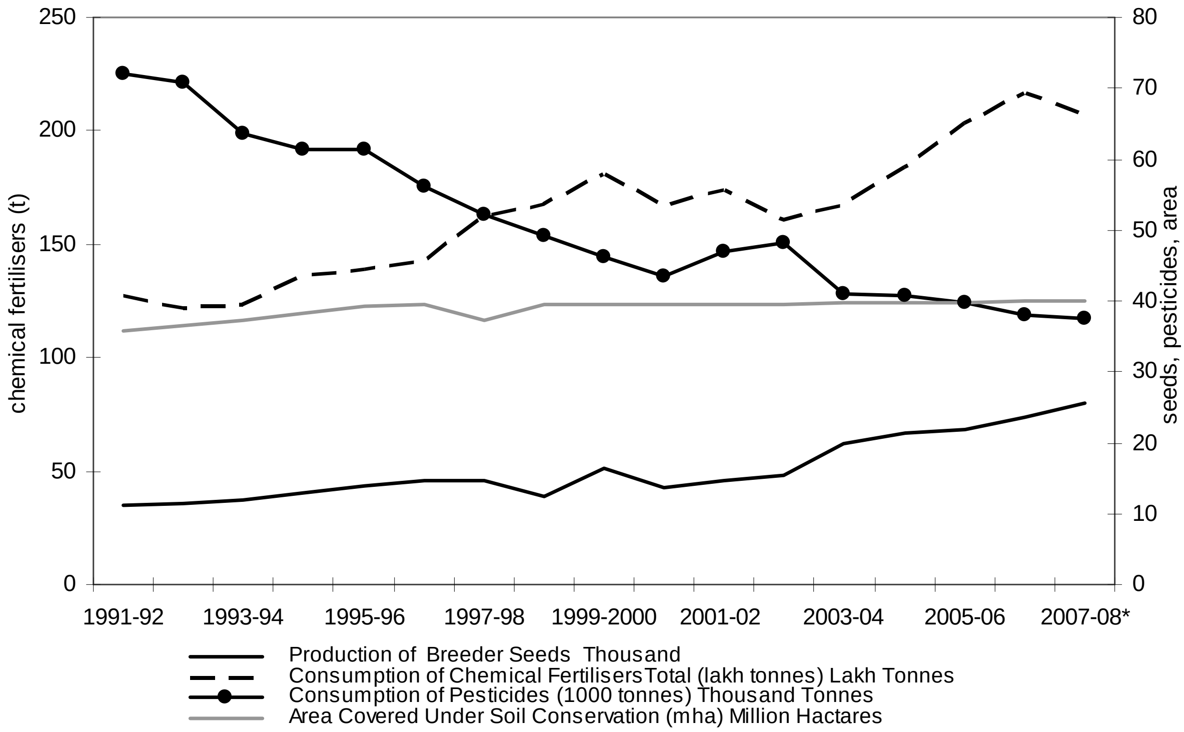
3.3. Figure: Sown and irrigated area during 1950-2007
(in million hectares)



Source: Own calculation based on Ministry of Agriculture, India

Fertilizers have constituted yet another key input in addition to expanded irrigation and spread of HYVs in achieving goals of high production and productivity. India currently occupies third position in the world, after China and USA, in terms of fertilizer production and consumption. Consumption of fertilizers has increased from 1.54 million tonnes in 1967-68, representing the pre green revolution era, to 17.31 million tonnes (2005-06). The average per hectare use of fertilizers currently around 85 kg per hectares is the lowest among several Asian countries. However, rice and wheat account for a major fraction, around 65 percent of the total fertilizer consumed in the country, with very little fertilizers going to the rainfed areas. According to some current projections, fertilizer's use will need to increase to 30-35 million tonnes to meet the foodgrains need of 2020. The demand for nutrients will stretch by almost another 15 million tonnes if requirements for horticulture, vegetables and plantation and commercial crops are included. At present domestic production of N and P fertilizers (13.42 million tonnes) falls short of consumption by over 20 percent. In addition the entire requirement of K fertilizer is imported (Figure 3.5).

3.4. Figure: Production and use of agriculture inputs in India during 1991-92 to2007-08



Source: Own calculation based on Ministry of Agriculture, India
Note: * Evaluation

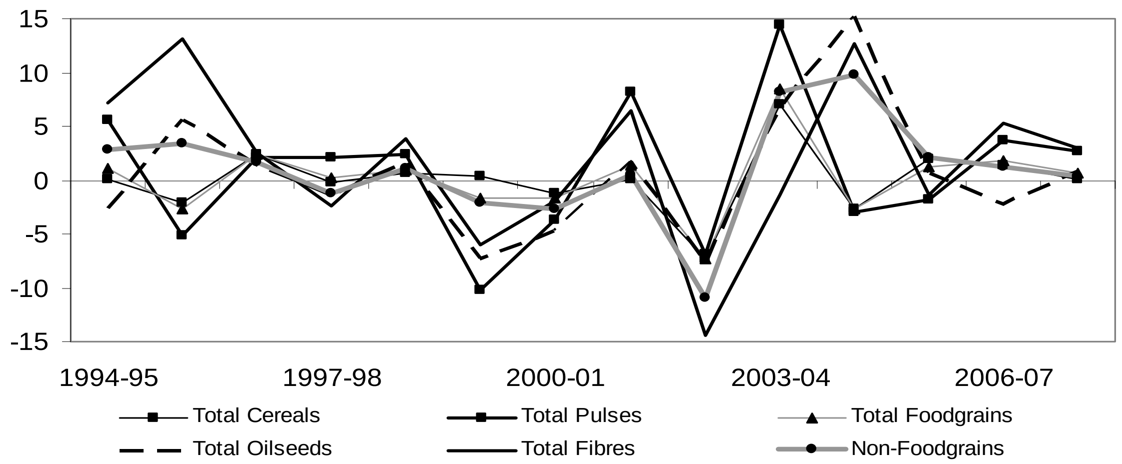
Most agricultural development programmes initiated in 1960s were concentrated in regions of high potential. Thus five states, Punjab, Haryana, Uttar Pradesh, Andhra Pradesh and Tamil Nadu account for 50 percent of the country's net irrigated and 53 percent of the gross irrigated area. The combination of expanding irrigation coverage and widespread adoption of short duration HYVs led to significant increases in cropping intensities. Acreage cropped more than once per year increased from 13 million ha in 1950-51 to about 44 million ha at present. Average cropping intensity for the country as a whole rose from 115 percent in 1960-61 to 131 in 1993-94. By 2005-06 cropping intensity has risen to 187 percent in Punjab, 167 percent in Haryana and 142 percent in Uttar Pradesh [MITRA ET AL, 2003, PALANISAMI ET AL. 2007].

An important consequence of the strategies adopted since sixties has been to boost production of, chiefly, two crops rice and wheat. Their share in total foodgrains production went up from 57 percent in 1970-71 to more than 75 percent in 1990-91. Production of foodgrains other than rice and wheat did not increase significantly and in the eastern region even the yield of rice did not increase. Agricultural production and income rose substantially in the north-western states of Punjab, Haryana, and Western Uttar Pradesh, parts of Rajasthan, Tamil Nadu and Andhra Pradesh. By contrast productivity and output growth have been modest in eastern and central India and in Deccan plateau. Progress was particularly slow in rainfed areas, which account for over 60 percent of the cropped area and where a great majority of rural poor are concentrated. An important impact of the strategies pursued in the 'Green Revolution' period has been intensification of regional disparities and imbalances in agricultural development and food availability and hence levels of food security. For the country as a whole while per capita availability of cereals has increased substantially, that of pulses has decreased significantly [PARIKH ET AL, 2002; HUNDAL ET AL, 2007].

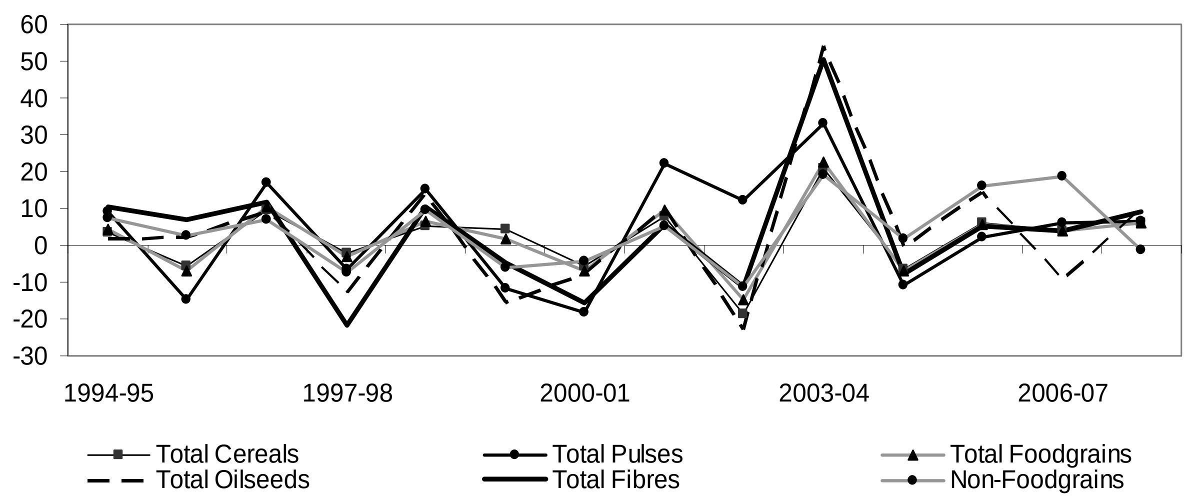
In summary an annual increase in food grains production of 3.22 percent during fifties was mainly because of expansion in area. Sixties recorded a low annual growth rate of 1.72 percent necessitating large-scale imports of food grains. Annual growth of 2.08 percent was recorded during seventies. This decade was the turning point in India's food grains economy leading to self-sufficiency through significant productivity increase first in wheat and later in rice in the eighties. An annual growth of 3.5 percent in food grains in eighties was the hallmark of green revolution that enabled India to become self-sufficient and even a marginal exporter. The pace of growth slowed in nineties barely making or even slower than the population growth rate.

3.5. Figure: Growth rate of (i) area, (ii) production and (iii) yield of staple crops of India from 1994-95 to 2007-08, in %

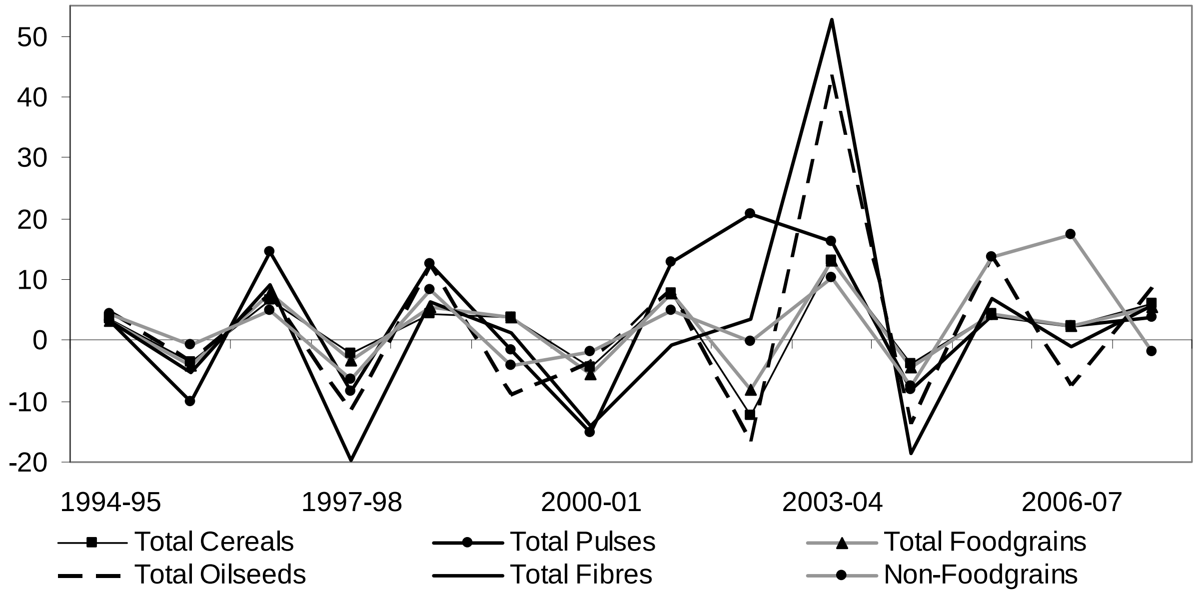
(i)



(ii)



(iii)



Source: Own construction based on Ministry of Agriculture, India

3.3.1 Sustainability Concerns

Several indicators highlight increasing concerns of sustainability in areas which have largely contributed to increased production in the 'Green Revolution' era. Adoption of high yielding cultivators is virtually complete. Almost entire wheat and rice crops in the states of Punjab, Haryana and Western Uttar Pradesh are irrigated. In the higher production regions yields are plateauing and most traditional sources of productivity growth having been exhausted future gains in production have to come from elsewhere [PRABHJYOT-KAUR ET AL., 2007].

At farmers' level concerns are being expressed in several ways. Many farmers believe that the input levels have to be continuously increased in order to maintain high yields. In sixties and seventies most farmers used only nitrogenous and phosphate fertilizers to achieve high yields. Due to widespread deficiencies of several secondary and micronutrients, most farmers now have to apply higher doses and a greater variety of fertilizers to maintain crop yields. Results from many long term studies on rice-wheat cropping system show a declining yield trend when input levels were kept constant – thus the growth rate of system productivity has been declining relative to growth rate of nutrients use. Lowering of groundwater tables due to intensive rice-wheat system in many areas is resulting in increased costs of lifting water in the intensively cultivated high production areas, diseases and pest problems are turning more serious than ever before and pose both short and long large problems. It is reported that some weeds have developed resistance to the commonly used herbicides. What this implies is that the farmers are applying increasing amount of herbicide incurring increasing cost without the benefit of effective control. Pesticide residues entering the food chain and overall safety in use of pesticides continue to be serious problems [RAVINDRANATH ET AL, 2003; PRABHJYOT-KAUR ET AL., 2007].

Other emerging problems threatening sustainability of intensive cropping system e.g. rice-wheat include loss in biodiversity related issues. Large areas planted to a single/few varieties of a crop is a potential cause of concern. As the diversity is reduced natural processes that control and affect habitat quality and genetic expression weaken and for this reason internal and natural control mechanisms must be replaced by more externally applied artificial controls in the form of management and inputs which in due course lead the system towards unsustainability.

Groundwater is the major source of meeting the irrigation needs of irrigated agriculture. Currently about half the area under irrigation in the country is irrigated from groundwater sources. Large-scale groundwater development has led to fall in the water table in many areas. Over pumping is leading to declining water table levels and failure of tube-wells. Pumping costs are increasing, as is the energy consumption. In the coastal areas this has led to ingress of sea water, with serious environmental implications.

Changes in water quality are adversely affecting agriculture and vice-versa. Inefficient and/or over use of fertilizers and pesticides in agriculture and untreated disposal of industrial and urban wastes are leading to increasing contamination by such elements as lead, zinc, copper, chromium, cadmium particularly in areas having high industrial activity e.g. in districts of Ludhiana, Faridabad, Kanpur, Varanasi etc [ROY ET AL, 2005].

An increase in the content of arsenic has been reported in several of the districts of West Bengal. This is attributed amongst other causes to the lowering of groundwater table due to excessive groundwater withdrawal and is leading to serious and widespread toxicity problems adversely affect the health of hundreds of thousands people of the region.

Agriculture in the Changing Global Scenario

Steady globalization of trade has profound implications for future agricultural development. The diversity of India's agro-ecological setting, high bio-diversity and relatively low cost of labour provide potential for agricultural competitiveness in a globalized economy. It is expected that with increasing globalization of markets over the years there will be demands for agricultural intensification. This will also be favoured because of greater backward and forward linkages between agriculture and food industry. Therefore, increase in production and productivity is bound to be strategically important to economy. Intensification will not only favour alleviation of rural poverty but will also improve resource conservation particularly in the small farming sector where farmers can be encouraged to take up organized production of high value crops such as fruits, specialty vegetables, flowers medicinal and aromatic herbs etc. Stronger demands for crops of the small farmers' will not only improve incomes and welfare but will also make investments in technology and resource conservation more attractive [SATHAYE ET AL, 2006].

The World Trade Organization (WTO) and liberalization of global trade is bound to have impact on future land use and production pattern. Understanding the local, national and international environment under which agricultural production is taking shape will be crucial in developing our own strategies.

3.3.2 Extension Strategies

Since early fifties a number of public by funded agricultural development programmes have been sponsored. These have included programmes like the National Extension Service (NES) Blocks in 1953, the Intensive Agricultural District Programme (IADP) in 1961-62, the Intensive Agricultural Area Programme (IAAP) 1964-65, the High Yielding Variety (HYV) programme 1966-67 and the Small and Marginal Farmers' Development Programmes (SMFDP) in 1969-70. Though these programmes had a perceptible impact the efforts did not get replicated over different areas and categories of farmers. In mid seventies based on pilot level project in Rajasthan Canal and Chambal command area a 'Training and Visit' (T&V)

system of extension was promoted in different states. Extension efforts of the Indian Council of Agricultural Research through its research Institutes and the State Agricultural University were largely limited to demonstration of new technologies through such programmes as National Demonstration Project, Operational Research Project, the Lab to Land Programme and the Krishi Vigyan Kendras. However, there appears much to be desired in the way that extension programmes are conceived and implemented [ROY ET AL, 2004].

At present extension programmes are implemented in largely a top-down fashion leaving little scope for localized planning and action. Farmers are almost passive receivers and their involvement in the process of technology generation and adoption is almost absent. Extension services, at present, are almost exclusively in the public sector domain and there is no effort or institutional support for other operators e.g. the NGOs, the corporate bodies etc.

Extension programmes sponsored by the government operate largely in isolation and there appears a strong need to view the extension programmes as an integral part of the research and development process [RUPA KUMAR ET AL. 2006].

The challenges facing agricultural development call for fundamental changes in our approach to technology transfer/extension programmes. Changes are necessary in the context of changing economic environment following policy adjustments in relation to privatization, deregulation and globalization calling for greater efficiency and effectiveness of the extension system. More importantly there is need for

- Greater emphasis on providing producers with knowledge and understanding needed to overcome the problems or to exploit opportunities of their own specific production systems. Correspondingly there will be a need to de-emphasize 'package of practices' or the blanket recommendations, top down approach followed thus far.
- Shift in the focus of public extension systems from promoting inputs use to one on sustainable management of resources and improvements in the production system as a whole.
- Closer interaction between farmers, extension scientists and production system researchers in diagnosing problems and identifying location specific recommendations emphasizing participation and education rather than being prescriptive.
- Widening the range of extension delivering agencies. While the publicly operated extension systems will continue to be important, there will appear a greater role for NGOs, farmers' associations and corporate sectors in particular situations. Role of commercial suppliers of seeds, agrochemicals, machinery, vaccines and medicines in providing advisories, as is already being done in a limited way, will need to be encouraged and factored into public system's own priorities.
- Wider and more creative use of mass media in tune with current developments in information technology to get information across to the farming community whose ability to overcome constrains at farm level will increasingly depend on access to reliable and up-to-date information.

3.3.3 Technological Needs and Future Agriculture

It is apparent that the tasks of meeting the consumption needs of the projected population are going to be more difficult given the higher productivity base than in 1960s. There is also a growing realization that previous strategies of generating and promoting technologies have contributed to serious and widespread problems of environmental and natural resource degradation. This implies that in future the technologies that are developed and promoted must result not only in increased productivity level but also ensure that the quality of natural resource base is preserved and enhanced. In short, they lead to sustainable improvements in agricultural production [SHUKLA ET. AL, 2002, 2003].

Productivity gains during the 'Green Revolution' era were largely confined to relatively well endowed areas. Given the wide range of agroecological setting and producers, Indian agriculture is faced with a great diversity of needs, opportunities and prospects. Future growth needs to be more rapid, more widely distributed and better targeted. Responding to these challenges will call for more efficient and sustainable use of increasingly scarce land water and germplasm resources.

Technical solutions required to solve problems will be increasingly location-specific and matched to the huge agroecological/climatic diversity. Detailed indigenous knowledge and greater skills in blending modern and traditional technologies to enhance productive efficiency will be more than ever before, key to the farming success and sectoral growth. Most technological solutions will have to be generated and adapted locally to make them compatible with socio-economic conditions of farming community [SATHAYE ET AL, 2006].

New technologies are needed to push the yield frontiers further, utilize inputs more efficiently and diversify to more sustainable and higher value cropping patterns. These are all knowledge intensive technologies that require both a strong research and extension system and skilled farmers but also a reinvigorated interface where the emphasis is on mutual exchange of information bringing advantages to all. At the same time potential of less favoured areas must be better exploited to meet the targets of growth and poverty alleviation.

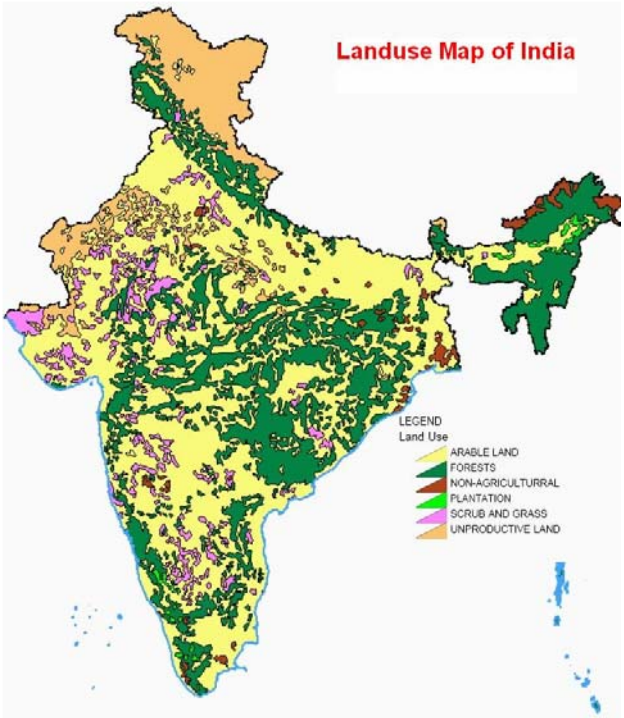
These challenges have profound implications for products of agricultural research. The way they are transferred to the farmers and indeed the way research is organized and conducted. One thing is, however, clear – the new generation of technologies will have to be much more site specific, based on high quality science and a heightened opportunity for end user participation in the identification of targets. These must be not only aimed at increasing farmers' technical knowledge and understanding of science based agriculture but also taking advantage of opportunities for full integration with indigenous knowledge. It will also need to take on the challenges of incorporating the socio-economic context and role of markets [ROY ET AL, 2004].

With the passage of time and accelerated by macro-economic reforms undertaken in recent years, the Institutional arrangements as well as the mode of functions of bodies responsible for providing technical underpinning to agricultural growth are proving increasingly inadequate. Changes are needed urgently to respond to new demands for agricultural technologies from several directions. Increasing pressure to maintain and enhance the integrity of degrading natural resources, changes in demands and opportunities arising from economic liberalization, unprecedented opportunities arising from advances in biotechnology, information revolution and most importantly the need and urgency to reach the poor and disadvantaged who have been by passed by the green revolution technologies [SATHAYE ET AL, 2006].

Another important implication of increasing globalization relates to the need for greater attention to the quality of produce and products both for the domestic and the foreign markets. This would imply that production must be tuned to actual rapidly changing product demand. Such adaptation to global markets would require state of the art research, which can be achieved only by setting global standards of research, focus on well defined priorities and mechanisms which permit close interaction of farmers with researchers, the private sector and markets [RAVINDRA BABU ET AL., 2007].

3.4 Land Use Change in India

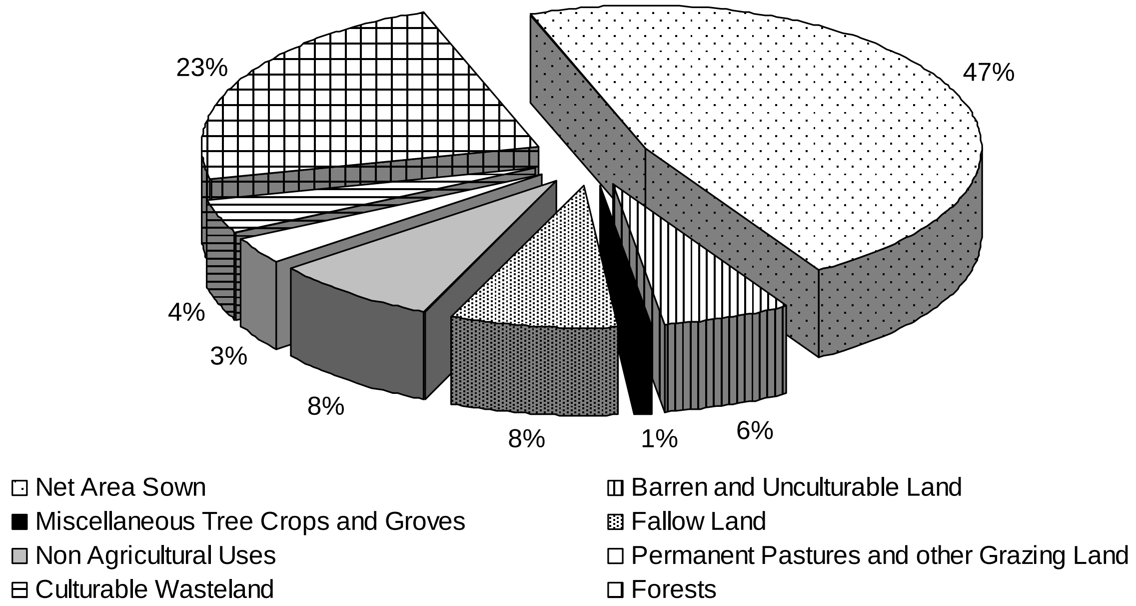
3.6. Figure: Land use map of India



Source: Indian Agriculture Research Institute

India is the seventh largest country in the world, with a total land area of 3,287,263 sq. km. (1,269,219 sq. miles). It measures 3,214 km (1,997 miles) from North to South and 2,993 km (1,860 miles) from East to West. It has a land frontier of 15,200 km (9,445 miles) and a coastline of 7,517 km (4,671 miles). Ever-growing population and urbanization is creeping into its forests and agricultural lands. Although India occupies only 2.4 per cent of the world's total land area, it supports over 16.7 per cent of the entire global population. Of the total geographical area of 328.73 Mha., 306 Mha. Comprise the reporting area and 146.82 Mha. Land is degraded land.

