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Vulnerability and Adaptation of Agriculture and Coastal Resources in India to Climate Change

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FINAL REPORT

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Preface

This study was undertaken as part of the research programme of the Environmental Economics Research Committee (EERC), coordinated by Indira Gandhi Institute of Development Research, Mumbai, sponsored by MoEF and aided by the World Bank. This study falls under the broad theme of *International Issues* identified by the EERC.

The study focuses on assessing vulnerability of some of the key climate sensitive sectors in India due to potential changes in climate. The estimates are expected to provide crucial inputs in formulating viable climate policy, both at national level and global level. Given the growing emphasis on manifestation of climate change, the study specifically focused on extreme climate events in the analysis. One of the main arguments advocated by the study is that reducing (and improving) the present day vulnerability (and adaptive capacity) would be a useful first step in addressing future challenges.

I would like to thank Dr. Satyanarayana Murthy (Singapore) for all the valuable discussions during the initial phases of the study; and Mr. Tholkappian, research scholar at MSE, for efficient research assistance.

I would also like to thank the EERC members for their support; Prof. Jyoti Parikh, Chairperson EERC, for her encouragement; and Dr. Anand Patwardhan for providing helpful suggestions on the draft final report. Special thanks are also due to Dr. Raghuram and Mrs. Radha Ramamurthy of EERC Secretariat for their help during the execution of project.

Finally I would like to place on record my sincere thanks to the Chairman, Director, and staff of MSE for their help during the project.

7 February 2003 K.S. Kavi Kumar

Chennai Principal Investigator

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Introduction and Motivation

Accumulation of trace gases such as carbon dioxide (CO_2), methane (CH_4) etc. in the atmosphere, caused mainly due to anthropogenic activities such as burning of fossil fuels, is believed to be altering the Earth's climate system. The third assessment report of Intergovernmental Panel on Climate Change has concluded that "there is new and stronger evidence that most of the warming observed over the last 50 years is attributable to human activities". The expected changes in climate system could have significant impacts on a number of climate sensitive sectors of the world economy.

Analysis of various pollution abatement strategies is well documented in the field of environmental economics. However, the study of climate change problem poses a special and formidable challenge due to a variety of reasons including the global and inter-disciplinary nature of the problem, long time periods involved, and the associated uncertainties. Also, the differences among world nations in terms of their historic, present and future contributions to greenhouse gas (GHG) emissions, and their respective vulnerabilities to potential changes in the climate makes it a complex problem to resolve.

The climate change policies can be broadly divided into two categories: GHG mitigation strategies and adaptation strategies. The GHG mitigation strategies dominate the current global negotiations on climate change and the Kyoto Protocol signed at the Third Conference of Parties in 1997 has for the first time placed quantitative restrictions on the GHG emissions from the developed countries. However, the implementation of the Protocol is still surrounded by lot of uncertainty and the recent decision by the US government not to ratify the protocol puts further doubts about the success of the mitigation policies. Moreover, it is widely believed that implementation of the Kyoto Protocol does little to reduce the potential impacts due to climate change.

The available evidence from various climate change impact studies suggests that the developing countries are likely to get more adversely affected than the developed countries. This could be due to the typical geographical location of developing countries and their large dependence on climate sensitive sectors, such as agriculture. Most of the available impact estimates do not account for impacts due to extreme climate events such as cyclones and droughts, whose frequency and intensity could increase following climate change. These natural disasters cause significant damages in developing countries. Asia, for example, accounts for almost 38 per cent of hydrological and meteorological disasters occurred during the period 1991 and 2000 all over the world. Of those reported killed by natural disasters, 83 percent lived in Asia, while 67 percent lived in nations of low human development.

Thus, from the developing country perspective the present day vulnerability due to natural disasters, the possibility of increase in frequency and intensity of such events under climate change regime, and potential high impact of climate change on the performance of climate sensitive sectors make a strong case for focus on adaptation options as part of climate change policy. Simultaneous focus on adaptation options to address climate change problem seems both inevitable and prudent.

A fundamental input necessary for formulating adaptation policies is knowledge on climate change induced impacts and vulnerability of climate sensitive sectors. This study focuses on this aspect through an analysis of two climate sensitive sectors in India.

Objective of the Study

Among a large number of climate sensitive sectors, agriculture and coastal resources have special significance in Indian context. Agriculture still plays a vital role in Indian economy by providing employment for more than 60 percent of the total labor force and accounting for about 27 percent of gross domestic product. Despite significant strides made in food grain production since advent of green revolution, growing population and increasing biotic and abiotic stresses are likely to widen the supply demand gap in future. Climate change induced pressure is expected to further worsen the situation. India has more than 6500 km of coastline; spread over 53 coastal districts and six union territories. With high population density these coastal districts account for nearly 50 percent of the country’s total population. Change in sea level is likely to cause devastating effects on the coastal areas and also affect the activities related to the on-shore oil exploration. The rush of an enormous volume of sea water accompanied by the fury of hurricane-force cyclone winds and torrential rainfall would bring about mass devastation in human and economic terms along with vast inundation of low lying areas.

Impact assessment studies in India, including those corresponding to the above two sectors, used predictions on mean climate changes for a double CO_2 concentration scenario or hypothetical climate change scenarios. Climate change impact studies worldwide are now focusing on analyzing impact due to changes in mean climate as well as climate variability, and manifestation of climate change. It is widely believed that the climate change manifestation could be through extreme climate events such as cyclones and droughts. Given their direct dependence on climate, among all the climate sensitive sectors agriculture and coastal resources are likely to get affected more due to climate variability and extreme events. Thus, the present study focuses on these two sectors and extends the previous analyses in these sectors by specifically incorporating the climate variability and extreme events in the impact/vulnerability assessment. Further, the study also attempts to identify various adaptation strategies specific to these two sectors.

Methodology

The increasing interest in adaptation to climate change is reflected in the development of the theory and practice of climate change vulnerability assessments. Impact assessments often focus on long-term changes in average climate conditions (such as annual mean temperature, precipitation and sea level rise) because these results are most readily available from climate models. The impact assessments do not explicitly address adaptation and thus represent a ‘dumb farmer’ assumption. A vulnerability assessment constitutes an extension of a climate impact assessment. Besides climate change these assessments explicitly consider climate variability, climate extremes and non-climatic factors. Vulnerability assessments can be further refined by considering the feasibility of adaptation through the concept of adaptive capacity – which takes into account the requirements for, and limitations to, implementing adaptation measures.

Agriculture

The study extends the net-revenue approach, which uses the cross-sectional evidence from farms facing wide range of climatic conditions, developed in previous studies to examine the impact of climate variation on Indian agriculture. The study specifically explores the impact of including inter-annual and diurnal variation in climate variables on the farm-level net-revenue. As climate change is likely to be associated with change in the climate variation also, inclusion of climate variation terms in the model is expected to improve the model specification and take the analysis closer to vulnerability assessment.

In previous analyses, it was demonstrated that both long-run averages of temperature and precipitation have quadratic relationships with farm level net-revenue. Hence the present study adopts similar specification for the model but extends it to specifically study the influence of climate variation terms as shown below.

$$R = f(T_j, T_j^2, P_j, P_j^2, T_jP_j, DT_j, YT_j, YP_j, SOIL, BULLOCK, TRACTOR, POPDEN, LITPROP, HYV, LAT, ALT)$$

where, R is the farm level net-revenue per hectare;

T_j and P_j are the normal temperature and precipitation respectively, and j denotes the seasons; (along with linear terms, the quadratic and interaction terms of these variables are also included)

DT_j denotes the diurnal variation of normal temperature;

YT_j and YP_j denote the yearly variation of temperature and precipitation;

SOIL represents the soil characteristics such as soil types and top-soil depth classes;

CULTIV, BULLOCK, TRACTOR are the number of cultivators, bullocks and tractors respectively in per hectare terms;

POPDEN is the population density;

LITPROP is the proportion of literate people;

HYVFR is the proportion of area under high yielding varieties (HYV); and

LAT and ALT are the latitude and altitude of the cross-sectional unit.

For accurate assessment of impacts on agriculture, it would be necessary to perturb both the average climate variables and their variation variables. Even if one were not to incorporate the possible changes in the climate variation variables for impact assessment, inclusion of climate variation variables is expected to improve the model specification. In above equation, variable *DT* represents the diurnal range in temperature, which is the difference between the maximum and minimum daily temperature; and *YT* and YP represent the standard deviation of temperature and precipitation over a period.

Coastal Resources

Given that the impacts due to sea level rise are likely to be not uniform across different parts of the country, regional level composite vulnerability index is developed to identify the most vulnerable regions. Also, vulnerability index would take both climate and non-climate factors into consideration and hence the analysis is a step forward from impact assessment. The vulnerability index is expected to be useful in prioritising the response strategies. For the purpose of index calculation, vulnerability is hypothesized to be a function of *impact* on the region, and *resistance* and *resilience* of the region in responding to the impact it experiences.

The composite vulnerability index developed using the following characteristics of various coastal regions across India: (a) demographic characteristics – such as population density, annual population growth rate; (b) physical characteristics – such as coast length, insularity, frequency of cyclones, probable maximum surge height; (c) economic characteristics – such as agricultural dependency, income; (d) social characteristics – such as literacy, spread of institutional set up. The composite index is calculated by taking average of all the standardized observations of each region over all the components. The averaging procedure implies that equal weights are assigned to each component. The procedure is similar to that followed in the construction of Human Development Index by the UNDP. The index computations are made for a range of combinations of the parameters listed above to check robustness of the index.

The study also attempts to model storm induced damages. However, given the data limitations a two-pronged approach has been adopted. In the first approach the concept of 'surge influence factor' is used to estimate the loss of human lives due to cyclonic storms. Broadly, the loss of human lives would depend on the risk level of the region, warning time and compliance to the evacuation plan. The loss of human lives due to a storm in any region is estimated as:

$$H = \sum_I P\ C\ \alpha_I\ r_i$$

where, P is the population of the region;

C is the non-compliance factor;

α_i is the fraction of the region's area related to a given hazard level; and

r_i is the risk coefficient for the hazard level.

The second approach on the other hand attempts to develop a functional relationship between human loss and surge using econometric methods. The choice of human loss as the end-point of analysis is due to non-availability of reliable data on economic damages.

Data

Agriculture

The net-revenue model specified above is estimated using pooled cross-sectional and time-series data for 271 districts covering most of India[1]. The farm-level net revenue is estimated using agricultural production data for as many as 20 major and minor crops. The climate data is based on a recent publication of India Meteorological Department (IMD) on climate normals for about 391 meteorological stations spread across India. The data on climate normals corresponds to the period 1951-1980. The data on yearly climate variation also matches with the above time

[1] It may be noted that the 271 districts used in the analysis correspond with the 1961 census definitions.

period. As the climate data is available at the meteorological station and the analysis is attempted at district level, surface interpolation technique is used to transfer climate data from the meteorological station level to district level. The interpolation technique uses geographical parameters such as latitude, longitude, altitude, and distance from the nearest seashore as independent variables. The procedure also takes into account differences between high and low altitude regions. The climate and climate variation variables corresponding to months January, April, July and October are used in the analysis to represent the four seasons respectively.

Coastal Resources

For vulnerability index calculations district level data on various characteristics of the coastal districts is assembled from a range of sources such as census, IMD, vulnerability atlas (developed by the Ministry of Urban Affairs and Employment, Government of India) and center for monitoring Indian economy. Data on coast length is estimated using geographic information system (GIS) software. Similarly, district level income is generated using a simple procedure based on allocating state income.

For storm induced human loss estimations data on district specific area in different hazard levels is assembled from vulnerability atlas, while data on corresponding risk coefficients and non-compliance factor are collected from disaster management literature. The analysis uses four hazard levels: Very High *plus* Surge, Very High, High, and Moderate. The surge influence factor is calculated for two different scenarios of surge penetration – 10 km and 30 km. Three different scenarios for non-compliance factors have been used: 0.004, 0.008 and 0.08 to reflect different levels of preparedness.

For estimating storm damage model, data on human loss, surge height, time and duration of the storm, and location and period of its occurrence are used. The data set corresponds to the period 1952 to 1996 and covers all the major storms that have hit both east and west coasts of India.

Results

Agriculture

An F-test comparing the model with and without the climate variation terms showed that the climate variation variables together are significantly different from zero. The t-statistic showed that barring a few all the climate variation variables are significant in improving the model specification.

To gain insight about the effect of climate variation terms in the model the climate change induced impacts are estimated for a few representative scenarios. The climate change induced impacts are measured through changes in net revenue triggered by expected changes in the climate variables. The impacts are estimated at individual district level and are then aggregated to derive the national level impacts.

As the net-revenue approach uses the cross-sectional evidence from farms facing wide range of climatic conditions for estimating the response function with farms differing not only in terms of their average climate but also in terms of the climate variation they experience, not incorporating the climate variation variables in the model could lead to bias in the estimated climate coefficients. Hence impacts estimated based on the model without the variation terms could be upwardly biased. The results presented in the table below capture this aspect. The impacts calculated using the model with climate variation are uniformly lower than those calculated using the model without climate variation. The last column in this table reports estimated impacts under a climate change scenario that incorporates higher climate variation along with changes in mean climate. The reported estimates are for a 5 percent increase in climate variation and the impacts are uniformly more. Thus the results show that changing climate involving increases in both mean and variation would lead to significantly more impacts on Indian agriculture.

Net-revenue Estimates with Climate Variation

∆T/∆P	Impacts as percentage of Net Revenue		
	Without Variation Terms	With Variation Terms	With Variation Terms and 5% Higher Variation
2^{o}C/7%	-7.8	- 6.8	-9.5
3.5^{o}C/14%	-24.0	- 17.8	-28.1

Note: The figures represent percentage change in net-revenue (1990 value).

Among various adaptation strategies special mention could be made of insurance. The new-generation micro-insurance schemes by attempting to achieve financial viability at the design stage itself could not only cover the future risks such as those expected under the climate change conditions, but also avoid moral hazard and adverse selection problems that commonly plague insurance schemes.

Coastal Resources

Vulnerability index estimations have been carried out for different specifications of the index. The results based on the rank correlations show that the vulnerability rankings across districts are significantly robust. The vulnerability index estimated for the Indian coastal districts indicate that:

- The districts along the eastern coast are relatively more vulnerable than those on the western coast.
- The coastal districts in the states West Bengal, Orissa, Andhra Pradesh and Tamil Nadu are only marginally different from each other in terms of their vulnerability.
- The districts that are frequently affected by cyclonic storms are relatively more vulnerable – these include districts like 24_Paraganas, Baleshwar, Krishna.

Comparison of district-wise expected casualties due to storms with district-wise vulnerability index shows that the relative ranking of districts remains more or less similar between the two analyses. This is an important result because the two analyses address vulnerability from two related, but different perspectives and their similarity shows robustness of the finding.

The estimated storm damage model is as follows:

lnloss = 6.19 (sd1) + 4.37 (sd2) + 4.56 (sd3) + 3.46 (sd4) + 0.439 (seasurge)

(8.51) (5.95) (7.06) (4.09) (3.34)

(Adj. R^2 = 0.95)

where, lnloss – human loss (in log)

sd1, sd2, sd3, sd4 – state dummies for AP, TN, Orissa & WB, Gujarat

seasurge – interaction dummy of season and surge height

Model estimates show:

- Storm surge has positive and significant influence on human loss
- Storm induced vulnerability is more for AP followed by Orissa & WB, TN and Gujarat
- Storms in the winter season are more destructive than those occurring in summer season
- Storm duration and its period of occurrence (i.e., sixties, seventies, eighties, or nineties) are not significant.

A prudent adaptive response to the threat of climate change may be to improve adaptation to existing climate and its variability, including extreme events such as cyclones. As argued in the case of crop insurance, insurance to natural disasters should have little or no government subsidy to avoid moral hazard and adverse selection problems. New approaches like index-based or area-based contracts to insure natural disasters should be attempted and these approaches in conjunction with developments in micro-finance could make insurance an increasingly viable proposition for poor people to better manage risk.

Policy Implications

The scope of the study does not warrant policy suggestions that feed directly into climate negotiations. However, a number of policy relevant conclusions can be made on the basis of results obtained from this study.

- For India (and other developing countries) there are a number of more demanding development priorities that need immediate attention compared to climate change. Hence the issues related to climate change should be placed in the sustainable development framework to gain wider acceptability.

- Adaptation to climate change is an issue of considerable interest to India, given its high vulnerability to climate change. The results of this study for two climate sensitive sectors, agriculture and coastal resources, highlight this. Equal emphasis, if not more, should be placed on adaptation policies in the climate change negotiations.

- Vulnerability indices such as those developed for the coastal districts of India in this study could provide insights on prioritizing adaptation strategies for specifically vulnerable regions.

- Understanding vulnerability to present day climate extremes such as cyclones would provide useful insight about the adaptive capacity of a region. Such knowledge could be useful in formulating adaptation strategies.

- Immediate benefits can be gained from better adaptation to climate variability and extreme atmospheric events. Immediate benefits also can be gained by removing maladaptive policies and practices.

- Anticipatory and precautionary adaptation could be more effective and less costly than forced, last minute, emergency adaptation or retrofitting.

- India could benefit by ensuring that its legal and economic structures and price signals encourage the private sector to take adaptive measures. Insurance, and more specifically micro-insurance, should be encouraged to help people adapt to the climate change conditions.

- India and other developing countries could also benefit by encouraging research that fosters identification of new and cost-effective adaptation strategies. The global community also has a significant role to play in this endeavor.

- The global community should address and resolve on priority basis the barriers mentioned above with regard to financing the adaptation options in developing countries.

- Even though the impacts and hence the adaptation needs are local in nature, given the global nature of the climate change problem responsibility rests on all the countries. Moreover, the principle of 'common but differentiated responsibilities' should be applied here also. The developed countries should shoulder bulk of the cost of adaptation in developing countries on the basis of fairness principles such as equality and vulnerability.

Chapter 1: Introduction and Motivation

Accumulation of trace gases such as carbon dioxide (CO_2), methane (CH_4) etc. in the atmosphere, caused mainly due to anthropogenic activities such as burning of fossil fuels, is believed to be altering the Earth's climate system. The third assessment report of Intergovernmental Panel on Climate Change has concluded that "there is new and stronger evidence that most of the warming observed over the last 50 years is attributable to human activities" (IPCC, 2001a). The expected changes in climate system could have significant impacts on a number of climate sensitive sectors of the world economy.

Analysis of various pollution abatement strategies is well documented in the field of environmental economics. However, the study of climate change problem poses a special and formidable challenge due to a variety of reasons including the global and inter-disciplinary nature of the problem, long time periods involved, and the associated uncertainties. Also, the differences among world nations in terms of their historic, present and future contributions to greenhouse gas (GHG) emissions, and their respective vulnerabilities to potential changes in the climate makes it a complex problem to resolve.

The climate change policies can be broadly divided into two categories: GHG mitigation strategies and adaptation strategies. The GHG mitigation strategies dominate the current global negotiations on climate change and the Kyoto Protocol signed at the Third Conference of Parties in 1997 has for the first time placed quantitative restrictions on the GHG emissions from the developed countries. However, the implementation of the Protocol is still surrounded by lot of uncertainty and the recent decision by the US government not to ratify the protocol puts further doubts about the success of the mitigation policies. Moreover, implementation of the Kyoto Protocol does little to reduce the potential impacts due to climate change (Parry et. al., 1998).

The available evidence from various climate change impact studies suggests that the developing countries are likely to get more adversely affected than the developed countries (see for example, Rosenzweig and Parry, 1994). This could be due to the typical geographical location of developing countries and their large dependence on climate sensitive sectors, such as agriculture. With the potential impacts of changing climate remaining at the centre of the climate change debate, the climate change policies viewed from the developing country perspective should focus on adaptation strategies. This emphasis on adaptation strategies is not at the cost of mitigation strategies and the current mitigation efforts by the developed countries should continue, if not with more seriousness. Bringing the developing countries into climate policy arena should be more through the adaptation strategies than their contribution towards GHG emission abatement efforts.

An important step in the direction of developing adaptation strategies is to assess potential impacts and/or vulnerability of key climate sensitive sectors to the climate change risks. Given this background this study focuses on assessing climate change induced potential impacts/vulnerability on two key climate sensitive sectors in India, namely agriculture and coastal resources. It is expected that such assessment would be useful to formulate the long-term response strategies for climate change by focusing on adaptation strategies.

Structure of the Report:

The report is structured as follows: The first chapter introduces the climate change problem and the relevant policy responses under consideration. This chapter also highlights the need for focus on adaptation and provides motivation through available evidence on climate change induced impacts and increasing losses due to climate related extreme events. The second chapter introduces the concepts of impacts, sensitivity, vulnerability and adaptation in the context of climate change. Discussing the evolution of literature on vulnerability assessment, the chapter highlights similarities with the disaster management literature. This chapter also provides justification for the choice of agriculture and coastal resource sectors for analysis. The third and fourth chapters focus on agriculture and coastal resource sectors, respectively and discuss estimated impacts/vulnerability and potential adaptation options. Finally the fifth chapter concludes the report.

1.1 Climate change – Evidence and projections

The anthropogenic activities are believed to be mainly responsible for the build-up of GHG concentrations in the atmosphere. The third assessment report of IPCC observes that concentrations of atmospheric greenhouse gases and their radiative forcing[2] have continued to increase as a result of human activities (IPCC, 2001a). The changes in main GHG concentrations since Industrial Revolution and their radiative forcing are documented as follows:

- The atmospheric concentration of CO_2 has increased by 31% since 1750. The present CO_2 concentration (about 367 ppm) has not been exceeded during the past 420,000 years and likely not during the past 20 million years. The current rate of increase is unprecedented during at least the past 20,000 years.

- The atmospheric concentration of CH_4 has increased by 1060 ppb (151%) since 1750 and continues to increase. The present CH_4 concentration has not been exceeded during the past 420,000 years.

- The atmospheric concentration of nitrous oxide (N_2O) has increased by 46 ppb (17%) since 1750 and continues to increase. The present N_2O concentration has not been exceeded during at least the past thousand years.

- While the concentrations of many halocarbon gases that are ozone-depleting in nature are decreasing, the concentrations of their substitute compounds (e.g., CHF_2Cl and CF_3CH_2F) and some other synthetic compounds (e.g., perfluorocarbons (PFCs) and sulphur hexafluoride (SF_6)) are increasing.

- The radiative forcing due to increases of the greenhouse gases from 1750 to 2000 is estimated to be 2.43 Wm-2 with contributions from various GHGs as: 1.46 Wm-2 from CO_2; 0.48 Wm-2 from CH_4; 0.34 Wm-2 from the halocarbons; and 0.15 Wm-2 from N_2 O.

A number of climate parameters have been observed to change in the recent past and IPCC (2001a) attributes these changes to manifestation of human induced

[2] *Radiative forcing* is a measure of the influence a factor has in altering the balance of incoming and outgoing energy in the Earth-atmosphere system, and is an index of the importance of the factor as a potential climate change mechanism. It is expressed in watts per square metre (Wm-2).

climate change. Some of the observed changes in climate parameters are as follows:

- Over the 20th century the increase in global average surface temperature has been 0.6±0.2°C. Globally, it is very likely that the 1990s was the warmest decade and 1998 the warmest year in the instrumental record, since 1861.

- Tide gauge data show that global average sea level rose between 0.1 and 0.2 metres during the 20th century.

- It is very likely that precipitation has increased by 0.5 to 1% per decade in the 20th century over most mid- and high latitudes of the Northern Hemisphere continents, and it is likely that rainfall has increased by 0.2 to 0.3% per decade over the tropical land areas.

- In the mid- and high latitudes of the Northern Hemisphere over the latter half of the 20th century, it is likely that there has been a 2 to 4% increase in the frequency of heavy precipitation events.