3.7. Figure: Land Use Classification in India (2005-2006)



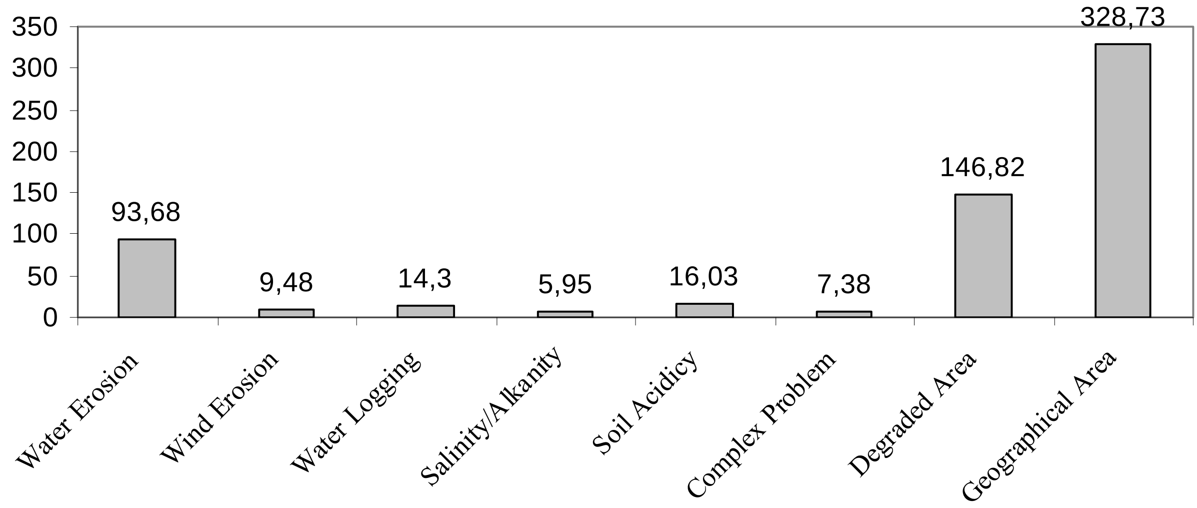
Source: Own calculation based on Ministry of Agriculture 2008

3.1. Table: Land Use Classification in India, (2005-2006)

Classification	2000-01	2001-02	2002-03	2003-04	2004-05	2005-06
I. Geographical Area	328,73	328,73	328,73	328,73	328,73	
II. Reporting Area For Land Utilisation Statistics (1 to 5	305,08	305,01	3,5,24	305,23	305,23	328,73
1. Forests	69,62	69,51	39,64	69,67	69,67	305,27
2. Non Available for Cultivation (a+b)	41,55	41,78	42,08	42,30	42,30	42,51
(a) Non Agricultural Uses	23,81	24,07	24,28	24,72	24,72	25,03
(b) Barren and Unculturable Land	17,74	17,71	17,80	17,58	18,58	17,48
3. other Uncultivated Land excluding fallow Land (a+b+c)	27,71	27,37	27,54	27,00	27,00	26,92
(a) Permanent Pastures and other Grazing Land	10,83	10,59	10,51	10,43	10,43	10,42
(b) Land under miscellaneous tree Crops and Groves not included in net Area Sown	3,32	3,37	3,36	3,38	3,38	3,38
(c) Culturable Wasteland	13,56	13,41	13,54	13,19	13,19	13,12
4. Fallow Land (a+b)	25,03	24,94	33,46	24,94	24,94	24,17
(a) Fallow Land other than current Fallows	10,19	10,30	11,76	10,72	10,72	10,50
(b) Current Fallows)	14,84	14,64	21,70	14,22	14,22	13,67
5. Net Area sown 6-7	141,16	141,42	132,66	141,32	141,32	141,89
6. Gross Cropped Area	185,70	189,75	185,66	190,91	190,91	192,80
7. Area sown More than once	44,54	48,33	13,00	49,59	46,59	50,90
8. Cropping intensity	131,30	134,20	132,40	135,10	135,10	135,90
III. Net irrigated Land	54,84	56,30	53,88	56,00	58,54	60,20
IV. Gross irrigated Land	75,82	78,07	72,89	77,11	79,51	82,63

Source: Ministry of Agriculture 2008

3.8. Figure: Extent of Various Kinds of Land Degradation in India
Land Degradation (Area in million hectare)



Source: National Bureau of Soil Survey and Land Use Planning, 2005

3.4.1 Land degradation status

In India, an estimated 146.82 Mha. area suffers from various forms of land degradation due to water and wind erosion and other complex problems like alkalinity/salinity and soil acidity due to water logging (see Figure 3.9). The varying degrees and types of degradation stem mainly from unstable use and inappropriate land management practices. Loss of vegetation occurs as a result of deforestation, cutting beyond the silviculturally permissible limits, unsustainable fuel-wood and fodder extraction, shifting cultivation, encroachment into forest lands, forest fires and over-grazing, all of which subject the land to degradational forces. Other important factors responsible for large-scale degradation are the extension of cultivation to lands of low potential or high natural hazards, nonadoption of adequate soil conservation measures, improper crop rotation, indiscriminate use of agro-chemicals such as fertilizers and pesticides, improper planning and management of irrigation systems and extraction of groundwater in excess of the recharge capacity. In addition, there are a few underlying or indirect pressures such as land shortage, short-term or insecure land tenancy, open access resource, economic status and poverty of the agriculture dependent people which are also instrumental, to a significant extent, for the degradation of land [ROY ET AL, 2004, RAVINDRA BABU ET AL., 2007].

3.4.2 Land use changes due to agricultural practice

Out of India's total geographical area (328.7 million hectares) 141.89 million hectares is the net sown area, while 192.80 million hectares is the gross cropped area. The net irrigated area is 60.20 million hectares and the cropping intensity is 135.90 per cent (Table 3.1). A change in land use pattern implies variation in the proportion of area under different land uses at a point in two or more time periods. Over the past fifty years, while India's total population increased by about three times, the total area of land under cultivation increased by only 20.2 per cent (from 118.75 Mha. in 1951 to 141.89 Mha. in 2005-06). Most of this expansion has taken place at the expense of forest and grazing land. Despite fast expansion of the area under cultivation, less agricultural land is available on per capita basis. Direct consequences of agricultural development on the environment arise from intensive farming activities, which contribute to soil erosion, land salination and loss of nutrients. The introduction of Green Revolution in the country has been accompanied by over-exploitation of land and water resources and excessive usage of fertilizers and pesticides. Shifting cultivation (or *Jhum* cultivation) has also been a major factor responsible for land degradation in hilly areas. Leaching due to extensive use of pesticides and fertilizers is a major source of contamination of water bodies. The extent of agricultural intensification and extensification is characterized by an increase in cropping and irrigation intensity and the imbalanced use of chemical fertilizers, pesticides and insecticides. It has also led to land degradation, overexploitation of underground water resources and increased use of chemical fertilizers, leading to eutrophication and water pollution in some regions. Enhanced intensification and extensification also leads to salination, alkalization and water logging in irrigated areas, along with eutrophication of water bodies and ill health of oceans, leading to loss of biodiversity. For achieving and maintaining food security and sustainable forestry, controlling of land/soil erosion is extremely vital. It is essential to control soil erosion in order to attain and maintain food security, sustainable forestry and agricultural and rural development. Statistics reveal that only 23 per cent of the applied fertilizer is consumed by plants, the remaining 77 per cent is either leached out beyond the root zone or lost by volatilization [SHARMA ET AL, 2003, RAVINDRA BABU ET AL., 2007].

3.4.3 Excessive Chemical Usage

Per hectare consumption of fertilizers has increased from 69.8 kg in 1991-92 to 113.3 kg in 2006-07, at an average rate of 3.3 per cent. There is excessive use of urea and a bias against micronutrients. As against the desirable NPK proportion of 4:2:1, the average use of urea now is 6:2 and 4:1. The Steering Committee of the Planning Commission has observed that "because nitrogenous fertilizers are subsidised more than potassic and phosphatic fertilizers, the subsidy tends to benefit the crops and regions which require higher use of nitrogenous fertilizers as compared to crops and regions which require higher application of P and K." The excessive use of urea has also affected the soil profile adversely (Table 3.2). Burning of wheat and rice straw and other agricultural residue has also contributed to loss of soil fertility, apart from causing air pollution. Open field burning of straw after combine harvesting is a common practice in states like Punjab, Haryana and Uttar Pradesh in order to ensure early preparation of fields for the next crop. Punjab alone produces around 23 million tonnes of rice straw and 17 million tonnes of wheat straw, annually. This straw is rich in nitrogen, phosphorus and potassium. However, instead of recycling it back into the soil by mulching, it is burnt in the fields. This raises the temperature of the soil in the top three inches to such a high degree that the carbon: nitrogen equilibrium in soil changes rapidly. The carbon as CO is lost to the 2 atmosphere, while nitrogen is converted into a nitrate. This leads to a loss of about 0.824 million tonnes of NPK from the soil. This is about 50 per cent of the total fertilizer consumption in the state. Considering that 90 per cent of rice straw and 30 per cent of the wheat straw is available for recycling, it will be equivalent to recycling of 0.56 million tonnes of nutrients worth Rs. 4 billion. Moreover, agriculture experts also maintain that fire in the fields kills friendly fauna and bacteria [SHUKLA ET AL, 2002, PRASADA RAO ET AL. 2008].

3.2. Table: All India Consumption of Fertilizers in Terms of Nutrients (N, P & K, 1000 tonnes)

Year	N	P	K	Total
2000-01	10 920.2	4 214.6	1 567.5	1 6702.3
2001-02	11 310.2	4 382.4	1 667.1	1 7359.7
2002-03	10 474.1	4 018.8	1 604.2	1 6094.1
2003-04	11 077.0	4 124.3	1 597.9	1 6799.1
2004-05	11 713.9	4 623.8	2 060.6	1 8398.3
2005-06	12 723.3	5 203.7	2 413.3	2 0340.3
2006-07	13 772.9	5 543.3	2 334.8	2 1651.0

Source: Ministry of Agriculture, 2008

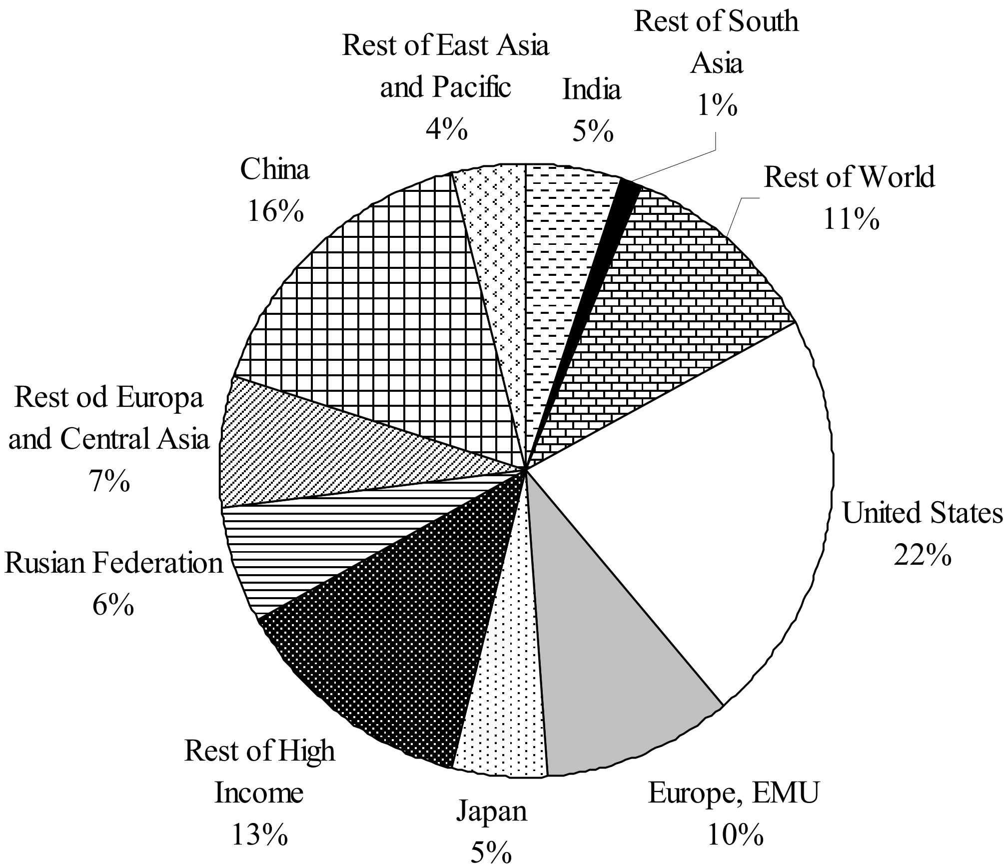
3.5 Climate Change in India

Ever since the industrial revolution began about 150 years ago, human activities have added significant quantities of GHGs to the atmosphere. An increase in the levels of GHGs could lead to greater warming which, in turn, could have major impact on the world's climate, leading to accelerated climate change. Global atmospheric concentrations of carbon dioxide, methane, and nitrous oxide have increased from 280 ppm to 379 ppm, 715 ppb to 1774 ppb and 270 ppb to 319 ppb respectively, between pre-industrial period and 2005 [IPCC ,2007). Eleven of the last twelve years rank among the 12 warmest years in the instrumental record of global surface temperatures since 1850. The updated 100-year linear for 1906-2005 is 0.74^0C. Globally, average sea level rose at an average rate of 1.8 mm per year over 1961 to 2003. The rate was higher over 1993 to 2003, about 3.1 mm per year [IPCC, 2007). The projected sea level rise by the end of this century is likely to be 0.18 to 0.59 metres. In its 2007 Report, the Intergovernmental Panel on Climate Change (IPCC) predicts global temperatures will rise by $2\text{-}4.5^0$C by the end of this century and for the next two decades a warming of about 0.2^0C per decade is projected. Even if the concentrations of all greenhouse gases and aerosols had been kept constant at year 2000 levels, a further warming of about 0.10^C per decade would be expected. This unprecedented increase is expected to have severe impact on global hydrological systems, ecosystems, sea level, crop production and related processes. The impact would be particularly severe in the tropical areas, which mainly consist of developing countries, including India [PRASADA RAO ET AL. 2008].

3.5.1 India’s Contribution to global GHG Emissions

In recent years, development planning in India has increasingly incorporated measurable goals for enhancement of human wellbeing, beyond mere expansion of production of goods and services and the consequent growth of per capita income. India has many future developmental targets, several of which are directly or indirectly linked to energy consumption and therefore to GHG emissions. The contribution of India to the cumulative global CO_2 emissions is only 5 per cent (Figure 3.9). Thus historically, and at present, India's share in the carbon stock in the atmosphere is relatively very small in terms of per capita emissions. India's per capita carbon emissions average one-twentieth of those of the US and one-tenth of most countries in Western Europe and Japan. Sectoral distribution shows that the highest CO_2 equivalent emission contribution is from the energy sector (61 per cent) (Figure 3.10).

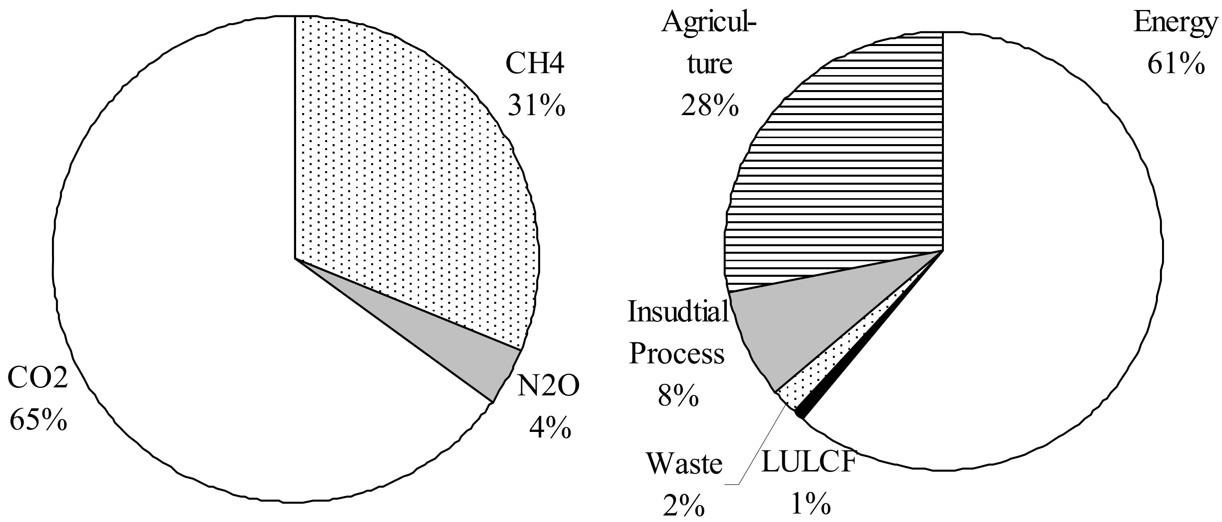
3.9. Figure: India's Share in Global CO_2 Emissions



Source: World Development Indicators, 2009

3.10. Figure: Distribution of GHG Emissions from India

Gas by Gas Emission Distribution — Sectoral Distribution of CO2 Equivalent Emissions



Source: India's Initial National Communication to UNFCCC, 2004

3.5.2 Impacts of climate change in India

Climate changes characterized as global warming are leading to large-scale irreversible effects at continental and global scales. The likelihood, magnitude, and timing is observed to be increasing and accelerating. Many projected consequences of global warming once thought controversial, are now being observed. The IPCC reports that the effects of global warming will be mixed across regions. For smaller values of warming (1 to 3°C), changes are expected to produce net benefits in some regions and for some activities, and net costs for others. Greater warming may produce net costs in all regions. Developing countries are vulnerable to reduced economic growth as a result of global warming. Most of the consequences of global warming would result from physical changes like sea level rise, higher local temperatures, and changes in rainfall patterns, but synergistic effects such as the release of methane hydrates or clathrates and forests and species die-off may cause many unforeseen impacts such as a decrease in the levels of oxygen in the Earth's atmosphere. Most scientists believe that the warming of the climate will lead to more extreme weather patterns such as:

Heat Spells: Extreme temperatures and heat spells have already become common over Northern India, often causing human fatalities. In 1998 alone, 650 deaths occurred in Orissa due to heat waves.

Storms/Cyclones: India's 7,517 km coastline will be particularly hard-hit by storm surges and sea-level rise displacing millions, flooding low-lying areas, and damaging economic assets and infrastructure. The super-cyclone of 1999 wreaked havoc in Orissa, knocking decades off its development and claiming more than 30,000 human lives.

Rainfall: Climate change has had an effect on the monsoons too. India is heavily dependent on the monsoon to meet its agricultural and water needs, and also for protecting and propagating its rich biodiversity. Subtle changes have already been noted in the monsoon rain patterns by scientists at IIT, Delhi. They also warn that by the 2050s, India will experience a decline in its summer rainfall, which accounts for almost 70 per cent of the total annual rainfall and is crucial to agriculture.

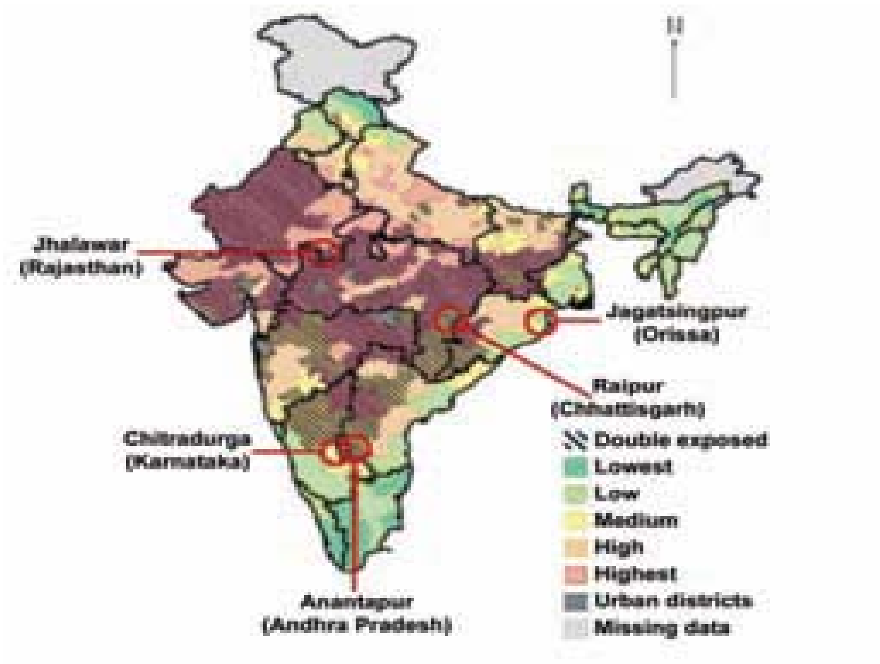
Melting of glaciers causing sea level rise & flooding:

According to International Centre for Integrated Mountain Development (ICIMOD), Himalayan glaciers could disappear within 50 years because of climate change, with far-reaching implications for more than a billion people in India. The Earth's temperature has increased by an average of 0.74^0C over the past 100 years. It is believed that global warming has pushed up the temperature of the Himalayas by up to 0.6^0C in the past 30 years. Ice melt's share in sea level rise is increasing, and will accelerate if the larger ice sheets crumble. As mountain glaciers shrink, large regions that rely on glacial runoff for water supply could experience severe shortages. In northern India, a region already facing severe water scarcity, an estimated 500 million people depend on the tributaries of the glacier-fed Indus and Ganga rivers for irrigation and drinking water. But, as the Himalayas melt, these rivers are expected to initially swell and then fall to dangerously low levels, particularly in summers. (In 1999, the Indus reached record high levels because of glacial melt.) Some of the glaciers in the Himalayas are receding at an average rate of 10 to 15 metres per year. As glaciers melt, many glaciers form lakes at their end which are held together only by frozen mud dams. The dams can break and cause flash floods of water, rocks and gravel, destroying villages and fields downstream imitating the phenomenon termed as Glacial Lake Outburst Flood (GLOF). As glaciers retreat, water flows are expected to be affected during the dry season, leading to freshwater scarcity in the summer months when melt waters contribute up to 75 per cent of the river water. The region's agriculture and power generation are partially dependent on this water supply. In the Ganga, one of the two biggest rivers in India, the loss of glacier melt water is expected to impact downstream water flows, causing water stress for several million people and also affect the irrigated land in the Ganga basin. In Indian Himalaya Region (IHR), Gangotri glacier, the largest ice mass in the Ganga basin, is receding and shrinking at an unsustainable rate. The Gangotri glacier system has a number of glacial lakes. These lakes are formed by displacement of transverse and longitudinal crevasses, rapid melting of glacial ice and high precipitation and seismicity. G.B. Pant Institute of Himalayan Environment and Development (GBPIHED) have been carrying out research on glacial hydrology and glaciofluvial aspect of the glacier since 1999. The study found that in the ablation period, the rising limb of hydrographs exhibited an abrupt increase to peak flow, arresting the GLOF dealings in the glacier. On 6th June 2000, large amount of sediment was transported from the glacier due to heavy rains and deposited as a huge bulk of debris in the valley near Bhujbas (four kilometres downstream of the glacier snout). This debris deposit blocked the Bhagirathi river to form a short-lived extensive lake. Bursting of this lake caused flash floods in the entire area sweeping a temple located on the riverbank and damaging the buildings at Bhujbas, including a pre-fabricated hut and base camp located there. The water level of the river was elevated by about 3m. Similar devastating events were observed at Gangotri town (located 18 km downstream of the snout of Gangotri glacier) where minor damages occurred to the Gangotri temple and three lodges. The bursting of such lakes could also spell disaster for the people living downstream [SHUKLA ET AL, 2003, MANGALA RAI, 2007].

Agriculture

Food grain production in India has increased from 50 million tonnes in 1951 to 212 million tonnes in 2002, while mean cereal productivity has increased from 500 kg/hectare to almost 1,800 kg/hectare. Despite the progress, food production in India is still considerably dependent on the rainfall quantity and its distribution, which is highly variable, both spatially and temporally. In the past fifty years, there have been around 15 major droughts, due to which the productivity of rain-fed crops in drought years was adversely affected. Limited options of alternative livelihoods and widespread poverty continue to threaten livelihood security of millions of small and marginal farmers in the rain-fed agriculture region. Food security of India may be at risk in the future due to the threat of climate change leading to an increase in the frequency and intensity of droughts and floods, thereby affecting production of small and marginal farms. Simulations using dynamic crop models, having the flexibility to independently assess the impacts of temperature rise and CO_2 increase on crop production, indicate a decrease in yield of crops as temperature increases in different parts of India. These reductions were, however, generally offset by the increase in CO_2. The magnitude of this response varied with the crop, region, and the nature of climate change (*pessimistic* or *optimistic*, where *pessimistic* scenario refers to high increase in temperature and low increase in CO_2 , while *optimistic* scenario refers to a large increase in CO_2 and a low rise in temperature). Irrigated rice yields may have a small gain, irrespective of the scenario throughout India. Wheat yields in central India are likely to suffer a drop in the crop yield upto two per cent in a pessimistic scenario, but there is also a possibility that yields may increase by six per cent if the global change is optimistic. Sorghum, being a C4 plant, does not show any significant response to increase in CO_2 and hence these scenarios are unlikely to affect its yield. However, if the temperature increases are higher, western India may show some negative impact on productivity due to reduced crop durations (Figure 3.12) [SHUKLA ET AL, 2002, RATHORE AND STIGTER, 2007].

3.11. Figure: Vulnerability of Indian Agriculture to Climate Change and Globalization

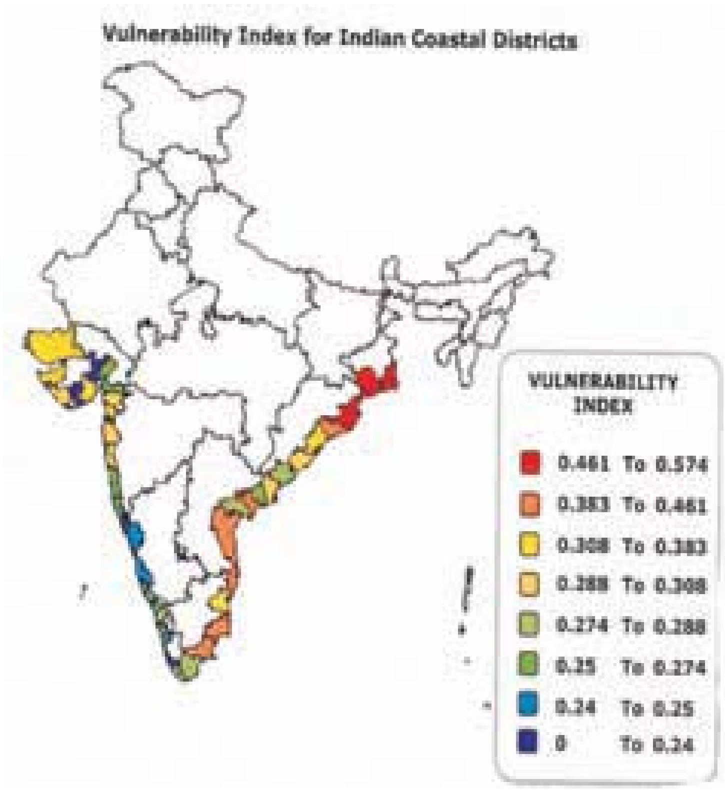


Source: Shukla et al, 2002

Desertification

Globally, about 1,900 Mha. of land is affected by land degradation. Climate change, leading to warming and water stress could further exacerbate land degradation, leading to desertification. It is important to note that the climate sensitive sectors (forests, agriculture, coastal zones) and the natural resources (groundwater, soil, biodiversity, etc.) are already under major stress due to socio-economic pressures. Climate change is likely to exacerbate the degradation of resources and socioeconomic pressures. Thus India, with a large population dependent on climate sensitive sectors and low adaptive capacity will have to develop and implement adaptation strategies.

3.12. Figure: Coastal Districts Vulnerable to Climate Change



Source: Shukla et al, 2002

Changing Ecosystem

Eco-systems will be particularly vulnerable to climate change; with a study estimating that between 15 and 40 per cent of species will face extinction, with 2^{o}C of warming. The impact of climate change would be particularly adverse on the forests, wetlands and coastal regions. The precipitation decline and droughts in most delta regions of India have resulted in the drying up of wetlands and severe degradation of ecosystems. In some regions, the remaining natural flood plains are disappearing at an accelerating rate, primarily as a result of changes in land use and hydrological cycle, particularly changes in stream-flows due to climatic and human related factors. According to IPCC, the most threatened flood plains will be those in South Asia. Evidence of the impacts of climate-related factors on mangroves remains limited to the severe destruction of mangroves due to reduction of freshwater flows and salt water intrusion in the Indus delta and Bangladesh [IUCN, 2003]. In addition, around 30 per cent of

Asia's coral reefs are likely to be lost in the next 30 years due to multiple stresses and climate change. The higher impact will be on the Savannah biomes, Teak and Sal forests of Central and East India and the temperate biomes of the Himalayas. Moist and dry Savannahs are likely to be replaced by tropical dry forests and seasonal forests. By 2050, significant impact will be witnessed. The impact will be lower on the evergreen rain forests of the Western Ghats and the North-East. Composition of species and their dominance could also be altered, and large-scale forest depletion and loss of biodiversity are likely to mark the beginning of the bleak scenario [HUNDAL ET AL, 2007].

Biodiversity

The impact of global warming on biodiversity has emerged as an active area in contemporary conservation biology research and it is extremely important for a country like India, where community dependence on forests is very high and climate change can have much worse impacts than expected or predicted on biodiversity of forest ecosystems [RAVINDRANATH ET AL., 2006]. In the Indian scenario, the two important measures of climate change which have direct and significant impact on the biodiversity are the variation in precipitation and temperature. The increase in precipitation can change the nature of the forest in terms of the floral species dominance, canopy cover, forest dynamics etc. It can rebuild the connections between fragmented ecosystems, support forest areas to encroach in to grasslands, alter tree species dominance and thereby change the forest class. Vice-versa, reduction in precipitation can support a shift towards deciduous category of forests, expansion of grass lands, lead to forest fragmentation and raise frequency of forest fires. All these can cause significant changes in faunal species distribution, demography and composition [RAVINDRANATH ET AL., 2006].

There is a threat to species in the three distinct ecological zones that make up the **Sundarbans** - the largest contiguous mangrove area in the world. If the saline water front moves further inland, many species could be threatened. These changes could result in economic impacts. Direct employment supported by the Sundarbans is estimated to be in the range of 500,000-600,000 people for at least half of the year, and a large number of these people, who are directly employed in the industries that use raw materials from the Sundarbans (e.g. fishing, woodcutting, collection of thatching materials, honey, beeswax, and shells) may lose their sources of income. Sea level rise also may threaten a wide range of mammals, birds, amphibians, reptiles and crustaceans.

The predicted increase in precipitation in the forest areas in the Indian subcontinent is higher than that of the non-forest area [RAVINDRANATH ET AL, 2006]. Climate models predict 2-3.50C increase in temperature and 250-500 mm increase in precipitation in the North Eastern region [RAVINDRANATH ET AL, 2006; IPCC TECHNICAL PAPER V]. Increase in rainfall may not have a significant impact on the forest areas of North East which are already experiencing high rainfall but any change in temperature regime may cause severe impact and significant changes [RAVINDRANATH ET AL, 1998].

4 Material and Methods

Measuring the socio-economics of climate change impact on agriculture land use changes in India can be analyse and calculated in several ways. In my research work, I used following methods, which are given below:

1). Literatures analysis and its correlation to the chosen topic

During my research work, I follow several specific scientific research articles both National and internationally published. I found that more research related to this topic work has been done in the western world then in India related with this topic. I followed all those available and accessible research papers and compared the findings of them with my own research.

2). Document analysis

During my research studies the most important aspect was to get from the Indian governmental official data's and documents, which could provide me the with up-to-date information about the recent changes and trends of socio-economic issues in India, climate change impact on agriculture land use changes.

3.) Case study

It was necessary for me not only analyzing the development or impact assessment trends at national level but also comparing the findings and results with regional level too. For this, I selected India's biggest state, which located in different climatic zones with highly productive river basins, and is a part of Himalayan tracts and also one of the most vulnerable regions in India.

4). Comparative analysis

This analysis was also a very important part of my research studies because comparing different socio-economics, agriculture, land use and climatic characteristics and trends can give us broad views on impact assessment and also the vulnerability count. India is a geographically very large country and the second most populated in the world and that's why comparative analysis can be beneficial for future trends and assumptions.

5.). Quantitative and Statistical Methods

During my studies, I collected a bunch of datasets in order to quantify for result analysis. In addition to that I also used statistical methods mainly correlation and reggration analysis, cluster analysis to measure the vulnerability and vulnerable zones in India, which was very useful for the statistical description of my research work.

6). SWOT Analysis

SWOT analysis is a strategic planning method used to evaluate the strength, weaknesses, opportunities and threats involved in my research topic, which specify the goal of my thesis and will identify the internal and external factors that are favourable and unfavourable to achieve my objectives and aims.

7). Interviews and personal consultations

I concluded interviews and personal consultations with national and international experts, also regional, national and international level which gave me great confidence and ideas to carry out my research work.

5 Results

The relationships between climate change and agriculture land use changes are complex and manifold. They involve climatic and environmental aspects, social and economic responses. These last can take either the form of autonomous reactions or of planned economic or technological policies. This picture is complicated further: indeed climate change and agriculture interdependencies evolve dynamically over time, they often span over a large time and space scale and are still surrounded by large uncertainties. The environmental and the socio-economic dimensions are strongly intertwined in modelling the relationship between climate change and agriculture land use changes. Both need to be accurately taken into account in order to eventually produce a reliable picture of the complexities involved.

Agriculture is one of the most important human activities. It is still one of the main sources of income and productive sector in developing countries like India. It provides a fundamental contribution to welfare and socioeconomic development. Accordingly, a relevant shock affecting the agricultural sector is likely to originate a whole set of responses in the socio-economic system. These responses span from the regional level up to the national economic level. They can be considered adaptation processes to the changing environment; in some cases they are autonomous reactions driven by self-regulatory mechanisms, in some other cases they respond to specific and planned policy interventions.

5.1 Statistical estimation of Agricultural Production in India

In the past, India has made great progress in providing food security for its people. However the growth rate of agriculture has decreased from 3.2 during 1985-90 (seventh plan) to 2.1 during 1997-2002 (Ninth plan) to 1.8 during 2004-2009 (Tenth plan) There has also been a decline in the growth rate of food grain production from 3.22 (1960) to 1.48 (2006). Food grain production is becoming a matter of concern again. The challenge facing the country is in achieving a higher production of food production over the next 2–3 decades. According to a study by [BHALLA ET.AL, 1999; PRASADA RAO ET AL, 2008], baseline projection for total cereal demand in 2020 is 246 million tons for direct human consumption. The relevant question that arises is whether India would be able to increase the food grain production in the coming years with the net-cropped area remaining same? Much of the additional food demand in the future will have to be met through productivity enhancement. What factors have contributed most to the productivity growth in the past? Reaching towards the goal of sustainable agriculture with high yield requires a crucial role of irrigation and other climatic factors. *In this part of my research, I explore the marginal contribution of factors like irrigation and fertilizer on yield of food grain using a regression model. I also tested the hypothesis that marginal effect of fertilizer on yield depends much on the irrigated conditions.*

Over the past 15 years, increase in irrigated area has mainly taken place from groundwater source. Yields in areas irrigated by groundwater are often substantially higher than the yield from surface water sources. Research indicates that yields in groundwater irrigated areas are higher by one third to one half than in areas irrigated from surface sources, and as much as 70-80% of India's agricultural output may be groundwater dependent. Higher yields from groundwater-irrigated areas are in large part due to increase in the reliability of water supply. *In this part of research, I explored how irrigated area driven by groundwater irrigation expansion will contribute in increasing the irrigation intensity.*

Much of the contribution in yield change in the last two decades is caused by high fertilizer usage [DANIEL 2000; AHLUWALIA 1996]. High use of fertilizer in agricultural production is also contributed by expansion of irrigation as the latter reduces the risk of investment in fertilizer. Two decades back, farmers applied only 30 kg of mineral fertilizers (nitrogenous, phosphates' and potassic fertilizers) to their land. Today, they apply 29kg per hectare which is three times as much. In the same period, food grain yields have increased every year, from about 1.023 tonnes/ha to 1.67 tonnes/ha. *One of the concerns regarding the factors constraining the yield growth is imbalanced use of fertilizer.* The pattern of fertilizer use is distorted to great extent. Data suggests extreme overuse of nitrogenous fertilizer, and to large extent it is due to under market price of nitrogenous fertilizer. The excessive use of nitrogenous fertilizer usage is sticking mainly in the irrigated area of the north zone. With declining ground water table over use of nitrogenous fertilizer may slow down the yield growth in future [RAO, 2007].

I hypothesize both time series and cross section variation in yield and the factors influencing the latter across the states in India. Using a panel data, I investigate the yield of food grains, and assess the future impacts of increasing irrigated area and fertilizer usage. I used annual time series and cross section data of 15 major states in India, which constitutes more than 95 % of the agrarian economy of India, for the period 1990-2006. Based on the regression results, I analyze the contribution of the different factors in the relative changes in yield growth. To get into further insights I also assess the contribution of the factors in relative change in yield in different zones of India, for instance North, South, East and West Zones.

It is essential to project India's future food production, as the current concern is to meet the food demand of the increasing population. The proportion irrigated area, fertilizer usage and gross cropped area are determined using a quadratic time trend of the last decade; and then based on the regression results and time trend values of the factors, I projected the yield of food grains in 2010, 2025 and 2050.

5.1.1 Agriculture scenario:

In the past, India has made great progress in providing food security for its people. The growth of food production has surpassed the growth of population, with per capita food availability increased from 167kg per year during 1980-1990 to 174 kg per year during 1990-2000 to 184 kg per year during 2000-2006. Indian policy makers have shifted their focus from self-sufficiency to generating additional income in rural area [AHLUWALIA 2004]. But will India continue to be self-sufficient in food grain in the years ahead with declining net cropped area for the same? Till 1990, food grain production was driving the agricultural sector growth- a natural consequence of high priority food policy regime pursued since independence. Since 1990, the non -food grain sector appeared to have taken over. Table 5.1 shows the production of major food grains over the last 50 years. The major growth has taken place in rice and wheat production while coarse cereals and particularly pulses are lagging behind. The table also illustrates a decelerating growth of food grains production during 1990-2006. In this part of thesis, I explore the factors influencing the gross area and yield of food grains, which determine the production of the same.

5.1. Table: Production of food grains

	Rice	Wheat	Coarse Cereals	Pulses	Total food grains	Growth Rate
1950-51	20.58	6.46	15.38	8.41	50.82	:
1960-61	34.58	11.00	23.74	12.70	82.02	4.90
1970-71	42.22	23.83	30.55	11.82	108.43	2.83
1980-81	53.63	36.31	29.02	10.63	129.59	1.80
1990-91	74.29	55.14	32.70	14.26	176.39	3.13
2000-01	84.98	69.68	31.08	11.07	196.81	1.10
2005-06	89.76	72.34	32.79	10.91	205.32	1.38

Source: Own calculation based on Ministry of Agriculture, Government of India

5.1.2 Gross cropped area of foodgrains:

In the post independence period until 1967-68, much of the increase in food production had taken place from expansion of farm areas. The area expansion slowed down by 1970; and since then, the total net area sown for crops has not increased much. Most of the increase in gross sown area, however, has been achieved from increasing cropping intensity, mainly driven by the development of irrigation.

Table 5.2 shows the cropping intensity, irrigation intensity and the rainfed intensity. In 2006, I observe a decline in cropping intensity in both irrigated and rainfed area, and if I exclude that year I, find considerable growth in the rainfed intensity. This is largely due to governmental policies directed towards improving the position of small farmers in the non-irrigated areas through extending the productivity revolution and production of high valued crops. However, cropping intensity growth in the irrigated area is still higher than that of the rain fed area.

5.2. Table: Cropping, irrigation and rainfed intensity of India during 1990-2006

	Irrigation intensity	Cropping intensity	Rainfed intensity
1990	1.31	1.30	1.29
1991	1.32	1.29	1.27
1992	1.33	1.30	1.29
1993	1.33	1.31	1.30
1994	1.33	1.32	1.31
1995	1.34	1.32	1.31
1996	1.33	1.33	1.33
1997	1.33	1.34	1.35
1998	1.32	1.35	1.37
1999	1.37	1.35	1.33
2000	1.35	1.32	1.30
2001	1.36	1.33	1.31
2002	1.33	1.33	1.31
2003	1.36	1.35	1.33
2004	1.31	1.32	1.34
2005	1.35	1.31	1.33
2006	1.35	1.33	1.34

Source: Ministry of Agriculture, Government of India

The growth in irrigation intensity is mainly contributed by groundwater expansion and increasing level of mechanization, while rainfall and the need to sustain livelihood determine the growth of intensity in the rainfed area, where majority of the rural poor people live. Most of the diversified and mixed farming are taking place in the rainfed part of the cropped area, and it contributes in increasing the cropping intensity [KUMAR ET AL, 2001, RAO, 2007].

I analyze the state wise variation in cropping intensity across states in the *last years*. Many climatic factors like rainfall, drought affects cropping intensity. So, I have taken an average for the period 1990-1993 and 1997-2006. Table 5.3 shows the average cropping intensity and the corresponding growth rate. I observe high growth of cropping intensity in the northern and eastern states, and mainly in Uttar Pradesh and West Bengal. In the latter two states, intensity is driven by higher irrigation expansion. In Tamil Nadu, however, there is decrease in cropping intensity. In Tamil Nadu, depletion of groundwater resource increases the opportunity cost of increasing the intensive margin, and resulting a decrease in cropping intensity.

5.3. Table: Cropping intensity in India during 1990-1993 and 2000-2006.

States	1990-1993	2000-2006	Growth Rates (Per Cent 2000-2006 over 1990-1993)
Haryana	1.58	1.72	8.81
Punjab	1.79	1.90	5.84
Himachal Pradesh	1.71	1.74	1.78
Uttar Pradesh	1.33	1.51	13.81
North Zone	1.45	1.61	11.12
West Bengal	1.37	1.71	24.52
Bihar-	1.29	1.35	4.61
Orissa	1.33	1.39	4.29
Assam	1.31	1.47	12.77
East Zone	1.35	1.47	8.67
Karnataka	1.14	1.17	2.51
Kerala	1.29	1.33	2.92
Tamil Nadu	1.26	1.18	-5.83
Andhra Pradesh	1.22	1.23	1.12
South Zone	1.20	1.21	0.46
Gujarat	1.12	1.12	0.46
Maharashtra	1.17	1.24	6.08
MP	1.20	1.28	6.99
Rajasthan	1.24	1.27	3.16
West Zone	1.19	1.25	4.79
INDIA	1.30	1.34	3.16
All major states	1.26	1.34	6.07

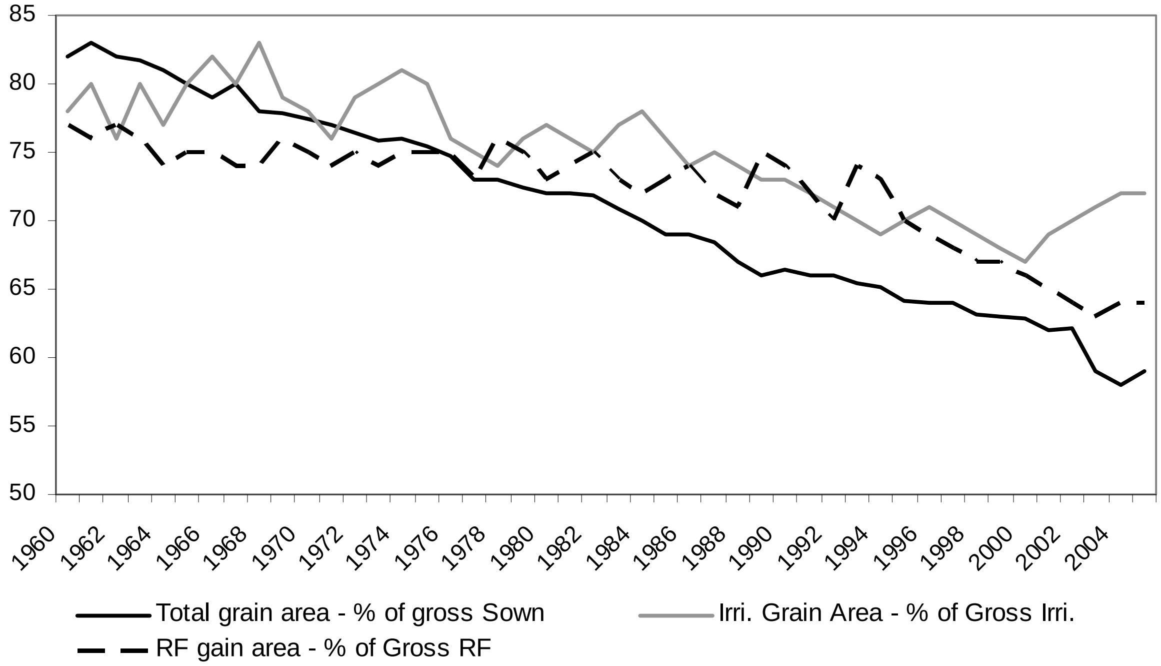
Source: Ministry of Agriculture, Government of India

5.1.3 Changing Grain Orientation:

With technologies developments in agriculture and rising demand of non-food grain, traditional farming is changing into modern commercial farming. From a much generalized perspective, Indian agriculture is increasingly getting influenced more and more by economic factors [HAZRA, 2000, PALANISAMI ET AL, 2007]. This is not surprising because development of irrigation driven by groundwater expansion, infrastructure development, development and spread of short duration and drought resistant crop technologies have all contributed to minimizing the role of non-economic factors in crop choice of even small farmers [HAZRA, 2000]. In the last decade, I have observed a decrease in grain orientation and diversification in crops. Crop diversification is intended to give a wider choice in the production of a variety of crops in a given area so as to expand production related activities on various crops and also to lessen risk. Between 1990-91 and 2000-06, around 4 percent of the gross cultivated area (GCA) – representing approximately about 6.7 million hectares – has shifted from food grain crops to non-food grain crops. Among the food grain crops, the area under superior cereals, i.e., rice and wheat, is increasing; while that of coarse cereals (millets) is on decline.

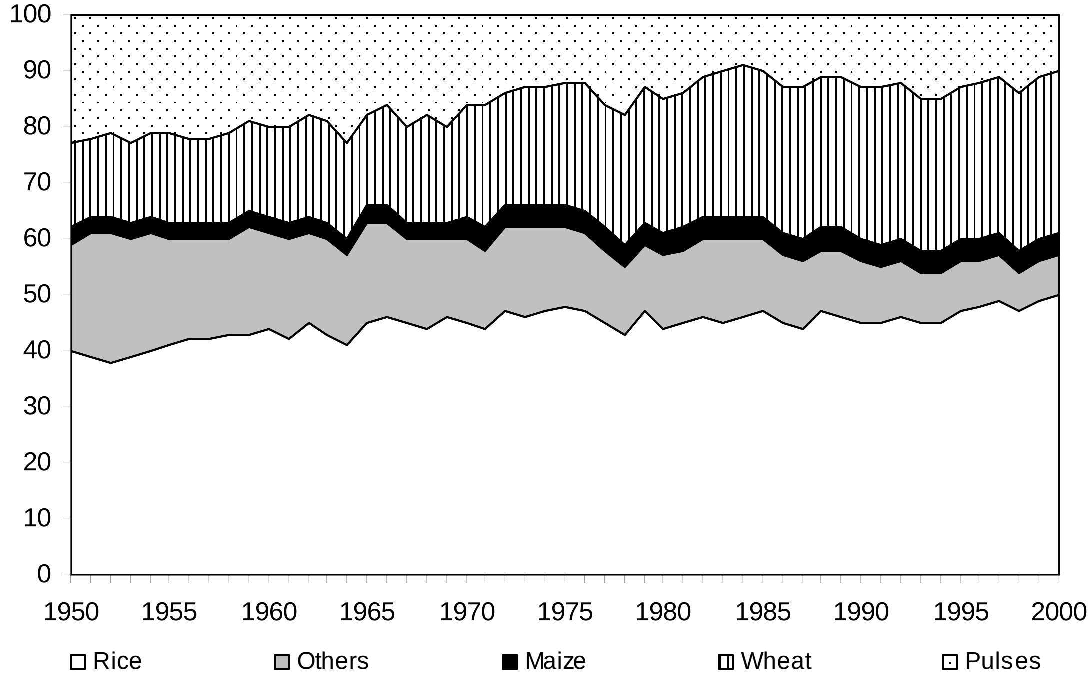
While cereals and pulses have lost area, the major gainers of this area shift are the non-food grain crops especially oilseeds. If I look at the grain orientation of agriculture defined as a ratio of gross cropped area for food grain to total cropped area, I observe a declining trend. Grain orientation of agriculture during the last decade has decreased from 71% to 67%. Most of the change in grain orientation, however, is taking place under rainfed conditions to reduce the risk factor of crop failures due to drought or less rain. This is also evident from figure 5.1. Although comparative advantage, yield difference and crop rotation considerations often favour diversification in irrigated areas.

5.1. Figure: Grain orientation in irrigated and rainfed area from 1960 onwards



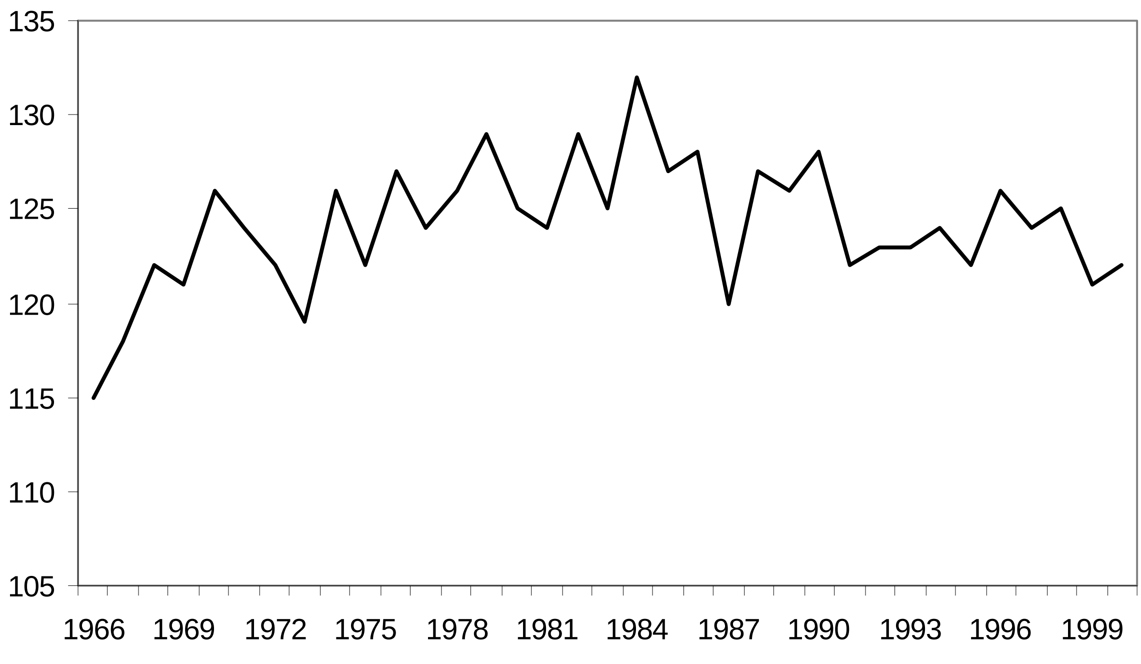
Source: Own construction based on Ministry of Agriculture, Government of India

5.2. Figure: Composition of foodgrains in India from 1950-2000



Source: Own construction based on Ministry of Agriculture, Government of India

5.3. Figure: Trend in gross sown area of foodgrains in India from 1966-2000



Source: Own construction based on Ministry of Agriculture, Government of India

Table 5.4. shows the grain orientation of 16 major states and the growth from the period 1990-1993 to 1997-2006. The table suggests changes in grain orientation are taking place in most of the major states and with greater prominence in the rain fed area. Area wise change in grain orientation is more among the southern states. In the rice wheat producing states of Punjab, Haryana and Uttar Pradesh, diversification is taking place slowly in irrigated area. Much of diversification in Punjab is taking place in the rain-fed area. The minimum support price provided to farmers in the northern agricultural states act as risk reducing insurance against fluctuation in price. Farmers have little incentive to change to other high valued crops. Considering the rice dominant states, I observe a decline in grain orientation in West Bengal. Among the southern states, crop diversification is taking place only under irrigated conditions during the period 1997-2000 in Andhra Pradesh and Tamil Nadu. One of the reasons of change in grain orientation in Tamil Nadu especially is rapidly decline in groundwater level, caused by higher withdrawal rate than the recharge rate. It induces farmers to shift to water saving commercial crops in irrigated area.