- Warm episodes of the El Niño-Southern Oscillation (ENSO) phenomenon (which consistently affects regional variations of precipitation and temperature over much of the tropics, sub-tropics and some mid-latitude areas) have been more frequent, persistent and intense since the mid-1970s, compared with the previous 100 years.

- In parts of Asia and Africa the frequency and intensity of droughts have been observed to increase in recent decades.

Based on climate model projections the expected changes in some of the key climate parameters over the next century are as follows. It may be noted that these projections are based on business-as-usual scenario with no policy intervention and expected rise in GHG emissions[3].

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[3] The projected ranges are based on emission scenarios documented in Special Report on Emission Scenarios of IPCC (SRES). The IPCC used six illustrative emissions scenarios in various climate models to project future atmospheric concentrations of greenhouse gases. For these illustrative scenarios, the IPCC projected that carbon dioxide concentrations in 2100 would range between 540 and 970 ppm (about 50 to 165 percent greater than the current concentration).

- The globally averaged surface temperature is projected to increase by 1.4 to 5.8°C over the period 1990 to 2100. These projected increases are greater than those in the SAR primarily due to the lower projected sulphur dioxide emissions.

- Global mean sea level is projected to rise by 0.09 to 0.88 metres between 1990 and 2100.

- The frequency and intensity of extreme events such as cyclones is very likely to increase during the 21st century.

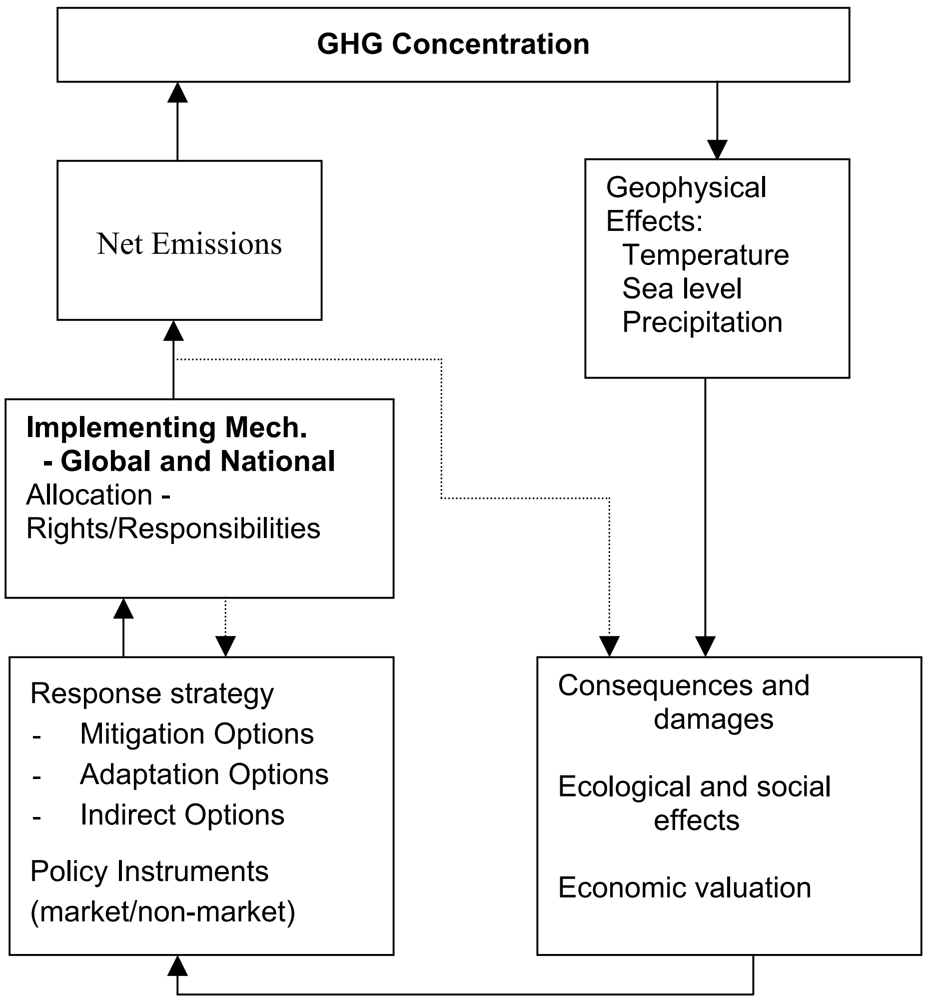

Figure 1.1: Casual Chain of Climate Change Problem

1.2 Economics of Climate Change

To develop a viable climate change policy one needs a clear (quantitative) understanding of the consequences of climate change and emission control. The loss of welfare from a change in the climate can be dealt with in terms of the benefits of GHG control or in terms of the damages from a lack of control and a continuation of emission growth leading to climate change. Many authors have preferred using the word 'benefits' rather than damage though the concepts are the same[4]. The costs of GHG control are relatively more straightforward (compared to benefits) but still fairly uncertain. Even though there are substantial 'no regret' options (such as removal of inefficiencies in the system) for controlling GHG emissions, which can be considered as options available at no extra cost, most analysts recognize that there are significant costs associated with reducing the emission level. Figure 1.1 illustrates the casual chain of climate change problem.

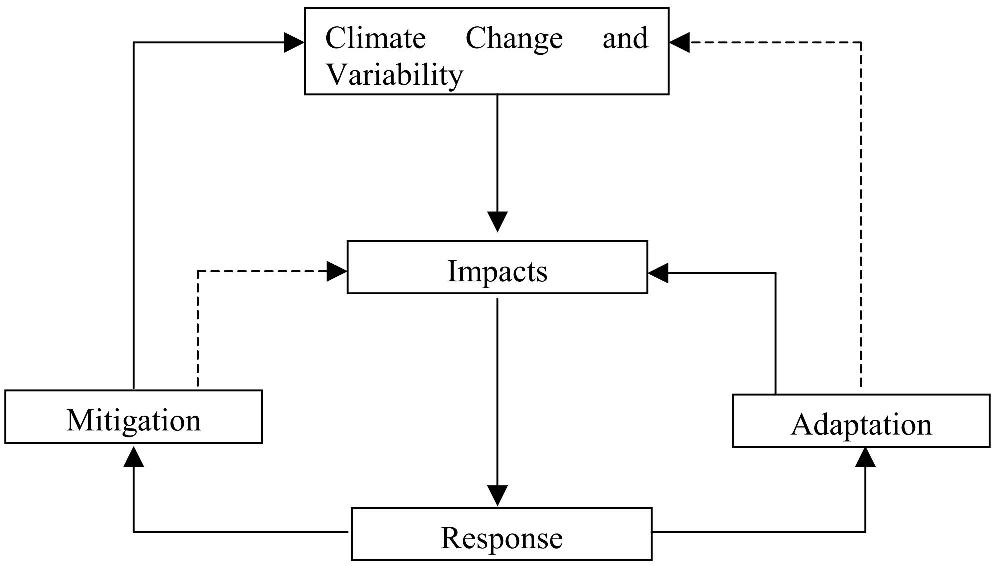

Figure 1.2: Climate Change Policy Options

The broad framework illustrated above underlies the so-called integrated assessment (IA) models of climate change (see for example, Nordhaus, 1994;

[4] The use of word 'benefits' (instead of damages) also go well with the dominant decision making paradigm, namely cost-benefit analysis.

Nordhaus and Yang, 1996; Wigley et al., 1996; Pizer, 1999; Nordhaus and Boyer, 2000 etc.). The IA models bring together the benefits and costs of policy intervention through a decision-making paradigm (such as cost-benefit analysis or safe-minimum standards approach). The IA models have increased in their complexity over the years and to capture the effects of human activities on the climate and the effects of climate change on human well-being these model incorporate the following elements (it may be noted that models differ substantially in terms of the extent to which they incorporate these features):

Human activities generate GHGs and alter land use (for example, forest area), which also affects the concentration of GHGs in the atmosphere. These activities, by altering the chemical composition of the atmosphere, are thought to lead to long-term changes in the climate system (temperature level and variability, rainfall patterns etc.).

Changes in the climate system are thought to have consequences for human well-being.

These changes would occur through a variety of channels (productivity of food cultivation, impacts on natural ecological systems, threats to coastal areas, human health etc.). Thus, a close connection exists between human impacts on climate and climatic impacts on human society.

Responses to these feedback effects can reflect a mix of mitigation (reduced emissions, reduced deforestation), and adaptation (before as well as after the fact), which makes human well-being less vulnerable to climatic change.

Time is a critical element of the problem. GHGs accumulate in the atmosphere over long periods (decades or even hundreds of years). Capital stock investments that are made in response to climate change threats are also long-lived (decadal periods for electricity generation or road infrastructure), and long-term technical change is another key influence on the cost of response. Thus, a complete economic analysis of climate change must be dynamic.

Uncertainty also is a critical element of the problem. The severity of the climate change problem includes uncertainty in the mapping from emissions to temperature and other climatic changes, and in the impacts of climate change on human well-being. The costs of reducing emissions, the evolution of new technologies that will lower that cost, and the opportunities for adaptation are all uncertain as well. Uncertainty further interacts with the dynamic nature of the climate problem in giving rise to issues related to irreversibility. Thus, a complete economic analysis of climate change must also include stochastic elements.

The costs of emission control are borne in the short-term; whereas the benefits of emission control through reduced climate change induced damages would be seen in the medium to long-term. Thus inter-generational equity issues need to be addressed in the economic analysis of climate change.

With this background the next section discusses in detail the two main categories of climate change policy options, namely mitigation and adaptation.

1.3 Policy Options – Mitigation and Adaptation

The policy options available to address climate change problem can broadly be divided into two categories: mitigation and adaptation. Figure 1.2 illustrates these two options and their inter-connection.

Mitigation Options

Mitigation consists of activities that aim to reduce GHG emissions directly or indirectly, by capturing GHGs before they are emitted to the atmosphere or sequestering GHGs already in the atmosphere by enhancing their sinks.

The most obvious way of addressing climate change problem is to reduce emissions of GHGs into the atmosphere, particularly CO_2 emissions from fossil fuel combustion. This entails either reducing use of carbon rich fuels or using efficient production technologies to reduce emissions of GHG from what otherwise would be the case. Availability of environmental friendly technologies (such solar energy, wind power etc.) would fundamentally alter the economic analysis of climate policy by creating a new kind of 'backstop technology' (Kolstad and Toman, 2001)

Since the atmosphere already has significant quantities of GHGs (particularly CO_2), another strategy for managing the climate change problem is to capture and store carbon that is currently in the atmosphere. This process is known as sequestration. One obvious form of sequestration is carbon stored in trees. However there are concerns about the extent to which sequestration can be considered as a reliable mitigation option, because the sequestration process can be easily reversed, say through felling of forests and burning the logged wood.

Adaptation Options

Adaptation activities include behavioural, institutional, and technological adjustments aimed at reducing the impacts of climate change. They capture a wide array of potential strategies, such as coastal protection, altering cropping patterns etc.

Agriculture has traditionally been practiced in a wide range of climatic conditions all over the world and this observation led to the conclusion from a strand of literature dealing with farmer adaptation (see for example Schimmelpfennig et al., 1996) to conclude that agriculture is highly adaptable when the farmers have the capacity to anticipate and react to prospective changes. Viewed from this perspective, climate change will not pose a significant threat to global food supply, even though substantial regional variations may exist.

It is still not very clear whether other sectors also have similar capacity to adapt to new climatic conditions. It is also important to note that costs of adjusting from one climate to another could be significant and they depend among other things on the speed at which the climate changes, and the resilience of natural system being affected. The potential to adapt depends on a society's wealth and on various kinds of social infrastructure such as educational and public health systems. For example, it is widely believed that climate change induced health impacts would be less severe in rich countries than in poor countries with less infrastructure.

A commonly used classification groups adaptation measures into eight categories (Burton et al., 1993):

Bear losses: All other adaptation measures may be compared with the baseline response of "doing nothing" except bearing or accepting the losses. In theory, bearing loss occurs when those affected have no capacity to respond in any other ways (for example, in extremely poor communities) or where the costs of adaptation measures are considered to be high in relation to the risk or the expected damages.

Share losses: This type of adaptation response involves sharing the losses among a wider community. Such actions take place in traditional societies and in the most complex, high-tech societies. In traditional societies, many mechanisms exist to share losses among a wider community, such as extended families and village-level or similar small-scale communities. At the other end of the spectrum, large-scale societies share losses through public relief, rehabilitation, and reconstruction paid for from public funds. Sharing losses can also be achieved through private insurance.

Modify the threat: For some risks, it is possible to exercise a degree of control over the environmental threat itself. When this is a “natural” event such as a flood or a drought, possible measures include flood control works (dams, dikes, levees).

Prevent effects: A frequently used set of adaptation measures involves steps to prevent the effects of climate change and variability. An example would be for agriculture: changes in crop management practices such as increased irrigation water, additional fertiliser, and pest and disease control.

Change use: Where the threat of climate change makes the continuation of an economic activity impossible or extremely risky, consideration can be given to changing the use. For example, a farmer may choose to substitute a more drought-tolerant crop or switch to varieties with lower moisture. Similarly, crop land may be returned to pasture or forest, or other uses may be found such as recreation, wildlife refuges, or national parks.

Change location: A more extreme response is to change the location of economic activities. There is considerable speculation, for example, about relocating major crops and farming regions away from areas of increased aridity and heat to areas that are currently cooler and which may become more attractive for some crops in the future.

Research: The process of adaptation can also be advanced by research into new technologies and new methods of adaptation.

Educate, inform, and encourage behavioural change: Another type of adaptation is the dissemination of knowledge through education and public information campaigns, leading to behavioural change. Such activities have been little recognized and given little priority in the past, but are likely to assume increased importance as the need to involve more communities, sectors, and regions in adaptation becomes apparent.

Considering adaptation options to address climate change problem brings a range of issues for further analysis. These include, adapt to what?; who and what is that adapts?; how does adaptation occurs?; when does adaptation take place?; what is capacity to adapt?; how to increase the capacity to adapt? etc. Many of these issues still need to be clearly understood as adaptation itself as a policy option has received relatively less attention so far (see below for further discussion on this).

Table 1.1 summarizes the characteristics of mitigation and adaptation options. While mitigation of GHG emissions helps virtually every system to face relatively lower climate change induced impacts, adaptation options can be considered only for a few systems (for instance, it may not be feasible for some natural systems to adapt successfully to climate change). Similarly mitigation options can be conceived at global level, whereas adaptation options can only be visualized at local or regional level. For adaptation options ancillary benefits often exist, which in themselves can justify the adaptation options. The implications of mitigation options can manifest for centuries, whereas the effects of adaptation options may last for few years to decades. The concept of polluter pays can be imbedded in the design of mitigation strategy. On the other hand most of the adaptation options may have to be designed for developing countries, who are not the main polluters. It is relatively easy to monitor GHG emissions reductions, whereas it is much more difficult to measure the effectiveness of adaptation in terms of avoided impacts.

Table 1.1: Characteristics of Mitigation and Adaptation Options

	Mitigation	Adaptation
Beneficiary systems	All systems	Selected systems
Scale of operation	Global	Local to regional
Co-benefits	Sometimes	Often
Implications manifest for	Centuries	Few years to decades
Penalizing the main polluters	Possible	Not necessarily
Attribution	Relatively easy	More difficult

1.4 International Policy Response – Rio to New Delhi

Last two decades have seen rapid evolution of global climate policy. The pace of policy response has been significant and it speaks largely about the seriousness attached by the world community to the climate change problem. Table 1.2 summarizes the important events that shaped the global climate policy in the last two decades.

Table 1.2: Road Map of Important Events in Global Climate Policy

Year	Event
1979	First World Climate Conference held in Geneva
1987	Montreal Protocol to protect the Ozone layer
1989	IPCC Established
1990	IPCC First Assessment Report – suggested that human activities might be affecting climate.
1992	Rio Summit – UNFCCC established. No legally binding commitments, but Annex-I Parties commit to reduce their emissions to 1990 levels by 2000.
1995	IPCC Second Assessment Report – suggested with more certainty that human activities are responsible for discernable change in climate system.
1995	COP-1 - Berlin Mandate; AIJ pilot phase launched.
1996	COP-2 - Geneva Declaration; Reviewed and accepted the Second Assessment Report of IPCC; Agreement on legally binding commitments for the Annex-I Parties gained momentum.
1997	COP-3 - Kyoto Protocol. Legally binding commitments on Annex-I Parties - 5.2% below the 1990 levels in the first commitment period 2008-12; Demonstrable progress by Annex-I Parties by 2005; Agreement on Flexibility Mechanisms - JI (Article 6), CDM (Article 12), ET (Article 17); Call for 'Meaningful Participation' by key developing countries.

Year	Event
1998	COP-4 - Buenos Aires Action Plan; Work program on the flexibility mechanisms with a view to take decisions at the fist meeting of the Parties to the Protocol.
1999	COP-5 – Bonn, Germany; Work program on CDM and JI and developing criteria for project eligibility; Progress on legally-binding consequences for non-compliance of parties.
2000	COP-6 – Hague, deadlock on implementing key provisions of the Kyoto Protocol. Reconvened in Bonn within six months to foster an agreement.
2001	COP-7 – Marrakech Accord. The United States opposed the Kyoto Protocol and continued its demand for 'meaningful participation' of key developing countries (such as China, India and Brazil) in GHG emission control. Despite the US boycott other Annex-I Parties agreed on a range of key issues and the prospects for ratification of the Kyoto Protocol appeared brighter.
2002	COP-8 – New Delhi Declaration. Focus on sustainable development.

As could be seen from the above table there has been an over emphasis so far on mitigation policies in the global climate policy. One of the reasons for this overemphasis on mitigation is that climatic changes today still are relatively small, thus there is little need for adaptation, although there is considerable need for mitigation to avoid more severe future damages. By this logic, it is more prudent to invest the bulk of the resources for climate policy in mitigation, rather than adaptation. However it is becoming more and more clear now that mitigation alone cannot address climate change problem effectively. The emission reductions being discussed at present (even if they were to be fully implemented) may not have any significant impact on the potential changes in climate and hence on the associated damages. The following section discusses the vulnerability due to climate change with special focus on developing countries.

1.5 Vulnerability due to Climate Change

Changes in climate system in themselves may not be of major concern, but the potential impact of those changes on a number of climate sensitive systems that sustain human societies could be of concern. Impacts, for example, can be expected in the productivity and structure of natural ecosystems; the productivity of agricultural, grazing, and timber lands; and the geographic distribution, behavior, abundance, and survival of plant and animal species, including vectors and hosts of human disease. Human welfare would be impacted through changes in supplies of and demands for water, food, energy, and other tangible goods that are derived from these systems; changes in opportunities for non-consumptive uses of the environment for recreation and tourism; changes in incomes; changes in loss of property and lives from extreme climate phenomena; and changes in human health. Despite numerous studies in the field of climate change impact assessment, considerable uncertainty still surrounds the estimates. Particularly policy relevant estimates of impacts in various sectors together with their autonomous adaptive capacity are not available. One main reason for the uncertainty is the long time periods involved in the impact estimation, which calls for careful scenario development.

Table 1.3 reports the aggregate impacts due to climate change in different regions of the world for a doubling of CO_2 concentration scenario[5]. Despite the wide variation among different study results there are some common findings:

- Developing countries, on the whole, are more vulnerable to climate change than developed countries.
- At low magnitudes of temperature change, damages are more likely to be mixed across regions, but at higher magnitudes virtually all regions have net damages.

Table 1.3: Aggregate Impacts Across World Regions

	IPCC SAR (1996)	**Mendelsohn et al. (2000)**		**Nordhaus and Boyer (2000)**	**Tol (1999)**
	2.5°C Warming	1.5°C Warming	2.5°C Warming	2.5°C Warming	1°C Warming[a]
United States			0.3	-0.5	
OECD Europe					3.7 (2.2)
India			-2.0	-4.9	
China			1.8	-0.2	2.1 (5.0)
Africa				-3.9	-4.1 (2.2)

[5] In this scenario the changes in climate parameters are estimated from climate models following a doubling of CO_2 concentration from the pre-industrial revolution level – i.e., from 280 ppm to 560 ppm.

	IPCC SAR (1996)	Mendelsohn et al. (2000)		Nordhaus and Boyer (2000)	Tol (1999)
	2.5°C Warming	1.5°C Warming	2.5°C Warming	2.5°C Warming	1°C Warming[a]
Developed	-1.0 to -1.5	0.12	0.03		
Developing	-2.0 to -9.0	0.05	-0.17		

[a] Figures in brackets denote standard deviations.

(Source: IPCC, 2001b)

The aggregate estimates presented above mask a number of concerns and these include:

(a) Impacts on unique systems such as Tropical glaciers, coral reefs, mangroves, and biodiversity "hot spots" are not clearly understood and the existing estimate do not capture the true impact on these systems.

(b) Non-uniform distribution of impacts across regions may exacerbate income inequalities between and within countries.

(c) Aggregation of impacts across sectors and regions presents conceptual problems – for example, positive impacts in some regions may not necessarily cancel out the negative impacts in some other regions.

Most of the available estimates do not capture the potential changes in the frequency and magnitude of extreme climate events such as cyclones and droughts. As tables 1.4 and 1.5 show natural disasters cause significant damages, especially in developing countries. Asia, for example, accounts for almost 38 per cent of hydrological and meteorological disasters occurred during the period 1991 and 2000 all over the world. Of those reported killed by natural disasters, 83% lived in Asia, while 67% lived in nations of low human development. Looking at damages caused by natural disasters it may appear that the impacts are more severe on developed countries. Nations of high human development accounted for 58% of all estimated damage but just 2% of deaths due to natural disasters. Nations of low human development accounted for just 4% of all estimated damage but 67% of deaths due to natural disasters. The reason for low damages in developing or low income countries could be due to under-reporting and non-market nature of losses.

Table 1.4: Number of People Reported Killed in Natural disasters - 1991 to 2000

	Africa	Americas	Asia	Europe	Oceania	Grand Total
Avalanches/landslides	274	2172	5754	1071	279	9550
Droughts/famines	6326	0	273583	0	98	280007
Earthquakes	784	2301	35092	21001	71	59249
Extreme temperatures	105	1941	5745	1310	23	9124
Floods	8163	35687	52437	1438	22	97747
Forest/scrub fires	101	130	238	150	7	626
Volcanic eruptions	0	70	863	0	9	942
Wind storms	1274	23187	180206	715	253	205635
Other natural disasters	0	15	521	0	2182	2718
Subtot. hydro-meteorological disast.	16243	63132	518484	4684	2864	605407
Total natural disasters	17,027	65,503	554,439	25,685	2,944	665,598

(Source: EMDAT)

Table 1.5: Estimated Damage (000 US $) due to Natural Disasters – 1991 to 2000

	Africa	Americas	Asia	Europe	Oceania	Grand Total
Avalanches/landslides		1,081,400	309,490	24,689		1,415,579
Droughts/famines	380,939	4,660,000	8,621,996	9,546,600	4,676,000	27,885,535
Earthquakes	282,129	29,842,160	157,952,440	25,365,564	255,000	213,697,293
Extreme temperatures	809	8,954,000	3,950,000	1,909,600		14,814,409
Floods	542,529	32,452,257	112,260,254	90,254,933	857,600	236,367,573
Forest/scrub fires	3,500	4,786,600	19,002,500	189,249	156,700	24,138,549
Volcanic eruptions		23,722	212,488	16,500	400,000	652,710
Wind storms	756,565	98,519,253	55,245,255	15,508,734	3,697,168	173,726,975
Other natural disasters	5,200	104,000	267	0	120,000	229,467
Subtot. hydro-meteorological disast.	1,689,542	150,557,510	199,389,762	117,433,805	9,507,468	478,578,087
Total natural disasters	1,971,671	180,423,392	357,554,690	142,815,869	10,162,468	692,928,090

(Source: EMDAT)

Greenhouse gas–induced climate warming potentially could affect tropical cyclones in a number of ways, including their intensity, frequency of occurrence, geographical distribution, and storm tracks. A warming of the surface supplies more water vapor to the atmosphere, thus making more moisture available to storms. One would therefore expect an increase of intense precipitation and more rainfall from a given storm, both results seen in climate model simulations. Concerning future changes in tropical cyclone frequency, no consensus has emerged yet among global models. Regarding tropical cyclone intensities, some of the global climate models suggest an increase of intensities with CO_2 induced warming. However, the highest resolution global climate model experiment reported to date still has a resolution too coarse (1°) to simulate the most intense storms and/or realistically simulate structures such as the hurricane eye. Recent experiments with a nested high-resolution regional model (resolution of up to 1/6 degree or 18 km) indicate a 5%–11% increase in surface wind speeds and a 28% increase in near-storm precipitation, based on a comparison of strong north Pacific typhoons simulated under present day and high CO_2 conditions (Meehl et al., 2000). This simulated increase of wind speeds is similar to the increase in tropical cyclone upper-limit intensities predicted by theories based on thermodynamic considerations.