5.4. Table: Grain orientation in India during 1990-1993 and 2000-2006

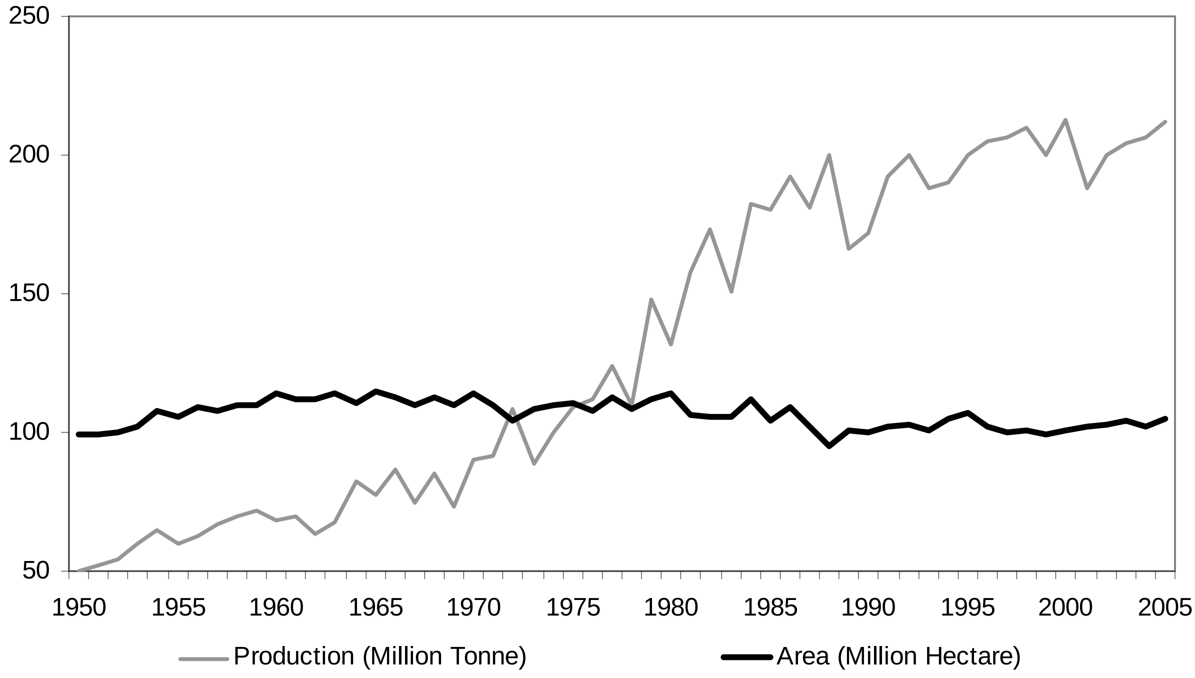
States	1990-1993		2000-2006		Growth Rates (% 2000-2006 over 1990-1993)	
	Grain orientation (GOA)	Grain orientation-Irrigated (GOA-IR)	Grain orientation (GOA)	Grain orientation-Irrigated (GOA-IR)	Grain orientation (GOA)	Grain orientation-Irrigated (GOA-IR)
Haryana	0.77	0.70	0.70	0.70	-9.22	-0.88
Punjab	0.93	0.78	0.76	0.78	-17.77	-0.98
Himachal Pradesh	0.87	0.63	0.86	0.85	-0.48	34.99
Uttar Pradesh	0.88	0.81	0.84	0.77	-4.75	-4.96
North Zone	0.88	0.79	0.81	0.76	-7.85	-3.07
West Bengal	0.86	0.95	0.70	0.77	-18.36	-19.18
Bihar-	0.92	0.89	0.95	0.92	3.46	2.60
Orissa	0.81	0.70	0.64	0.80	-20.26	13.90
Assam	0.76	0.94	0.69	0.66	-8.97	-29.79
East Zone	0.85	0.86	0.76	0.83	-10.50	-2.62
Karnataka	0.58	0.52	0.62	0.55	7.25	6.07
Kerala	0.22	0.55	0.13	0.46	-41.10	-15.83
Tamil Nadu	0.55	0.66	0.56	0.62	1.74	-5.97
Andhra Pradesh	0.54	0.74	0.55	0.71	0.93	-3.64
South Zone	0.53	0.66	0.54	0.64	1.10	-3.31
Gujarat	0.40	0.42	0.34	0.34	-14.68	-19.73
Maharashtra	0.83	0.60	0.73	0.55	-11.92	-8.04
MP	0.59	0.93	0.53	0.84	-11.32	-9.51
Rajasthan	0.60	0.53	0.60	0.51	0.77	-3.65
West Zone	0.63	0.64	0.58	0.59	-8.71	-7.88
Total	0.70	0.74	0.65	0.71	-6.33	-4.76
INDIA	0.68	0.71	0.65	0.71	-3.98	0.31

Source: Ministry of Agriculture, Note: GOA=GSA-fg/GSA; GOA-IR=GIA-fg/GIA

5.1.4 Yield of Food grains

Increase in cropped area is not sufficient enough to meet the demand for food grain. In the last few decades, yield of food grain has increased by more than two fold. From figure 5.4, it is evident that from late 70's, which also marked the beginning of the period of green revolution, the yield of food grain has increased which results in higher gap between the growth of production and gross grain cropped area.

5.4. Figure: Food production and gross sown area for food grain from 1950-2005

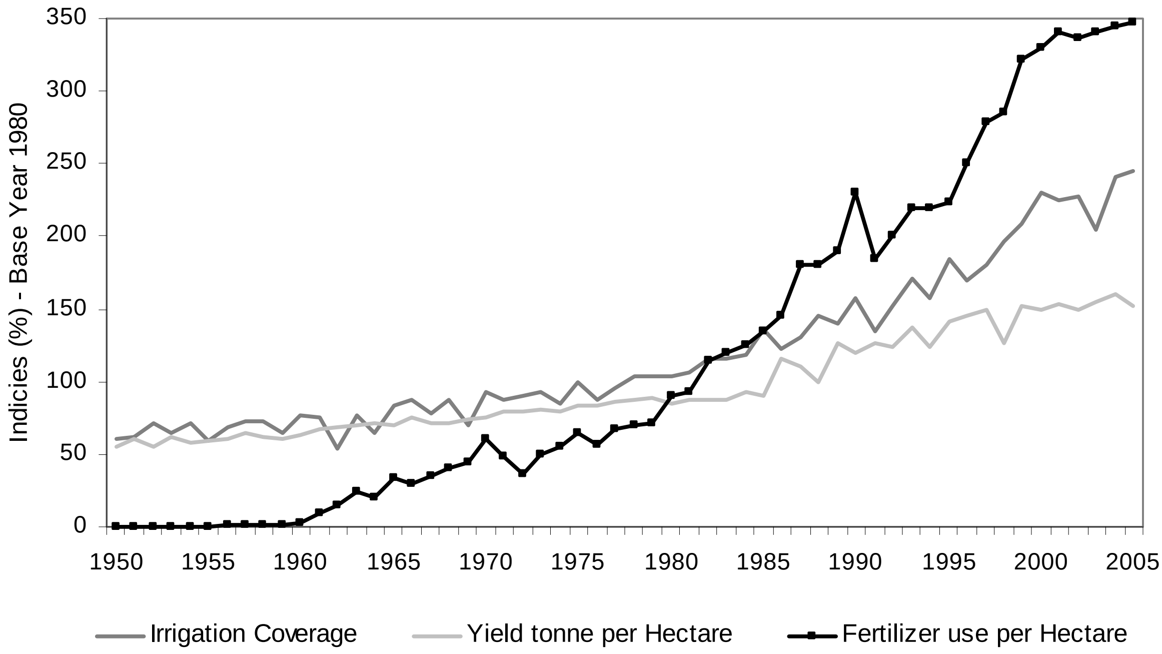


Source: Own construction based on Ministry of Agriculture

Reaching towards the goal of sustainable agriculture with high yield requires a crucial role of irrigation. Irrigation has played a contributory role in the production of food grain in the past and it is also evident from the figure shown below.

The yield and irrigation grew at the same rate for longer time period. The question, however, remains whether irrigation would continue to play similar role in future. From figure 5.5. I observe that 1990 onwards irrigation has played a less significant role in yield change compare to pre 1990 period, and is highlighted by the increasing differences between yield and irrigation ratio. Much of the yield change in the last two decades is caused by high fertilizer usage. High use of fertilizer in agricultural production is also contributed by expansion of irrigation as the latter reduces the risk of investment in fertilizers.

5.5. Figure: Irrigation coverage, fertilizer usage and yield of foodgrain from 1950-2000



Source: Own construction based on Ministry of Agriculture and Fertilizer Association of India, Government of India

5.5. Table: Yield of food grains in India during 1990-1993 and 2000-2006

States	1990-1993	2000-2006	Growth Rates (Per Cent 2000-2006 over 1990-1993)
Haryana	2.40	2.77	15.62
Punjab	3.38	3.70	9.40
Himachal Pradesh	1.57	1.70	8.53
Uttar Pradesh	1.75	1.90	8.44
North Zone	2.13	2.33	9.37
West Bengal	1.85	2.20	18.74
Bihar-	1.18	1.48	26.15
Orissa	1.07	1.06	-1.25
Assam	1.24	1.31	6.22
East Zone	1.33	1.56	17.32
Karnataka	1.02	1.24	21.27
Kerala	1.93	2.04	5.92
Tamil Nadu	1.79	2.28	27.18
Andhra Pradesh	1.62	1.85	14.23
South Zone	1.44	1.69	17.65
Gujarat	1.00	1.42	42.04
Maharashtra	0.66	0.78	16.69
MP	1.21	1.46	20.74
Rajasthan	0.80	1.02	27.38
West Zone	0.89	1.09	23.35
INDIA	1.42	1.63	14.92
All major states	1.38	1.62	17.89

Source: Ministry of Agriculture, Government of India

Table 5.5 shows the yield of food grains during the period 1990-1993 and 2000-2006. The yield of food grains in India has increased by around 15% from 1990-93 to 2000-06. In the past, the gains in productivity remain confined to select areas. Part of this disparity can be explained by the fact that during the period of Green Revolution Punjab and Haryana were way ahead of other states in terms of irrigated area, intensity of irrigation, and intensity of cropping. Availability of irrigation is one of the crucial factors governing regional variations. However, from 1990 there are signs of diminishing returns as a result of decreasing fertiliser productivities and long-term extraction of ground water and soil minerals, and thus raising the question of sustainability of growth and possible exhaustion of the green revolution potential.

During the periods 1990-93 and 2000-06, major increase in yield growth has taken place in the west zone where the average yield was low compare to other regions. Growth is striking in Gujarat, where water harvesting is the primary source of water for agriculture.

Table 5.6 and 5.7 show the yield of rice and wheat and percentage coverage under irrigation of all the major states for these crops. The national growth rates of yield mask variability in the performance of different states. In few states, like Punjab, Haryana, Orissa and Gujarat rice yield has decreased in the period 2000-2006. The decrease in yield is due to the presence of salinity in the groundwater level caused by over exploitation. Zone-wise analysis of growth suggests an equally disquieting trend with the most productive north zone showing slow growth in productivity. The only redeeming factor is the impressive growth rate of the eastern and southern zone the gap between state yield and national yield is high among the western states. Ecology and agro climatic conditions accounts for such gap in this region.

5.6. Table: Yield of Rice in India during 1990-1993 and 2000-2006

	1990-1993		2000-2006	
	yield	% coverage under irrigation	yield	% coverage under irrigation
Haryana	2.73	0.99	2.46	0.99
Punjab	3.43	0.99	3.39	0.97
Himachal Pradesh	1.31	0.61	1.54	0.62
Uttar Pradesh	1.84	0.51	2.05	0.67
North Zone	2.32	0.67	2.44	0.78
West Bengal	2.06	0.23	2.32	0.34
Bihar-	1.13	0.37	1.44	0.41
Orissa	1.36	0.36	1.24	0.38
Assam	1.33	0.21	1.46	0.15
East Zone	1.53	0.30	1.68	0.34
Karnataka	2.36	0.64	2.49	0.70
Kerala	1.98	0.42	2.16	0.57
Tamil Nadu	3.15	0.92	3.47	0.93
Andhra Pradesh	2.56	0.95	2.83	0.96
South Zone	2.65	0.85	2.91	0.89
Gujarat	1.46	0.59	1.37	0.66
Maharashtra	1.56	0.25	1.59	0.29
MP	1.12	0.23	0.91	0.24
Rajasthan	1.11	0.32	1.17	0.55
West Zone	1.24	0.26	1.09	0.29
INDIA	1.84	0.48	1.97	0.53
Major States	1.85	0.50	1.96	0.55

Source: Ministry of Agriculture, Government of India

Regarding wheat, India has made much progress in the productivity growth. The major wheat producing states, Uttar Pradesh, Punjab, Haryana, Rajasthan, Madhya Pradesh and Bihar contribute more than 90 % of the wheat production. In these states, there has been considerable growth of yield. Among the major factors that affect yield, expansion in irrigated and high yielding variety (HYV) area seem to play an important role in raising yield.

5.7. Table: Yield of wheat in India during 1990-1993 and 2000-2006

	1990-1993		2000-2006		
	Yield	% Coverage under irrigation	Yield	% Coverage under irrigation	Δ Yield
Haryana	3.61	0.98	3.96	0.99	0.35
Punjab	3.86	0.97	4.36	0.97	0.50
Himachal Pradesh	1.43	0.18	1.42	0.18	-0.02
Uttar Pradesh	2.29	0.90	2.63	0.93	0.33
North Zone	2.80	0.91	3.17	0.93	0.37
West Bangal	2.16	0.86	2.29	0.76	0.13
Bihar-	1.89	0.87	2.19	0.89	0.30
Orissa	-	-	1.28	2.95	1.28
Assam	-	-	1.20	0.00	1.20
East Zone	1.92	0.88	2.17	0.85	0.25
Karnataka	0.74	0.35	0.76	0.41	0.02
Kerala	-	-	-	-	-
Tamil Nadu	-	-	-	-	-
Andhra Pradesh		-	0.58	0.75	0.58
South Zone					
Gujarat	2.11	0.91	2.30	0.86	0.18
Maharashtra	1.19	0.72	1.20	0.74	0.01
MP	1.50	0.61	1.67	0.71	0.17
Rajasthan	2.17	0.93	2.48	0.97	0.31
West Zone	1.71	0.73	1.92	0.80	0.21
INDIA	2.37	0.85	2.64	0.87	0.27
Major States	2.38	0.87	2.65	0.89	0.27

Source: Ministry of Agriculture, Government of India

5.1.5 Fertilizer Usage:

With ground water tables declining, there are growing pressure to increase the yield. The key factor behind high yield growth could be the development of new technology that will produce higher yields per hectare, and fertilizer remains a key player in this most important task as it has been in the past. However, fertilizer application should be optimum in quantity to meet the crop's nutrient requirement fully so as to achieve the set yield target. Table 5.8 shows the usage of fertilizer per hectare of gross cropped area in year 2000-06. The table illustrates significant difference in the consumption of fertilizer in the irrigated and rain fed area. Mainly, the nitrogenous fertilizer usage is almost double in the irrigated area than in the rainfed area. The pattern of fertilizer use is distorted to great extent. On the basis of agronomic efficiency the ratio of N: P: K should be 4:2:1, whereas usage is 8:3:1 in irritated area and 8:4:1 in the rain fed area. The distortion in the pattern of fertilizer usage is caused by under price of nitrogenous fertilizer [AHLUWALIA, 1996, PALANISAMI ET AL. 2007]. There is substantial subsidy on both domestic production and imports of nitrogenous fertilizer, while the prices of phosphatic and potassic fertilizers are largely market determined. The excessive use of nitrogenous fertilizer usage is sticking mainly in the irrigated area of the north zone. With declining ground water table over use of nitrogenous fertilizer may slow down the yield growth.

5.8. Table: Usage of fertilizer per hectare of cropped area during 2006

Consumption of fertilizer per hectare of gross cropped area (kg)			
Irrigated	Irrigated	Rain fed	Total
N	85.5	43.9	66.6
P	33.1	22	28
K	10.1	5.7	8.1
Total	128.8	71.5	102.8

Source: Own calculation based on Fertilizer Association of India Government of India

5.9. Table: Total consumption of fertilizer in different geographic zones during 2002-06

Zones	Nutrient	Consumption (1000 tonnes) 2002-06		
		Kharif	Rabi	Total
East	N	743.5	810.8	1554.4
	P	262.5	347.6	610.12
	K	153.1	230.2	383.26
	Total	1159.0	1389	2547.7
North	N	1861	2481	4341.5
	P	380.5	919.2	1299.7
	K	58.04	141.9	199.92
	Total	2299	3542	5841.1
South	N	1030	1133	2163
	P	452.6	484.5	937.1
	K	315.9	338.3	654.22
	Total	1799	1955	3754.3
West	N	1268	1148	2415.3
	P	620.1	551.8	1171.9
	K	187.6	176.2	363.76
	Total	2075	1875	3950.9

Source: Own calculation based on Fertilizer Association of India Government of India

5.1.6 Estimation of yield

In this section using regression analysis, I attempted to review the relationship of yield of food grains with irrigation and fertilizer and test the hypothesis that the marginal effect of fertilizer on yield is higher with higher irrigation endowment. I also determine the marginal effects of the factors on yield of rice and wheat. I used annual time series and cross section data of 15 major states in India, which constitutes more than 95 % of the agrarian economy of India, for the period 1990-2006. Unlike earlier studies, instead of using aggregate time series data for these crops, I use panel data, where the cross sectional units are the different states. This allows for state –specific variation in all the variables included, as compared to all- India data, which could reduce such variation by aggregating some variables and averaging others. All the data were available from various sources in the public domain. Separate data for consumption of fertilizer for rice and wheat are not available, and I have used fertilizer per hectare of food grain as proxy in estimating rice and wheat yield Application of same data of fertilizer usage for rice and yield would not make much difference in the result as the recommended fertilizer usage per hectare is similar for both the crops.

I have used two different regression techniques for estimation. First, I have used panel-corrected standard error (PCSE) estimates for linear cross-sectional time-series models where the parameters are estimated by Prais-Winsten regression. When computing the standard errors and the variance-covariance estimates, the estimation assumes that the disturbances are, by default, heteroscedasticity and contemporaneously correlated across panels. Second, I have used random effect model where the individual state specific effects were treated as random variables.

The estimation model I have used is as follows

$$yield = IRfg + IRfg * Fert$$

where the variables are described in table 5.10.

5.10. Table: Description of variables.

Variables	Definitions
GIA-fg	Gross irrigated area of foodgrains
GSA-fg	Gross sown area of foodgrains
Irrigation coverage (IR-fg)	Proportion of gross irrigated area to gross cropped area of foodgrain (GIA-fg/GSA-fg)
Fertilizer (Fert)	Consumption of fertilizer per Ha of net cropped area
Yield	Production of foodgrains per hectare of cropped area.

Source: Own construction

Irrigation and fertilizer are correlated and would cause multicolinearity, if included both. But LUBINSKI & HUMPHREYS [1990] point out that, to the extent that if two variables, X and Z are related, linearity and additivity become confounded in the interaction term such that X*Z is, to some extent, a measure of nonlinear effects. Thus even if irrigation and fertilizer are correlated, the interaction term can be well included in the model to capture the nonlinear quadratic term. The estimation results of yield of food grains are provided in table 5.11. The results suggests that irrigation ratio and the interaction term involving both fertilizer and irrigation are well significant in explaining the yield of food grains, and is also reflected in high R square. The marginal effect of irrigation ratio on yield is high compare to that of fertilizer. I achieve similar results in the random effect model, between R sqr 0.80 suggests high significance of the variables in explaining the yield of food grains between the states.

To get the further insights, I have estimated the yield in two time periods 1990-1995 and 1996-2006. The value of R square was little lower in the period 1996-2006 than in the period

1990-1995. Morever, the marginal effect of irrigation and fertilizer on yield is also higher in the period 1990-1995 than the period 1996-2006. Results also indicate that $\frac{\partial^2 yield}{\partial Fert \partial IRfg} > 0$ for all periods during 1990-2006. It suggests that higher marginal effect of fertilizer per hectare on yield is due to higher irrigation endowment.

5.11. Table: Regression analysis of yield of foodgrain

Yield – Dependent Variable	Irrigation	Irrigation*Fertilizer	constant	R-square
1990-2000	2.018	0.002	0.657	0.751
1990-1995	1.512	0.005	0.704	0.762
2000-2006	2.215	0.002	0.656	0.734

Source: Own construction

5.12. Table: Regression analysis of yield of foodgrain: Random effect model

Dependent variable- yield	Irrigation	Irrigation*Fertilizer	constant	Wald Chi sqr	Between R sqr
1990-2006	1.911	0.002	0.766	106.500	0.796

Source: Own construction

Using similar modeling framework as in above equation, I have estimated the yield of rice and wheat. The regression results are described in tables 5.13 and 5.14. Results show that factors, irrigation and fertilizer explain the rice yield better than that of wheat yield, and are reflected in the difference in R square in the respective estimation. It indicate that the marginal productivity of water is higher for rice yield and lower for wheat yield in the period 1996-2006 than in the period 1990-1995.In case of fertilizer, the marginal effect of fertilizer ha increased in the period 1996-2006 compare to the period 1990-1995 for both rice and wheat.

I also have computed the factor elasticity with respect to yield of rice and wheat. I have taken log linear form of the model to estimate the elasticity. The estimated coefficients of the model are described in table 5.15 and the computed elasticities are presented in table 5.16. Results indicate that elasticity of irrigation water and fertilizer with respect to yield of wheat is higher than that of rice and other food grains, and also the elasticity of irrigation water is higher than fertilizer for both rice and wheat.

5.13. Table: Regression analysis of yield of rice:

Yield of rice– Dependent Variable	Irrigation	Irrigation*Fertilizer	constant	R-square
1990-2000	1.784	0.002	0.703	0.563
1990-1995	1.393	0.004	0.767	0.615
2000-2006	1.974	0.001	0.646	0.547

Source: Own construction

5.14. Table: Regression analysis of yield of wheat

Yield of wheat– Dependent Variable	Irrigation	Irrigation*Fertilizer	constant	R-square
1990-2000	-0.331	0.010	1.430	0.353
1990-1995	0.936	0.010	0.580	0.731
2000-2006	-0.364	0.008	1.571	0.218

Source: Own construction

5.15. Table: Regression analysis explaining log linear relationship between yield of foodgrains and factors

Ln (Yield) – Dependent Variable	Ln (Irrigation)	Ln(Irrigation)*Ln(Fertilizer)	constant	R-square
Foodgrain	0.442	0.026	1.008	0.611
Rice	0.625	-0.042	0.904	0.445
Wheat	-2.247	0.673	0.853	0.361

Source: Own construction

5.16. Table: Elasticity of irrigation and fertilizer with respect to foodgrain, rice and wheat.

	Elasticity Irrigation	Fertilizer
Foodgrain	0.57	0.02
Rice	0.42	0.03
Wheat	0.97	0.11

Source: Own construction

I analyse the sources of changes in yield of food grains, which has increased by 14.7% from the period 1990-93 to 2000-06. The computation of the source of yield is based on the sensitivity analysis. Table 5.17 shows the contribution of different sources to the relative change in average irrigation intensity. The first shows the factor contributing to irrigation intensity change. The second and the third column indicate absolute and percentage contribution of different factors to the relative change in average yield during the period 1990-2000. The table shows that growth in irrigated area explains the yield growth to a significant extent during the period 1990-2006. The last decade witnessed a significant growth in ground water irrigation, and is reflected in nearly 92% of the change in yield from irrigated area.

5.17. Table: Contribution to relative change of yield of foodgrains from irrigation and fertilizer in India and zone wise.

	Change	Contribution (%)
India		
Irrigated coverage (IR=GIAfg/GSAfg)	0.2196	91.50
fertilizer per hectare	0.0204	8.50
Total	**0.24**	91.50
North Zone		
Irrigated ratio (IR=GIAfg/GSAfg)	0.1344	67.19
fertilizer per hectare	0.0656	32.81
Total	**0.2**	67.19
East Zone		
Irrigated coverage (IR=GIAfg/GSAfg)	0.1930	83.92
fertilizer per hectare	0.0370	16.08
Total	**0.23**	83.92
South Zone		
Irrigated coverage (IR=GIAfg/GSAfg)	0.2134	85.36
fertilizer per hectare	0.0366	14.64
Total	**0.25**	85.36
West Zone		
Irrigated coverage (IR=GIAfg/GSAfg)	0.1946	97.30
fertilizer per hectare	0.0054	2.70
Total	**0.20**	97.30

Source: Own construction

The increase in fertilizer consumption per hectare of cropped area only contributes around 8% of the change in yield. However, in the north zone, fertilizer contributes significantly more than 30% of the relative change in yield, while in the south zone it contributes less than 3%. The regional variation in the contribution of fertilizer can be explained by the endowment of irrigation. In the north zone, where more than 90 % of the cropped area is irrigated, farmers can take the risk of utilizing more fertilizer. On the contrary farmers in the west region are risk averse and apply less fertilizer on less irrigated cropped land.

5.1.7 Projection

The challenges facing Indian agriculture today are more serious, complex and exceed those that we encountered prior to the Green Revolution period. India faces the growing challenge to meet the food demand of increasing population. In this part of my research, I project from the supply side, the potential food production in future.

Based on the estimation results and the projected values of the explanatory variables, I projected the yield of food grains of India in year 2010, 2025 and 2050. The time dimension for the projections has also been adopted by both National Commission on Integrated Water Resource Development Plan (NCIWDP) and the Indian Water resource Society (IWRS). A longer time frame with target year, 2050 has been chosen as many water development projects involve a long gestation period, while a shorter time span with 2025 as a target year has been chosen to allow institutional changes in Indian irrigation scenario. Year 2010 represent closer to present scenario as much growth in factors influencing irrigation are not expected to take place during the next five years.

From the regression results, I have determined the marginal effect of the factors influencing yield of food grains. The growth rates of proportional irrigated area, usage of fertilizer per hectare of cropped area and gross cropped area are determined using a quadratic time trend from the last decade. Then using the regression results explaining the yield, I project the latter. Such estimation procedure has been taken to achieve realistic and reasonable growth rates of the factors determining irrigation intensity.

5.18. Table: Regression Results: Quadratic time trend

Variable	constant	trend	Trend-sqr
Irrigation Coverage	0.0193	-0.0001	0.2542
Consumption of Fertilizer per Ha of cropped area (AP)	3.3013	-0.0198	110.4969
Gross cropped area of foodgrains	187.6321	-7.0240	121 410.2000

Source: Own construction

Table 5.19 shows the different scenarios that may guide the development of irrigated water demand in India in future. The first scenario, which may be looked as a business as usual scenario, illustrates the growth of the factors based according to the time trend during the period 1990-2006. Such scenario is plausible with no major changes in the government agricultural and irrigation policy in the next 40 years. In a longer time frame, many may view this as unreasonable given India had experienced two major structural economic policy changes in the first fifty years of its independence. Keeping the possibility of some changes in policy with the potential of altering the factors responsible for changes in irrigation intensity, I have developed alternative scenarios. The alternative scenarios are developed based on the faster rate of change the factors, irrigation coverage (GIAfg/GSAfg), fertilizer usage per hectare of cropped area and climate variation.

In the last decade groundwater irrigation has played a crucial role in influencing the net irrigated area and meeting the irrigated water demand of India in the past. With good groundwater governance, and higher productivity of groundwater, the contribution of groundwater may increase in future. The role of surface water irrigation may also increase with the implementation of national interlinking of rivers project. In the fourth scenario analysis, I assume a 50% per year faster growth in irrigated coverage.

The second scenario assumes the condition if the growth of fertilizer consumption is 50% faster per year, with all other factors maintaining the time trend. In the final scenario, I considered the case where both the factors may change at a faster rate specified by scenario 2 and 3 (Table 5.19).

5.19. Table: Description of scenarios

Scenario 1	Proportional irrigated area for foodgrain and consumption of fertilizer per hectare is changing according to the time trend
Scenario 2	The rate of increase in the proportional irrigated area for foodgrain is 50% more than time trend.
Scenario 3	The growth rate of fertilizer per hectare of cropped area is 50% more than time trend.
Scenario 4-all factors changing	Both factors changing more than time trend.

Source: Own construction

In the past, India's groundwater irrigation has played an influencing role in increasing the irrigated area. According to the time trend, the growth rate of proportional irrigated area for food grains driven by groundwater irrigation would be 2.82% in 2010,1.64% in 2025 and 0.62% in 2050,and at those growth rates the irrigation coverage would be 48%, 59% and 67% respectively. The growth assumes no major changes in surface water. However, if we assume 50% higher growth rate in irrigation coverage for exogenous reasons, the proportional irrigated area for food grain (GIA-fg/ GSA-fg) will increase to 0.88 in 2050.

My projection suggest in India, consumption of fertilizer usage will increase at the rate of 2.94% in 2010, 1.17% in 2025 and by 0.63% in 2050 following the 1990-2000 time trend. Given such growth rate, the fertilizer usage per hectare is expected to be 195 and 226 kg per hectare in 2025 and 2050 respectively. In the scenario with 50% higher growth rate the corresponding figures would be 237 in 2010 and 284 in 2050 (Table 5.20).

5.20. Table: Growth rate according to time trend

Year	Irrigation Coverage	Consumption of Fertilizer per Ha of cropped area (AP)	Gross cropped area of foodgrains
2010	2.82	2.94	0.19
2025	1.64	1.17	-0.26
2050	0.62	0.63	-1.09

Source: Own construction

5.21. Table: Projected values of proportional irrigated area of foodgrains, consumption of fertilizer per hectare of cropped area and yield of foodgrains during 2010, 2025 and 2050

Scenarios	Irrigation-GIAfg/GSAfg			Fertilizer per hectare of gross cropped area			Yield of foodgrains		
	2010	2025	2050	2010	2025	2050	2010	2025	2050
Scenario 1—time trend	0.48	0.59	0.67	165.58	195.20	226.57	1.84	2.15	2.41
Scenario 2-proportional irrigated area changing at a faster rate	0.59	0.76	0.88	171.09	203.67	238.18	2.12	2.58	2.97
Scenario 3-consumption of fertilizer changing at faster rate	0.48	0.59	0.67	193.12	237.56	284.61	1.87	2.21	2.50
Scenario 4-all factors changing at faster rate	0.59	0.76	0.88	195.88	241.79	290.41	2.16	2.65	3.09

Source: Own construction

Given the projected irrigated area of food grains and fertilizer consumption, I have estimated the yield of India in 2010, 2025 and 2050. In 1999-2006 the average yield of food grain of India was 1.67. My projection results suggest that under business as usual scenario, yield of food grain will increase to 1.84 in 2010 and to 2.41 in 2050. In scenario 2 with higher contribution of irrigation, the yield will increase to 2.97 in 2050. Higher change in fertilizer consumption alone, however, would not change the projected yield much. Faster development in irrigation will induce higher usage of fertilizer, and in scenario 4 with both factors changing at a faster rate, the average yield would be 3.09 in 2050 (Table 5.21).

In the recent past, we observe not much change in the gross sown area of food grains. In fact, the average gross sown area for food grains was 127 million hectares during 1980-1990 and it has reduced to 123 million hectares in 1990 – 2000. My projection, based on time trend, suggests that the gross sown area of India will increase slowly till 2010 and then it will start declining. Taking those growth rates as described in table 5.22 the gross sown area would be 128 million hectares in 2010, 125 million hectares in 2025 and in 2050 it would be 112 million hectares. With attainable increase in irrigation and fertilizer according to time trend, the production of food production will be around 271million tons in 2050 and according to higher growth rate scenario the production of food grains would be 322 and 334 million ton in 2025 and 2050 respectively. This is a supply side projection. India’s consumption of food grains can change dramatically as economy grows. As projected, if more land is brought under irrigation, then farmers would response more to economic factors like price, and we could expect a projection figure.

5.22. Table: Projected values of gross sown area and production of foodgrains in 2010, 2025 and 2050

Year	GSAfg	Production of foodgrains According to time trend	Production of foodgrains if the growth of irrigation is 50 % more per year.
2010	128.25	235.98	271.89
2025	125.06	268.88	322.65
2050	112.72	271.65	334.79

Source: Own construction

In this part of my research studies, I have projected the future food production of India. My methodology was based on sensitiveness of the factors, aided with quadratic time trend of those factors. Projection according to time trend only suggests that the food production of India will be 268 million tonnes in year 2025 and it will not change much after that. It means food production will increase by 3.42 metric tonnes per year. According to a projection study by AHLUWALIA, 2004, the cereal demand is expected to be 296 metric tonnes in 2020. Given the time trend, India would be deficient in food production. However, if the growth of irrigation is 50% more, then India could enjoy self-sufficiency in food production. The projection results indicate that there is need of a policy to achieve a higher irrigation growth to meet the growing food demand and to sustain the self-sufficiency in food production.

5.23. Table: States and the geographical zones

North	Punjab	South	Karnataka
	Haryana		Kerala
	Uttar Pradesh		Tamil Nadu
	Himachal Pradesh		Andhra Pradesh
East	Assam	West	Madhya Pradesh
	Bihar		Rajasthan
	Orissa		Gujarat
	West Bengal		Maharashtra

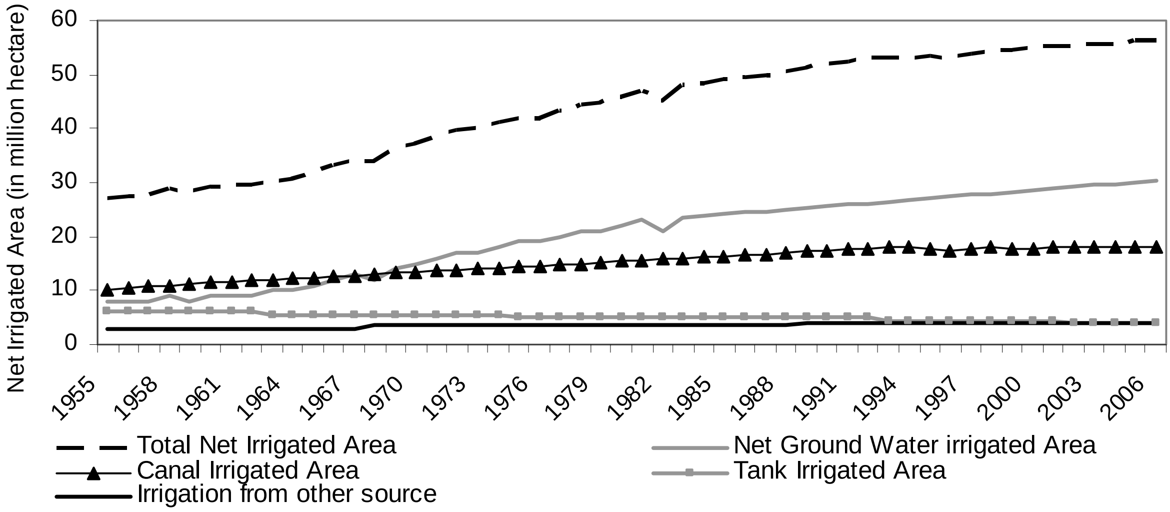
Source: Own construction

5.2 Statistical estimation of irrigation in land use changes

5.2.1 Recent changes in structure of irrigation in India

Though the main objective of this part of my research study was to estimate the contribution of irrigation and other environmental factors in the agricultural productivity, it is important to understand the changes that have taken place in irrigation development in India since 1970. Figure 5.6, illustrates the major structural changes that have taken place in the development of irrigation over the last three and half decades in India.

5.6. Figure: Changes in Net Irrigated Area at all India level (in million ha), 1960-2006

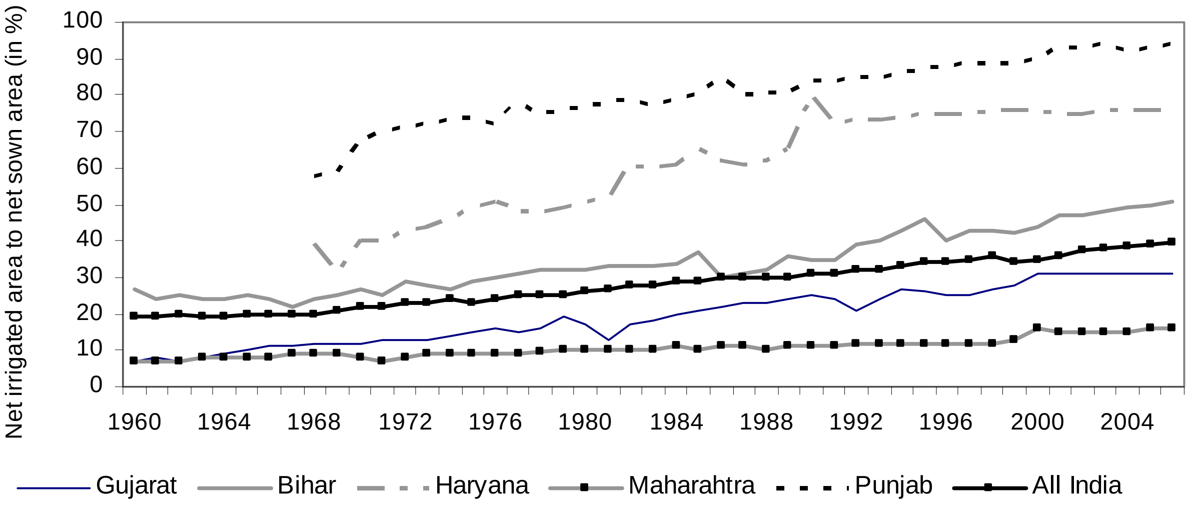


Source: Own calculation based on RAMAKRISHNA ET AL. 2007

The canal irrigated area was larger than groundwater irrigated area until 1972-73, but now groundwater irrigated area is nearly double than that of canal irrigated area. About 5 million hectares of additional canal irrigated hectares (net irrigated area) were added during 1970 to 2000, [PRASADA RAO ET AL. 2008] whereas more than 20 million hectares of net groundwater irrigated area were added during the same period (Figure 5.6). There is a continuous decline in area irrigated by tank and other sources over the years.

As observed at the national level, structural changes have also taken place across different states in India. Overtime changes in the net irrigated area with respect to the net sown area across selected states are illustrated in the Figure 5.7. Some of the agriculturally developed states like Punjab and Haryana have got relatively higher share of percentage of net irrigated crop area than other states, but the irrigated area is not the only one factor for the development of agriculture and that of the state economy in general, as illustrated by the relatively lower percent of net irrigated area of Maharashtra and Gujarat- that are relatively well-off states in India than others. The percent of irrigated crop area of Punjab is above 93 % in 2005, which is more than double than that of the percent of net irrigated crop area at all India level. Similarly the structural changes in irrigation sector across the 14 states of India, in particular, how the gross irrigated area, ground water irrigated area, and pump numbers are added across the states in India over the three and half decades (1970 to 2005). The rate of expansion on ground water irrigated area and pump numbers in the eastern India (West Bengal) are phenomenally high than rest of the other state in India. On an average of half a million of pumps are annually added in West Bengal during the period of 17 years from 1992 to 2007.

5.7. Figure: Percentage of net irrigated area to net sown area across selected states in India
(1960-2006)



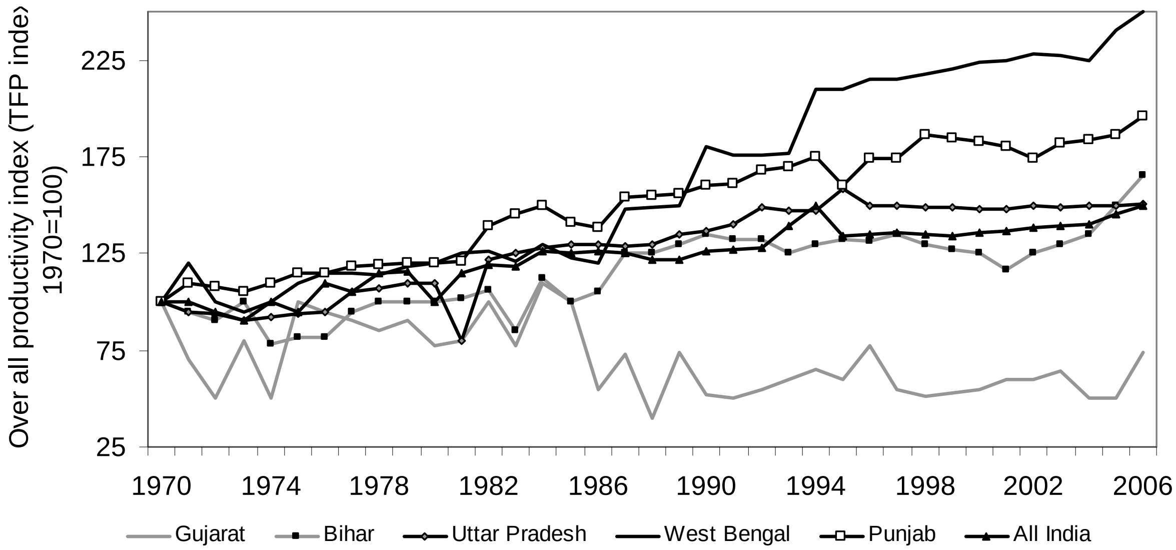
Source: Own calculation based on RAMAKRISHNA ET AL. 2007

Changes taken place in the development of total and source wise irrigation (structural changes) over the years across the states must have played a significant role in increasing the agricultural productivity, that also significantly vary across the states (Figure 5.8 below). Therefore, an attempt is made here to assess the average contribution of irrigation vis-à-vis other factors to the growth of multifactor productivity in agriculture as well partial productivity (production growth) across the state which is applicable to all India level. This is done using statistical analysis (panel regression analysis), which provides us better pictures on the over time changes in the above relationship between agricultural productivity and factor inputs.

5.2.2 Regression results with factors contribution to agricultural productivity

The regression results, from a time series and cross section (states) analysis, show marginal impact of selected factor inputs on the variation of two different indicators of agricultural productivity. They are: overall productivity growth (productivity model) created by taking into account of all factor inputs used in agriculture (Multifactor Productivity Model in table 5.24). The other is over all changes in total production level (Production Model). The elasticity value which estimates the factor inputs in percentage terms (unit free measurement) is also shown in the right hand side of each of the marginal impact. The multifactor agricultural productivity, or agricultural productivity of all factor inputs taken together (TFP index; 1970= 100 index) is defined as growth in all crops and livestock outputs minus growth in all agricultural inputs in a year (estimated separately for a state), and it measures the overall technical and economic efficiency (and technical change) in agriculture production process, not just increased crops yield. Hence, the overall productivity measured by changes in TFP index here is different than the commonly measured crop productivity indicator such as crop yield (or land productivity). Whereas, the production index (1970=100) is estimated here with gross value returns of 19 major crop and 3 major livestock in each states of India, which is in principle equivalent to the land productivity (gross value returns, or partial productivity of crop lands). The overall productivity index (TFP index) and production index used in this study [FAN ET AL,1999]. The variation of overall productivity taking into all inputs (TFP index) across selected states of India is shown in Figure 5.8 below.

5.8. Figure: Changes on multifactor productivity (TFP) across selected States in India, 1970-2006



Source: Own calculation based on Government of India

The regression results reported in table 5.24 imply that two factors namely irrigation and rural literacy level, with elasticity of 0.33 and 0.41 respectively, played a very critical role in explaining the inter-state variation of the agricultural productivity (TFP index) in India over the last few decades (1970-2006), more than any other factor inputs selected in this study. This implies that the future growth of agriculture in India may also heavily depend on the performance of the irrigated agriculture and the level of improvement in rural sector human capital to efficiently utilize the potential created in the irrigated agriculture.

The higher marginal impact of rural literacy variables in this study illustrates the increasing importance of human capital development in agricultural growth and development. This also reflects the changes of farming in India from subsistence based production to knowledge and skill based rural economy over the years. In addition, factors like fertilizers, *High yielding varieties (HYV)* and road infrastructures have also played an important role on increasing the overall efficiency and productivity of agriculture sector in India.

When I included the ground water factor in the above model, the incremental impact of groundwater source of irrigation is very significant in explaining the interstate variation of agricultural production (yield) and overall productivity of all inputs use (TFP index). The marginal impact of ground water is however more noticeable in the case of interstate changes in production index (with elasticity of 0.23) rather than the changes in multifactor productivity index (with elasticity of 0.09). This implies that though groundwater irrigation is significant for improving the growth of production (or crops yield), its impact on overall returns, or resources use efficiency, in farming is relatively low. This could be possibly because of relatively higher farmers' level cost of cultivation under groundwater source of irrigation than in irrigation from surface sources. The decreasing trend of TFP index (productivity of al inputs use) of Gujarat in figure 5.8 above also clearly illustrates this fact.

The marginal impact of Fertilizer use and HYVs adoption is lower in interstate variation of overall productivity (change in TFP index) than in the variation of total production level. The impact of improved crop varieties (HYVs adoption) was increasing at rising rate up to 2000 and thereafter the impact of other policy and infrastructural factors on agriculture productivity has started to increase more than the HYV adoption in the Indian economy.

The marginal impact of road infrastructures on interstate variation of the agricultural production level (in index) is negative. To investigate further on this negative relation with road, I again estimated the production model with two road variables, Road and "Road squared term". Where the road term was positive and the road squared term was negative, and both the terms were statistically significant. That means there is a no straight but a curve linear relationship between agricultural production growth and road factor across the states in India during 1970 to 2006. The agricultural production was positively affected by the road infrastructure in the state with relatively low level of road infrastructures, but the important of road density (i.e., increases in permanent rural road density) declined as the basic level of road access (permanent road) is met. The cursory look at the rural road and production index data series across the states also supports this fact.

Factors responsible for variation of multifactor productivity of all factor inputs (TFP index) and Production level across the states in India, 1970-2006.

Dependent variable:

1. **Multifactor Productivity Model**: Productivity of all inputs taken together (TFP) index in each state, 1970 = 100.

2. **Production Model**: Agricultural production in index level in each state, 1970=100

Independent Variable	Multifactor Elasticity Productivity model	Elasticity value	Production Model	Value
Time Trend	-0,35		-0.21	
	(-0,01)NS		(-0,44)NS	
% of gross cropped area under irrigation (GIA/GCA)	1,2	0,33	0,44	0,11
	(-5,25)***		(-1,74)*	
Fertilizer use per cropped area (in Kg/ha)	0,1	0,004	0,34	0,12
	(-1,62)		(-5,26)***	
HYV adoption rate (in%)	0,18	0,06	0,27	0,08
	(-1,61)		(-2,16)**	
Rural literacy rate (%)	1,59	0,41	4,62	1,07
	(-4,84)***		(-8,17)***	
Road density (in Km/1000km^2 land	0,03	0,13	-0,03	-0,12
	(-3,87)***		(-2,6)***	
Adjusted R^2 (Un-weighted)	0,68		0,8	
Number of states used	14		14	
Number of observation	350		350	

Notes: 1). Values in parentheses are absolute t-statistics; * - significant at 10 percent; ** - significant at 5 percent; *** - significant at 1 percent. F statistics of all above models are significant at 1percent.
2). Both models were estimated fixed effects panel model using Weighted Least Squares (GLS model) techniques. The GLS model was further iterated to minimize the Mean Sum Squared Error, and the results from the converged models are reported here.
3). TFP index is growth in output minus growth in all inputs used in agricultural production process, and it represents overall efficiency in production process. Production index here includes the outputs of 19 crops and 3 livestock sectors.
4. Elasticity value in economics is unit free measurement of factors impacts on dependent variable, estimated at the sample mean of all the observations.

Source: Own calculation based on RAMAKRISHNA ET AL. 2007

5.24. Table: Changes on multifactor productivity (TFP) and structures of irrigation development across the states in India during 1970-2006.

States	% change on TFP index, 1970 to 2006 (1970=100 index)	% of gross crop irrigated areas 1970 and 2006		% of groundwater irrigated area 1970 and 2006		Total no of pumps 1972 and 2004 (in million)		Annual avg. Growth in%	Annual avg Total pumps added (1000)
1. Andrha Pradesh	33	30	43	15	40	0.256	1.100	17%	41.74
2. Bihar	65	28	40	26	50	0.095	0.671	30%	28.8
3. Gujarat	-32	14	27	79	79	0.121	0.631	3%	10.83
4. Haryana	6	40	77	38	49	0.115	0.500	17%	19.5
5. Himachal Pradesh	12	15	18	1	12	0.000	0.002	45%	0.1
6. Kanataka	32	13	26	23	35	0.199	0.611	10%	20.6
7. Madhya Pradesh	46	9	19	38	54	0.113	0.925	36%	40.6
8. Maharashtra	50	9	11	57	61	0.420	1.190	12%	42.3
9. Orissa	98	17	18	4	40	0.006	0.038	27%	1.58
10. Pujab	108	75	93	55	61	0.327	0.714	6%	40.8
11. Rajasthan	19	15	30	51	61	0.072	0.885	56%	40.7
12. Tamil Nadu	40	47	46	30	51	0.888	1.210	2%	16.0
13. Uttar Pradesh	52	38	58	56	70	0.309	2.282	10%	98.6
14. West Bengal	152	24	31	1	37	0.007	7.70*	7000%	512*
All India level average	52	23	34	38	55	3.163	19.000	80%	775.0

Note. 1). Data sources: Economics intelligence unit, Bombay;.
2). * refers to the total pump number in 2000 because of unavailability of data for 2004.

Source: Own Calculation based on RAMAKRISHNA ET AL. 2007

Explanations: This table 5.24 shows the state level changes in multifactor agricultural productivity (TFP), and the corresponding percentage changes in gross crops irrigated area and in percentage of groundwater water irrigated area during the period of 1970 to 2006. This table clearly illustrates that the impact of overall irrigation and of ground water irrigation is not same across the states in India. The annual average increases in pumps number for all

India level was about 80% between 1970 to 2006 including West Bengal, whereas, it was 20% per annum when we exclude West Bengal from the sample.

5.3 Climate change and Vulnerability Index Assessment in India (Case Study)

Vulnerability indices are commonly used for characterizing the impacts on a region or comparing relative vulnerability across regions. Such indices are usually computed as a composite/aggregate across different components of vulnerability. Though such a single numerical value can be useful in many situations, a major disadvantage is that it leads to loss of information about how the different factors that went into making the composite index interact with each other, and contribute to making a place vulnerable.

This part of my research studies, I attempt to construct a picture of socioeconomic context of vulnerability by focusing on indicators that measure both the state of development of the region as well as its capacity to progress further. The first aspect is reflected through agricultural and industrial development, while the second through infrastructure and others. In this study, the climate change impacts are examined from agriculture, infrastructure and demographic characteristics. The analysis is carried out at the district level. Vulnerability of a particular district is measured by the frequency of occurrence of extreme events, in this case the occurrence of cyclones, storms and depressions. From the data on the frequency of occurrence of extreme events it is clear that the districts in the states of Orissa and Andhra Pradesh are highly vulnerable than the other states. *The study aims to build a vulnerability index and rank the various coastal districts of these highly vulnerable states in terms of their performance on the index.* The index tries to capture a comprehensive scale of vulnerability by including many indicators that serve as proxies. The analysis carried out in this part points out that the clusters of districts of poor infrastructure and demographic development are also the regions of maximum vulnerability. Some districts exhibit very low rate of growth in infrastructure, alongside a high growth rate of population. Also these districts show a higher density of population. Hence any occurrence of extreme events is likely to be more catastrophic in nature for the people living in these districts. People living in absolute poverty (those who cannot afford US $2 a day′) will not be able to cope up with the challenges posed by climate change. Therefore, the analysis carried out in this part suggests that climate change policies have to be integrated with sustainable development strategies in general, and poverty alleviation measures, in particular.