Thus, from the developing country perspective the present day vulnerability due to natural disasters, the possibility of increase in frequency and intensity of such events under climate change regime, and potential high impact of climate change on the performance of climate sensitive sectors make a strong case for focus on adaptation options as part of climate change policy. Simultaneous focus on adaptation options to address climate change problem seems both inevitable and prudent.

A fundamental input necessary for formulating adaptation policies is knowledge on climate change induced impacts and vulnerability of climate sensitive sectors. This report focuses on this aspect and the next chapter discusses the underlying conceptual issues.

Chapter 2: Impacts, Adaptation and Vulnerability: Conceptual Framework

As mentioned in previous chapter an essential input for appropriate formulation of adaptation strategies is knowledge on climate change induced impacts and vulnerabilities of various climate sensitive sectors. However, there is close connection between a system's adaptive capacity and its vulnerability. Moreover since the climate change induced impacts could manifest over a long horizon the vulnerability of a system would be influenced by a variety of non-climatic driving forces, which themselves would change over time. Thus vulnerability assessment should take all these into consideration. In the climate change context the concept of vulnerability is still emerging, but it is well developed in disaster management literature and also in famine early warning literature. Hence there could be useful insights that climate change communities pick from developments in other literatures.

This chapter is organized as follows: The first section discusses the concepts of impacts, sensitivity, adaptation and vulnerability in the context of climate change. This is followed by a brief discussion on a possible analytical specification for vulnerability analysis. The third section traces the evolution of the literature on climate change impacts and describes the emerging conceptual framework for vulnerability assessment. The fourth section links the climate change impact/vulnerability literature with the disaster management literature and looks for potential synergies. Finally, the last section discusses the available estimates on climate change impacts for various climate sensitive sectors in India.

2.1 Impacts, Adaptation and Vulnerability – Linkages

The exact definitions of terms, 'impacts', 'sensitivity', 'vulnerability', 'adaptation' etc. are still being debated and discussed in the climate change literature. Much of the debate arises because of inter-disciplinary nature of these terms and with IPCC functioning as a common platform a consensus is slowly emerging. Based on latest IPCC glossary (IPCC, 2001a,b) one can define these terms as follows:

Impacts: Consequences of climate change on natural and human systems. Depending on the consideration of adaptation, one can distinguish between potential and residual impacts.

Sensitivity: The degree to which a system is affected, either adversely or beneficially, by climate-related stimuli.

Exposure: The nature and degree to which a system is exposed to significant climatic variations.

Climate impacts are a function of (the change in) the exposure of a system to climatic stimuli and of its sensitivity to these stimuli. Potential impacts are determined in assessments where the exposure of a system changes but its sensitivity is assumed to be unaffected by climate change. The determination of residual impacts requires assessments that explicitly consider adaptation measures.

Adaptation: Adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities. Various types of adaptation can be distinguished, including anticipatory and reactive adaptation, private and public adaptation, and autonomous and planned adaptation.

Adaptive Capacity (or Adaptability): The ability of a system to adjust to climate change (including climate variability and extremes) to moderate potential damages, to take advantage of opportunities, or to cope with the consequences.

Vulnerability: The degree to which a system is susceptible to, or unable to cope with, adverse effects of climate change, including climate variability and extremes. *Vulnerability is a function of the character, magnitude, and rate of climate variation to which a system is exposed, its sensitivity, and its adaptive capacity*.

Thus it can be inferred that vulnerability as a broader concept than potential impacts. Impact potential is an important determinant for the vulnerability of a system, but it does not suggest that impacts cause vulnerability. Some of the important features of vulnerability assessment are listed below:

- Most vulnerability assessments explicitly consider the uncertainty of climatic and non-climatic scenarios. Reilly and Schimmelpfennig (1999), for instance, emphasize the stochastic nature of vulnerability by defining it as the 'probability weighted mean of damages and benefits'.

- Vulnerability assessments generally perform an evaluation of projected climate impacts, including distributional aspects.

- A system is only considered vulnerable if goods and services that are valuable to society are adversely affected.

- Most vulnerability assessments also pay attention to socio-economic factors that determine the differential vulnerability of communities to external stresses.

- Most importantly, assessments of vulnerability to gradual changes, such as climate change, need to consider the potential of a system to adapt to changing conditions over time.

  With this background on terminology the next section presents an analytical specification of vulnerability assessment.

2.2 Analytical Specification of Vulnerability Assessment

Vulnerability in the context of climate change depends on interaction between the social and environmental systems and their responses to multiple and interacting stresses originating again in social and environmental realms. Thus a comprehensive vulnerability analysis should consider;

- A fundamental distinction between regular (smooth) and singular (discontinuous or extreme) disturbances has to be made.

- Plausible scenarios for development trends affecting system sensitivity and adaptive capacity – for e.g., population growth, urbanization etc.

- Understanding of critical response potentials in relevant exposure units due to intrinsic thresholds or positive feedbacks.

- Valuation schemes for quantifying the natural and socio-economic elements at stake as well as the generalized costs of adaptive measures.

- Generation of probabilistic results independent of particular uncertainties.

For example, a strictly static approach to formal vulnerability analysis could be described as follows: Let *E* denote a global change sensitive entity characterized by the properties $e_1, e_2, \ldots e_N$. Let P denote a global change related perturbation composed of the disturbance factors $p_1, p_2, \ldots p_M$. The vulnerability of *E* with respect to *P*, $V_E(P)$, is an entity-specific damage function of the entity-specific factor sensitivity, $S_E(P)$, and adaptation, $A_E(P)$. Hence,

$$V_E(P) = f_E(S_E(P), A_E(P)) \qquad (1)$$

where, $f_E(S_E(P), 0) = S_E(P)$, which implies that sensitivity corresponds to the 'gross' vulnerability without any adaptation processes. For simplification one can assume some universal function *F*, instead of f_E, that relates sensitivity and adaptation. A plausible further simplification results from factorizing *F* in the following manner:

$$F(S_E(P), A_E(P)) = S_E(P)\, G(A_E(P)),$$

Where, *G* is again a universal function. The general formulation represented in equation (1) can be simplified by expressing $S_E(P)$ and $A_E(P)$ in general forms that relate the fundamental set of properties $e_1, e_2, \ldots e_N$ to the fundamental set of disturbance factors $p_1, p_2, \ldots p_M$. That is,

$$S_E(P) = \sigma\ (e_1, e_2, \ldots e_N; p_1, p_2, \ldots p_M)$$

$$A_E(P) = \alpha\ (e_1, e_2, \ldots e_N; p_1, p_2, \ldots p_M).$$

Under certain circumstances it may even be possible to consider α as independent of the specific type of perturbation, i.e.,

$$A_E(P) = \alpha\ (e_1, e_2, \ldots e_N)$$

Thus, one can rewrite equation (1) as follows:

$$V_E(P) = \sigma\ (e_1, e_2, \dots e_N; p_1, p_2, \dots p_M)\ G\ (\alpha\ (e_1, e_2, \dots e_N))$$

$$= \beta\ (e_1, e_2, \dots e_N)\ \sigma\ (e_1, e_2, \dots e_N; p_1, p_2, \dots p_M) \quad (2)$$

Here, β represents a modulation factor that reduces the 'gross' vulnerability and its value lies between 0 and 1.

To illustrate the above formulation the following fictitious example can be considered. Let the entity under consideration be a segment of east coast of India. The properties of this entity can be characterized by e_1 = exposed monetary value per unit area, e_2 = population density, e_3 = degree of technological development. The climate perturbation P is characterized by p_1 = average rate of sea level rise, p_2 = relative change in cyclone frequency. Using equation (2) one can express vulnerability of the entity under consideration as follows:

$$V_E(P) = \beta\ (e_1, e_2, e_3)\ \sigma\ (e_1, e_2, e_3; p_1, p_2)$$

The approach discussed here is both static and deterministic. However, an appropriate vulnerability assessment needs to be both dynamic (i.e., reflecting time evolution of perturbation, sensitivity, and adaptation) and statistical (i.e., employing probability distributions to calculate expected values).

The climate change impact literature is not yet uniformly following the vulnerability assessment but clear signs are there to show its wider acceptance. The next section traces the evolution of vulnerability assessment from impact assessment.

2.3 Evolution from Impact Assessment to Vulnerability Assessment

The increasing interest in adaptation to climate change is reflected in the development of the theory and practice of climate change vulnerability assessments. This section traces the evolution of vulnerability assessment from impact assessment. At this stage it is important to note that the evolution of vulnerability assessments has been motivated by changing stakeholder needs, and it has been facilitated by increasing scientific knowledge in a range of relevant disciplines. Each assessment type provides valuable results, and the most appropriate one in a specific situation depends, among other things, on the research or policy questions addressed, on impact sectors considered, on the geographical scope of the analysis and on the availability of resources. Thus, the discussion here should not be interpreted to imply vulnerability assessment is superior to impact assessment.

The evolution of vulnerability assessments can be traced through the following stages:

Impact Assessment:

As mentioned in section 2.1 climate impacts are a function of exposure of a system to climatic stimuli and of its sensitivity to these stimuli. Figure 2.1 presents a schematic view of impact assessment.

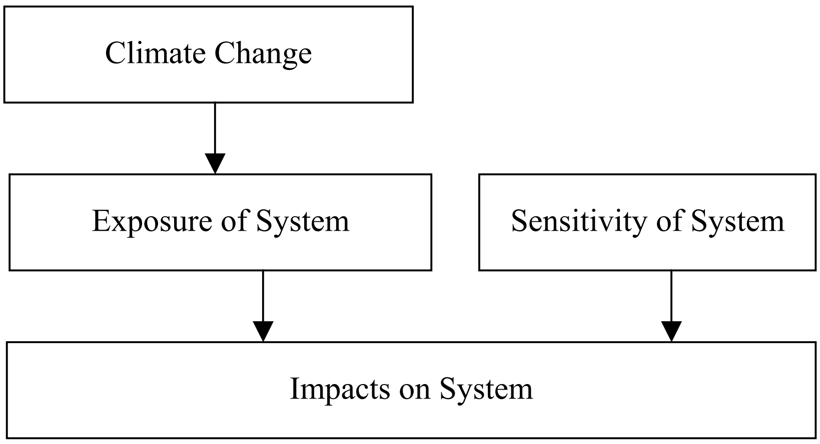

Figure 2.1: Impact Assessment

Impact assessments often focus on long-term changes in average climate conditions (such as annual mean temperature, precipitation and sea level rise) because these results are most readily available from climate models. The impact assessments do not explicitly address adaptation and thus represent a 'dumb farmer' assumption. Examples include Rosenzweig and Parry (1994), Leemans and Solomon (1993) and Kumar and Parikh (2001a).

Vulnerability Assessment:

A vulnerability assessment constitutes an extension of a climate impact assessment. Figure 2.2 presents a schematic view of vulnerability assessment. Besides climate change these assessments explicitly consider climate variability, which as defined as follows in IPCC parlance.

Climate variability – can be defined as variations in the mean state and other statistics (such as standard deviations, the occurrence of extremes etc.) of the climate on all temporal and spatial scales beyond that of individual weather events. Variability may be due to natural internal processes within the climate system (internal variability), or to variations in natural or anthropogenic external forcing (external variability).

Vulnerability assessment also takes into account non-climatic factors – which denote a wide range of properties that affect the vulnerability of a system or society to climate change. They include ecological, economic, social, demographic, technological and political factors. Some non-climatic factors are linked to the concentrations of radiatively active GHGs. Well-known examples include the direct

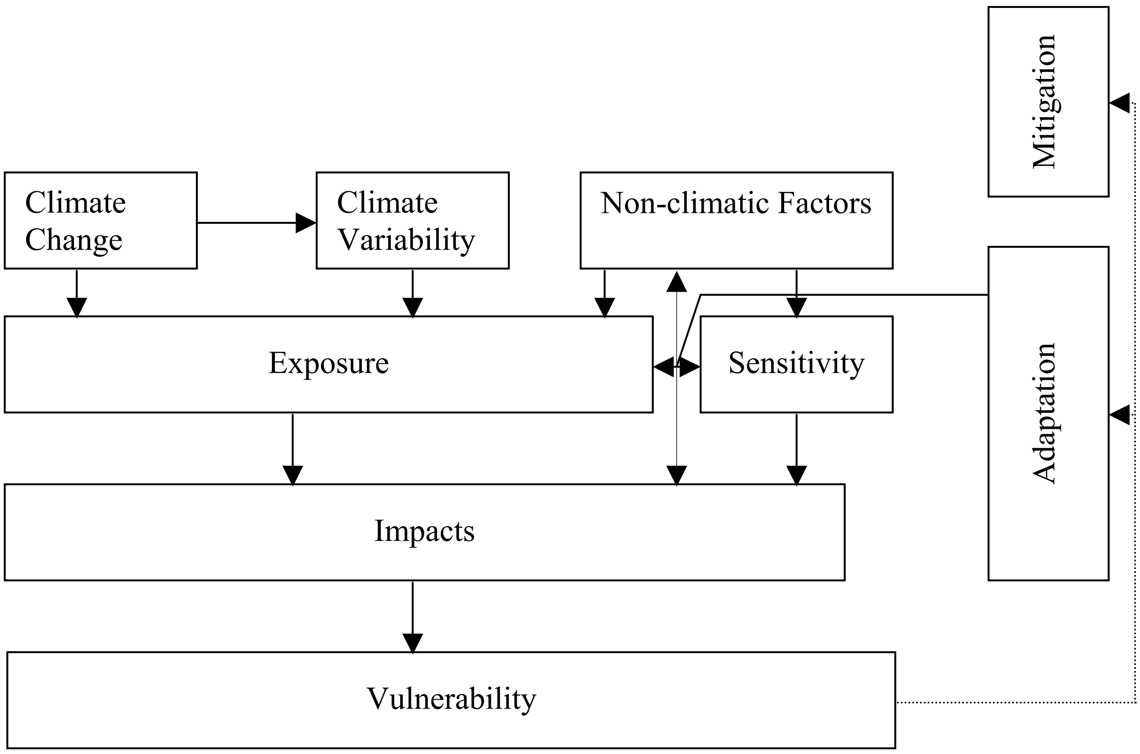

Figure 2.2: Vulenarability Assessment

effect of CO_2 on plant physiology and the combination of local air pollution and high temperatures in causing respiratory diseases in human beings.

Recognition of the vulnerability of valued systems to climate change is likely to trigger policy responses at different levels. This is indicated in figure 2.2 through dashed arrows. Two types of responses are possible – mitigation and adaptation. The various links from adaptation to other components of the assessment framework can be explained through examples referring to climate impacts on human health. Vaccination against climate sensitive vector-borne diseases and early-warning systems for heatwaves and floods are examples for adaptations that aim at reducing the sensitivity and exposure of people to climatic health hazards, respectively. The treatment of persons who already fell ill (denoted as 'reactive adaptation' by climate change community) can alleviate the impacts of climate change. An improvement in the nutritional conditions of children to enhance their immune system illustrates how adaptation can reduce stressful non-climatic factors that, in turn, affect their sensitivity or exposure to climate change.

Adaptation Policy Assessment:

Vulnerability assessments can be further distinguished on the basis of level of adaptation. The framework presented in figure 2.2 does not explicitly consider the feasibility of adaptation, and introduction of adaptive capacity – which takes into account the requirements for, and limitations to, implementing adaptation measures – further refines the assessment. Achieving this objective requires a closer look at the available response options, including considerations as to the feasibility of their implementation and to their integration with existing policies and practices on resource management, disaster reduction, economic development, public health etc.

In numerical impact models, assumptions about perception and adaptation are more commonly arbitrary or based on principles of efficiency and rationality and assume full information (Yohe *et al.*, 1996; Hurd *et al.*, 1997; Mendelsohn *et al.*, 1999). As Tol *et al.* (1998), Schneider *et al.* (2000), and others have noted, however, actual and assumed behavior do not necessarily match. In an analysis of global food production, Parry *et al.* (1999) assume farm-level and economic system adaptations but recognize that the "adoption of efficient adaptation techniques is far from certain." In addition to questions relating to rationality principles, adaptation behavior is known to vary according to the amount and type of information available, as well as the ability to act. Hence, rational behavior that is based on assumed perfect information differs from rational behavior under uncertainty (Yohe *et al.*, 1996; West and Dowlatabadi, 1999). Replacing the "no adaptation" model with one that assumes rational, unconstrained actors with full information replaces the "dumb farmer" assumption with the "clairvoyant farmer" assumption (Smit *et al.*, 1996). Reilly (1999) questions the ability and hence the likelihood of agents to detect and respond efficiently to the manifestations of climate change. Tol (1998) also questions whether perfect foresight and rational behavior are realistic assumptions for predictive models. Schneider (1997) explores further the assumptions that underlie equilibrium approaches (ergodic economics), including the equivalence of temporal and spatial variations.

Two types of adaptation can be considered in adaptation policy assessment framework. Facilitation refers to activities that enhance adaptive capacity, thereby improving the conditions for the implementation of adaptation measures. Such activities include awareness raising, capacity building and the establishment of institutions, information networks and legal frameworks for action. Implementation refers to activities that actually avoid adverse climate impacts on a system by reducing its exposure or sensitivity to climatic hazards, or by moderating non-climatic factors. The relationship between adaptive capacity and adaptation is thus two-fold – adaptive capacity determines the feasibility of implementing adaptation measures (of the implementation type) but it is also determined by adaptation measures (of the facilitation type)[6].

2.4 Climate Change and Disaster Management Communities

In the natural hazards and disaster management literature, vulnerability is seen as one aspect of risk. The conventional definitions are presented by the United Nations Department of Humanitarian Affairs (UNDHA, 1993):

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[6] It may be noted that similar concept can also be considered for mitigation policies. For example, establishment of a carbon trading scheme is a facilitation measure that enhances the mitigative capacity of a region. The

Hazard: A threatening event, or the probability of occurrence of a potentially damaging phenomenon without a given time period or area.

Vulnerability: Degree of loss resulting from a potentially damaging phenomenon.

Risk: Expected losses (of lives, persons injured, property damaged, and economic activity disrupted) due to a particular hazard for a given area and reference period.

Disaster: A serious disruption of the functioning of society, causing widespread human, material or environmental losses which exceed the ability of affected society to cope using only its own resources.

It may be noted that in this literature the inter-relationship between risk, hazard and vulnerability is perceived as: **Hazard + Vulnerability = Risk**.

Climate change and disaster management communities are both concerned with the reduction of risks associated with climatic hazards. Collaboration between these two communities is so far hampered by a number of conceptual and semantic differences.

Disaster management community focuses on the effects of discrete, localized hazard events that are regarded as a manifestation of natural variability. The only way to reduce the risks associated with natural hazards is by reducing the internal vulnerability of a system to these hazards, which is only relevant for social systems and built infrastructure. Options to reduce the vulnerability are analyzed in normative vulnerability assessments and the responsibility for implementing them lies primarily with the vulnerable community itself. Climate change community bases its work on the recognition that anthropogenic emissions of GHGs are affecting climate on a global scale. Assessing the need for mitigation and adaptation actions as well as the level of residual damages is the subject of positive vulnerability assessments in this field. In view of the uneven distribution of causes and impacts of climate change, the UNFCCC requires the main polluters to assist particularly vulnerable communities in

replacement of an old power plant by a less carbon intensive one (which may have become economically viable due to the possibility for trading carbon permits) constitutes an implementation measure.

reducing their vulnerability to climate change. Thus the climate change community adheres to polluter-pays-principle to some extent.

The focus on discrete hazard events allows the disaster management community to employ a static view, where risk is determined by the current characteristics of the vulnerable system and by the climatic hazard potential, the stochastic properties of which are assumed to be well known from the historical data. Hazards are by definition rare events. Thus, ensuring the continued functioning of society while in 'emergency mode' is therefore the main purpose of adapting to hazards. In contrast, climate change is a dynamic process that manifests itself as change in the mean and variability of a multitude of climate variables at different spatial and temporal scales, which can be simulated with varying degrees of certainty. The climate change community is interested in the whole set of these changes, some of which are expected to create climatic hazards that are new to a region. Because the mean climate state is also affected, adaptive responses need to go beyond improvements in the emergency mode of a society by adjusting its normal mode of operations as well.

Despite these differences between the disaster management community and climate change community in terms of their perception about vulnerability there are significant conceptual similarities as table 2.1 illustrates.

Table 2.1: Disaster Management and Climate Change Communities - Similarities

Disaster Management Community	**Climate Change Community**
Change in climate-related *risks*	*Vulnerability* to climate change
Change in *hazard potential*	Change in *exposure*
Current *vulnerability*	Sensitivity
Future *vulnerability*	*Sensitivity,* including *adaptive capacity*
Disaster *mitigation*	Planned *adaptation*
Expected *effects*	Expected *impacts*
Element at risk	Exposure unit

2.5 Objective of the Study

As mentioned in the introduction chapter the objective of the study is to assess impacts/vulnerability of climate sensitive sectors in India. Such analysis is expected to provide useful inputs to the development of adaptation strategies. This section provides rationale behind the choice of agriculture and coastal resources for analysis and places the methodology adopted for assessing impacts/vulnerability of these two sectors in the context of evolution of climate change vulnerability literature presented above.

In India, with its significant influence on the economy, agriculture still plays a vital role, providing employment for more than 60 percent of the total labor force in India, and accounting for about 27 percent of total gross domestic product (GDP) in the country. With only about 30 percent of cultivated land under irrigation, a significant amount of land is still cultivated under rainfed conditions. Due to the impacts of science, technology, and resource development, the production of food grains in India has increased from 130 million tonnes in 1980–81 to 209 million tonnes in 1999–2000, with an annual growth of about 4 million tonnes (GOI 2000). Per capita food production during the period 1981–99 grew at an annual rate of 0.8 percent. However, population growth demands increased production, though under difficult conditions of land and moisture availability, along with increasing biotic and abiotic stresses.

India has more than 6500 Km of coastline covering Gujarat, Konkan and Malabar coasts in the west, and Tamil Nadu, Andhra Pradesh, Orissa and West Bengal coasts in the east. The regions adjacent to the coastline are densely populated as they have agriculturally fertile areas. There are a total of 53 coastal districts and 6 union territories including islands of Andamans and Nicobar and Lakshadweep, with nearly 50% of the country's total population living in these areas. Change in sea level is likely to cause devastating effects on the coastal areas and also affect the activities related to the on-shore oil exploration. Envisaged change in sea level and increased moisture in the middle troposphere could increase the number of cyclones. The rush of an enormous volume of sea water accompanied by the fury of hurricane-force cyclone winds and torrential rainfall would bring about mass devastation in human and economic terms along with vast inundation of low lying areas. Though the combined economic cost associated with the change in sea level has not yet been analyzed, some studies have studied the various sub-components.

Impact assessment studies in India, including those corresponding to the above two sectors, used predictions on mean climate changes for a double CO_2 concentration scenario[7] or hypothetical climate change scenarios. Climate change impact studies worldwide are now focusing on analyzing impact due to changes in mean climate as well as climate variability, and manifestation of climate change. It is widely believed that the climate change manifestation could be through extreme climate events such as cyclones and droughts. Given their direct dependence on climate, among all the climate sensitive sectors agriculture and coastal resources are likely to get affected more due to climate variability and extreme events. Thus, the present study focuses on these two sectors and extends the previous analyses in these sectors by specifically incorporating the climate variability and extreme events in the impact/vulnerability assessment. Further, the study also attempts to identify various adaptation strategies specific to these two sectors.

[7] The results from climate models predict the average temperature in India to change between 2.3 to 4.8^oC following a doubling of CO_2 concentration from its pre-Industrial levels (Lonergan, 1998).

Chapter 3: Agriculture

Given its direct dependence on climate parameters, agriculture is likely to be one of the main sectors to be affected by climate change. In the climate change impact literature also agriculture has been one of the keenly studied sector in both developed and developing countries. Agriculture sector also provides scope for a wide range of adaptation options to be implemented both at farm level and at macro level. This chapter focuses on climate change impacts on Indian agriculture sector and potential adaptation options. In terms of the evolution of vulnerability assessment literature discussed in Chapter 2, the analysis presented in this chapter goes beyond impact assessment but does not include all factors to be qualified as vulnerability assessment. Firstly, the analysis here includes a broader definition of climate change and includes changes in means of climate parameters as well as their variability. The analysis considers autonomous adaptation by the farmers and assumes no hindrances in implementing the adaptation. In a sense the farmer in this analysis represent 'clairvoyant' farmer (as against 'dumb' farmer) who could foresee all the changes and accordingly adjust her practices.

The chapter is organized as follows: the first section describes the expected changes in climate parameters, and projections on climate variation and climate extremes as relevant for agriculture; the next section reviews the literature with specific focus on Indian agriculture; the following section presents estimates on potential impacts of climate change and climate variation on Indian agriculture; the next section highlights the limitations of the current estimates; and finally the last two sections discuss the role of technology and adaptation in ameliorating the climate change induced impacts on Indian agriculture.

In India, with its significant influence on the economy, agriculture still plays a vital role, providing employment for more than 60 per cent of the total labor force in India, and accounting for about 27 per cent of total gross domestic product in the country. With only about 30 per cent of cultivated land under irrigation, a significant amount of land is still cultivated under rainfed conditions. Due to impact of science, technology, and resource development, the production of food grains in India has increased from 130 million tones in 1980-81 to 209 million tones in 1999-2000, with an annual growth of about 4 million tons. Per capita food production during the period 1981-

1999 grew at an annual rate of 0.8 per cent. Figure 3.1 shows the food production in *Kharif* (summer) and *Rabi* (winter) seasons during the period 1960 to 1999. However, population growth demands increased production, though under difficult conditions of land and moisture availability, along with increasing biotic and abiotic stresses. Table 3.1 presents projections of demand for various agricultural products for the yeas 2010 and 2020. Looking at food grains the production should increase by almost 50 percent in the next 20 years to meet the projected demand. The baseline cereal supply projections for the year 2020 are about 256 million tons (Bhalla et al., 1999). Thus, even while not accounting for the climate change induced stress the existing stresses could imply significant supply demand gap by the year 2020.

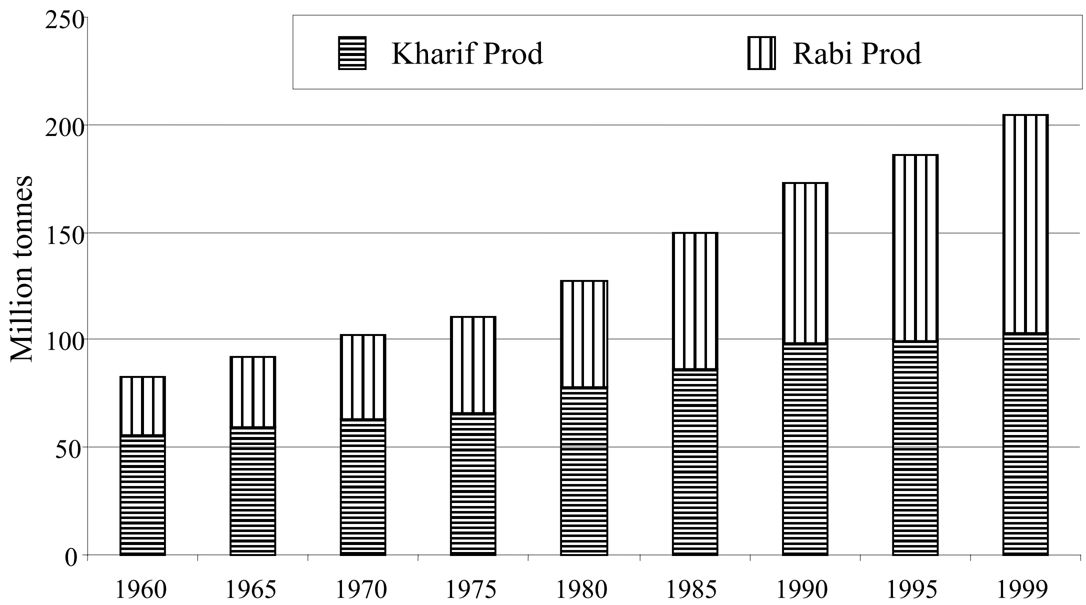


Figure 3.1: Season-wise Contribution to Production of Food Grains

Table 3.1: Indian Food Production and Demand – Future Projections

Items	Production (million tons)	Demand (million tons)	
	2000	**2010**	**2020**
Rice	85.4	103.6	122.1
Wheat	71.0	85.8	102.8
Coarse grains	29.9	34.9	40.9
Total cereals	184.7	224.3	265.8
Pulses	16.1	21.4	27.8
Food Grains	200.8	245.7	293.6
Fruits	41.1	56.3	77.0
Vegetables	84.5	112.7	149.7
Milk	75.3	103.7	142.7
Meat and eggs	3.7	5.4	7.8
Marine products	5.7	8.2	11.8

(Source: Aggrawal et al., 2002)

The climate change impacts on Indian agriculture should be assessed taking into account the possible interactions between the effects of climate change and ongoing economic changes associated with globalization. This link has not been thoroughly explored and it may have strong implications for the distributional issues related to the impacts. In India the main rationale with which the economic reforms were undertaken is to remove distortions and create appropriate incentive structure for increasing agricultural production (Gulati and Kelley, 1999). Macroeconomic policy, trade policy and fiscal policy reforms are considered to lead, in the long run, to higher agricultural incomes and employment. For consumers, increases in relative prices for food grains could worsen the living conditions for the poorest in both rural and urban areas, exacerbating the problems of food security for the most vulnerable sections of the population. For agricultural producers, the full effects of economic reforms are yet to be felt. Currently, India's main crops, including rice, wheat, sugar cane, and oilseeds remain subject to many trade barriers, procurement policies, and subsidies. Removal of these barriers, as part of reforms and globalization, may lead to dramatic changes in agricultural cropping patterns (Gulati and Kelley, 1999).

These changes in turn may have significant influence on vulnerability of Indian agriculture to climate change and climate variability.

3.1 Expected Changes in Climate

Results from equilibrium climate models predict the average temperature in India to rise by between 2.33 and 4.78°C, following a doubling during the twenty-first century of ambient concentration of carbon dioxide (CO_2) from pre-Industrial Revolution levels (Lonergan 1998). The climate models also predict higher monsoonal activity over the Indian sub-continent. Recent results from transient scenarios provide predictions about temperature and precipitation changes for different periods during 21st century. Table 3.2 shows the expected changes in temperature and precipitation for the decades 2020, 2050 and 2080 for the two main crop seasons, namely *kharif* and *rabi*.

Table 3.2: Climate Change Scenarios for Indian sub-Continent

Year	Season	Increase in Temperature, ^oC		Change in Rainfall, %	
		Lowest	Highest	Lowest	Highest
2020s	Rabi	1.08	1.54	-1.95	4.36
	Kharif	0.87	1.12	1.81	5.10
2050s	Rabi	2.54	3.18	-9.22	3.82
	Kharif	1.81	2.37	7.18	10.52
2080s	Rabi	4.14	6.31	-24.83	-4.50
	Kharif	2.91	4.62	10.10	15.18

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

Climate change could also lead to changes in climate variability and frequency and intensity of extreme events. No reliable regional predictions for expected changes in climate variability and climate extremes exist as of now for India. In the absence of reliable estimates hypothetical scenarios are often assumed, as it is done in this study. For the analysis in this study changes in mean climate and its variability are considered to represent climate change.

3.2 Review of Literature

Crop growth and yield crucially depend on the atmospheric temperature, precipitation, solar radiation and CO_2 concentration. The response of a crop to a rise in temperature from the threshold minimum temperature tends to be positive up to a characteristic optimum temperature for maximum growth. When temperature exceeds this optimum temperature, crops respond negatively, with a steep drop in net growth and yield. High temperatures may also hasten the maturation of plants and as a result the growth cycle may get shortened and the yield potential limited. At higher temperatures plants generally exhibit increased rates of respiration, which reduces the net accumulation of biomass and yield. Agriculture in all regions is strongly influenced by the water regime, which in turn is governed by the prevailing climate. A change in climate can result in changes in total seasonal precipitation, within-season pattern of precipitation, and between-season variability of precipitation. Changes in the rate and seasonal pattern of evaporation can also affect water regime. Higher CO_2 concentration leads to increase in the diffusion gradient between the outside of the leaf and the inside of the leaf. As a result, more CO_2 will diffuse into the leaf. Thus, the limitations imposed by the existing CO_2 concentrations on the rate of photosynthesis in green plants are overcome (Cure and Acock, 1986; Kimball et al., 1993). Accordingly most plants respond favourably to increases concentrations of CO_2. This is referred as carbon fertilisation effect.

Climate change impacts on agriculture have been assessed using a range of methods in the literature and these methods can be categorized under three broad approaches: agronomic-economic approach; agro-ecological zone approach; and spatial analogue approach. This section provides a brief review of the literature under these three categories and also discusses in detail the India specific impact studies.

Agronomic-economic Approach

This most widely used approach assess the impacts of various climate change scenarios and atmospheric CO_2 concentration levels on crop yields with the help of carefully calibrated crop simulation models. The estimated yield changes are then incorporated into either agricultural sectoral or general equilibrium models to assess the associated economic impacts. A number of studies have used this approach for assessing climate change impacts at global level (Rosenzweig and Parry, 1994), regional level (Matthews et al., 1994), and national level (Adams et al., 1999; Kumar and Parikh, 2001b). For careful calibration of the crop model, detailed data on soil and farm management practices is essential. The main strength of this approach is its ability to assess the changes in crop yields under climate change conditions using an agrnomically rigorous crop model. The use of such crop models would allow consideration of carbon fertilisation effects in satisfactorily.

The most successful introduction of adaptation into crop simulation models has come from agronomic-economic models. These farm-level studies begin with agronomic models but then examine efficient responses by farmers to climate change using an economic model of the farm. For example, Kaiser et al. (1993) alter crop mix, crop varieties, sowing times, harvesting dates, and water saving technologies (tillage) for farms in the United States and find that these adaptations reduce the damages from climate change. This careful inclusion of microeconomic farm responses is unfortunately expensive and so it has been done rarely. Almost all the examples come from the United States. Most agronomic models in developing countries do a poor job of including adaptation.

The agronomic models have also historically ignored adoption of new technologies. Almost all studies impose climate change scenarios on current agricultural systems. This is problematic because climate change will not impact agricultural systems for decades. By the time climate actually changes, the farming systems could dramatically evolve from their current form. It is important to capture the technical change in the farming system in order to predict what climate change will do when it occurs. Kumar and Parikh (2001b) deal with this dilemma by explicitly forecasting how agricultural sector would change in India by 2060. Although these forecasts were simply extrapolations of past technical progress, they at least attempted to measure future baseline conditions. Including adoption is especially important in developing countries that are rapidly moving to more advanced technologies. The farming system that will actually experience climate change is likely to be very different from the system in place today. In developing countries, it is important to model adoption; the transition from low input labor-intensive agriculture to high input modern farming. By examining a range of assumptions concerning the speed of this transition, one can determine how sensitive climate change results are to assumptions about baseline conditions.

Agro- ecological Zone Approach:

Using the agro-eclological zones methodology of the Food and Agriculture Organisation (FAO, 1996), this approach attempts to assess potential changes in distribution and production of various crops under different climate change scenarios. The basic feature of the approach is that the land is divided into what are referred as agro-ecological cells (AEC) defined by a unique combination of climatic and soil characteristics and they are compared against the requirements of various crops to assess suitability. With changes in climate the configuration and distribution of AEC changes, and accordingly the crop yield and distribution also changes. Studies, which applied this approach to assess climate change impacts include, Darwin *et al*., 1995; IIASA, 2002; Kumar, 1998. While most of the studies using this approach estimated the physical impacts only, a few studies incorporated the estimated physical impacts into economic modelling framework to assess the net economic impacts (see, Darwin et al., 1995). The main strength of this approach is its ability to analyse the changes in crop distribution under climate change conditions.

The AEZ model was developed to look at potential production capacity across various ecological zones, not what was actually occurring. Partly, this focus on predicted values reflected the lack of reliable and accurate yield data on a widespread basis. Maximum potential yields for a given production area are estimated using a yield biomass simulation model. This model uses information on radiation and temperatures associated with the specific latitude and longitude of the proposed growing site, together with the photosynthetic capacity of crops, and an index of economically harvestable yield to produce an estimate of maximum potential yield. Within the AEZ model, this maximum attainable yield is then adjusted to reflect varying levels of technology (low, medium and high) as well as the impact of agro-climatic factors such as length of growing period, water stress, presence of disease, pests etc. AEZ simulation results are highly sensitive to climate change impacts on precipitation and cloud cover and to a lesser extent on temperature changes.

Spatial Analogue Approach:

The spatial analogue approach examines farm performance across climate zones. The technique has been named the Ricardian method because it draws heavily from an observation by Ricardo that land values would reflect land productivity at a site (under competition). The approach has been used to value the contribution environmental measures make to farm income. By regressing land value on a set of environmental inputs, one can measure the marginal contribution of each input to farm income. The approach has been applied to the United States (Mendelsohn et al., 1994; 1996; 1999) and Brazil (Sanghi, 1998). A corollary of the approach has also been used in India where annual net revenue was substituted for land value (Kumar and Parikh, 2001a). In all these studies, the countries are large enough to contain a sample with a wide range of climates. The range of climates in all these countries is relatively large in comparison to the predicted change in temperature over the next century of 1.4 – 5.8^{o}C (IPCC, 2001a). By estimating the economic performance of farms across this range of climates, one can measure climate sensitivity in each country. Economic performance is measured using farmland value in the United States and Brazil and annual net income in India.

The most important advantage of the Ricardian approach is its ability to incorporate efficient private adaptation. Private adaptation involves changes that farmers have made to tailor their operations to their environment in order to increase profits. Because private adaptation enriches the farmer, there is every reason to expect that it will occur. One of the most important adaptations that farmers will make is crop choice. Depending on what climate a farmer finds himself in; there is a particular crop that will be optimal. As climate changes, the farmer should change crops.

One of the drawbacks of the cross-sectional method is that the experiment is not carefully controlled across farms. Farms may vary for many reasons in addition to just climate. In order to control for this problem, the Ricardian studies try to include other important variables such as soil quality, market access, and solar radiation. However, it is often not possible to get perfect measures of these variables so that all of these factors may not be taken into account. This is specifically a problem in many developing countries where data is often incomplete. For example, household labor and animal power are two important variables in many developing country farms that are difficult to control for.

Another valid criticism of the cross-sectional approach is that it rarely considers price effects. Because the existing studies rely on a cross-section within a country, there is little price variation across farms. The studies have consequently been unable to estimate the consequence of prices. Ricardian studies have generally assumed that prices are constant which leads to a bias in the welfare calculations (Cline, 1996). The cross-sectional approach only measures the loss to producers from the climate change. By ignoring the price change that would occur if supply changed, changes in consumer surplus are omitted. The Ricardian studies consequently underestimate damages (omit lost consumer surplus) and overestimate benefits (overstate value of increased supply).

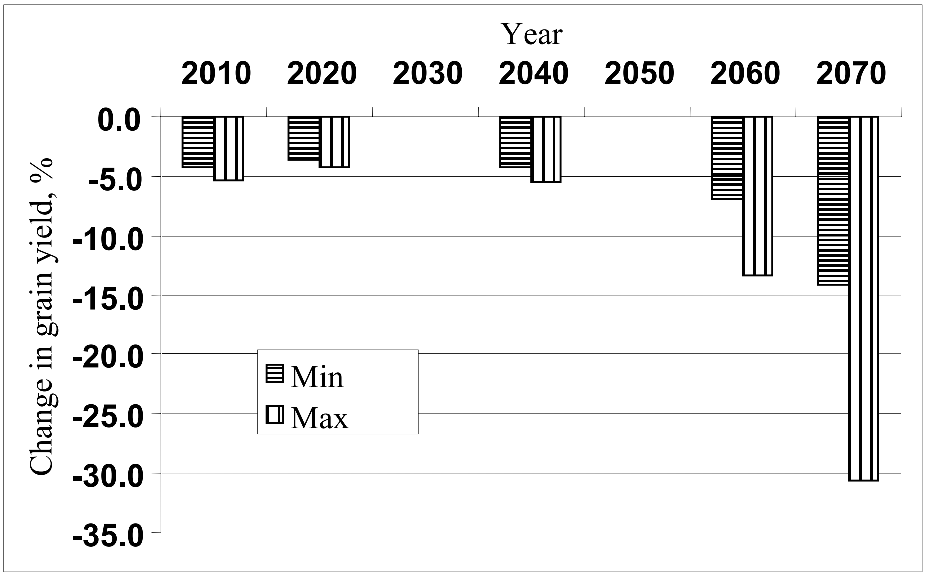
Another important limitation of the cross sectional approach is that the method cannot evaluate the fertilization effect of carbon dioxide concentrations since they are relatively uniform across the world. Even with a time series, it would be difficult to estimate the effect of carbon dioxide because it has been monotonically increasing for decades and would be easily confused with many other phenomenon that also have been increasing over time (such as technical change). Unfortunately, carbon fertilization effects must be added exogenously based on the results from agronomic experiments.

Studies of Climate Change Impacts on Indian Agriculture:

For India Seshu and Cady (1984) have studied the impact of temperature rise on rice production. They estimated a decrease in 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 as temperature rises from 22^{o}C to 23^{o}C. In another study, Sinha and Swaminathan (1991) have concluded that an increase of 2^{o}C in the mean air temperature could decrease the rice yield by about 0.75 ton/ha in the high yield areas and only by about 0.06 ton/ha in the low yield coastal regions. They have also estimated that a 0.5^{o}C increase in winter temperature would reduce wheat crop duration by seven days and reduce yield by 0.45 ton/ha. In other words, an increase of 0.5^{o}C in mean temperature in the high yield states of Punjab, Haryana and Uttar Pradesh would reduce the wheat production by 10%. Using a dynamic crop growth model, WTGROWS, Aggarawal and Sinha (1993) have showed that in north India, a 1°C rise in mean temperature would have no significant effect on wheat yields, while a 2°C increase would decrease yields in most places. Rao and Sinha (1994) have assessed the changes in wheat yield using CERES-Wheat crop simulation model under various equilibrium climate change scenarios. They have estimated that the wheat yields could decrease between 28 to 68% without considering the CO_2 fertilization effects; and would range between +4 to -34% after considering CO_2 fertilization effects. In a study of rice crop in northwest India, Lal et.al. (1996) showed that carbon fertilization effects would not be able to offset the negative impacts on yields due to higher temperatures under the changed climatic conditions. More recently Saseendran et al. (2000) studied the impact of climate change on rice production in the southern Indian state of Kerala and showed that for every one degree rise in temperature the decline in yield is about 6 per cent. All these studies have analysed the physical impacts only and no attempt has been made to assess the associated socio-economic impacts.

Figures 3.2, 3.3, and 3.4 show the estimated impact of climate change scenarios presented in section 3.1 on irrigated wheat yield in northern India, rainfed wheat yield in central India, and wheat production in India, respectively. These estimates are based on WTGROWS crop model (Aggarwal *et al.*, 2002).

Figure 3.2: Impact on Irrigated Wheat Yield in Northern India



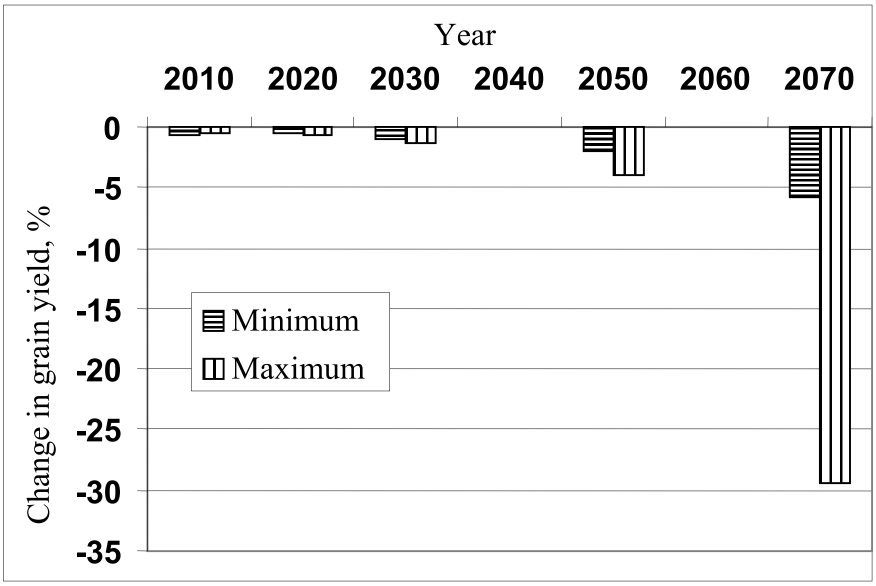


Figure 3.3: Impact on Rainfed Wheat Yield in Central India

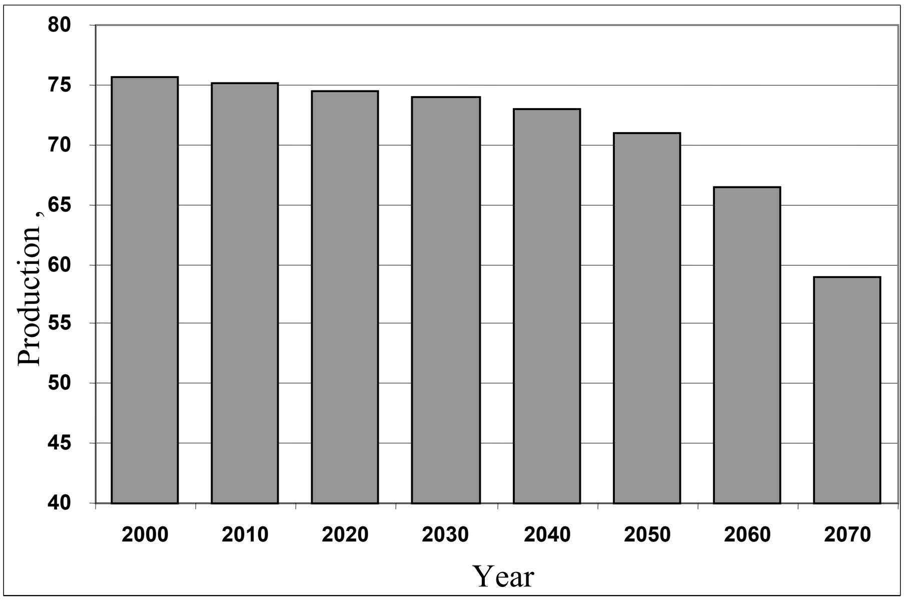


Figure 3.4: Potential Impact on Wheat Production in India

Moving beyond the physical impact estimation, recently Kumar (1999) and Kumar and Parikh (2001a, 2001b) estimated the socio-economic impacts due to climate change on Indian agriculture using both the modeling approaches outlined in the beginning of this section. In the crop-modeling approach (Kumar and Parikh, 2001b), the impact of change in climate parameters on crop yields is captured through EPIC crop simulation model. The physical impacts are then integrated with an applied general equilibrium model, AGRIM, to assess the associated welfare implications. The results showed that climate change associated with double CO_2 concentration could lead to significant adverse economic impacts and welfare losses. In the net-revenue approach (Kumar and Parikh, 2001a), district level cross-sectional data on farm inputs, outputs and various other characteristics are used to establish functional relation between net-revenue and climate parameters. Tables 3.3 and 3.4 present results from these studies, respectively. The results showed that even after incorporating the farm-level adaptations (i.e., impacts estimated using Ricardian approach), the climate change induced impacts on agriculture are significant for India.