Data Source

The data sources for this study are

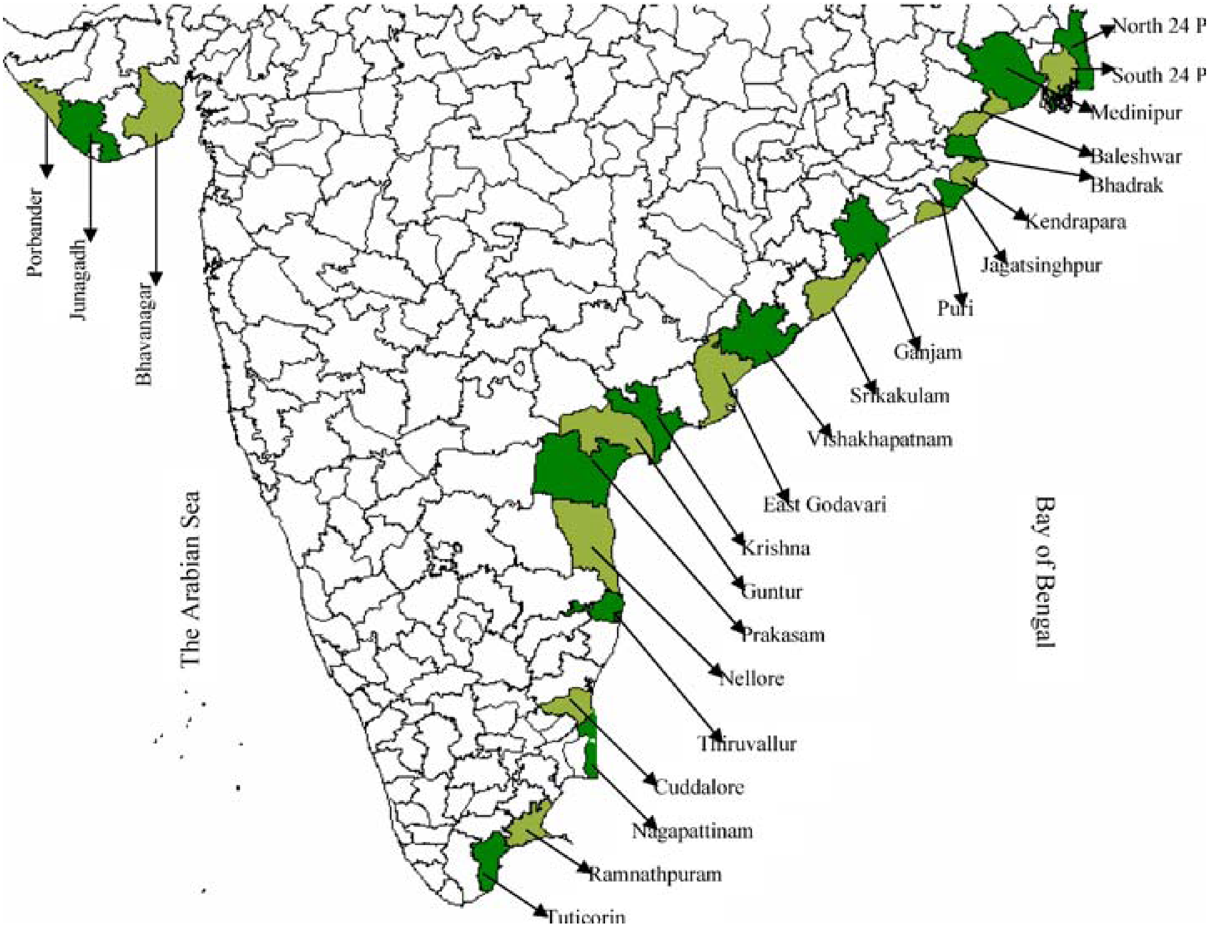
- **(i)** infrastructure from Statistical Abstracts, published by Directorate of Economics and Statistics of respective state governments,
- **(ii)** cyclonic events from the Indian Meteorological Department,
- **(iii)** (iii) agricultural activities from the District Level Database of International Crop Research Institute in Semi-arid Tropics (ICRISAT), and the demographic aspects from various Census Publications, Government of India.

The ***methodology*** includes review of literature and use of descriptive statistics, building of indices for capturing vulnerability and the use of simple and rank correlations, and cluster analysis.

5.3.1 Climate Change and Vulnerability in India

India is the seventh largest country in the world with a geographical area extending from 8° 4′ to 37° 6′ in the north and from 68° 7′ to 97° 25′ in the east. It is bounded by the world's highest mountain range The Himalayas in the north and bounded by Bay of Bengal, Arabian Sea and the Indian Ocean in the south. The coastline along the southern part of India is about 7500 Km. long.

5.9. Figure: Sample of coastal districts in the study (this map has been adapted from the 2001 district map of India.



Source: PALANISAMI ET AL. 2007

In developing countries like India, climate change could represent an additional stress on ecological and socioeconomic systems that are already facing tremendous pressures due to rapid urbanization, industrialization and economic development. With its huge and growing population, a 7500-km long densely populated and low-lying coastline, and an economy that is closely tied to its natural resource base, India is considerably vulnerable to the impacts of climate change [DOD, 2002]. Despite the rapid growth of India's industrial and service sectors over the past decade, agriculture continues to dominate India's economy. Among a population of almost 1 billion people, approximately 68% are directly or indirectly involved in the agricultural sector. Because the majority of Indian agriculture is rainfed, climatic changes that alter temperature and precipitation patterns may pose serious threats to agricultural production. Scenarios generated by computer models show that India could experience warmer and wetter conditions as a result of climate change, including an increase in the frequency and intensity of heavy rains [WATSON ET AL., 1998]. The net impacts of climate change on agricultural output in India are uncertain, yet specific regions and certain groups of farmers, particularly those farming on marginal, rainfed lands, are likely to suffer significant damages as the result of climate change [SELVARAJ ET AL, 2002]. West coast agricultural regions, including Gujarat, Maharashtra and Karnataka, are expected to be among the most negatively affected by climate change [SELVARAJ ET AL, 2002, PALANISAMI ET AL, 2007].

With regard to agriculture, the main rationale for economic reforms in India is to remove distortions and create an appropriate incentive structure for increasing agricultural production which is likely to produce new patterns of climatic vulnerability. With respect to infrastructure provision, it can be seen that in areas where investments in agricultural infrastructure have lagged, such as Maharashtra and Madhya Pradesh, rates of growth in agricultural productivity and poverty reduction have also lagged [DATT ET AL, 1995]. Climate change may further exacerbate these regional differences, because regions with limited irrigation infrastructure are also the areas where agriculture is most vulnerable to climate variability and change [RAO, 1994, PALANISAMI ET AL, 2007].

India is one of the most important countries in the world with regard to the environment. With a large and growing population, India's emissions of greenhouse gases are increasing. Potential climate impacts in India include sea level rise, changes in the monsoon (timing and intensities), increased severe storms and flooding, and drought. And its continuing dependence upon agriculture for food and livelihood (67%, 1995 estimate) makes the Indian people vulnerable to climate variation and change. The climate change and its potential impacts on agriculture are addressed by several studies in recent times. There are a number of studies in the agricultural sector that signify the effect of climate change. [SINHA ET AL, 1991] have estimated a decrease in rice yield at the rate of 0.71 ton/ha with an increase in minimum temperature from 18^{o}C to 19^{o}C and a decrease of 0.41 ton/ha with a temperature increase from 22^{o}C to 23^{o}C. [SINHA ET AL, 1991] show that a 2^{o}C increase in mean air temperature could decrease rice yield by about 0.75 ton/hectare in the high yield areas and by about 0.06 ton/hectare in the low yield coastal regions. Also, a 0.5^{o}C increase in winter temperature would reduce wheat crop duration by seven days and reduce yield by 0.45 ton/hectare. Additionally an increase in winter temperature of 0.5oC would thereby result in a 10% reduction in wheat production in the high yield states of Punjab, Haryana and Uttar Pradesh. The study by [ACHANTA, 1993] concluded that the impact on rice production would be positive in the absence of nutrient and water limitations. [RAO ET AL, 1994] in their crop-simulation study have estimated that under a 2 times carbon dioxide climate change scenario, the wheat yields could decrease by 28%–68% without considering the carbon dioxide fertilization effects. [AGGARAWAL ET AL, 1994] showed that in North India, a 2^{o}C increase would reduce yields in most places [PRASADA RAO ET AL. 2008].

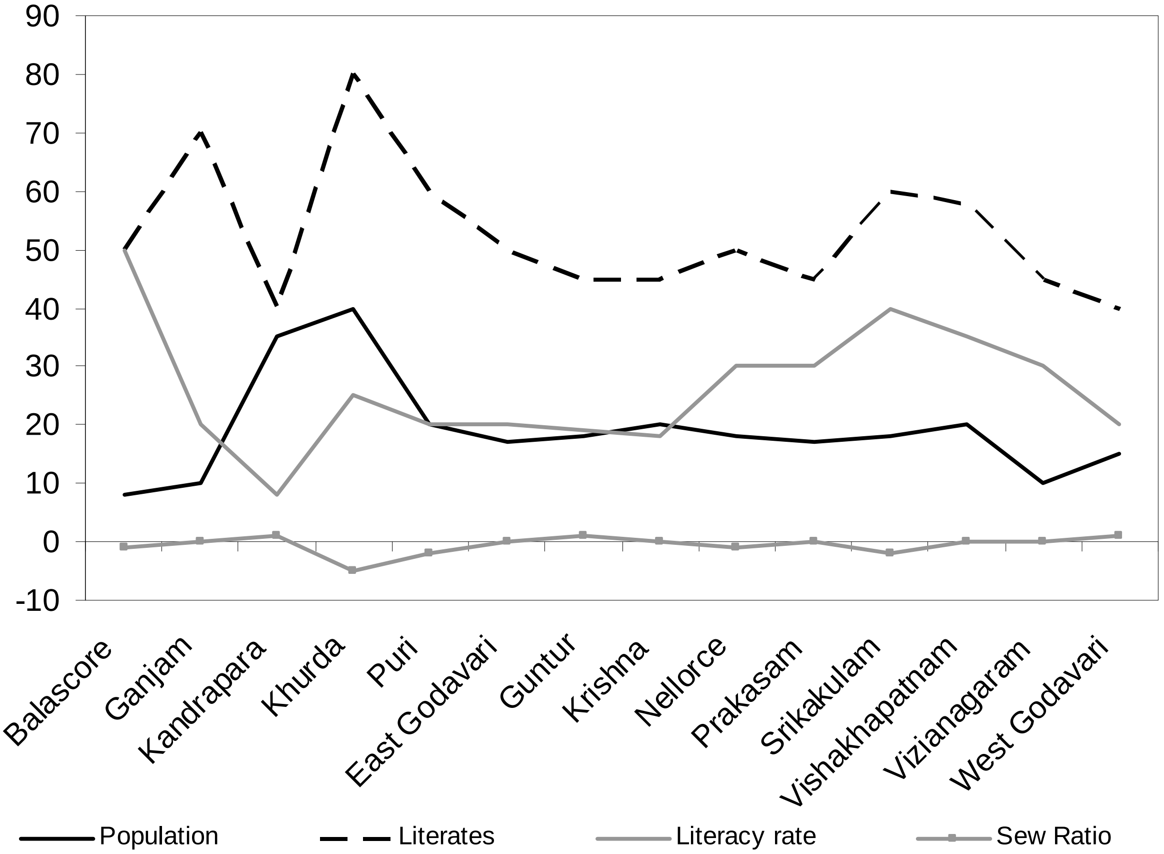
With regards to India it can be said that the Eastern Coast is more vulnerable than the Western Coast with respect to the frequency of occurrence of extreme events like cyclones and depressions [PATWARDHAN ET AL, 2003]. Therefore, in this part of my research, I concentrate on the vulnerability scenario in the eastern coastal districts of India. Within the eastern coast the districts in Orissa and Andhra Pradesh are the most vulnerable in terms of exposure to storms, super storms and depressions [RAMAKRISHNA ET AL, 2007].

5.3.2 Characteristics of the vulnerable eastern coastal districts of India

The coastal zone is an important and critical region for India, which is endowed with a coastline of over 7500 km 3 of the 4 major Indian metropolitan areas are located in the coastal region (Mumbai, Kolkata and Chennai). The total area occupied by coastal districts is around 379610 sq. km, with an average population density of 455 persons per sq. km, which is about 1.5 times the national average of 324. On the eastern coast we have 2 metropolitan cities Kolkata and Chennai.

The impacts of climate change on infrastructure and to the population take place through a variety of ways. Physical infrastructure is directly affected by climate related changes. The economy of the area in concern can also be affected in an indirect way. This is through the change in market demand for goods and services produced in the concerned area. In terms of our analysis I found that the most vulnerable areas to climatic changes as accounted by the frequency of storms, severe storms and depressions perform very low in terms of infrastructure. Relief services post extreme events are dependent on physical and social infrastructure such as roads, communication, banks etc., and the lack of these can inhibit effective provision of relief services. Therefore the presence of infrastructure services in a particular region will seriously affect the vulnerability condition of that area. Taking some of the indicators of infrastructure development as proxies for poverty, one can figure out the different aspects of vulnerability. Therefore the vulnerability will increase in the sense that these areas are less resilient in coping with the shocks of climatic changes. In terms of demography, human settlements and the people living in the area also directly affected by the negative shocks like cyclones, floods, droughts, sea level rise etc. Here I find that the density of population in these coastal districts of India is quite high. This increases the scale of vulnerability because a larger proportion of the population is exposed to extreme events. In the demographic set up I will look at four indicators population, literates, literacy (number of literates divided by the population of a particular district) and sex ratio. The demographic structure of coastal districts in India is characterized by large population growth in the last decades. The density of population is quite high in these districts. The literacy rate is also not very high. Figure 5.10 below summaries the growth rates of population, literates, literacy rate and sex ratio in the coastal districts.

5.10. Figure: Average decadal growth rates of indicators of demography and literacy for Orissa and Andhra Pradesh



Source: Own calculation based on Palanisami et al. 2007

From the Figure above we can see that the average decadal growth rate in population across the districts has been around 20-25 percent as measured by average decadal growth rate. The highest growth rate is observed in Thane district, which is due to the large-scale migration of people from all other states to this part. Similarly the high growth rate in Surat is also due to this reason. If we look at the growth rate of literates we see that the average is 40- 45 percent. But if we consider the literacy rate the mean is around 20-25 percent. This suggests that although the literates have increased by a greater amount the literacy rate has not experienced a high growth rate. This also means that the growth of literacy has been outweighed by the growth in population. Looking at the sex ratio we see many negative values implying that the sex ratio has decreased in many of the districts. The negative values are far more than the positive values suggesting that overall there has been a decline in sex ratio in the last three decades as measured by their average decadal growth. For arranging the districts into relatively homogeneous groups I made use of cluster analysis.

5.3.3 Cluster analysis for demographic indicators for coastal districts in Orissa and Andhra Pradesh

From Table 5.25 below we see that there are two clusters. There is no distinct pattern and each cluster is a combination of districts from various states. These particular clusters follow a similar pattern of growth on the basis of the indicators in consideration. Most of the districts in cluster 1 show a high rate of growth of population and also exhibit similar trends in terms of literacy, literates and sex ratio. Cluster 2 represents districts with lower growth rates in population but higher growth rates in literates and literacy rate. Also the district of Ganjam shows a positive growth in terms of sex ratio.

5.25. Table: Cluster analysis in two district of India

No. of Clusters	Districts
1.	Guntur, Krishna, Nellore, Prakasam, Vizianagram, Puri
2.	Srikakulam, Vishakhapatnam, Ganjam

Source: Own construction

5.3.4 Infrastructure Developments in Coastal Districts of India

Infrastructure plays a key role in influencing vulnerability and enhancing adaptive capacity. For comparing the infrastructural development of the coastal districts in India an infrastructure index has been developed based on integration of some key variables. The following indicators were used in the calculation of Infrastructure Index. The time period of reference coincides with the planning periods of India.

1. Finance:
   - Number of Banks (Scheduled Commercial including regional rural banks)
2. Education:
   - Total number of Schools (Primary and Secondary)
   - Total number of Teachers (Primary and Secondary)
3. Health:
   - Total medical institutions (Hospitals and Dispensaries)
   - Total medical beds available
4. Transport
   - Number of motor vehicles

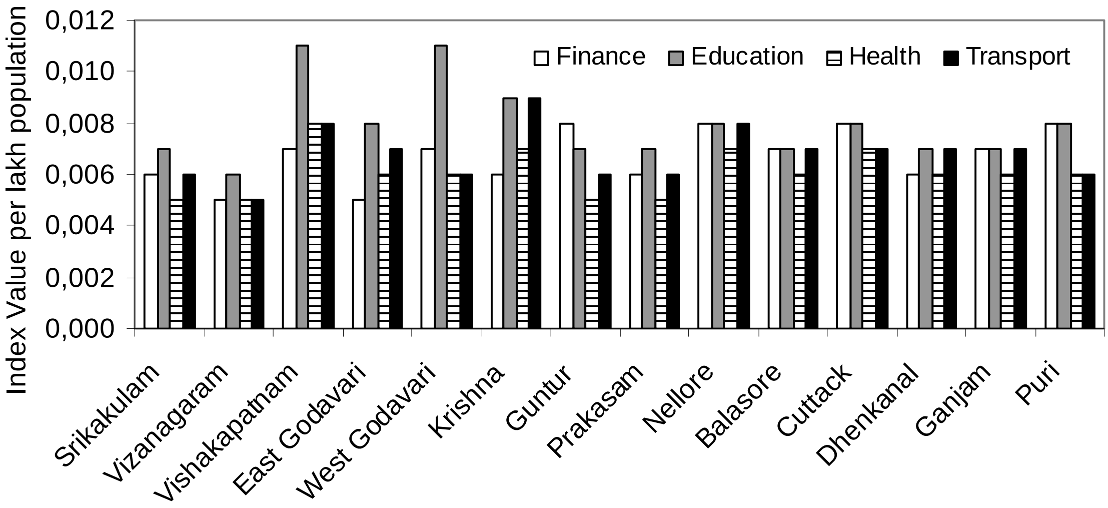
Data on all the above variables was collected on a district level for the time periods 1990, 1995, 2000 and 2005. The population figures used for 1995 are the same as that of 1981 and that for 2005 are same as of 2001. The population data was collected for the time periods 1991 and 2001. Figure 5.11 and Table 5.26 below shows the performance of districts as measured by Infrastructure Index per lakh of population. The infrastructure index was calculated according to the formula:

$$INDEX = [Indicator_I / \sum_{D=1}^{n} Indicator_I + ... + Indicator_J / \sum_{D=1}^{n} Indicator_J] / Population_D$$

Here, D refers to various districts in consideration (1, 2… n) and

Indicators (I ……. J) are the various indicators used

5.11. Figure: Absolute value of Infrastructure per hundred thousand population in eastern coastal districts of India



Source: Own calculation based on Palanisami et al. 2007

5.26. Table: Growth Rate of Infrastructure Index and frequency of extreme events in eastern coastal districts of India:

District	1990-95	1995-2000	2000-2005	Rank	Frequency of Severe Storms, Storms and depression
Puri	0.34	-14.88	9.56	11	84
Cuttack	2.29	-13.31	11.55	9	80
Balasore	-0.70	-21.33	15.95	5	76
Srikakulam	10.54	-21.71	7.80	13	70
Vishakapatnam	51.08	-27.96	19.34	3	31
East Godavari	49.83	-23.18	8.60	12	31
Nellore	3.86	-20.61	15.91	6	30
Ganjam	7.33	-14.07	11.38	10	28
Krishna	70.22	-29.12	29.84	1	25
Prakasam	22.33	-29.83	15.45	7	7
Vizanagaram	16.69	-23.6	7.42	14	5
Guntur	-10.59	-25.97	25.64	5	5
Dhenkanal	10.98	-13.68	17.37	4	0

Source: Own Calculation based on RATHORE ET AL, 2007

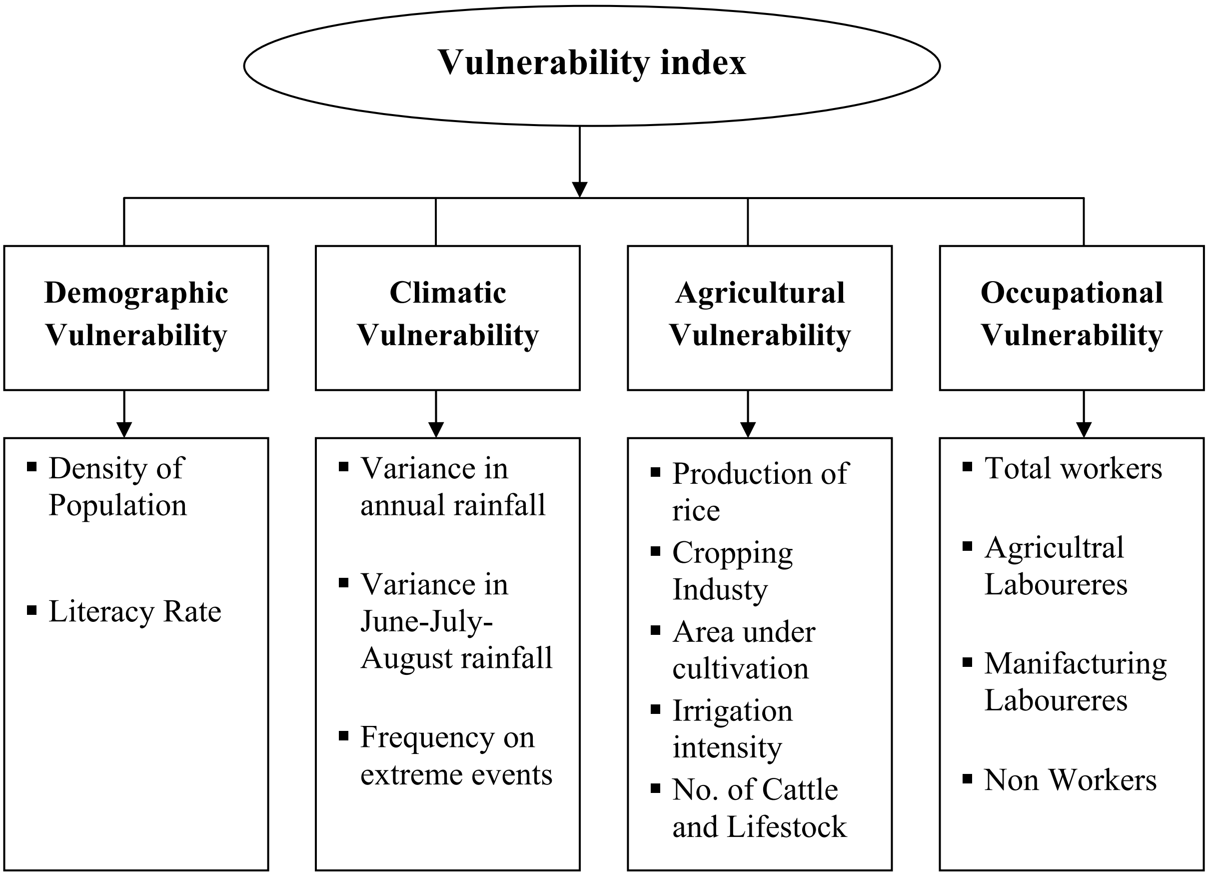
The ranking has been done according to the growth rate of Infrastructure Index during the period 1990 to 2005. Frequency refers to total number of Depressions, Storms and Severe Storms from 1990 to 2005. The infrastructure levels show an increase in terms of the indicators measured over the first period that is from 1990 to 1995. In the second period of the analysis that is from 1995 to 2000 there is overall decrease in infrastructure levels as measured in terms of indicators across all the districts. One of the reasons for this can be that during this time period there were many district divisions and reallocations for the formation of new districts. Again in the last part of my study that is from 2000 to 2005, we see that there is growth in terms of infrastructure index. In general districts in Andhra Pradesh have high level of infrastructure growth followed by Orissa. From the figures in Table 5.26

corresponding to the frequency of depressions, storms and severe storms, we see that of the top ten districts in terms of frequencies of events, only one district (Krishna) scores high in terms of infrastructure growth, while all the others have low growth rates in infrastructure. A district like Puri, which has the maximum number of these events, is ranked quite low in terms of infrastructure index. The maximum vulnerability as measured in terms of historic data for cyclones is to the districts in the state of Orissa and these perform quite badly in terms of indicators considered in infrastructure index. Next vulnerable districts are that of Andhra Pradesh but districts like Srikakulam and East Godavari are also lowly ranked. On the whole the vulnerable districts perform low in terms of infrastructure setup as considered by the infrastructure index. Therefore to conclude we can say that lower the district is in terms of infrastructure index and the growth of it, the more exposed it is to climate change and hence people living in this region are likely to be highly vulnerable. Rehabilitation of people and the place would require tremendous effort and huge resources.

5.3.5 Vulnerability Index Estimation

In this section, the analysis of the index of vulnerability of the eastern coastal districts of India is presented. The vulnerability index, measured here, tries to capture a more comprehensive scale of vulnerability. This is done by including many indicators that serve as proxies to look at different aspects of vulnerability. In other words I assume that vulnerability can arise out of a variety of factors. In particular I look at four different sources of vulnerability. This includes the climatic factors, demographic factors, agricultural factors and occupational factors which are trivial in determining the overall vulnerability of an area. The idea is to prepare an index to map the vulnerability among the various coastal districts of the eastern coast of India and rank the districts in terms of vulnerability. Figure 5.12 shows the framework undertaken to estimate the extent of vulnerability through the vulnerability index. The construction of the Index is based on the districts of Orissa, Andhra Pradesh and Tamilnadu, which are states or provinces on the eastern coast of India. The methodology used to calculate the vulnerability index follows the basic approach developed by [ANAND ET AL, 1994]for the calculation of the human development index (HDI). To construct the vulnerability index for the different coastal districts I go through the steps as described below.

5.12. Figure: Sources and Dimensions of Vulnerability



Source: IPCC, 2007

Methodology for calculation of the index:

Step 1: Calculate a dimension index of the each of the indicators for a district (X I) by using the formula (Actual X I – Minimum X I) / (Maximum X I – Minimum X I)

Step 2: Calculate a average index for each of the four sources of vulnerability viz. Demographic, Climatic, Agricultural and Occupational vulnerability. This is done by taking a simple average of the indicators in each category.

Average Index i = [Indicator 1 +………. + Indicator J] / J

Step 3: Aggregate across all the sources of vulnerability by the following formula.

$$\text{Vulnerability Index} = \left[\sum_{i=1}^{n} \left(\text{Average Index}_i \right)^{\alpha} \right]^{1/\alpha} / n$$

Where,

J = Number of indicators in each source of vulnerability

n = Number of sources of vulnerability (in the present case n = α = 4)

After the values of the index are calculated for all the districts a ranking of the various districts can be carried out to identify the most vulnerable districts in terms of the indicators used for measurement. This analysis will be repeated for different time periods 1981, 1991 and 2001 in order to see how the vulnerability profile has changed over the years for the districts in terms of the indicators used to measure the vulnerability.

The following table shows the values of the vulnerability index at the three different time periods and the corresponding ranks of the districts at the three different time periods. In the table a rank of one shows the maximum vulnerable district and the vulnerability decreases as we go on increasing the rank.

5.27. Table: Vulnerability Index and Ranks for eastern coastal districts

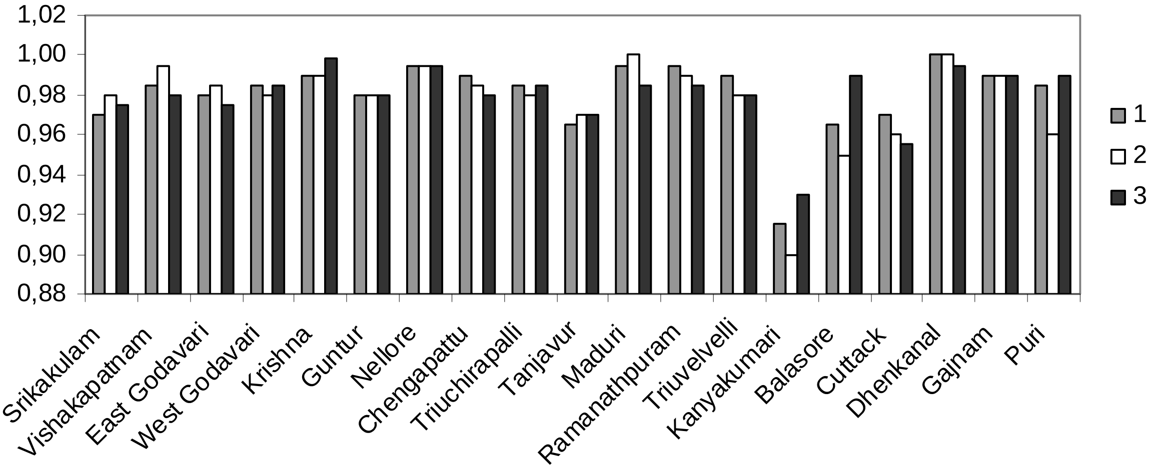
Districts	1981	Rank	1991	Rank	2001	Rank
Srikakulam	0,027	15	0,017	10	0,022	16
Visakhapatnam	0,013	10	0,01	5	0,015	10
East Godawari	0,018	14	0,015	9	0,022	15
West Godavari	0,014	11	0,018	11	0,017	12
Krishna	0,011	6	0,012	7	0,013	8
Guntur	0,017	13	0,02	13	0,02	14
Nellore	0,005	2	0,009	3	0,007	4
Chengalpattu	0,012	8	0,013	8	0,018	13
Tiruchirapalli	0,016	12	0,019	12	0,015	11
Tanjavur	0,37	18	0,03	15	0,031	17
Madurai	0,005	3	0,002	2	0,014	9
Ramanathpuram	0,007	4	0,011	6	0,007	3
Tiruvelveli	0,011	7	0,021	14	0,012	7
Kanyakumari	0,087	19	0,097	19	0,065	19
Balasore	0,035	17	0,05	18	0,006	2
Cuttack	0,03	16	0,039	16	0,044	18
Dhenkanal	0,001	1	0,001	1	0,002	1
Ganjam	0,009	5	0,01	4	0,01	6
Puri	0,013	9	0,042	17	0,009	5

Source: own calculation

From table 5.27 above, it can be seen that the vulnerability profile has undergone a complete change for some of the districts being considered. But one fact is quite evident that some of the districts of Orissa are the most vulnerable ones throughout the time frame of consideration. Especially the district Dhenkanal remains the most vulnerable district throughout. This is also the case in reality. This district comprises of the areas now divided into Kendrapara and Jagatsinghpur which are the most affected areas due to tropical cyclones and storms. The districts of Andhra Pradesh show a decline in vulnerability over the years.

There is also the same decreasing trend in terms of the districts of Tamilnadu. The following figure shows the vulnerability among the different districts. For this the value of vulnerability index is subtracted from absolute one for all the districts. Therefore a higher value of the index now shows higher vulnerability.

5.13. Figure: Vulnerability pattern across eastern coastal districts in India



Source: own calculation based on Rathore et al, 2007

From figure 5.13, it can be seen that the vulnerability of the people is very high in the districts of Orissa and Andhra Pradesh as compared to that of Tamilnadu. There is a decreasing trend in case of the districts of Andhra Pradesh from 1991 to 2001. This can be due to the better disaster mitigation policies of the Andhra Pradesh government. They are actively involved in the adaptation of disaster mitigation policies and have developed suitable mitigation strategy to help the vulnerable people out of the problem. The index takes into account a variety of sources of vulnerability into consideration. Therefore the variation in the index can be due to all these factors. The sources like demographic and agricultural vulnerability have a direct impact on the people living in the area. *The areas along the coastline of India are thickly populated and are also prime agriculture producing lands. Therefore any changes on to these sources will have a direct impact on the vulnerability of the people living in this region. The next source, which is climatic vulnerability, will also have an impact on the vulnerability of the people through their impact on the agricultural production and the demographic structure.* As far as occupational vulnerability is concerned, it will also influence the vulnerability of the people. The occupational structure of an area has very important significance. *The more the people become vulnerable the more will be the change in the occupational structure of the workforce. Hence this is also related to the overall vulnerability of the people living in the particular region.* From the above figure another observation that is quite worth noticing is that the vulnerability index although has increased (or decreased) but the changes that have occurred are not very large. Therefore in some districts overall vulnerability of the people has decreased but that change is not that significant. To check whether the ranks assigned in Table 5.28 are significant or not I do a ***Spearman's rank correlation analysis***. This will also show how the indices moved vis a vis each other. The following table (Table 5.28) reports the results obtained out of the analysis [RATHORE ET AL, 2007].

5.28. Table: Results of Spearman's Rank Correlation for Vulnerability Index

	Vulnerability Index 1981	Vulnerability Index 1991	Vulnerability Index 2001
Vulnerability Index 1981	1		
Vulnerability Index 1991	0,819**	1	
Vulnerability Index 2001	0,718**	0,433*	1

** implies significance at 1% level and * implies significance at 5% level (2- tailed)
Source: own calculation based on Rathore et al, 2007

From the above table (Table 5.28), we can see that the district ranks are highly significant and correlated with each other. This further means that the rankings assigned in terms of vulnerability to different districts are significant. The strength of the correlation is also very high; to the tune of 0.8 suggesting a high degree of correlation of each index vis a vis each other. Also the various ranks that I assigned to the different districts are over the different time periods are also significant. For a deeper analysis of the nature of vulnerability we have to look at the linkages between the vulnerability index, infrastructure index and frequency of occurrence of extreme events in these districts [AGGARWAL AND SINHA, 1994, RATHORE AND STIGTER, 2007].

5.29. Table: Correlation results for Infrastructure, Vulnerability Indices and frequency of occurrence of extreme events

	Infrastructure Index- 91	Infrastructure Index- 2001	Vulnerability Index- 91	Vulnerability Index- 2001	Events-91	Events-2001
Infrastructure Index- 91	1					
Infrastructure Index- 2001	0,132	1				
Vulnerability Index- 91	0,428	-0,116	1			
Vulnerability Index- 2001	0,126	0,054	0,268*	1		
Events-91	0,629**	N.A.	0,828**	N.A.	1	
Events-2001	N.A.	0,355	N.A.	0,479	N.A.	1

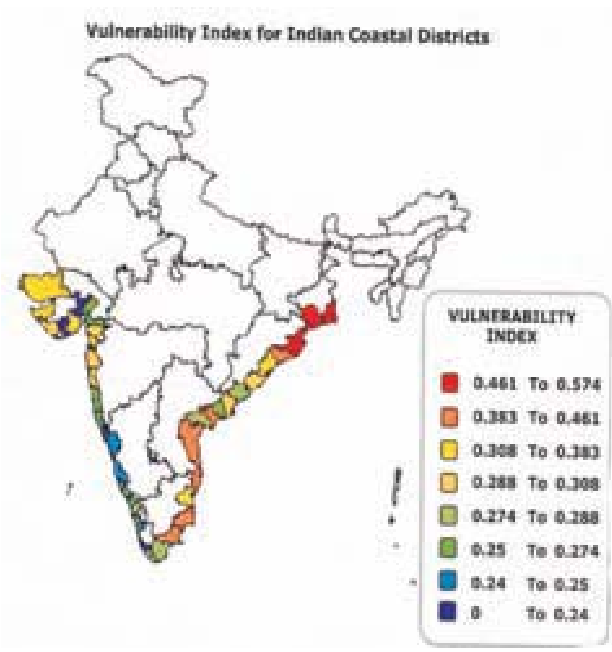
** implies significance at 1% level and * implies significance at 5% level (2- tailed); N.A.= Not Applicable

Source: own calculation based on Palanisami et al. 2007

From the above Table (Table 5.29), we can note that some of the correlation results are significant either at one percent or five percent significance levels. It is interesting to see that Infrastructure Index of 1991 and the frequency of occurrence of extreme events is highly correlated and is also significant at one percent level. Also the vulnerability index of 1991 and

2001 are highly correlated and significant. This is understood since the frequency of occurrence of extreme events is one of the sources of vulnerability considered in the study. But the important thing that is noteworthy is that there is also correlation between vulnerability index of 1991 and 2001. This result is of great importance for analysis and policy formulation purposes. This correlation coefficient of 0.268 suggests that past vulnerability also has some effect on the present vulnerability. In other words the vulnerability pattern is interrelated across different time periods. If the people of any region have been vulnerable for past certain periods then they are more likely to be vulnerable in the present period also. This result will be of quite relevance to policy makers in fact. The various disaster mitigation policies should try to incorporate this result in their planning and formulation purposes. The most policies will be of great importance to the people in these regions. The distribution of people is highly skewed in favour of the poor in the coastal districts of India. The incidence of poverty is also on the higher side in these coastal districts of India. Also there is a high amount of inequality in the distribution of resources in these regions [RAO, 2007].

5.14. Figure: Coastal Districts Vulnerable to Climate Change



Source: Ministry of Agriculture, India

5.4 Changing Land-Use and Future of Agriculture

One of the most important consequences of growing pressure on land is the declining trend in the average farm size and the pattern of holdings. According to the latest Agricultural Census in 1970-71 there were 70 million holdings operating 162 million ha. By 2000-01 there were 105 million holdings operating 165 million ha. The average farm size decreased from 2.30 ha in 1970-71 to 1.57 ha in 2000-01. As of 2000-01 about 78 percent of holdings were small (1.0 to 2.0 ha) and marginal (<1.0 ha). A little more than 20 percent of the farmers were semi-medium (2.0 to 4.0 ha) and medium (4.0 to 10.0 ha). Large farmers (>10.0 ha) constituted only 1.6 percent of the total holdings. Over the twenty-year period since 1970 the proportion of marginal farmer has increased from 50 to 59 percent and that of large farmer has declined from about 4 to 1.6 percent. The proportion of total area operated by marginal farmers increased from nine percent in 1970-71 to nearly 15 percent in 2000-01 while the proportion of large farmers declined from about 31 percent to 17 percent in the same period. The size of average holding is very unevenly distributed among the states. States with relatively large average size of operational holding are a mixed lot – they include states with large tracts of barren lands e.g. Rajasthan, Maharashtra and Madhya Pradesh on the one hand and agriculturally advanced state like Punjab on the other. These trends in farm size changes will have a profound effect on the future agricultural development strategies [TERI, 2002, 2003, SATHAYE ET AL, 2006, RAO, 2007].

Although India's population growth rate has slowed from 2.1 percent in 1980s to 1.8 percent in the 2000s and is expected to slow further in the coming decades, yet the population is projected to reach 1.33 billion by 2020 from the current one billion. The urban share of total population is projected to increase from 26 percent to 35 percent of the total population. Although incidence of poverty is falling, it is estimated that in 2005-06 (up to which data is available) 320 million people constituting 36 percent of the population were below the officially defined poverty line [RUPA KUMAR ET AL. 2006, RAVINDRANATH ET AL, 2003, RAO, 2007].

The nature of the poverty line has been shifting. About 30 years ago 48.4 percent of those living in rural areas were poor and 20 percent of those living in the urban areas were classed as poor. Recent studies show that the numbers of poor in urban areas have been increasing at relatively higher rate compared to the rural areas. At present those below the poverty line in rural sector constitute 37 percent of the population while in the urban sector the percentage is 32 percent. In the context of poverty alleviation, therefore, emphasis will be required to be placed both on production of food by the poor as well as on the availability of food for the urban poor. It needs to be recognized that a large proportion of the rural poor are located in regions of low potential for food production e.g. arid and semi-arid areas, hilly regions, degraded land and forest areas. Widespread hunger and malnutrition are the direct manifestation of poverty and will call for increasing efforts to produce more food at affordable price [PARIKH ET AL, 2002, MITRA, 2004, PALANISAMI ET AL. 2007].

Increasing population and economic growth are changing patterns of land use making potentially unsustainable demands on the country's natural resources.

- Since early fifties the net area sown was expanded rapidly at first but at a diminishing rate since 1970 to reach approximately 142 million ha at present. During 1950s and 1960s areas under agriculture expanded substantially as the fallows were reduced and cultivable wastes were put under the plough. The net area sown increased from 119 million ha in 1950-51 to 133 million ha by 1960-61 and further to 140 million ha by 1970-71. Fallow lands declined from 28 million ha in 1950-51 to 20 million ha by 1970-71. Cultivable wastelands declined from 23 to 17.5 million ha [MANGALA RAI, 2007].

- Land use intensity i.e. fraction of net sown area to total geographical area increase from 36 percent in 1950-51 to 40.5 percent in 1960-61 and 43 percent by 1970-71 where it has since stabilized [MANGALA RAI, 2007].
- Cropping intensity i.e. gross sown area as percent of net sown area increased from 111 percent in 1950-51 to 115 percent in 1960-61, 118 percent in 1970—71 and 130 percent by mid 2000s [PETER HOPPE, 2007].
- While the contribution of increased area in the growth of agriculture has declined over time, that of productivity has increased. The yield of all crops grew at 1.5 percent per annum between early 1950s and mid 1960s. The pace accelerated to 1.7 percent in the 1970s and then to 3 percent per annum between early 1980s and mid 90s. Unlike the gains in area, which benefited non-foodgrains, the gains in productivity accrued mostly to foodgrains.
- India's forest resources have been dwindling. According to the 'State of Forest Report' (2005) the total forest cover of the country is estimated at 63.34 million ha i.e. 19.27 percent of the geographic area of the country. Of these the dense forest (crown density more than forty percent) and open forest (crown density 10 to 40 percent) occupying about 11 and 8 percent of the geographic area respectively and mangroves occupy 0.15 percent of the geographic area. The country has lost about 5482 sq. km. of forest cover since the 1995 assessment. By any estimate the area under forest is far below the national policy goals and many areas nominally under forest are being used for non-forest purposes. Similarly 'uncultivated lands' such as permanent pastures, miscellaneous tree crops, cultivable wastes and fallow is subject to increasing competition from uses other than feeding livestock [PETER HOPPE, 2007].
- The growth of livestock population is an important source of competition for land. The increase in number of major classes of livestock.
- The area sown to fodder crops is not recorded. Information available from other sources provide an estimate ranging from 4 to 5.5 percent of the net sown area and suggest that the area under fodder crops will have to increase to 10 percent or more to support increasing livestock based activity.

The pressure on India's land and water resources is seriously threatening native plant and animal diversity. India has uniquely rich and diverse genetic base. With increasing agriculture and economic development the genetic pool is declining. This decline, if unchecked and poorly managed can have unforeseen and adverse consequences for the sustainability of agriculture of the region.

5.5 Socio-economic Vulnerability Estimation (Case of poverty in Uttar Pradesh)

The incidence of poverty fluctuates in response to variations in real agricultural output per head, but there is no significant time trend. There is a statistically significant inverse relationship between rural poverty and agriculture performance for India as a whole, suggesting that agricultural growth by itself tends to reduce the incidence of poverty. *The analysis for individual slates presents a somewhat different picture*. The inverse relationship be: output per head and rural poverty is observed in several stales but there is also evidence that there are processes at work which tend to increase the incidence of poverty, independently of variations in agricultural output per head.

Recent years have seen the development of an extensive and disquieting literature on trends in rural poverty in India and their relationship to agricultural growth. A recurring theme in much of this study is that agricultural growth has been accompanied by a steady deterioration in distributional terms, involving not only an increase in relative inequality but also an increase in absolute impoverishment Indeed, it is argued that these trends are the natural consequence of the type of agricultural growth which can be expected within the existing institutional structure in Indian agriculture. This latter proposition has important implications for policy. It raises doubts about the scope for achieving even the fairly minimal welfare objective of alleviating absolute poverty in the future, at least through the kind of agricultural development that is currently deemed feasible, i.e. growth without radical institutional change.

The principal sources of data for my study are the various consumption surveys conducted by the National Sample Survey (NSS) which report the distribution of the population across per capita expenditure classes.

My concern is principally with the extent of absolute poverty in rural India, denned with respect to a fixed poverty line in terms of real per capita consumption. I have attempted, first, to document changes in incidence of poverty over time, and second, to relate these changes to some measures of agricultural performance. The analysis is based on two alternative measures of the extent or incidence of absolute poverty:

i) The first measure is the percentage of the population below the fixed poverty line.

ii) Cross section analysis.

Poverty ratios in Uttar Pradesh have been relatively high. According to the latest estimate of the Planning Commission based on NSS 61st round, about one-third of the population of the state was living below the poverty line in 2005-06 as compared to the figure of 27.5 percent for the country on the basis on uniform recall period. Only Bihar, Chhattisgarh, Jharkhand, Madhya Pradesh and Orissa had a higher poverty ratio as compared to U.P. Around 80 percent of the poor in the state live in the rural areas. However, rural and urban poverty ratios do not show much difference in U.P.

Both rural and urban poverty have steadily declined in U.P. in the last three decades (Table 5.30). On the basis of the uniform recall period, poverty ratio declined by 8.1 percentage points in U.P. between 1993-94 and 2005-06, which compares well with the decline of poverty in India as a whole during the period. The decline was higher in rural areas where poverty ratio declined by 8.3 percentage points as compared to the urban areas where the decline was by 4.8 percentage points only.

5.30. Table: Trends in Poverty Ratios in U.P. and India (%)

NSS Round	Uttar Pradesh			All-India		
	Rural	Urban	Combined	Rural	Urban	Combined
1973-74	56.53	60.09	57.07	56.44	49.01	54.88
1977-78	47.60	56.23	49.05	53.07	45.24	51.32
1983-84	46.45	49.82	47.07	45.85	40.79	44.48
1987-88	41.10	42.96	41.46	39.09	38.20	38.86
1993-94	42.28	35.39	40.85	37.27	32.36	35.97
1999-00*	31.22	30.89	31.15	27.09	23.62	26.10
2004-05	33.40	30.61	32.80	28.36	25.70	27.58
2005-06	25.34	26.38	25.55	21.81	21.76	21.83

Source: Planning Commission estimates based on NSS rounds.
Note: * Based on 30 days recall period.

Doubts have been expressed about the comparability of poverty estimates between 1993-94 and 1999-00 due to differences in the reference period. However, a rough comparison based on mixed reference surveys reveals that poverty ratio declined from 31.2 percent in 1999-00 and further to 25.2 percent in 2005-06, i.e. a decline of 6 percentage point. This would suggest that the rate of decline in poverty was relatively faster during 1999-2006 as compared to the period 1993-00. It may also be noted that the mixed reference period estimates indicate a lower incidence of poverty (around 25 per cent).

It is remarkable that the decline in poverty in U.P. has taken place at the same rate as in India, despite of the fact that the growth rate in U.P. was markedly below the national average. Also, poverty ratio has continued to decline although agricultural growth has slowed down in the recent period. A number of factors including the gradual diversification of the economy, rise in real wage rate and government programmes for poverty alleviation and employment generation seem to be responsible for the decline in poverty.

Despite the substantial decline in the poverty ratio, the absolute number of poor has remained high in the state. Almost 6 million people in U.P. were living below the poverty line in 2004-05 constituting over one-fifth of the total poor in the country on the basis of uniform recall period (Table 5.31). In fact, the proportion of the poor living in U.P. has increased over time.

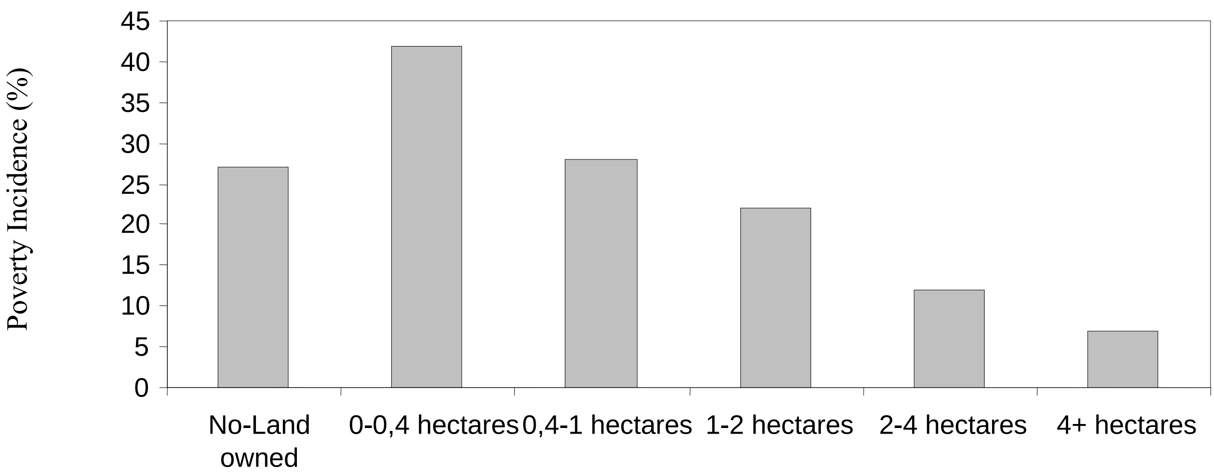
5.31. Table: No. of Poor in U.P. by Area

NSS Round	Uttar Pradesh			U.P. as % of All-India		
	Rural	Urban	Combined	Rural	Urban	Combined
1973-74	449.99	85.74	535.73	17.22	14.28	16.67
1977-78	407.41	96.96	504.37	15.42	15.00	15.34
1983-84	448.03	108.71	556.74	17.78	15.32	17.24
1987-88	429.74	106.79	536.53	18.53	14.21	17.47
1993-94	496.18	108.28	604.46	20.33	14.18	18.87
1999-00*	412.01	117.88	529.89	21.32	17.59	20.36
2004-05	473.00	117.03	590.03	21.41	14.48	19.56
2005-06	357.68	100.47	458.15	21.00	14.73	19.21

Source: Planning Commission estimates based on NSS rounds.
Note: * Based on 30 days recall period.

In rural areas poverty is found strongly associated with land ownership, which is the main productive asset. Only 7 percent of large landowners were poor in 1999-06 as compared to 41 per cent with marginal holdings (Figure 5.15). The latter comprised almost 60 per cent of the rural poor though their share in rural population was around 44 per cent. Significantly poverty incidence has declined over time in all the land size categories.

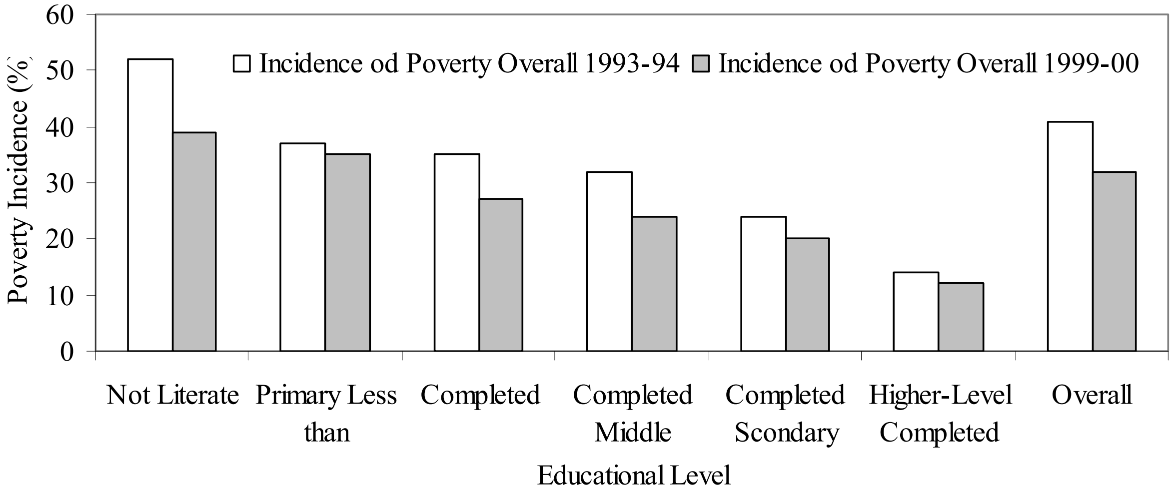
5.15. Figure: Rural Poverty Incidence by Land Ownership



Source: own construction based on Planning Commission of India 2007

Education is a crucial instrument for raising income levels of people and moving out of the vicious circle of poverty. Studies indicate a strong correlation between educational attainment and poverty levels. This is true for Uttar Pradesh as well. As educational attainment of head of household improves, poverty level declines sharply (Figure 5.16). In fact, poverty levels are almost four times higher among illiterates as compared to persons with higher education. Nearly 60 per cent of poor belong to the category of illiterates.

5.16. Figure: Poverty Incidence by Level of Education of the Household Head

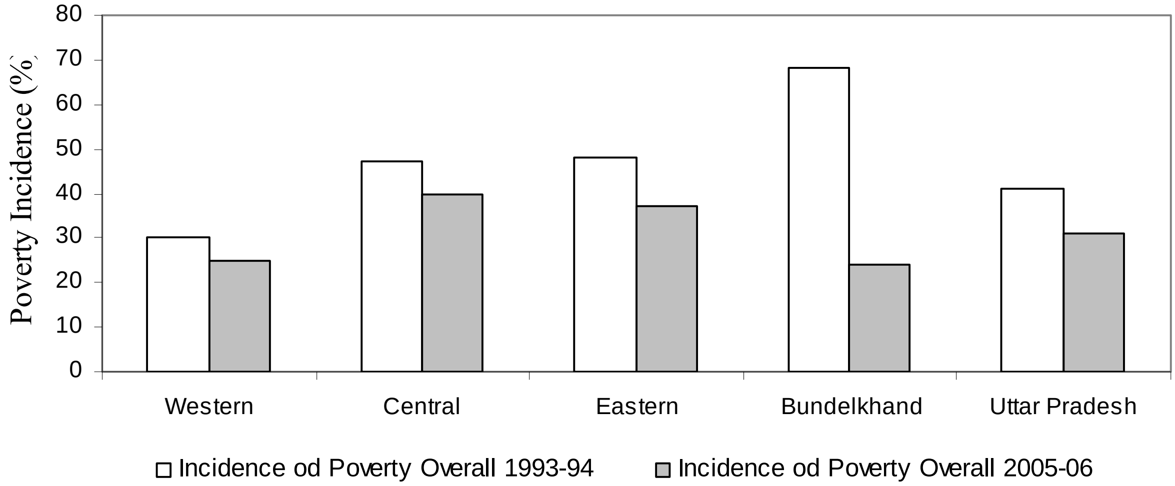


Source: own construction based on Planning Commission of India 2007

5.5.1 Regional Variations in Poverty

Considerable variations in poverty levels are observed across regions of the state. The relatively developed Western region has a lower incidence of poverty, while Eastern region had much higher incidence of poverty. Bundelkhand had the highest proportion of population below poverty line in 1993-94. However, 2005-2006 NSS survey shows a much sharper reduction in poverty in this region, while Central region shows the highest incidence of poverty (Figure 5.17). Variations in population pressure, resource endowment and productivity levels lie behind the regional variations in poverty levels.