Table 3.3: Results Based on Agronomic-Economic Approach

Variable	Climate Change Scenario		
	GFDL	**GISS**	**UKMO**
GDP (%)	-1.8	-2.5	-3.4
Cal per cap (%)	-18.2	-19.5	-21.6
Pop. prop. in bottom two expenditure classes - rural (base 0.183)	0.283	0.294	0.311
Pop. prop. in bottom three expenditure classes – urban (base 0.145)	0.208	0.214	0.226

Note: The figures represent change in variable value under climate change scenario when compared to a baseline projection. Negative sign indicates decline. The estimates correspond to final year of simulation, namely 2060.

Table 3.4: Results Based on Ricardian Approach

ΔT \ ΔP	0%	+7%	+14%
+1.0°C	-3.1	-1.3	+0.5
	(-2.3 to –3.9)	(-0.5 to –2.2)	(+1.5 to –0.4)
+2.0°C	-9.6	-7.8	-6.0
	(-8.5 to –10.7)	(-6.7 to –8.9)	(-4.7 to –7.2)
+3.5°C	-27.5	-25.7	-23.7
	(-25.5 to –28.8)	(-23.6 to –27.0)	(-21.6 to –25.2)

Note: The figures represent percentage change in net-revenue (1990 value) under various climate change scenarios. The figures in parenthesis show the 95% confidence interval of the estimated impacts.

3.3 Model Specification, Data and Results

For assessing the climate change induced impacts on Indian agriculture the present study adopts the spatial analogue approach discussed in the previous section. This approach is based on the hedonic pricing methodology of environmental valuation. In this approach the climate change impacts are measured as changes in net-revenue or land value (see, Dinar *et al*., 1998; Mendelsohn *et al*., 2001 for more details). The present study attempts to extend the net-revenue model developed in previous studies Kumar and Parikh (1998) and Kumar and Parikh (2001a) to examine the impact of climate variation on Indian agriculture. The study specifically explores the impact of including inter-annual and diurnal variation in climate variables on the farm-level net-revenue. As climate change is likely to be associated with change in the climate variation also, inclusion of climate variation terms in the model is expected to improve the model specification. Moreover such representation of climate change takes the analysis closer to vulnerability assessment discussed in previous chapter.

In previous analyses, it was demonstrated that both long-run averages of temperature and precipitation have quadratic relationships with farm level net-revenue (Kumar and Parikh, 1998; Dinar *et al.*, 1998). Also, Kumar and Parikh (2001a) showed that while inclusion of yearly temperature and precipitation along with their long-run average values improved the model specification, the climate coefficients remained significant in the modified specification. Thus the base model linking the farm-level net revenue to climate variables along with various control variables appears to be robust. Hence the present study adopts similar specification for the model but extends it to specifically study the influence of climate variation terms as shown below.

$$R \quad = \quad f(T_j, T_j^2, P_j, P_j^2, T_j P_j, DT_j, YT_j, YP_j, SOIL, BULLOCK, TRACTOR, POPDEN, LITPROP, HYV, LAT, ALT)$$

where, R is the farm level net-revenue per hectare;

T_j and P_j are the normal temperature and precipitation respectively, and j denotes the seasons; (along with linear terms, the quadratic and interaction terms of these variables are also included)

DT_j denotes the diurnal variation of normal temperature;

YT_j and YP_j denote the yearly variation of temperature and precipitation;

SOIL represents the soil characteristics such as soil types and top-soil depth classes;

CULTIV, BULLOCK, TRACTOR are the number of cultivators, bullocks and tractors respectively in per hectare terms;

POPDEN is the population density;

LITPROP is the proportion of literate people;

HYVFR is the proportion of area under high yielding varieties (HYV); and

LAT and ALT are the latitude and altitude of the cross-sectional unit.

The rationale for including the climate variation terms in the model specification is that the climate change may involve not only changes in the average climate variables, but also their corresponding variation variables. Hence while assessing the climate change induced impacts on agriculture it would be necessary to perturb both the average climate variables and their variation variables. Even if one were not to incorporate the possible changes in the climate variation variables for impact assessment, inclusion of climate variation variables is expected to improve the model specification. In above equation, variable *DT* represents the diurnal range in temperature, which is the difference between the maximum and minimum daily temperature; and *YT* and YP represent the standard deviation of temperature and precipitation over a period.

The net-revenue model specified above is estimated using pooled cross-sectional and time-series data for 271 districts covering most of India[8]. The farm-level net revenue is estimated using agricultural production data for as many as 20 major and minor crops. More details on the revenue calculations and the control variables used in the analysis can be found in Kumar and Parikh (1998, 2001a).

The climate data is based on a recent publication of India Meteorological Department (IMD) on climate normals for about 391 meteorological stations spread across India. The data on climate normals corresponds to the period 1951-1980. The data on yearly climate variation also matches with the above time period. As the climate data is available at the meteorological station and the analysis is attempted at district level, surface interpolation technique is used to transfer climate data from the meteorological station level to district level. The interpolation technique uses geographical parameters such as latitude, longitude, altitude, and distance from the nearest seashore as independent variables. The procedure also takes into account differences between high and low altitude regions. The climate and climate variation variables corresponding to months January, April, July and October are used in the analysis to represent the four seasons respectively[9].

Above model is estimated using weighted least squares procedure once by including the climate variation terms and once without including them in the model specification. The estimated coefficients are presented in Table 3.5. An F-test comparing the models with and without the climate variation terms showed that the climate variation variables together are significantly different from zero. The t-statistic showed that barring a few all the climate variation variables are significant in improving the model specification.

Presence of climate interaction terms makes it difficult to interpret the marginal effects of temperature and precipitation. To gain insight about the effect of climate variation terms in the model the climate change induced impacts are estimated for a

[8] It may be noted that the 271 districts used in the analysis correspond with the 1961 census definitions.

few representative scenarios. The climate change induced impacts are measured through changes in net revenue triggered by expected changes in the climate variables. The impacts are estimated at individual district level and are then aggregated to derive the national level impacts. Table 3.6 presents these results for scenarios with temperature increase ranging from 2.0 to 3.5°C and precipitation increase ranging from 7 to 14 per cent[10].

As discussed in the previous section, the net-revenue approach uses the cross-sectional evidence from farms facing wide range of climatic conditions for estimating the response function. Since the farms could differ not only in terms of their average climate but also in terms of the climate variation they experience, not incorporating the climate variation variables in the model could lead to bias in the estimated climate coefficients. Hence impacts estimated based on the model without the variation terms could be upwardly biased. The results presented in Table 3.6 capture this aspect. The impacts calculated using the model with climate variation are uniformly lower than those calculated using the model without climate variation. The last column in this table reports estimated impacts under a climate change scenario that incorporates higher climate variation along with changes in mean climate. The reported estimates are for a 5 percent increase in climate variation and the impacts are uniformly more. Thus the results show that changing climate involving increases in both mean and variation would lead to significantly more impacts on Indian agriculture.

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[9] District-wise estimates of climate and climate variation variables can be obtained from the author.

[10] It may be noted similar window of temperature and precipitation change has been used in earlier study discussed in previous section. For comparability of results similar window has been used in this study also. Moreover the window used still falls within the recent IPCC predictions on temperature and precipitation change.

Table 3.5: Climate Response Function With and Without Variation Terms

Variable	Without Variation Terms		With Variation Terms	
	Coefficient	T-ratio	Coefficient	T-ratio
January Temp.	79.151	5.550	96.295	6.720
April Temp.	-11.370	-0.990	-42.522	-3.470
July Temp.	-35.352	-2.680	-38.861	-2.740
October Temp.	-50.287	-3.650	-14.711	-0.980
January TempSq	-10.191	-7.160	-5.694	-3.450
April TempSq	-4.347	-1.440	-9.019	-2.700
July TempSq	1.009	0.430	-2.880	-1.200
October TempSq	-4.271	-1.460	4.730	1.470
January Rain	18.693	11.190	23.767	12.890
April Rain	2.417	1.480	13.153	6.340
July Rain	-1.119	-8.530	-1.062	-6.450
October Rain	0.549	0.920	-1.629	-1.730
January RainSq	-0.568	-7.580	-0.611	-7.770
April RainSq	-0.182	-6.140	-0.400	-10.660
July RainSq	0.001	9.860	0.001	7.000
October RainSq	-0.033	-8.290	-0.034	-6.050
January (Temp*Rain)	-2.763	-5.180	-2.009	-3.570
April (Temp*Rain)	-2.711	-6.730	-4.315	-9.170
July (Temp*Rain)	-0.077	-2.670	-0.149	-4.960
October (Temp*Rain)	0.947	6.470	0.648	4.140
January Daily Temp. Var.			93.208	7.870
April Daily Temp. Var.			-36.836	-3.850
July Daily Temp. Var.			55.649	3.220
October Daily Temp. Var.			12.879	1.030
January Temp. SD			-119.845	-3.860
April Temp. SD			-146.897	-9.340
July Temp. SD			-7.013	-0.370
October Temp. SD			37.365	1.890
January Rain SD			2.143	2.400
April Rain SD			-1.153	-3.410
July Rain SD			0.439	1.700
October Rain SD			2.543	3.600

Table 3.5: Climate Response Function With and Without Variation Terms (contd.)

Variable	Without Variation Terms		With Variation Terms	
	Coefficient	T-ratio	Coefficient	T-ratio
Soil 1	270.148	14.010	307.126	15.890
Soil 2	292.167	12.150	393.364	16.130
Soil 3	259.509	10.520	343.417	13.780
Soil 4	349.221	14.200	434.613	16.980
Soil 5	50.195	0.940	92.988	1.720
Soil 6	29.445	0.510	70.236	1.230
Latitude	24.943	2.300	15.619	1.400
Altitude	-0.464	-5.120	-0.755	-8.000
Pop. Density	87.436	12.920	94.415	13.730
Literacy	1553.779	16.950	1551.741	17.060
Cultivator	120.031	3.470	91.753	2.670
Bullock	365.286	8.970	367.093	9.080
Tractor	42534.890	14.640	40325.110	14.210
HYV Fraction	450.120	7.140	412.527	6.560
Dummy 1966	503.100	9.950	491.756	10.040
Dummy 1967	654.454	13.240	647.582	13.520
Dummy 1968	400.012	8.040	392.904	8.150
Dummy 1969	387.686	7.920	381.230	8.040
Dummy 1970	486.876	10.080	481.286	10.290
Dummy 1971	428.154	8.890	421.298	9.040
Dummy 1972	397.024	8.240	396.039	8.500
Dummy 1973	638.008	13.530	634.922	13.920
Dummy 1974	587.764	12.160	586.621	12.540
Dummy 1975	533.301	11.270	531.875	11.630
Dummy 1976	373.494	7.810	370.199	8.000
Dummy 1977	416.408	8.860	412.549	9.080
Dummy 1978	331.061	7.090	329.825	7.310
Dummy 1980	262.191	5.630	265.726	5.900
Dummy 1981	134.091	2.920	137.053	3.090
Dummy 1982	68.150	1.460	72.230	1.610
Dummy 1983	189.715	4.160	192.858	4.380
Dummy 1984	-19.041	-0.400	-16.088	-0.350
Dummy 1985	-93.039	-1.930	-89.952	-1.930
Dummy 1986	-243.549	-5.030	-238.074	-5.080
Constant	-643.401	-2.380	-383.345	-1.380
Observations	5691		5691	
Adj. R sq.	0.466		0.501	

Table 3.6: Net-revenue Estimates with Climate Variation

ΔT/ΔP	Impacts as percentage of Net Revenue		
	Without Variation Terms	With Variation Terms	With Variation Terms and 5% Higher Variation
2°C/7%	-7.8	- 6.8	-9.5
3.5°C/14%	-24.0	- 17.8	-28.1

Note: The figures represent percentage change in net-revenue (1990 value) under various climate change scenarios.

3.4 Limitations of Current Estimates

The available estimates (including those presented in this report) have a number of limitations and considerable scope of further research exists. The limitations include:

- The impacts estimated using agronomic-economic approach are likely to be upwardly biased (compared to the Ricardian estimates) as they do not account for adaptation.
- On the other hand the Ricardian estimates by not capturing the carbon fertilization effects tend to over estimate the impacts.
- The use of cross-section variation to predict time series behavior requires many assumptions to be satisfied: (a) that variations over time and space are equivalent, (b) only one steady state occurs per set of exogenous conditions, and (c) that a few climatic variables (say, average temperature and precipitation and perhaps a simple measure of variability – as it is done in this study) capture all the relevant information about climate change and its impacts on agriculture.
- A number of agronomic links – such as impact of climate change on behavior of pests and diseases - are still not very clearly understood and hence their economic implications are also not incorporated in the current estimates.
- Present estimates do not account for impacts due to extreme weather events, whose frequency and intensity is likely to get altered with climate change. For Indian agriculture these extreme events are of considerable importance as states

such as Orissa and Andhra Pradesh almost every year are affected by droughts and cyclones.

Vulnerability

For assessing vulnerability of Indian agriculture to climate change, as discussed in previous chapter, the impacts should be assessed taking into account all possible stresses that act on the agricultural sector and its adaptive capacity. The next section discusses the issues related to adaptive capacity. In this context it may be noted that understanding present day vulnerability would be a useful starting point for vulnerability assessment. A recent study by MSSRF (2001) used a number of indices to compare different states of India in terms of their agricultural vulnerability (Table 3.7).

Table 3.7: Vulnerability Status of Indian States

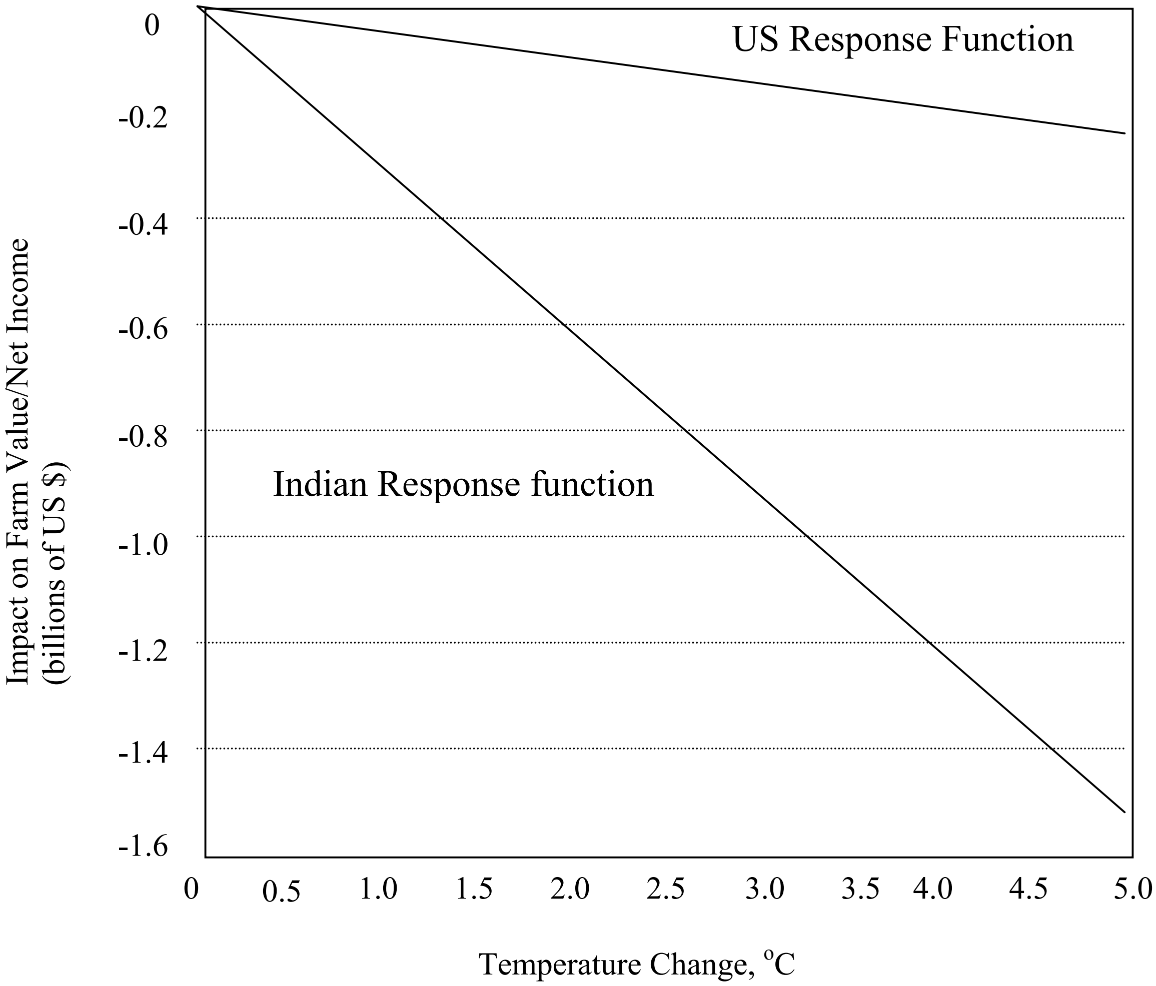
Indices/status	**Extremely poor**	**Severely poor**	**Moderately poor**
Food Security Index	Jharkahnd, Bihar, Madhya Pradesh	Rajasthan, Uttar Pradesh, Chattisgarh, Orissa	West Bengal, Assam, Andhra Pradesh, Uttaranchal, Gujarat, Haryana
Instability in Cereal Production	Gujarat	Rajasthan, Tamil Nadu, Maharasthra, Orissa	Himachal Pradesh, Bihar, Andhra Pradesh, Haryana, Karnataka, Madhya Pradesh
Environmental Sustainability Index	Haryana, Punjab, Rajasthan	West Bengal, Uttar Pradesh, Gujarat	Himachal Pradesh, Tamil Nadu, Maharasthra, Karnataka, Bihar, Assam, Kerala, Andhra Pradesh, Orissa
Disaster Index	Gujarat, Uttar Pradesh	Bihar, Orissa, Maharasthra, Rajasthan	Karnataka, West Bengal
Rural Infrastructure Index	Bihar, West Bengal, Uttar Pradesh	Assam, Orissa, Madhya Pradesh, Rajasthan	Andhra Pradesh, Kerala, Punjab, Karnataka

(Source: MSSRF, 2001)

3.5 Technology Change

Technology is an important issue that must be addressed in climate change studies. For example, India had in the past large and successful drives to enhance farming technology. These drives tended to be concentrated on the more temperate farmlands – around the Ganges River delta. There consequently was a possibility that technology was facilitating improvement in temperate versus tropical climate zones and would affect climate sensitivity. This hypothesis was examined for India (McKinsey and Evenson, 1998). McKinsey and Evenson (1998) built a technology-climate model to measure how the green revolution affected crops in India. They find that the green revolution in India increased farm net revenue substantially but that technology had a neutral impact on climate sensitivity. McKinsey and Evenson argue that the green revolution in India did not try to move crops to new climate zones, it merely attempted to increase productivity on a site. Because technological development has not specifically been designed to enhance heat tolerance, the historic interaction between technology and climate appears to be minimal.

Even if new technology has not historically tried to move crops into new climate zones, technology could affect climate sensitivity by changing the production function. The relationship between development and climate sensitivity depends upon whether new technology encourages capital to be a complement or a substitute for climate. By examining Ricardian functions over time as the level of technology increases and by examining Ricardian functions across countries with different levels of technology, one can determine which hypothesis is empirically correct. Comparison of Ricardian functions of Indian and American agriculture revealed that the Ricardian function for Indian agriculture is far more climate sensitive than the American Ricardian function (figure 3.5).



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

Figure 3.5: Climate Sensitivity and Development

3.6 Adaptation Options

Even though the estimates based on Ricardian approach suggest that impacts can be significantly reduced through adaptation, it is not still clear how it could happen. Can agriculture adjust rapidly and autonomously, slowly and only with careful guidance, or is there little scope for adjustment? Does response of the system require planning by farmers specifically taking into account climate change, and if so what is their capability to detect change and respond? Do the individuals and institutions that must adapt currently have the knowledge or technology to respond or must it be invented, developed, and learned?

Table 3.8 describes the adaptation measures (discussed in chapter 1) in the context of agriculture and identifies appropriate actors and institutional/infrastructural requirements.

Table 3.8: Adaptation Measures for Crop Cultivation

Measures	Actors	Requirements	Comments
Bear loss (no adaptation) - Loss of production - Loss of assets	Individual farmers and farming community		Hypothetical, not likely to take place
Share losses - Crop insurance - Cooperative management - Governmental subsidies	- Individual farmers and insurance companies - Farming communities - Farming communities and state	Additional investment in terms of premium. Agreement for sharing the output. State allocation for offering subsidies. Adequate legal and institutional framework.	Provisions to be made. Political motivation is required.
Modify the threats - Preparedness (early warning) - Awareness and training - Investment for structural measures	- Research community and farmers - Local government, NGOs and farmers - Central and local governments	- Research and extension - Extension and media campaign - Investments (anticipatory) - Crop calendar adjustment - Opting for less susceptible crops	Farmers are already practicing it, based on ancestral behaviour/knowledge. Manifold opportunities are plausible, barrier removal and implementation could be less costly. High priority option.

Table 3.8: Adaptation Measures for Crop Cultivation (contd.)

Measures	Actors	Requirements	Comments
Prevent adverse effects - Structural measures	- Government institutions - Farming cooperatives	- Large investment - Political motivation - Long-term planning	Investment intensive option. Financial constraints might hinder implementation process.
Change land use - Alternative cropping - Abandon crop agriculture	- Researchers, extension workers, farmers - Individual farmers	- Innovation through research, investment - Means of survival, skills for alternative employment	Unless alternative employment opportunities are created, it is not likely to be accepted socially.
Change location - Relocate to less vulnerable places	- Individual farmers and farming communities	- Free cultivable land	Heavily constrained due to non-availability of fallow cropland.

Among various adaptation measures listed above crop insurance can be seen as an incentive compatible adaptation measure and is discussed in more detail here.

Crop Insurance as Adaptation Measure

If the consumer were risk averse, she would be willing to insure against the total value of a loss even if the loss is equal to her entire wealth, because she would expect on average that her expected net benefit from the insurance would be zero. Under these conditions it is argued that the insurance company will perhaps only want to insure part of the loss to give the consumer the incentive to be careful. This theory implies that a subsidized insurance program will have high rates of participation, especially where subsidies reduce premiums so that the cost of a policy is less than the expected value of the policy. Thus, if there were two schemes – one fully subsidized catastrophic insurance and another buy-up revenue insurance – it is expected that participation in the first one would be universal, and later one may not have sufficient participation to afford the spread of risk that will drive premiums down to commercial levels. Experience from the US supports this theoretical observation (Chite, 2000).

Subsidies for risk management have similar effects as subsidies on any other farm input; it encourages over use. And since the reduction in production costs is partly paid for by the subsidy, the dead weight loss of the subsidy is always greater than the combined benefits to producers and consumers. In practice, this implies that risk management subsidies reduce risk costs to farmers to below their true social value, leading to excessive risk taking (e.g. growing unsuitable crops in high risk regions) and increased exposure to future drought losses by the farmer. However, it must be kept in mind that publicly owned crop insurance programs are probably impossible to design as sustainable financial entities without some level of government support if they are to continue to reach intended target groups.

In India comprehensive crop insurance scheme has been introduced in 1985 and at present the scheme covers ten *kharif* crops and seven *rabi* crops. The scheme provides insurance to cover yield losses due to non-preventable risks such as storms, cyclones, floods, droughts, and pests and diseases. The State and Central Governments grant a subsidy on the insurance premium to small and marginal farmers on a 75:25 sharing basis. The Central and State Government, General Insurance Corporation of India and the participating banks jointly implement the comprehensive crop insurance scheme. All farmers including sharecroppers, tenant farmers growing the notified crops in the notified areas are eligible for coverage. The Scheme covers on a compulsory basis all farmers growing notified crops and availing seasonal agricultural operations loans from financial institutions, and on a voluntary basis all other farmers growing notified crops.

One measure of financial viability of crop insurance schemes is the ratio of indemnities to premiums. For India this ratio remained high at 5.11 during 1984-89 (Skees et al., 1999) and 6.1 during 1985-94 (Mishra, 1996) suggesting that the scheme never achieved financial viability. The multiple-risk crop insurance schemes world over have proved disappointing as they fulfilled few of the expected objectives. One of the most important reasons for this failure is that many of the risks covered by multiple risk insurance are inherently uninsurable, leading to large actuarial losses for the insurer.

For twenty plus years the micro-finance industry has been seeking to fill a market failure across the developing world in the form of loans for the rural poor. And as this industry has grown, it has developed a diversified range of financial products, including now, insurance. Some of the impetus behind this new age of institutional innovation has been derived from the World Development Report (2001), which puts major emphasis on risk and vulnerability as a determinant of well-being, and thence on strategies such as insurance that may reduce vulnerability.

In this context the role of emerging micro-insurance schemes such as BASIX, Hyderabad could be worth analyzing. These new-generation schemes by attempting to achieve financial viability at the design stage itself could not only cover the future risks such as those expected under the climate change conditions, but also avoid moral hazard and adverse selection problems that commonly plague insurance schemes. The BASIX, Hyderabad is a NGO operated scheme with peer monitoring of claims to defend against moral hazard and peer pressure helping to weed out the bad risks (i.e., defense against adverse selection). The scheme is part of village self-management has similarities with other schemes like those being attempted in Ethiopia and Uganda (Mosely, 2000). These new-generation schemes are still in their infancy, but provide useful lessons:

- Defense against moral hazard/adverse selection problem should be built-in
- Where risks are large and covariant premiums may have to be high
- Focus should be on *insurable* risks
- Reinsurance should be budgeted to safeguard against liquidity.

Cost of Adaptation

One measure of the potential and cost of adaptation is to consider the historical record of past speeds of adoption of new technologies. For example, Reilly and Schimmelpfenng (1999) show the relative speed of adoption of various measures:

Table 3.9: Adaptation Measures and Adjustment Time

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

Jodha (1989) while constructing a similar table from observations of adoption and technological response in post-independent India, further included items such as the productive life of farm assets, crop rotation cycles, and recovery from major disasters with an estimated response time of anywhere from 5-15 years. These adjustment times indicate that for effective implementation of adaptation strategies appropriate planning must start well before the manifestation of climate change.

Finally, broad categories of responses - ***some of which could be beneficial regardless of how or whether climate changes*** - include:

- Improved training and general education of populations dependent on agriculture.
- Identification of the present vulnerabilities of agricultural systems.
- Agricultural research to develop new crop varieties.
- Food programs and other social security programs to provide insurance against supply changes.
- Transportation, distribution, and market integration to provide the infrastructure to supply food during crop shortfalls.
- Removal of subsidies, which can, by limiting changes in prices, mask the climate change signal in the marketplace.

Chapter 4: Coastal Resources

The threat of rise in sea levels as a result of changing climate makes the coastal resources, coastal infrastructure and population living the coastal areas highly vulnerable. At the same time, as the rise in sea level is likely to be a gradual process numerous adaptation options also exist. Moreover, climate change could manifest through extreme events such as cyclones and hence a proper understanding of the current coastal zone management practices could provide useful insights about the potential adaptation strategies. This chapter focuses on impact on coastal resources in India in the context of climate change and sea level rise and attempts to assess their vulnerability and adaptation strategies.

The chapter is organized as follows: The first section provides motivation by looking at the potential impacts due to sea level rise and extreme events along Indian coast. The following section discusses the available evidence on sea level rise along Indian coast and also future projections. This section also presents historic evidence on occurrence of cyclones along the coast. The third section reviews the literature on impact due to sea level rise and presents India specific impact estimates. The next section discusses relevance and literature on vulnerability index and presents results on vulnerability index estimation for Indian coastal districts. The fifth section develops relationship between damages induced by cyclones and their physical characteristics using historic data on storms. Finally the sixth section discusses adaptation strategies relevant for coastal resources and looks at possible insights that could be derived from literature on disaster management and integrated coastal zone management.

4.1 Profile of Indian Coasts

The territory of India includes the Indian Peninsula, which faces both the Bay of Bengal to the east and Arabian Sea to the west, Andaman and Nicobar Islands located between the Bay of Bengal and the Andaman Sea, and the Lakshadweep Islands located in the Arabian Sea. The total length of coastline is about 7000 km, and is classified into 11 coastal regions. Table 4.1 shows profile of Indian coastal states.

The Coastal zones in India are frequently affected by cyclones. In particular, the east coast is vulnerable to flooding induced by the heavy rains of cyclones. In addition, the Bay of Bengal is vulnerable to storm surges caused by cyclones.

Table 4.1: Profile of Indian Coastal States

State	Length of coastline (km)	Area of coastal districts (sq km)	Coastal population (1991) (millions)	Coastal population density (per sq km)	Wetland area* (sq km)	Flood prone area* (sq km)
Gujarat	1600	119379	22.87	192	28500	161
Maharashtra	720	30728	19.40	631	932	NA
Goa	105	3702	1.17	316		NA
Karnataka	300	18732	3.92	209	173	NA
Kerala	560	24591	23.78	966	2203	7
Tamil Nadu	950	35454	19.62	553	9481	2772
Andhra Pradesh	1014	92906	28.70	309	8665	1442
Orissa	720	40166	15.10	376	5134	503
West Bengal	950	28135	21.30	757	5778	NA

* Space Application Centre (ISRO), Coastal Environment, Ahmedabad, May 1992.

The six most important biogeophysical (or natural system) effects of sea level rise are identified as:

- Increasing flood frequency probabilities
- Erosion
- Inundation
- Rising water tables
- Saltwater intrusion
- Biological effects

These biogeophysical effects in turn could affect a number of economic sectors as shown below

Sector	**Biogeophysical Effect**					
	Flood Frequency	*Erosion*	Inundation	*Rising Water Tables*	*Saltwater Intrusion*	*Biological Effects*
Water Resources			*	*	*	*
Agriculture	*		*	*	*	
Human Health	*		*			*
Fisheries	*	*	*		*	*
Tourism	*	*	*			*
Human Settlements	*	*	*	*		

4.2 Evidence and Projections of SLR and Extreme Events

The studies by Emery and Aubrey (1989) and Mahadevan *et al*. (1992) have established weak evidence for rise in the sea level along the Indian coast over years (see Table 4.2). Analysis of historical tide gauge data along peninsular India showed an average rise of sea level by 0.67 mm/yr as against the global average of 1.8 mm/yr (JNU, 1993).

Table 4.2: Evidence for Sea Level Rise along Indian Coast

Station	Land Level Trend mm/yr	Relative Sea Level		Net trend in sea level, mm/yr
		Period	Trend mm/yr	
Mahadevan *et al.* (1992)				
Sagar	4.2	1937-86	-1.4	2.8
Visakhapatnam	-0.7	1937-86	1.0	0.3
Ganden Reach	-6.9	1932-86	7.2	0.3
Emery and Aubrey (1989)				
		Period	Slope	
Madras		1916-77	-0.36	
Visakhapatnam		1937-78	-0.76	

Note: Positive trend in Mahadevan et al. (1992) study and negative slope coefficient in Emery and Aubrey (1989) study indicate a rise in sea level.

More recently, Shankar (1998) studied the low frequency variability of sea level along Indian coast and concluded that:

- The annual mean sea level is higher along the east coast of India than along the west, the difference between Vishakhapatnam and Mumbai being about 30 cm. Simulations show that purely wind-forced circulation accounts for half this difference, the other half being due to the gradient in salinity along the coast.

- Annual mean sea level along the coast is significantly correlated with the annual extrema and seasonal averages. Cross-correlations of annual mean sea level at the stations along the coast are statistically significant, showing that these changes are coherent and are part of a basin-scale response. The annual mean and extrema of sea level are also correlated with annual all-India rainfall, as is the local rainfall at Mumbai with the annual sea level there. These correlations retain their significance when the rainfall and sea-level data are decimated with a 10-year running mean. The interdecadal changes in monsoon rainfall are reflected in sea-level changes at Mumbai, which has the only century-long tide-gauge record in the Indian Ocean; both increase from a low in the first quarter of this century to a high in the 1950s and decrease thereafter.

- The interdecadal changes in sea level along the coast of India can be linked to the variability of the monsoon, the major aspect of the climate of the region. This hypothesis is different from those generally proposed to link sea level to climate change. Based on this hypothesis sea level rises (falls) along the coast of India when rainfall over India increases (decreases), changes in the ocean thereby reflecting those in the atmosphere.

Table 4.3 shows the occurrence of cyclonic storms in the Bay of Bengal during the period 1877 to 1995. India is hit by 3.34% of the world's total tropical cyclonic storms (based on data from 1877 to 1995). In terms of cyclone related deaths crossing 5000, 11 out of the 35 cyclonic storms during the above period occurred in India, while 16 of such storms occurred in Bangladesh. India and Bangladesh together are hit by 4.27% of the world storms but suffer most with 76% of total deaths occurring in the two countries.

Table 4.3: Cyclonic Storms in Bay of Bengal (1877-95)

	India	Bangladesh	Dead	Total
All types	848	154	115	1223
Depressions	539	68	69	715
Cyclonic storms (CS)	197	43	35	310
Severe cyclonic storms (SCS)	112	43	11	198
CS+SCS	309	86	46	508
% of global total (CS+SCS)	3.34	0.93	0.5	5.5

Climate Change and Tropical Cyclones

One necessary but not sufficient condition for tropical cyclone formation is that the sear surface should have a minimum temperature of about 26 to 27^{o}C. This leads to the speculation that any rise in sea surface temperature (SST) due to climate change is likely to be accompanied by an increase in cyclone frequency. However evidence from the Bay of Bengal region suggests that even though there has been an increase in the SST since 1950 no corresponding increase in the frequency of cyclones could be established. Besides evidence from historic records, predictive climate models can also be used to analyze extreme climate events. In a recent study Palmer and Raisanen (2002) analyzed the output of 19 climate models and estimated that the Asian monsoon region will experience a five times increase in wet summers, escalating the risk of flooding in already flood-prone areas.

On the other hand there are reasons to expect the surge height to increase both due to climate change (and hence increase in SST) and sea level rise. With climate change and an increase in SST, de to increase in convective instability wind speed over sea could increase. As stress exerted by wind on sea water is proportional to square of wind velocity, increase in SST could lead to increase in surge height. The sea level rise may reduce surge height in the present sea water, but it can increase the surge height in the newly converted (from land to sea) sea area. Using numerical storm surge model, Ali (1999) showed that the surge height of a cyclonic storm that had hit the Bangladesh coast in April 1991 could increase by as much as 40 per cent if SST were to increase by 4^{o}C and the sea level were to rise by 1m.

4.3 Literature Review and Impact due to SLR for India

As the impacts due to sea level rise (SLR) associated with climate change are easy to visualize there has been a wide spread attention all over the world on the coastal resources. The impact assessment studies in the literature can be broadly categorized under the following four generations of models (West and Dowlatabadi, 1999). It may be noted in this classification, the SLR is hypothesized to result in land loss due to erosion and/or inundation, and damage to structural property.

First generation models: The economic impacts from inundation in these early models were assessed using a 'colouring book' approach – i.e., a scenario of future SLR was overlaid on topographical maps of coastal regions, and the economic impact was taken as the present market value of the inundated land and property. The impact assessment study by Yohe (1990) falls under this category.

Second generation models: The basic difference in these models is the recognition of the fact that SLR would be a gradual process and hence human adaptation could be possible. One way the adaptation could be visualized is in the form of structural protection, akin to similar such measures undertaken by countries like the Netherlands under present climatic conditions. The structural protection visualized in the literature was either in the form of hard protection through the construction of sea walls or bulkheads, and soft protection through beach replenishment and dune-building. The economic impact of SLR with protection is estimated simply as the cost of protection. The impact estimates from the second generation models thus turned out to be lower than those estimated from the first generation models. The lower rise in sea-level considered in these studies also contributed towards reduced impacts. The study by Titus *et al.* (1991) falls under this category.

Third generation models: In estimating the economic damages from the loss of land to erosion, Yohe (1990) argued that when an ocean-front lot is inundated or lost to erosion, the next lot inland becomes an ocean-front lot, and its value increases. The values of other inland lots also increase to reflect their increased proximity to the sea. The economic loss to the community is therefore not the value of an ocean-front lot, but is instead that of a comparable inland lot. Using this principle, Yohe *et al*. (1996) propose that since erosion is a gradual process, the market will reduce the value of developed property that is at risk of inundation. With foresight, the market can anticipate when the structural damage will occur, and can appropriately depreciate the value of the structure by the time that inundation occurs. Thus, zero is proposed as a lower bound for the social loss from structural damage when the market has perfect foresight.

Fourth generation models: The impact of sea level rise is expected to manifest through the extreme events such as cyclones. Thus, the recent studies by West and Dowlatabadi (1999) and West *et al*. (2000) while incorporating the features of the third generation models also account for the influence of cyclones on coastal resources.

Most of the studies related to SLR impacts are carried out for developed countries. Table 4.4 below shows the estimated economic impacts of SLR for a U.S. coast using the above four generations of models. Over the years the SLR projections showed declining trends and hence the estimates from different generation models are not strictly comparable. However, the third row shows the impact estimates for a uniform SLR. It may also be noted that while incorporating the storm damages in the SLR impacts, the fourth generation models do not explicitly model for the possible change in the frequency of extreme events under climate change scenario.

Table 4.4: Economic Damages of Sea-Level Rise in 2100 for the US

	Model Category			
	First	**Second**	**Third**	**Fourth**
Sea-level rise (cm)	200	50-100	50-100	40
Impacts in Duck, NC (variable SLR)	7.5	1.7	2.3	3.2
Impacts in Duck, NC (SLR = 40 cm)	2.0	0.9	1.2	3.2

Note: 1. The impacts are expressed in millions of 1990 US dollars.

2. The third generation damages exceed those of the second generation because different methods of projection erosion yield higher estimates of eroded land.

3. The fourth generation models include losses due to storm damages and hence estimates of damages from these models exceed those from the third generation models.

India Specific Studies

The study by Asthana (JNU, 1993) is by far the most comprehensive effort undertaken to assess the potential land loss due to sea level rise and the associated people at the risk. Using the methodology of the first generation models outlined above this study projected land loss due to one meter SLR in eight coastal states of India. In terms of physical impacts the study estimated that a total area of 5763 sq.km. (i.e., 0.4 per cent of total area of coastal states) would be affected, and that about 7.1 million people (i..e., 4.6 per cent of total costal population) would be at risk (see Table 4.5). ADB (1994) expressed these physical impacts in value terms by making some broad assumptions about the land value and population displacement costs. The overall economic damages are estimated to be as high as 43 per cent of India's 1988 GDP, while the annualised costs spread over a period of 40 years are estimated as 0.18 per cent of GDP.

Table 4.5: Impact of 1–m Sea-level Rise on Coastal Area and Population in India

State/Union territory	Coastal area (million hectares)			Population (millions)		
	Total	Inundated	%	Total	Affected	%
Andhra Pradesh	27.50	0.06	0.19	66.36	0.617	0.93
Goa	0.37	0.02	4.34	1.17	0.085	7.25
Gujarat	19.60	0.18	0.92	41.17	0.441	1.07
Karnataka	19.18	0.03	0.15	44.81	0.25	0.56
Kerala	3.88	0.01	0.30	29.08	0.454	1.56
Maharashtra	30.77	0.04	0.13	78.75	1.376	1.75
Orissa	15.57	0.05	0.31	31.51	0.555	1.76
Tamil Nadu	13.01	0.07	0.52	55.64	1.621	2.91
West Bengal	8.87	0.12	1.38	67.98	1.6	2.35
Andaman and Nicobar Islands	0.82	0.01	0.72	NA	NA	NA
Total	139.59	0.57	0.41	416.74	7.1	1.68

Note: Coastal area and population are based on the 1981 and 1991 census.

Source: JNU (1993)

More recently, TERI (1996) made more detailed economic impact assessment using the physical impact estimates from JNU (1993). The study assumed that land and capital losses due to SLR could be proxied through changes in gross domestic product. Thus the study projects the GDP to future time period and proportionately reduces it to account for the land and capital losses. The study estimated the overall economic losses associated with SLR under different scenarios such as 'no protection' and 'protection'. In these aspects the study by TERI (1996) incorporates some features of the second generation models outlined above. Table 4.6 presents the impacts due to 1 metre sea level rise estimated by TERI (1996).

Table 4.6: Impact of 1-m Sea-level Rise on Coastal Districts (billion 1990 rupees)

Coastal District	Economic impact	Value of anticipation	Cost of protection
Mumbai	2287	1061	0.76
Goa	81	36.5	1.42
Balasore	3.6	1.3	1.25

Source: TERI (1996)

4.4 Vulnerability Index for Indian Coastal Districts

As discussed in the previous section, only a few studies attempted to estimate impacts due to SLR for India. The physical impact study carried out by JNU (1993) projected land loss and population at risk due to one meter rise in sea level. These physical impacts provided basis for all the economic impact estimations, which have incorporated some features of first and second generation models described in the literature review section. Lack of more precise physical impact estimations makes it difficult to extend the economic impact assessment work.

Given that the impacts due to sea level rise are likely to be not uniform across different parts of the country, district level composite vulnerability index is developed to identify the most vulnerable coastal districts. Also, vulnerability index would take both climate and non-climate factors into consideration and hence the analysis is a step forward from impact assessment (see Chapter 2 for more details on vulnerability assessment and its evolution from impact assessment). This section first presents a brief overview of literature on vulnerability index computation and then presents the methodology adopted along with the results.

Vulnerability Index – Literature Review

There are at least two benefits that can be derived from the construction of a composite vulnerability index:

- The index can draw attention to the issue of economic and environmental vulnerability of regions (depending on the aspect which the index is supposed to measure).

- The index presents a single-value measure of vulnerability based on meaningful criteria, which can be used when taking decisions regarding the allocation of financial and technical assistance.

Most of the literature on vulnerability index computation has been with reference to vulnerability of small island states. There are three basic methods for computing a vulnerability index:

- Normalization procedure.
- Mapping on a categorical scale.
- Regression method.

Normalization procedure: The method most commonly used is to obtain data for the components of the index, with each component representing a facet of vulnerability. Since the components of the index are often measured in different units, the observations have to be 'standardized' or 'normalized' to permit averaging, with the average being called a composite index.

The normalization procedure most commonly used is that which adjusts the observation to take a value of between 0 and 1 using the formula:

$$V_{ij} = (X_{ij} – \text{Min } X_i) / (\text{Max } X_i – \text{Min } X_i),$$

where: V_{ij} stands for the standardized observation associated with the i^{th} component for region j; X_{ij} stands for the value of the i^{th} component in the vulnerability index, for region j; Max X_i and Min X_i stand for the maximum and minimum value of the i^{th} component for all regions in the index. The method is further refined to reduce the undue impact of outliers on the distribution of the observations, by assigning the value of 1 to the top decile of values in the observations of a particular variable and a value of 0 to the bottom decile.

The averaging procedure can be based on equal or varying weights assigned to each component. Briguglio (1995) experimented with varying weights for each component, but the preferred method was that involving equal weights. Composite indices using this methodology were those by Briguglio (1995; 1997) and Wells (1996). The most important shortcoming of this method is that the weights for averaging the components of vulnerability are arbitrarily chosen, and that the distribution of the normalized variables is heavily influenced by outlier observations.

Mapping on a categorical scale: This method, suitable for qualitative data, involves mapping the scores on a categorical scale ranging from the lowest possible incidence to the highest. This approach was used in the study by Kaly *et al.* (1998), where the scale set was 1 to 7. The scores for each component of the index were averaged to derive a composite index for each country. Kaly *et al.* (1998) applied the index to three countries only, namely Australia, Fiji and Tuvalu, since the exercise was a preliminary one and constrained by the funding provided. The results show that Tuvalu is the most environmentally vulnerable while Australia is the least environmentally vulnerable. Again, with this method, there is a degree of arbitrariness and subjectivity in assigning scores and in weighting the components of the index.

The regression method: The third method used for constructing the vulnerability index, proposed by Atkins *et al.* (1998) and Wells (1997), is based on a regression procedure. Wells (1997) and Atkins *et al.* (1998) assumed that GDP volatility is a manifestation of vulnerability and can therefore be taken as a proxy of vulnerability. They then regressed GDP volatility on a number of explanatory variables, which represented causes of vulnerability. The coefficients on the explanatory variables of estimated equation were then taken as weights for averaging the three vulnerability components.

This method lets the data produce the weights and does not require the 'normalization' of the observations. However it has a number of methodological problems, which limit the operationalization and the reliability of the index. The most important limitation is that the analyst had to assume that the dependent variable (namely GDP volatility) is a proxy for vulnerability, and therefore they had no need to go through a cumbersome regression procedure to compute the vulnerability index.

An additional problem with the Atkins *et al.* (1998) method is that the predictive ability of the model is poor.

Components of the index

Vulnerability index computations differ substantially in terms of the components selected for index computation. A good index should capture three aspects of environmental vulnerability, namely:

- The level of risks (or pressures) which act on the environment forming the risk exposure sub-index.
- Intrinsic resilience of the environment to risks, forming the intrinsic resilience sub-index (IRI) which refers to characteristics of a region which would tend to make it less/more able to cope with natural and anthropogenic hazards.
- Extrinsic vulnerability or resilience as a result of external forces acting on the environment, forming the environmental degradation sub-index (EDI) which describes the ecological integrity or level of degradation of ecosystems.

Weaknesses of the index

The indicators share a number of weaknesses, principally associated with the subjectivity in their computation, in particular with regard to the choice of variables, the method of measurement and the averaging procedure.

- *Subjective choice of variables*: The question of subjective choice of variables is difficult to resolve. This is, however, not a problem peculiar to the vulnerability indices but to most empirical work, especially that which purports to quantify data which is essentially qualitative.
- *Problems of measurement*: The measurement problems arise in part because of an absence of data for certain variables or for certain countries; different methods of statistical compilation across countries; and errors in measurements of the variables.
- *Weighting*: Composite indices are averages of different sub-indices, and the single value which they produce may conceal divergencies between the

individual components or sub-indices, possibly hiding useful information. Furthermore, a composite index implies some form of trade-off between the sub-indices of the composite index and averaging would conceal, for example, situations where the effect of one variable cancels out the effect of another. In addition there is the problem of whether to take a simple average or a weighted average and, in the latter case, which weights are to be assigned to the different variables. In general, the weighting problem remains in the realm of subjectivity, with the simple average having a favourable edge on grounds of simplicity.