5.17. Figure: Regional Trends in Poverty (%)



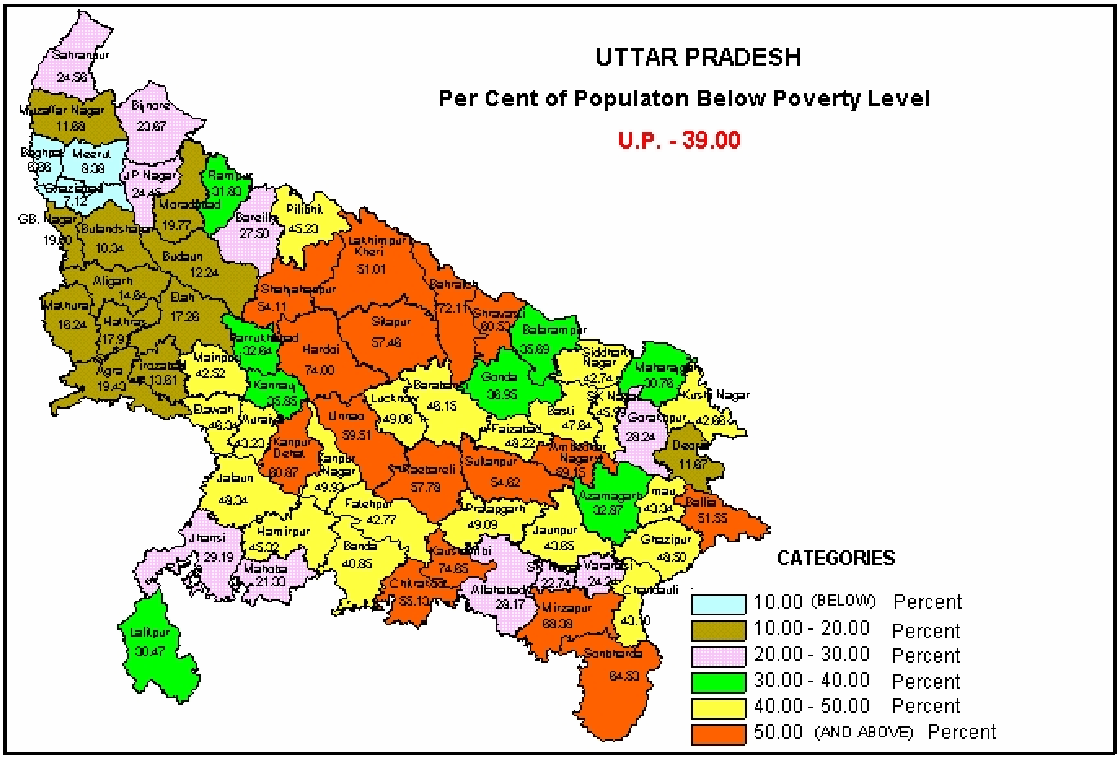
Source: own construction based on Planing Commission of India, 2007

5.5.2 Poverty at the District Level

NSS sample design is not aimed at measuring poverty at the district level. The recent Below Poverty Line Survey (BPL) of the Ministry of Rural Development, however, makes it possible to study district level variations in poverty. The advantage of BPL survey is that it is based on a complete census of rural households and identifies BPL households on the basis of multiple indicators of deprivation. The results of BPL Survey are, however, not comparable with poverty ratios derived from NSS data on consumer expenditure.

Table 5.32 arranges districts according to the level of poverty according to BPL survey 2006. The variations in poverty levels among districts are very stark, ranging from a low of 6.7 per cent to as much as 74.65 percent in Kaushambi. In 16 districts poverty levels are above 50 percent. These districts mostly belong to central U.P. and Bundelkhand. In another 21 districts poverty ratios are high (between 40 and 50 per cent). Majority of these districts falls in Eastern U.P. In 18 districts poverty levels are between 20 and 40 percent. Poverty levels are relatively low in (below 20 percent) in 15 districts. All these districts except one belong to Western U.P. (see map).

5.18. Figure: Per cent population Below poverty Level Uttar Pradesh



Source: Government of Uttar Pradesh, India

5.32. Table: Districts classified according to proportion of Rural Population Below Poverty Line (%)

Very High (Above 50%)		High (40% To 50 %)		Moderate (20% To 40%)		Low (Below 20%)	
District	%	District	%	District	%	District	%
Kaushambi	74.65	Kanpur (Nagar)	49.93	Gonda	36.95	Moradabad	19.77
Hardoi	74.00	Pratapgarh	49.09	Kannauj	35.85	Agra	19.43
Bahraich	72.11	Lucknow	49.06	Balrampur	35.69	Gautam Budh	
Nagar	19.00						
Mirzapur	68.38	Ghazipur	48.50	Azamgarh	32.87	Hathras	17.91
Sonbhadra	64.53	Jalaun (Orai)	48.34	Farukkhabad	32.64	Etah	17.26
Kanpur Dehat	60.87	Faizabad	48.22	Rampur	31.83	Mathura	16.24
Shravasti	60.53	Basti	47.64	Maharajganj	30.76	Aligarh	14.64
Unnao	59.51	Etawah	46.34	Lalitpur	30.47	Firozabad	13.61
Ambedkar Nagar	59.15	Barabanki	46.15	Jhansi	29.19	Budaun	12.24
Rae Bareli	57.78	Sant Kabir Nagar	45.99	Gorakhpur	28.24	Muzaffarnagar	11.68
Sitapur	57.46	Hamirpur	45.32	Allahabad	28.17	Deoria	11.67
Chitrakoot	55.13	Pilibhit	45.23	Bareilly	27.50	Bulandshahar	10.34
Sultanpur	54.62	Jaunpur	43.65	Saharanpur	24.56	Meerut	8.38
Shahjahanpur	54.11	Mau	43.34	Jyotiba Phulle			
Nagar	24.45	Ghaziabad	7.12				
Ballia	51.55	Orraiya	43.23	Varanasi	24.24	Baghpat	6.66
Lakhimpur Kheri	51.01	Chandauli	43.10	Bijnor	23.67		
		Fatehpur	42.77	Sant Ravidas			
Nagar	22.74						
		Siddharth Nagar	42.74	Mahoba	21.33		
		Kushi Nagar	42.66				
		Mainpuri	42.52				
		Banda	40.85				

Source: Ministry of Rural Development, Government of India, BPL Survey 2006.

5.5.3 Determinants of Poverty

The discussion on the determinants of rural poverty has emphasized the role of increase in agricultural output, relative prices of foodgrains, rural wages and government expenditure on rural infrastructure and poverty alleviation programmes in reducing rural poverty. In case of U.P. also the impact of agricultural growth and improvement in real rural wages on rural poverty is clearly visible. The spread of green revolution since the mid-seventies resulted in marked increase in real rural wage and a sharp decline in rural poverty. The relative decline in agricultural growth rate witnessed since the mid-eighties is also accompanied by a slowing down of the increase in real wages as well as the decline in rural poverty ratio.

Cross section analysis across districts based on district wise poverty ratios for 2005-2006 calculated from NSS unit data helps in identifying the main determinants of rural poverty (Table 5.33). Per capita NDDP and per capita monthly consumption expenditure, both of which are strongly correlated, show statistically significant negative relation with rural poverty. Thus, higher growth helps in reducing poverty, even though accompanied by higher consumption inequalities. Higher agricultural productivity and a relatively high proportion of medium/large holdings are also associated with lower poverty levels, though the relationship is less strong. Districts with a higher proportion of agricultural labourers in total workers show higher level of poverty. Similarly a higher proportion of scheduled caste population, from which majority of agricultural labourers are drawn, exerts a positive influence on rural poverty.

5.33. Table: Some Correlates of Rural Poverty at District Level, 2005-06

Variable	Value of Coefficient of Correlation at District Level (N=63)
1. Per Capita Net District Income	-0.37***
2. Per Capita Monthly Consumption Expenditure (Rs.)	-0.45***
3. Gini Coefficient of Per Capita Monthly Consumption Expenditure	-0.36***
4. Value of Agricultural Output per Ha. of Net Sown Area (Rs.)	-0.23*
5. Gross Value of Agricultural Output per Agricultural Worker (Rs.)	-0.21*
6. Proportion of Medium Holdings	-0.22*
7. Per cent of Scheduled Caste Population	0.48***
8. Per cent of Agricultural Labourers to Total Workers	0.34***

Source: own construction

Note: * Significant at 10 per cent level.
** Significant at 5 per cent level.
*** Significant at 1 per cent level.

5.6 SWOT ANALYSIS

Finally during my research study, I used SWOT Analysis, which is a strategic planning method used to evaluate the ***S**trengths, **W**eaknesses, **O**pportunities, and **T**hreats* involved in analysis impact assessment of socio-economic issues related with climate change and agriculture in India.

5.34. Table: Diagrammatic illustration of SWOT Analysis

	Helpful to achieving the object	**Harmful** to achieving the object
Internal origin (attributes of the organization)	Strengths	Weaknesses
External orgin (attributes of the organization)	Opportunities	Treats

Analysis of different parameters of socio-economic issues of climate variability and agriculture related issues are classified according to the SWOT parameters given below:

Strengths

Diversity

- Mixed farming systems in India
- Increase economic stability in changing climate

Resourcefulness of producer community

- Indian producer community most highly skilled, more then 60% have the farming skills from generation to generation.

Most aware of climate change issues

- of those 55% believe producers should take responsibility for reducing GHG emission
- most willing to undertake voluntary action

Strong linkage to rural community

- Good monsoon
- Perennial rivers
- Forest resources
- Experienced Panchayati Raj Institutions
- Cheap and abundant labour
- Experience of running participatory development programme
- Large Livestock population
- Ample and diverse bio-resources which include the local soil and water
- Enabling environment in the district for collective actions/ convergence actions.
- Availability of land for agriculture and wide scope for increased agriculture production.

Weaknesses

- Unskilled human resource
- Low productivity of land
- Land distribution pattern averse to community development
- Low and uneconomic land holding among the targeted population.
- Undulating topography
- Large number of landless and marginal farmers
- Low productivity of cattle
- Majority of land dependent upon rain fed agriculture
- Inadequate access to health services
- High rate of infant mortality
- Lack of quality education
- Low literacy rate.
- Weak marketing linkage
- Inefficient use of existing irrigation facilities and lack of water harvesting structures.
- Seasonal Migration of people in search of livelihoods
- Lack of modern inputs to agriculture
- Erratic power supply/absence of electrical infrastructure.
- Lack of industrial development.
- Lack of field staff to provide services in rural areas particularly in Agriculture, health, and education.
- Poor connectivity of villages.

Profit Margins

- Small differences between input costs and returns increases vulnerability
- high debit ratio

Age of agricultural community

- average age 53
- 36% intend to retire in next 5 years
- who will be our future producers?

Indian agricultural industry 38% of national GDP

- Sufficient governmental support?

Concentration in agricultural sector

- 23% corporate ownership

Tools for adaptation

- currently have few tools identified
- Limited research and extension capacity

Producer awareness

- only 1 in 100 producers aware of climate change and greenhouse issues

Producer skepticism

- 1/3 of agricultural producers feel there will be no impact on climate change

Opportunities

Introduction of new crops to the region

- Increased rice, wheat and sugarcane acreage?

Improved yields of existing crops

- longer growing season
- CO_2 fertilization
- warmer temperatures

Impetus to develop risk management

Linkage between adaptation and mitigation

- must address entire system
- stress co-benefits
- provide integrated solutions
- Land under cultivation can be increased.
- Percentage of irrigated land can be increased through tapping the available water resource.
- Supply of food grains, vegetables, fruits, milk and animal products to the consumers in the district and also nearby cities.
- Conducive agro-climatic condition for horticultural crops.
- Large cattle resources (Cow)
- Availability of bio –diverse food crops.
- Eco- tourism
- Skill development and capacity development of community based institutions particularly SHGs, farmers etc.

Threats

Uncertainty

- do not have good future datasets

Frequency of extreme events

Economic Risks

- direct - producer and larger community
- indirect – volatility of markets

Environmental impacts

Pest impacts

- greater numbers
- change in pest spectrum

Sea level rise

- loss of agricultural land
- salt water intrusion

Issues

Agricultural land management

- Will there be sufficient agricultural land for agricultural use

Agriculture land quality

- potential for increased impacts on land quality
- desertification issues
- excessive use of fertilizer impact

Economic risk management

- rationalize programs
- stable, predictable programs that can be part of long term planning

Needs

Improved future climate impact on economy, agriculture and land use scenarios

Increased understanding of vulnerability

Capacity research and extension support

6 Conclusion

From the statistical analysis of food production, it is evident that supply response of food production is greatly influenced by irrigation and fertilizer usage. Irrigation is a crucial factor for reducing the fluctuation in food production in last decade. It is however, true that now with over 50% of the area under rainfed, rainfall is still one of the most important factors determining average yield. Due to vagaries in rainfall, I observe fluctuation in yield. In year 2006 out of 89 million tonnes of rice production nearly30 million tonnes are produced in the unirrigated area. In case of wheat, out of 56 million tonnes only 6 % of the total production comes from rain fed area.

There is also a growing concern about the growth rate of yield. In the period 1980-1990, yield of food grain was increasing at 3.2% per year but in the next decade the growth has slowed down to 1.7%. The slow growth in yield may be contributed by declining ground water table, salinity intrusion and over use of fertilizer. This slow growth of yield is prominent in the north zone where growth in food grain yield is not significantly higher compare to other geographic zones. This is also the region where fertilizer usage is very high and contributes more than 30% of the relative change in yield.

The incremental effect of factor inputs has been one of the controversial issues in literature of rural development. Declining international food prices have raised questions on the commonly held perception on usefulness of several factor inputs (such as, irrigation, road, agriculture research, extension, etc.) in agriculture growth, and past policy thrust for maintaining regional food security (food production).

Examination of cross-state panel data analysis for irrigation and related factor contribution to the agricultural growth and development in India quantifies the incremental benefits of major factor inputs (such as, irrigation, crop technology and infrastructures) in over time variation of agricultural performance and agricultural productivity across the states in India and then it discussed the policy implications of these findings. This is done using annual time series and cross section data of 14 major states of India for the period of 1970 to 2006, which accounts for more than 90 % of the agrarian economy of the country. It adopts fixed effect panel model with weighted least squared estimation technique (Generalized Least Square technique) to correct for scale and size effect related biases associated with state level aggregate data series across the states in India.

Given the facts about the likely impacts of climate change, India has several reasons to be concerned about climate change. India being a developing country is primarily dependent on climate sensitive factors like agriculture and forestry, which account for a major portion of its GDP and also has low financial adaptive capacity. This makes India more vulnerable. Although there is uncertainty about the degree of the impacts because of coexistence of many processes like presence of multiple climatic conditions, non climatic stress and regional scale variations there is bound to be some impact.

The research pertaining vulnerability from the extreme climatic events in India as well as the data on exposure indicate that the coastal districts on the East Coast experience extreme events such as storms and depressions more than districts on the western coast, with the exception of a few districts in Gujarat. Impacts of these events, apart from those related to life and property are likely to be on agriculture, infrastructure and on the population and human settlements of the area in concern. *The eastern coast districts are major producers of rice in India, and adverse effects of climate change will have an impact on production and availability of food grains in the country.* The research shows that these *shortfalls have the* *potential to create market imbalances which can further lead to fluctuations in the market and prices of food. Agricultural production* in these coastal areas is heavily dependent on climatic conditions, as despite the availability of irrigation facilities they are heavily dependent on rainfall.

The analysis carried out in my research points out that the clusters of districts of poor infrastructure and demographic development are also the regions of maximum vulnerability. Some districts exhibit very low rate of growth in infrastructure, alongside a high growth rate of population. Also these districts show a higher density of population. Hence any occurrence of extreme events is likely to be more catastrophic in nature for the people living in these districts. Moreover, the lower the district is in terms of infrastructure index and the growth of it, the more exposed it is to the potential damage from extreme events and hence people living in these regions are likely to be highly vulnerable. Lower levels of infrastructure will result in lower adaptive capacity of the people to hedge against the catastrophe. Further, people living in absolute poverty will not be able to cope up with the challenges posed by climate change. Therefore, the analysis carried out in my research suggests that climate change policies have to be integrated with sustainable development strategies in general, and poverty alleviation measures, in particular.

From the analysis of the results obtained from the infrastructure and demographic sector, frequency of extreme events and the vulnerability index, I have many important interesting observations. The clusters of districts of low infrastructure and demographic development are also the regions of maximum vulnerability. The growth rate of infrastructure index is very low and growth rate of population is on the higher side. Also these districts show a high value for the density of population. Hence any occurrence of extreme events is likely to be catastrophic in nature for the people. Also the low levels of infrastructure in these districts will have an impact on the adaptation levels of the people. Also the damages to physical infrastructure will be to a greater extent in these districts due to the high vulnerability. This will make the problem of adaptation more chronic in nature. On the part of policy formulation a greater attention is required from policy makers to this problem. As pointed in the result, low levels development and high poverty in the areas is a much greater problem to be dealt with as this has a direct impact on the prospects of current and future vulnerability of the people living in these areas.

It is true that in the case of a developing country like India fundamental issues like alleviation of poverty and fulfilling the basic conditions for human development are of primary concern but the importance of climate change cannot be neglected. What is required is a development strategy that encompasses both these concerns. Therefore climate change policies have to be integrated with sustainable development strategy such as control of pollution. Evidence of observed impacts of regional climate changes from socioeconomic systems is much scanty than from physical and biological systems. Methodologically it is very difficult to separate climate effects from other factors such as technological change and economic development, because of the complexities of these systems. Vulnerability to climate change and climate variability is a function of exposure and adaptive capacity.

Exposure varies from region to region, sector to sector, and community-to-community and adaptive capacity may be even more variable. The adaptive capacity of socioeconomic systems also contributes to the difficulty of documenting effects of regional climate changes; observable effects may be adaptations to a climate change rather than direct impacts. A lot will depend on area in concern, the amount of economic activity, physical infrastructure, and social infrastructure of the area and also nature of disaster management policies formulated by the policy makers to hedge against the extreme impacts of climate change. Also the extent of the impacts will depend on the disaster mitigation strategies available at the area in concern.

Also a more comprehensive study should try to capture the linkages between poverty and climate change. Poor people and poor countries find it difficult to cope with climate variability. Floods in Uttar Pradesh and Bihar for example challenge the poverty reduction programs. They have a negative impact also on the relief and rehabilitation efforts and result in loss of assets thereby reducing the ability of the poor to cope up with the impacts of climate change. Impacts from climate change severely threaten the developmental efforts and opportunities across developing countries. This increases the vulnerability of the people in developing countries like India. People living in poverty will not be able to cope with the challenges posed by climate change. The situation becomes devastating for the people living in abject poverty that is the people living significantly below poverty line. Actions to enhance the ability of the poor to cope up with climate change should aim not only to reduce poverty but also increase the resilience of the poor.

7 New Findings

1. In India, growth rate of yield varies simultaneously depending on the climatic zones with the growth rate of irrigation patterns and fertilizer application. For example, the slow growth in yield is accompanied by declining ground water table, salinity intrusion and overuse of fertilizer. This slow growth of yield is prominent in the north zone where growth in food grain yield is not significantly higher compared to other geographic zones. This is also the region where fertilizer application is very high and contributing more than 30% of the relative change in yield

2. By using the actually realized indicators of factor inputs on variation of key agricultural sector productivity and performances than the level of sector specific governmental spending used in several research studies, my analysis has factored out the incremental marginal impact of factor inputs in a better more reliable and more sophisticated way than past studies. My research study has also addressed some of the issues on marginal factor contribution in agriculture that were not addressed (unresolved) earlier. The findings from this research study contribute to methodological development on estimation of factors contribution to agriculture productivity growth, and to designing an effective and efficient investment and financing policies in irrigation and other sectors of agriculture and rural development in general. The research findings are equally applicable in the context of other developing countries, even outside of India, with similar constraints and opportunities for agricultural and rural development.

3. The relationship between rural poverty and agricultural performance is much dependent upon the level of aggregation at which the analysis if conducted with the all-India results in presenting a somewhat different picture from that obtained at the level of individual states. Analysis carried out at the state level shows that there may be processes at work in the rural economy which tends to increase poverty over time. These results are open to the interpretation that agricultural growth offsets the adverse impact to other factors so that only agriculture can grow fast enough, so it is likely to reduce the incidence of rural poverty. However, this interpretation rests crucially on the assumption that increased agricultural output can be obtained without exacerbating those unidentified factors which tend to increase rural poverty, and which are reflected in the time term in our regressions. It is in this context that the evidence from Uttar Pradesh is disquieting, although, again, there are a number of reasons why this evidence may be misleading.

4. The clusters of districts in India of low infrastructure and socio-economic development are also the regions of maximum vulnerability. The areas along the coastline of India are thickly populated and are also prime agriculture producing lands. Therefore any changes on to these sources will have a direct impact on the vulnerability of the people living in this region. The next source, which is climatic vulnerability, will also have an impact on the vulnerability of the people through their impact on the agricultural production and the demographic structure. The more the people become vulnerable the more will be the change in the occupational structure of the workforce. Hence this is also related to the overall vulnerability of the people living in the particular region.

8 Summary

Climate change is one of the most important global environmental challenges, with implications for food production, water supply, health, energy, etc. Addressing climate change requires a good scientific understanding as well as coordinated action both at national and global level.

The issue of highest importance to developing countries is reducing the vulnerability of their natural and socio-economic systems to the projected climate change. India and other developing countries will face the challenge of promoting mitigation and adaptation strategies, bearing the cost of such an effort, and its implications for economic development.

Over time, there has been a visible shift in the global climate change discussions towards adaptation. Adaptation can complement mitigation as a cost-effective strategy to reduce climate change risks. The impact of climate change is projected to have different effects within and between countries. Mitigation and adaptation actions can, if appropriately designed, advance sustainable development and equity both within and across countries and between generations. One approach to balancing the attention on adaptation and mitigation strategies is to compare the costs and benefits of both the strategies. If adaptation of climate change could be carried out at negligible cost in a less expensive way, at least in the short-term, than any alternate strategy. Of course, there are complications in establishing the benefits of adaptation policies and consequent avoided damages. Furthermore, there are significant co-benefits of many mitigation and adaptation measures, which need to be estimated. The co-benefits could play a critical role in making decisions regarding the adoption of any mitigation or adaptation strategy.

The impact of mitigation will only be felt in the long run by the future generations. However, the impacts or benefits of adaptation measures are immediate and felt by the implementations of the measures. The regions implementing the mitigation measures could be different from the regions experiencing its impacts. The current generation of industrialized countries may invest in mitigation measures and the main beneficiaries may be the next generation largely in the developing countries. The choice between mitigation and adaptation strategies has spatial (geographic) and temporal (different generations) dimensions. An optimal mix of mitigation and adaptation strategies may elude the climate negotiations due to the spatial and temporal dimensions, as well as the differing perceptions of industrialized and developing countries. Under the Kyoto Protocol and UNFCCC, developing countries have insisted that Annex-I countries demonstrate commitment by promoting mitigation measures domestically and provide resources for adaptation measures in developing countries. However, over emphasis on adaptation might inhibit concerted mitigation actions by the Annex I governments, as adaptation measures are implemented and rewarded locally. Consequently, there is no incentive to participate in international negotiations, if a country considers itself to be able to fully adapt to climate change.

The Cost of addressing and not addressing climate change for India: India has potential to supply substantial mitigation at a relatively low price. Major opportunities exist both on the supply and demand side of energy, in case of carbon emissions. India is a large developing country with diverse climatic zones. The livelihood of vast population depends on climate-sensitive economic sectors like agriculture, forestry and fisheries. The climate change vulnerability and impact studies in India assume high degree of uncertainty in the assessment due to '… limited understanding of many critical processes in the climate system, existence of multiple climatic and non-climatic stresses, regional-scale variations and nonlinearity …'.

The costs of not addressing climate change or to adapt to it are very uncertain, but their welfare consequences are enormous. Early actions on adaptation therefore are prudent and consistent from the viewpoint of ‘precautionary principle’. The future regime architecture can reduce the climate burden by giving greater emphasis to adaptation, e.g. via an Adaptation Protocol, whereby mandatory funding by industrialized countries could support adaptation activities in developing countries. Additional policy options like support for adaptation planning and implementation creation of a public-private insurance mechanism and alignment of climate funds and development assistance can be deployed for gaining added benefits. Some of the critical scientific issues that need to be addressed include the following:

- Many uncertainties continue to limit the ability to detect, attribute and understand the current climate change and to project what future climate changes may be, particularly at the regional level. Further, there is a need to link physical climate-biogeochemical models with models of the human system in order to provide better understanding of possible cause- effect-cause patterns linking human and non-human components of earth systems.
- Improved understanding of the exposure, sensitivity, adaptability and vulnerability of physical, ecological and social systems to climate change at regional and local level.
- Evaluation of climate mitigation options in the context of development, sustainability and equity at regional, national and global level in different sectors (energy and non-energy).
- To develop sustainable and equitable international protocols, mechanisms and financial arrangements to promote mitigation and adaptation to achieve the goals of Article 2 of the UNFCCC.

India is a large developing country with nearly 70% of the population depending directly on the climate sensitive sectors such as agriculture, fisheries and forests. The projected climate change under various scenarios is likely to have implications on food production, water supply, biodiversity and livelihoods. Thus, India has a significant stake in scientific advancement as well as an international understanding to promote mitigation and adaptation. This requires improved scientific understanding, capacity building, networking and broad consultation processes.

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3. Annex: List of acronyms

COP:	Conference of the Parties
GBPIHED:	G. B. Pant Institute of Himalayan Environment and Development, India
GCA:	Gross Cultivated Area
GHG:	Greenhouse Gases
HDI:	Human Development Index
ICIMOD:	International Centre for Integrated Mountain Development
IHR:	Indian Himalaya Region
IIT, Delhi:	Indian Institute of Technology, Delhi, India
IPCC:	Intergovernmental Panel on Climate Change
MOP	Meeting of the Parties
NSS:	National Sample Survey
REDD:	Reducing Emissions from Deforestation and Forest Degradation in Developing Countries
Rs:	Rupees
TFP:	Total-Factor Productivity
U.P.:	Uttar Pradesh
UNFCCC:	United Nations Framework Convention on Climate Change
UNCCC:	United Nations Climate Change Conference
US:	United States

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