Coastal Vulnerability Index for India

To gain insights about relative vulnerability of various coastal regions across India the study attempts to construct a vulnerability index. The vulnerability index is expected to be useful in prioritising the response strategies. Districts are considered the units of analysis for constructing the vulnerability index. For the purpose of index calculation, vulnerability is hypothesized to be a function of *impact* on the district, and *resistance* and *resilience* of the district in responding to the impact it experiences. District specific data on the following parameters (which are considered to be influencing vulnerability) is assembled.

- **Demographic**: (a) Population density based on 2001 census; (b) Annual growth rate of population; (c) Population at risk due to sea level rise.

- **Physical**: (a) Coast length; (b) Insularity (defined as ratio of coastal length to the area of the district); (c) Frequency of cyclones (weighted to account for cyclones of different intensities) based on historic data; (d) Probable maximum surge height; (e) Area at risk of inundation due to sea level rise; (f) Vulnerable houses – both at the risk of damage and collapse (based on 1991 census).

- **Economic**: (a) Agricultural dependency (expressed in terms of population dependent on agriculture and other primary sectors); (b) Income and/or Infrastructure index.

- **Social**: (a) Literacy; (b) Spread of institutional set up.

While most of the above parameters capture the *impact* characteristic of vulnerability, the parameters listed under the headings ‘economic’ and ‘social’ indicate the ability of districts to *resist* and *bounce back*. Table 4.7 shows the assembled district specific data on all the above parameters. It may be noted that some of the districts are clubbed for data consistency[11]. Income for i^{th} district is estimated as:

Income_i = Agriculture NDDP_i + Industry NDDP_i + Services NDDP_i

where, NDDP is Net District Domestic Product and NSDP is Net State Domestic Product and sector wise NDDP for i^{th} district is calculated as:

$$\text{Agriculture NDDP}_i = \left[\frac{\text{Net Sown Area in the District}}{\text{Total Net Sown Area in the State}}\right] \times \text{Agriculture NSDP of the State}$$

$$\text{Industry NDDP}_i = \left[\frac{(\text{\% of Popn. working in Industry x Total Popn..})_i}{\sum_i (\text{\% of Popn. working in Industry x Total Popn.})_i}\right] \times \text{Industry NSDP}$$

$$\text{Services NDDP}_i = \left[\frac{(\text{\% of Popn. working in Services x Total Popn.})_i}{\sum_i (\text{\% of Popn. working in Services x Total Popn.})_i}\right] \times \text{Services NSDP}$$

[11] In Andhra Pradesh, Prakasam District is clubbed with the Nellore District; Vizianagaram District is clubbed with the Vishakapatnam District. In Tamil Nadu, Pudukottai District is clubbed with the Thanjavur District; Chidambaranar District is clubbed with the Tirunelveli-Kattabomman District.

Table 4.7: Coastal Districts Characteristics

Sl no.	District	**State**	Population2001	Popn. Growth Rate 91-01	Popn. Density 2001	Litrate 2001	Coast Length (km)[1]	Agri. Labour force 1991	Share of Agri. in value added	Income[2]	Cyclone Freq.[3]	PMSH[4]	Area affected (Ha.)[5]	No. of Vulnerable houses[6]	
														Damaged	Destroyed
1	EAST GODAVARI	Andhra Pradesh	4872731	7.30	451	58	195.7	67.89	25.51	185078	8	3.5	211265	116369	263149
2	GUNTUR	Andhra Pradesh	4405578	7.27	387	56	59.8	73.29	41.51	177144	3	6	2896	94858	116098
3	KRISHNA	Andhra Pradesh	4218519	14.05	483	62	124.8	66.27	33.96	178417	14	5.5	9081	79694	221357
4	NELLORE[7]	Andhra Pradesh	5714663	10.93	186	54	192.5	75.90	48.51	227115	21	5	5574	102039	265090
5	SRIKAKULAM	Andhra Pradesh	2499992	7.71	386	47	199.1	76.53	30.01	235801	14	3	20069	44642	267657
6	VISAKHAPATNAM[8]	Andhra Pradesh	6224866	15.36	340	52	129.8	62.24	21.36	148988	8	3	4896	93664	275456
7	WEST GODAVARI	Andhra Pradesh	3796159	7.92	490	65	13.7	71.99	35.35	144176	0	4	1219	80970	145852
8	NORTH GOA	Goa	757411	13.93	442	76	41.5	27.63	18.12	59482	0	3.4	9645	16104	0
9	SOUTH GOA	Goa	586595	16.16	301	71	67.2	28.53	15.54	42902	0	3.4	6042	12516	0
10	AHMEDABAD	Gujarat	6079574	26.61	667	70	35	26.59	11.99	401289	0	4	16425	67187	62223

11	AMRELI	Gujarat	1333381	6.45	206	58	57.9	67.20	48.60	81943	0	4	31828	17689	37485
12	BHARUCH	Gujarat	1823464	17.94	208	61	127.8	68.74	41.44	83100	0	4.8	8346	38870	0
13	BHAVNAGAR	Gujarat	2734158	19.29	221	57	155.9	55.97	32.72	154482	2	4.7	11327	41666	111006
14	JAMNAGAR	Gujarat	1913639	22.39	135	55	285.1	57.58	42.44	114594	3	2.5	11421	42806	121301
15	JUNAGARH	Gujarat	2791914	16.58	281	59	241	67.43	38.86	126270	10	2.8	3002	47822	221774
16	KACHCHH	Gujarat	1526371	20.90	33	61	472.2	57.68	52.52	110740	3	2.5	37774	56868	71767
17	KHEDA	Gujarat	3893011	13.14	539	64	27.8	70.43	29.87	143548	0	4.8	33872	38759	0
18	SURAT	Gujarat	4996272	47.04	653	65	51.5	44.84	14.45	226995	0	4.8	12526	75750	0
19	VALSAD	Gujarat	2639894	21.45	503	63	74.5	62.18	22.27	108127	0	5	14479	62325	0
20	DAKSHIN KANNAD	Karnataka	3005994	11.57	356	73	151.1	42.53	11.06	144389	2	3.4	19209	49834	0
21	UTTAR KANNAD	Karnataka	1353268	10.90	132	67	142.3	65.45	18.10	44401	0	3.7	9321	21125	0
22	ALAPPUZHA	Kerala	2105480	5.21	1676	84	82	40.13	22.45	72704	0	3	1148	45354	0
23	ERNAKULAM	Kerala	3073323	9.09	1287	84	46	32.21	24.15	116966	1	3	320	48226	0
24	KANNUR	Kerala	2412275	7.13	805	82	82	39.74	32.17	93263	1	3	952	43075	0
25	KASARAGOD	Kerala	1203303	12.30	614	74	70	48.21	44.67	47740	1	3	1820	24306	0

26	KOLLAM	Kerala	2584041	7.33	1002	81	37	46.28	27.17	83213	0	2.4	2358	52933	0
27	KOZHIKODE	Kerala	2878529	9.87	1228	82	71	32.26	23.97	107312	2	3.5	1430	57123	0

Table 4.7: Coastal Districts Characteristics (contd.)

Sl no.	District	State	Population2001	Popn. Growth Rate 91-01	Popn. Density 2001	Litrate 2001	Coast Length (km)[1]	Agri. Labour force 1991	Share of Agri. in value added	Income[2]	Cyclone Freq.[3]	PMSH[4]	Area affected (Ha.)[5]	No. of Vulnerable houses[6] Damaged	Destroyed
28	MALAPPURAM	Kerala	3629518	17.22	1023	76	70	53.16	32.52	97986	1	3.4	999	54658	0
29	THIRUVANANTHAPURAM	Kerala	3234832	9.78	1476	80	78	46.98	24.06	94122	1	2.3	2004	60353	0
30	THRISSUR	Kerala	2975457	8.70	981	83	54	38.45	23.92	103191	0	3.4	968	53588	0
31	GREATER BOMBAY	Maharashtra	11914276	20.03	11879	77	58.3	0.67	0.00	1377002	3	4.2	8675	69429	0
32	RAIGARH	Maharashtra	2206020	20.89	309	67	127.7	85.53	50.94	76459	2	4.1	4908	43139	0
33	RATNAGIRI	Maharashtra	1696455	9.87	206	65	184.7	76.14	24.68	69367	2	3	1808	4208	0
34	SINDHUDURG	Maharashtra	861693	3.55	165	71	110.9	75.76	21.25	36320	0	2.9	3241	22852	0
35	THANE	Maharashtra	8128797	54.86	850	70	184	32.81	3.68	528680	0	4.2	22727	93622	0
36	BALESHWAR	Orissa	3355204	19.73	532	62	130.3	77.91	40.62	70386	19	9.8	11800	9128	390930
37	CUTTACK	Orissa	6273724	13.60	422	68	150.6	65.99	24.97	172137	17	5.5	17700	56651	564168

38	GANJAM	Orissa	3664482	16.01	250	54	62	76.95	37.41	80987	7	2.7	100	64403	138449
39	PURI	Orissa	4313232	20.14	331	70	147.2	64.63	16.02	103205	10	3.2	17600	49549	216519
40	CHENGALPATTU	Tamilnadu	5608905	20.53	714	68	152.9	51.20	11.58	258011	15	3	13440	100471	366459
41	KANNIYAKUMARI	Tamilnadu	1669804	4.34	992	79	65	58.82	10.74	73601	2	2.7	117	25134	0
42	MADRAS	Tamilnadu	4216316	9.76	24231	73	17	0.94	0.00	376698	15	5.45	3378	86650	91635
43	RAMANATHAPURAM	Tamilnadu	1209593	5.73	280	64	186.2	74.21	40.48	48915	3	11	9908	22111	1725
44	SOUTH ARCOT	Tamilnadu	5224367	7.09	480	60	79.4	80.16	37.32	153419	5	3	4272	94603	219049
45	THANJAVUR[9]	Tamilnadu	6309967	7.70	488	67	225.9	73.03	30.49	224617	13	7	14300	259674	62062
46	TIRUNELVELI[10]	Tamilnadu	4366995	10.34	382	70	163.3	55.64	17.95	216787	2	6	21585	56973	0
47	MEDINIPUR	West Bengal	9638356	15.68	685	65	107.1	69.30	48.49	348638	12	12.5	20700	64721	1237475
48	NORTH 24 PARGANAS	West Bengal	8930499	22.64	2181	70	74.2	35.74	14.56	382458	23	12	29567	136002	570240
49	SOUTH_24_PARGANAS	West Bengal	6908900	20.89	694	60	118	59.58	31.00	233973	23	12.25	71933	67086	599244

Notes: 1 – Author’s calculation using GIS.

2 – Based on the author’s estimations.

3 – India Meteorological Department

4 – Probable Max Surge Height; from Vulnerability Atlas (1997).

5 – The figures are from Asthana (1993) and are for 1 m SLR.

6 – Vulnerability Atlas (1997).

The composite index is calculated by taking average of all the standardized observations of each district over all the components. The averaging procedure implies that equal weights are assigned to each component. The procedure is similar to that followed in the construction of Human Development Index by the UNDP. The index computations are made for a range of combinations of the parameters listed above. The components of different indices are as follows:

V1 = Insularity, Population density, Population growth, Population in agriculture, Literate Population, Vulnerable houses (Total), Probable Max surge height and Cyclone frequency

V2 = Insularity, Population density, Population growth, Population in agriculture, Literate Population, Vulnerable houses (Destroyed), Probable Max surge height and Cyclone frequency

V3 = Insularity, Population density, Population growth, Population in agriculture, Literate Population, Vulnerable houses (Damaged), Probable Max surge height and Cyclone frequency

V4 = **V1** + Income as Vulnerability Indicator

V5 = **V1** + Income as Resilience Indicator

V6 = **V1** - Insularity + Area Affected

V7 = **V6** + Income as Vulnerability Indicator

V8 = **V6** + Income as Resilience Indicator

Table 4.8 shows the computed indices for the coastal districts along with their ranks under each specification and Maps 4.1 to 4.8 show the relative vulnerability of coastal districts. Table 4.9 shows the rank correlation between various vulnerability indices computed above. From the rank correlations and maps it could be seen that the vulnerability rankings across districts are significantly robust.

Table 4.8: Vulnerability Indices for Coastal Districts

Sl. No.	District	V1	**V1 Rank**	V2	**V2 Rank**	V3	**V3 Rank**	V4	**V4 Rank**	V5	**V5 Rank**	V6	**V6 Rank**	V7	**V7 Rank**	V8	**V8 Rank**
1	EAST_GODAVARI	0.3192	17	0.3011	17	0.3260	21	0.2967	17	0.3818	16	0.4224	6	0.3885	7	0.4736	6
2	GUNTUR	0.2786	30	0.2633	31	0.3012	31	0.2600	30	0.3464	33	0.2752	26	0.2569	26	0.3434	26
3	KRISHNA	0.3887	9	0.3749	10	0.3852	12	0.3579	11	0.4441	11	0.3772	12	0.3477	11	0.4339	12
4	NELLORE	0.3872	10	0.3750	9	0.3862	11	0.3606	10	0.4388	12	0.3841	9	0.3578	9	0.4360	10
5	SRIKAKULAM	0.3416	15	0.3301	15	0.3123	27	0.3208	16	0.3976	14	0.3343	15	0.3143	15	0.3911	15
6	VISAKHAPATNAM	0.2875	28	0.2760	26	0.2829	41	0.2656	25	0.3566	28	0.2770	25	0.2562	27	0.3473	25
7	WEST_GODAVARI	0.2718	36	0.2560	37	0.2854	39	0.2512	32	0.3431	34	0.2719	27	0.2513	29	0.3432	27
8	NORTH_GOA	0.2363	48	0.2210	49	0.2795	43	0.2127	49	0.3185	48	0.2127	48	0.1917	48	0.2975	46
9	SOUTH_GOA	0.2443	45	0.2291	45	0.2871	37	0.2185	46	0.3270	42	0.2052	49	0.1837	49	0.2923	48
10	AHMEDABAD	0.2352	49	0.2268	48	0.2497	48	0.2399	37	0.2894	49	0.2414	34	0.2454	31	0.2949	47
11	AMRELI	0.2397	47	0.2291	46	0.2441	49	0.2175	48	0.3196	47	0.2491	33	0.2259	34	0.3280	32
12	BHARUCH	0.2735	35	0.2561	36	0.3224	22	0.2477	35	0.3496	31	0.2618	31	0.2373	32	0.3392	28

13	BHAVNAGAR	0.2938	23	0.2801	22	0.2921	36	0.2717	22	0.3618	24	0.2841	23	0.2630	23	0.3532	23
14	JAMNAGAR	0.3076	20	0.2893	20	0.3030	30	0.2806	20	0.3773	17	0.2898	20	0.2648	22	0.3615	19
15	JUNAGARH	0.3693	14	0.3567	14	0.3384	19	0.3364	14	0.4312	13	0.3433	13	0.3133	16	0.4081	13
16	KACHCHH	0.2935	24	0.2668	29	0.3334	20	0.2678	24	0.3651	20	0.3041	19	0.2772	19	0.3746	17
17	KHEDA	0.2502	40	0.2429	40	0.2710	46	0.2320	41	0.3240	43	0.2670	29	0.2469	30	0.3388	29
18	SURAT	0.3094	19	0.2935	19	0.3539	17	0.2914	18	0.3697	19	0.3097	17	0.2918	18	0.3700	18
19	VALSAD	0.2883	27	0.2645	30	0.3549	16	0.2629	26	0.3607	26	0.2801	24	0.2556	28	0.3534	22
20	DAKSHIN_KANNAD	0.2464	43	0.2343	44	0.2804	42	0.2286	43	0.3205	45	0.2362	39	0.2196	35	0.3114	40
21	UTTAR_KANNAD	0.2487	42	0.2362	42	0.2838	40	0.2225	45	0.3308	40	0.2380	36	0.2129	38	0.3212	35
22	ALAPPUZHA	0.2999	21	0.2862	21	0.3385	18	0.2704	23	0.3740	18	0.2271	45	0.2056	46	0.3092	41
23	ERNAKULAM	0.2462	44	0.2358	43	0.2756	44	0.2262	44	0.3226	44	0.2233	47	0.2059	45	0.3022	45
24	KANNUR	0.2608	38	0.2478	38	0.2976	34	0.2373	38	0.3375	39	0.2272	44	0.2074	44	0.3077	43
25	KASARAGOD	0.2762	31	0.2609	33	0.3192	25	0.2472	36	0.3550	29	0.2334	40	0.2092	43	0.3169	36
26	KOLLAM	0.2398	46	0.2275	47	0.2744	45	0.2178	47	0.3197	46	0.2236	46	0.2034	47	0.3053	44

Table 4.8: Vulnerability Indices for Coastal Districts (contd.)

Sl. No.	District	V1	**V1 Rank**	V2	**V2 Rank**	V3	**V3 Rank**	V4	**V4 Rank**	V5	**V5 Rank**	V6	**V6 Rank**	V7	**V7 Rank**	V8	**V8 Rank**
27	KOZHIKODE	0.2735	34	0.2583	35	0.3162	26	0.2497	34	0.3477	32	0.2368	38	0.2170	37	0.3150	37
28	MALAPPURAM	0.2832	29	0.2697	27	0.3211	24	0.2576	31	0.3570	27	0.2599	32	0.2368	33	0.3363	31
29	THIRUVANANTHAPURAM	0.2750	33	0.2630	32	0.3087	28	0.2499	33	0.3500	30	0.2317	42	0.2115	40	0.3116	39
30	THRISSUR	0.2502	41	0.2373	41	0.2865	38	0.2287	42	0.3273	41	0.2294	43	0.2102	42	0.3088	42
31	GREATER_BOMBAY	0.3835	13	0.3800	8	0.3934	8	0.4520	6	0.3409	36	0.2649	30	0.3466	12	0.2355	49
32	RAIGARH	0.3153	18	0.3001	18	0.3581	15	0.2843	19	0.3873	15	0.3071	18	0.2770	20	0.3800	16
33	RATNAGIRI	0.2595	39	0.2590	34	0.2607	47	0.2341	39	0.3383	38	0.2330	41	0.2106	41	0.3148	38
34	SINDHUDURG	0.2614	37	0.2448	39	0.3079	29	0.2331	40	0.3427	35	0.2374	37	0.2117	39	0.3213	34
35	THANE	0.3285	16	0.3175	16	0.3593	14	0.3332	15	0.3618	25	0.3186	16	0.3245	14	0.3531	24
36	BALESHWAR	0.5734	1	0.5734	1	0.4542	5	0.5133	3	0.6173	1	0.5553	2	0.4972	4	0.6012	2
37	CUTTACK	0.4614	6	0.4545	6	0.3907	9	0.4220	7	0.5093	6	0.4560	5	0.4172	5	0.5045	5
38	GANJAM	0.2900	25	0.2773	25	0.2955	35	0.2622	27	0.3645	22	0.2854	22	0.2581	24	0.3603	20
39	PURI	0.3844	12	0.3732	11	0.3599	13	0.3480	12	0.4466	10	0.3778	11	0.3421	13	0.4407	8
40	CHENGALPATTU	0.4063	7	0.3908	7	0.3875	10	0.3802	8	0.4533	7	0.3907	8	0.3663	8	0.4394	9
41	KANNIYAKUMARI	0.2894	26	0.2777	24	0.3223	23	0.2611	28	0.3645	21	0.2411	35	0.2181	36	0.3216	33
42	MADRAS	0.5349	4	0.5135	5	0.5708	1	0.5042	4	0.5578	4	0.4118	7	0.3948	6	0.4484	7
43	RAMANATHAPURA	0.3853	11	0.3716	12	0.4221	7	0.3443	13	0.4518	8	0.3358	14	0.3003	17	0.4078	14
44	SOUTH_ARCOT	0.2942	22	0.2798	23	0.2982	33	0.2719	21	0.3622	23	0.2890	21	0.2672	21	0.3576	21
45	THANJAVUR	0.3957	8	0.3628	13	0.4796	4	0.3680	9	0.4466	9	0.3832	10	0.3569	10	0.4355	11
46	TIRUNELVELI-KATTABO	0.2760	32	0.2677	28	0.2992	32	0.2609	29	0.3408	37	0.2719	28	0.2573	25	0.3372	30
47	MEDINIPUR	0.5256	5	0.5225	4	0.4263	6	0.4937	5	0.5519	5	0.5297	4	0.4973	3	0.5555	4
48	NORTH_24_PARGANAS	0.5467	3	0.5327	3	0.5205	2	0.5152	2	0.5678	3	0.5424	3	0.5114	2	0.5640	3
49	SOUTH_24_PARGANAS	0.5633	2	0.5550	2	0.4932	3	0.5177	1	0.5948	2	0.5921	1	0.5434	1	0.6204	1

Table 4.9: Rank Correlation between Various Vulnerability Indices

	V1	V2	V3	V4	V5	V6	V7	V8
V1	1							
V2	0.99	1						
V3	0.91	0.89	1					
V4	0.98	0.98	0.89	1				
V5	0.96	0.94	0.87	0.92	1			
V6	0.89	0.87	0.75	0.90	0.87	1		
V7	0.90	0.89	0.77	0.92	0.83	0.98	1	
V8	0.86	0.83	0.72	0.83	0.90	0.96	0.89	1

The results indicate that:

- The districts along the eastern coast are relatively more vulnerable than those on the western coast.
- The coastal districts in the states West Bengal, Orissa, Andhra Pradesh and Tamil Nadu are only marginally different from each other in terms of their vulnerability.
- The districts that are frequently affected by cyclonic storms are relatively more vulnerable – these include districts like 24_Paraganas, Baleshwar, Krishna.

4.5 Storm Damages and Storm Surge

The coastal districts of India are frequently affected by the cyclonic storms. The Indian subcontinent is one of the worst cyclone affected part in the world, as a result of a low-depth ocean bed topography and coastal configuration. The cyclonic storms are more severe along the East coast compared to the West coast. Table 4.10

shows the impacts caused by cyclones and floods in India during the period 1964-1998.

The cyclonic storms may have impacts on coastal community directly due to gale force winds, wave action or wind generated tides (storm surge) at the coast, and inland floods caused by heavy rainfall. According to the National Cyclone Review Committee, 147 damaging cyclones crossed the eastern coast of India in 1897–1970 hitting the coasts in West Bengal, Andhra Pradesh and Orissa. The committee found that almost 40% of the total damage caused by cyclones came from storm surges, which strike the hardest at the low-lying areas of coastal states. The hurricane winds associated with cyclones accounted for the other 60%. The damage caused by storm surges is severe on coastal areas and depends upon the distance from the shore and upon the elevation above mean tide level. The intensity of storm surge is measured in terms of the surge height, which depends upon the wind speed and direction, atmospheric pressure, coastline geometry, and bottom topography offshore. For example, Table 4.11 shows an indication of return periods for tropical cyclone parameters of maximum wind speed and storm surge height for Andhra Pradesh and West Bengal. It can be seen that the surge height of the cyclones of various intensities hitting West Bengal is considerably higher than those crossing the Andhra Pradesh coast.

Table 4.10: Impacts of Floods and Cyclones in India during 1964-1998

Year	Floods			Tropical Cyclone/Storm		
	Events	Killed	Affected	Events	Killed	Affected
1998	3	2,131	29,602,200	4	3,600	4,661,393
1997	5	2,026	292,590	1	25	-
1996	5	1,985	3,812,100	5	1,386	1,322,660
1995	3	2,329	48,254,000	1	130	-
1994	4	2,845	12,616,150	1	208	400,000
1993	5	1,862	130,560,000	2	186	72,500
1992	3	572	70,100	2	360	600
1991	8	1,024	4,525,000	1	125	-
1990	4	203	2,000	6	1,400	8,400,000
1989	3	1,097	2,550	3	132	3,700,000
1988	3	2,050	16,502,000	1	74	1,900,000
1987	4	1,314	18,300,000	4	166	80,000
1986	4	270	995,000	5	390	3,300,100
1985	6	1,328	11,150,000	3	709	105,000
1984	5	740	16,300,000	3	524	1,335,000
1983	6	1,852	250,000	6	862	1,556,900
1982	2	932	33,500,000	2	744	5,300,493
1981	1	553	16,000,000	6	3,805	131,700
1980	5	2,411	32,051,023	3	153	-
1979	6	2,588	31,027,000	1	594	1,605,772
1978	3	4,610	72,000,000	5	901	3,200
1977	2	560	1,045,000	2	14,206	14,479,800
1976	-	-	-	7	270	600,000
1975	1	350	34,000,000	5	501	2,000
1974	5	260	-	2	20	25,100
1973	6	4	-	-	-	-
1972	4	-	-	3	230	4,530,075
1971	6	1,323	165,000	2	7,660	6,900,000
1970	3	1,027	10,351,000	1	-	2,000
1969	-	-	-	4	815	280,092
1968	4	6,452	8,500,000	1	7	15,000
1967	1	300	1,000,000	1	1,000	-
1966	1	47	900,000	1	18	150,000
1965	-	-	-	-	-	-
1964	4	232	770,610	1	500	-

(Source: EM-DAT - The OFDA/CRED International Disaster Database)

Table 4.11: Tropical Cyclone Parameters and Return Periods

		Return Period (year)				
		10	**25**	**50**	**100**	**200**
Andhra Pradesh	Wind Speed (kt)	104	113	119	125	129
	Surge Height (m)	3.8	4.2	4.8	5.2	5.6
West Bengal	Wind Speed (kt)	90	105	116	125	135
	Surge Height (m)	4.5	6.3	7.8	9.2	10.9

Source: Jayanthi and Sen Sarma (1988)

The two cyclones that occurred in nearly the same locations in Andhra Pradesh in 1977 and 1990 and the two that occurred in Bangladesh[12] in 1970 and 1991 were of a similar intensity that lay within the 25-50 year return period in the above table. All these cyclones were catastrophic, but number of causalities in the Andhra Pradesh cyclones were significantly lower than those witnessed in Bangladesh in both the years – about 10000 and 1000 people died in Andhra Pradesh during the 1977 and 1990 cyclones, whereas about 300000 and 140000 died in Bangladesh during the 1970 and 1991 cyclones. While the dramatic reductions in the number of causalities in both the places over the years could be attributed to the advances made in early warning and response systems, the differences between the two regions could be partly explained by the differences in surge heights.

Storm Damage Assessment

If a storm damage model could be developed using historic data then the same could be used to forecast possible impacts due to cyclonic storms under climate change and sea level rise conditions. Very few studies have tried to address this issue related to climate change and there has been no attempt so far in the Indian context. Dorland et al. (1999) have recently studied the impacts due to wind storms in the Netherlands under climate change conditions. However, in India lack of reliable damage data makes it difficult to build such a model. While the institutional

[12] The data for the West Bengal reported in Table 4.11 are assumed to be representative for Bangladesh.

set up for accounting of the damages is well established in India under the central Agricultural Ministry, in practice the estimates are not well maintained. The estimates prepared by the local state governments are typically exaggerated, as they are prepared with a view to demand central government assistance. Table 4.12 shows the estimated damages due to major cyclones in Andhra Pradesh during the period 1977 to 1996 compiled by Sharma (1998) based on various government documents. The table also shows the revenue expenditure incurred by the state government. The wide difference between the estimated losses and revenue expenditure indicate that the state government's revenue expenditure, or central government's assistance may not serve as appropriate proxy for actual damages caused by the cyclones. Annexure A1 discusses the disaggregated damage data collected for two recent cyclones – 1996 Andhra Pradesh cyclone, and 1999 Orissa super cyclone.

Table 4.12: Damages due to Cyclones in Andhra Pradesh during 1977-96

Year	Dists. afftd	Physical Damages				Total Loss (Rs. Lakhs)	Revenue expenditure (Rs. Lakhs)
		Human (no.)	Livestock (no.)	Houses (no.)	Crop (Lakh Ha.)		
1977	8	9921	43176	1014800	33.36	17200	5306
1979	10	638	25082	609400	0.73	18000	7815
1984	4	575	90650	320000	2.07	9490	4929
1985	7	16	0	3196	1.06	2426	2618
1987	12	119	0	110553	9.61	12649	5073
1989	5	69	7117	149112	0.62	4082	1178
1990	14	976	5170301	1439659	4.80	224776	13864
1994	7	172	512	79220	3.97	62593	2968
1996	3	1077	19856	609628	5.11	214283	30822
Total		13563	5745304	4335568	87.15	565499	83573

Source: Sharma (1998)

Similar difficulties are experienced while collecting data on storm characteristics. Annexure A2 shows the physical characteristics of storms that have occurred during the period 1952 to 1996. The data has been compiled from various sources including *Mausam* journal and various IMD reports. As could be seen the data is not complete and far too many values are missing to make any meaningful estimation.

Given the data limitations a two pronged approach has been adopted for modelling the storm induced damages. In the first approach the concept of ‘surge influence factor’ is used to estimate the loss of human lives. The second approach on the other hand attempts to develop a functional relationship between human loss and surge using econometric methods. The choice of human loss as the end-point of analysis is due to non-availability of reliable data on economic damages as discussed above. However, an attempt has also been made to use damages as end-point based on a very small data set of cyclonic storms that crossed Andhra Pradesh coast. These results are discussed towards the end of this section.

Storms and Human Casualties

Given sufficient warning and resources, it is always possible to minimize the human loss during cyclonic storms. Broadly, the loss of human lives would depend on the risk level of the region, warning time and compliance to the evacuation plan. The compliance with a warning would further depend on the preparedness of the state to evacuate the affected population to cyclone shelters as well as the confidence of the people in the reliability of the warning. For developed countries the non-compliance factors would typically be low, where as the same for a developing country would be high.

The loss of human lives in any region is estimated using the following relation:

$$H = \sum_I P\ C\ \alpha_I\ r_i$$

where, P is the population of the region; C is the non-compliance factor; α_i is the fraction of the region’s area related to a given hazard level; and r_i is the risk coefficient for the hazard level.

Using the vulnerability atlas (1997), for each coastal district area under different hazard levels – which are defined based on wind velocities that would prevail during a storm, and the storm penetration – is assessed. The atlas defines the following hazard levels for various wind speeds:

Very High (VH) – 50 to 55 m/sec

High (H) – 47 to 50 m/sec

Moderate (M) – 39 to 47 m/sec

Low (L) – 33 to 39 m/sec

The VH hazard zone is further classified into two zones. A fraction of VH zone would be at higher risk due to surge influence. A surge influence factor for a region is defined as:

Surge influence factor = (coast length x inland penetration)/(area)

Thus for the analysis four hazard levels are considered: VH+Surge, VH, H, and M. The risk coefficients for various hazard levels are gathered from disaster management literature (Krishna and Bhandari, 1999): VH+surge – $5x10^{-2}$; VH – $5x10^{-3}$; H – $5x10^{-5}$; M – $5x10^{-8}$. The surge influence factor is calculated for two different scenarios of surge penetration – 10 km and 30 km. Three different scenarios for non-compliance factors have been used: 0.004, 0.008 and 0.08.

The analysis on vulnerability index presented in the previous section showed that districts on the east coast are more vulnerable compared to those on the west coast of India. Also, more cyclones hit the east coast compared to the west coast. Thus, the estimated human casualties for the coastal districts along the east coast under different scenarios are presented in Table 4.13. The last three columns show the likely losses under more severe cyclonic storms that are expected under climate change conditions. The values for non-compliance factor are chosen to reflect conventional wisdom and extreme conditions. For instance the value 0.08 is chosen to show the consequences of situations like the one witnessed during the 1999 super cyclone in Orissa. The most affected district Jagatsinghpur (part of erstwhile Cuttack district) had witnessed in the past only by moderate cyclones and hence its non-compliance to the warnings has been on the high side during the 1999 super cyclone. Moreover, the surge during 1999 cyclone was almost twice as that of a normal cyclone. Together these factors have resulted in high human casualties during the 1999 cyclone.

Comparison of results shown in Table 4.13 with those presented under the vulnerability index shows that the relative ranking of districts remains more or less similar between the two analyses. This is an important result because the two analyses address vulnerability from two related, but different perspectives and their similarity shows robustness of the finding.

Table 4.13: Expected Casualties due to Storms

District / NCF	Surge Penetration - 10 km			Surge Penetration - 30 km		
	0.004	**0.008**	**0.08**	**0.004**	**0.008**	**0.08**
East Godavari	167	334	3337	374	747	7473
Guntur	34	68	680	56	112	1116
Krishna	105	211	2109	224	448	4483
Nellore	79	158	1584	136	273	2727
Srikakulam	218	436	4361	476	952	9520
Visakhapatnam	94	187	1874	168	336	3364
West Godavari	33	66	657	42	84	837
Baleshwar	192	384	3836	441	882	8824
Cuttack	186	372	3720	390	780	7804
Ganjam	36	71	711	57	115	1149
Puri	98	196	1959	209	417	4174
South Arcot	71	142	1419	127	254	2540
Medinipur	310	620	6204	562	1124	11245
N 24 Parganas	470	940	9399	1053	2105	21052
S 24 Parganas	286	571	5710	580	1160	11604

Note: NCF – non-compliance factor

Storm Damage Model

As mentioned above in the absence of reliable data on storm induced damages the analysis here uses human loss as an end-point. The model uses data on human loss, surge height, time and duration of the storm, and location and period of occurrence. The data set corresponds to the period 1952 to 1996. While a number of models were considered, the following model provided the best fit. Figure 4.1 shows the observed and estimated values of the dependent variable, namely human loss. Barring a few instances the model predictions are very close to the observed values and adjusted R^2 reported below also shows this.

lnloss = 6.19 (sd1) + 4.37 (sd2) + 4.56 (sd3) + 3.46 (sd4) + 0.439 (seasurge)

(8.51) (5.95) (7.06) (4.09) (3.34)

(Adj. R^2 = 0.95)

where, lnloss – human loss (in log)
sd1, sd2, sd3, sd4 – state dummies for AP, TN, Orissa & WB, Gujarat

seasurge – interaction dummy of season and surge height

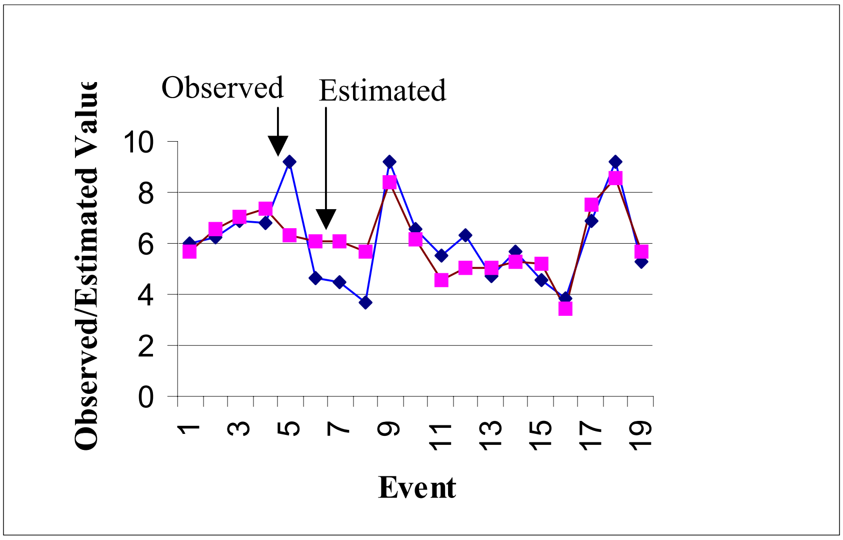


Figure 4.1: Validation of Storm Damage Model

Model estimates show:

- Storm surge has positive and significant influence on human loss
- Storm induced vulnerability is more for AP followed by Orissa & WB, TN and Gujarat
- Storms in the winter season are more destructive than those occurring in summer season
- Storm duration and its period of occurrence (i.e., sixties, seventies, eighties, or nineties) found to be not significant

Given that human-loss as an end-point of analysis is prone to criticism, an attempt is made to make use of available limited data on storm induced damages. The damage data for about seven severe cyclonic storms that crossed Andhra Pradesh coast have been analyzed in a recent study by Raghavan and Rajesh (2003). These storms have occurred during 1977 and 1998 and have comparable intensities. The study has normalized the reported damages by accounting for inflation, income growth and population growth. Table 4.14 shows the physical characteristics of the above mentioned storms and their normalized damages.

Table 4.14: Impact of Cyclones on Andhra Pradesh Coast

Year	Month	Category	T.No	MS SW	Stren-gth	Eye Dia.	Surge	Hum. Loss	Econ. Loss	Norm Loss
				(ms^{-1})	(ms^{-1})	(km)	(m)		(Rs. Cr.)	(Rs. Cr.)
1977	Nov	SCSCHW	7	125	50	60	5	9921	172	1040
1979	May	SCSCHW	6	110	40	20	3.5	638	243	1203
1984	Nov	SCSCHW	6	95	17	20	1	575	155	398
1989	Nov	SCSCHW	6.5	127	15	15	3.5	69	41	50
1990	May	SCSCHW	6.5	135	40	20	3.5	976	2137	2137
1996	Nov	SCSCHW	4.5	77	35	17	3.5	1077	6129	2618
1998	Nov	VSCS	4.5	77	30	20	2.5	16	306	99.4

Note: (i) MSSW – maximum sustained surface wind speed

(ii) Econ Loss – Estimated damages

(iii) Norm Loss – Normalized damages (1990-91 prices)

(iv) SCSCHW – severe cyclonic storm with a core of hurricane winds;

VSCS – very severe cyclonic storm

(Source: Raghavan and Rajesh, 2002)

As the number of observations are too small for carrying out any meaningful econometric exercise, only an attempt has been made to analyze the correlation matrix of human loss and the normalized damages. Table 4.15 shows these correlation coefficients. The results show that compared to normalized damages, human loss has better correlation with various storm characteristics. This is considered as a possible justification for the choice of human loss as end-point in the storm damage model presented above.

Table 4.15: Correlation Coefficients of Human Loss and Normalized Damages

Characteristic	Human Loss	Normalized Damages
Max T. No.	0.79	0.15
MSSW	0.24	0.46
Strength	0.68	0.73
Eye Diameter	0.99	0.13
Surge	0.66	0.33

4.6 Adaptation Options

Coastal adaptation to climate change can be considered as a multi stage and iterative process, involving four basic steps (Klein *et al.*, 1999):

- Information development and awareness raising
- Planning and design
- Implementation
- Monitoring and evaluation

As part of the planning and design stage a number of options for coastal adaptation can be considered and these include:

- Protect
    - Hard structural options – e.g., dikes, floodwalls, tidal barriers

        - Soft structural options – e.g., periodic beach nourishment, wetland restoration
        - Indigenous options – e.g., afforestation
- Retreat
    - Relocating threatened buildings
    - Phased-out or no development in susceptible areas
    - Creating upland buffers
- Accommodate
    - Emergency planning – e.g., early warning system, cyclone shelters
    - Hazard insurance
    - Modification of land use and agricultural practice

There are at least three stands of literature that are merging currently in the context of climate change and coastal zones – impact and vulnerability literature, disaster management literature, and literature on integrated coastal zone management (ICZM). Conceptual thinking on adaptation of coastal zones to climate change induced impacts could benefit from insights provided by the disaster management literature and ICZM literature. This section discusses two specific questions in this context – the first one deals with 'adapt to what?' and it links climate change literature with that on disaster management; and the second one deals with 'how to adapt?' and it provides link between climate change literature and coastal zone management literature.

Adapt to what?

Climate change may actually be experienced as a change in frequency or intensity of extreme events. For example, a severe drought, flood, or windstorm may be associated with climate change. Measures can be taken in advance to reduce impacts or damage, including provision of additional water supplies or more economical use of remaining supplies (in the case of drought), and steps to protect or remove vulnerable property from floods or windstorms. Hence disaster preparedness is an important component of climate change action plans. Adaptation measures taken in anticipation of climate change can and usually should be harmonized with responses to current extreme events. Adaptation to extreme climatic events in the present may or may not take account of future climate change. However, since such extreme events will be a feature of climate change in the future, it makes sense to improve responses to similar events now occurring. In effect, improving response to extreme climatic events in the present (reduce vulnerability, increase resilience, and strengthen adaptation capacity) provides a sort of training opportunity for learning how to improve response to future climate change.

Studies of adaptation to current climate also make it clear that human activities are not now always as well adapted to climate as they might be. The mounting losses from great natural disasters for example are in substantial part associated with extreme atmospheric events. It has been shown (Burton et al., 1993) that these losses cannot be ascribed to the events alone but are also due to lack of appropriate human adaptation (also called human adjustment) and that losses are in some cases being increased by maladaptation.

In this context it may be worth noting the experiences with the Super cyclone in 1999 that devastated the state of Orissa. There is a general agreement that cyclone devastation was worsened significantly by deforestation on the coast. Mangroves have been lost especially since 1960s. Before the early 1950s, there were hardly any people living on the coast. Resettling Bangladeshi refugees and industrialisation around Paradeep gave birth to settlements and large portions of the forests were opened for exploitation. Satellite pictures show that 2.5 square kilometres of mangroves were lost in the 70s every year. Previously forests had formed a five-kilometre wide buffer zone against strong winds and flash floods. Without the protection of forests, the Super cyclone was believed to have travelled as much as

100 kilometres inland. The lack of protective forest cover also made it possible for the floods to inundate large areas and cause so much destruction. An area near Paradeep where the forests are intact was largely saved from the ravage caused by the 1999 cyclone. Already earlier during the 1971 cyclone villages with buffer forests suffered precious little, but those that had lost the forest cover felt a deep impact. Likewise a tidal wave cost thousands of lives in 1991 in Sunderbans, Bangladesh while a similar tidal wave in 1960 did no harm to the villages that were at that time protected by mangrove forests.

In the development context, therefore, a prudent adaptive response to the threat of climate change may be to improve adaptation to existing climate and its variability, including extreme events. It may be worth reiterating that improving adaptation to current climate variability is not an alternative to preparing for adaptation to longer term changes in climate. It is an adjunct, a useful first and preparatory step that strengthens capacity now to deal with future circumstances.

How to adapt?

Coastal zone management is about making trade-offs aimed at resolving competing sectoral demands, rather than optimising the output of a single resource. Solving such problems requires integrates of management objectives and hence there is increasing interest in integrated coastal zone management.

It has been argued that ICZM is the most economically efficient way to manage the coastal zone. In terms of responding to climate change, ICZM can be seen as an essential institutional mechanism that can deal with all competing pressures on the coast, including short, medium and long-term issues[13]. Vulnerability assessment of the type addressed in this chapter (and previous chapters dealing with conceptual issues) is often described as one possible trigger for ICZM; at the same time ICZM will increase the need for more sophisticated and detailed assessment of implications of climate change – while accounting for other climatic and non-climatic stresses on the coastal zones. Thus, an interactive evolution of vulnerability assessment within ICZM framework can be envisaged, progressively contributing to an improved knowledge base for decision- making.

By adopting the ICZM principles of awareness rising, involvement of stakeholders and the installation of a legislative, institutional and organisational framework can be combined with consciousness of sustainable use and management of the coastal zone. In many cases the present knowledge of the natural and socio-economic coastal system is recognised as being too limited. Data collection and management, education, training and transfer of tools are therefore important pre-conditions for the successful introduction of ICZM. In India ICZM plans are being drawn for more and more coastal regions. The coastal zone regulations can be cited as an early manifestation of the ICZM plans.

Adaptation to catastrophic risks, such as those caused by cyclonic storms, are also important for sustainable use of coastal resources. Though the risk management is well developed in the Indian context with early warning systems and post-disaster management systems well in place, use of effective mechanisms for enabling people to better manage their own catastrophic risks are still lacking. While government's role in disaster management cannot be ruled out completely, efforts should be made to reduce the burden substantially. In this context the role of insurance needs special mention. A primary distinguishing feature of India and other developing countries is that the government is the primary bearer of the costs of catastrophes. Both insurance and re-insurance markets are not well developed and efforts should be made to avail benefits from these risk management options.

Once disaster assistance has been institutionalised, as it is done in the Indian context, and people know that they can count on it, then it has many of the longer term effects of an insurance subsidy that inadvertently worsen future problems by encouraging people to increase their exposure to potential losses. For example, compensation for cyclone damage to homes can lead to building more houses in cyclone prone areas. As argued in the case of crop insurance in the previous chapter, insurance to natural disasters should have little or no government subsidy to avoid moral hazard and adverse selection problems. New approaches like index-based or area-based contracts to insure natural disasters should be attempted and these approaches in conjunction with developments in micro-finance could make insurance an increasingly viable proposition for poor people to better manage risk.

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[13] In view of its gobal nature, climate change would facilitate more international and intra-national cooperation

The insurer often faces high risk because of the covariate nature of the insured risk. When a payment is due, then all those who have purchased insurance against the same risk must be paid at the same time. To hedge against this risk, the insurer can either diversify regionally by selecting risks that are not highly correlated, or sell part of the risk to the international reinsurance and financial markets. Even though the global reinsurance market is well developed the benefits of this market are reaped almost entirely by the developed world. While the US, the UK and Japan account for almost 55% of the total reinsurance market, the developing countries in Asia, where most of the natural catastrophe related damages are borne, accounts for less than 8% of the global market. It is in this area that government should put most of its efforts rather than in actual disaster assistance.

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than other classes of coastal problems and also requires a more strategic perspective.

Chapter 5: Summary and Policy Implications

This study addressed vulnerability of two important climate sensitive sectors in India. Given their direct dependence on climate agriculture and coastal resources are likely to get affected significantly due to climate change. The present study focused on these two sectors and extended the previous analyses in these sectors by specifically incorporating the extreme events in the impact/vulnerability assessment.

The chapter is organized as follows: the first section gives a brief summary of the study and the main results. This will be followed by discussion on a more pertinent question from Indian (and other developing country) perspective, namely cost and financing the adaptation. The discussion will highlight the available mechanisms and analyze need for augmenting the existing ones. Finally, the last section discusses the policy implications of the study.

5.1 Summary

The first chapter discussed the climate change problem briefly and highlighted the need for policy intervention by specifically looking at the climate change induced potential impacts and damages suffered at present due to natural disasters. In the second chapter a conceptual framework is illustrated to assess vulnerability and evolution of literature from impact assessment to vulnerability assessment is traced with adaptation and adaptive capacity operating as connecting theme. Highlighting the importance of knowledge on climate change induced impacts and vulnerability for policy purposes; the chapter also provided an overview of objectives of the study.

The study focused on two specific sectors – agriculture and coastal resources – in India to assess impacts and vulnerabilities and identify adaptation options. Chapters three and four presented the study results concerning these two sectors, respectively. For agriculture an extension of the Ricardian approach has been considered by incorporating climate variation along with climate change in the model formulation. The analysis assumed 'autonomous' adaptation and estimated the impacts associated with hypothetical scenarios of climate change and climate variability for India. The results indicate that increase in climate variability along with increases in temperature and precipitation would lead higher impacts for India. Even with ‘autonomous’ adaptation the impacts could be significant and hence make the sector highly vulnerable to climate change. Noting that technology penetration needs considerable lead-time the study argued for consideration and implementation of various adaptation options that could reduce the vulnerability of Indian agriculture. Discussing the problems associated with crop insurance scheme in use in India, the study argued for transition towards new-generation micro-insurance schemes that would avoid moral hazard and adverse selection problems that commonly plague insurance schemes. The study also argued for consideration of so-called ‘win-win’ or ‘no regret’ options to ameliorate adverse impacts.

For the coastal resources, the study developed an integrated vulnerability index and used the same to rank the Indian coastal districts in terms of their relative vulnerability due to the climate change induced stresses and other climatic and non-climatic stresses. The results showed that districts on the Eastern coast (belonging to the states of West Bengal, Orissa, Andhra Pradesh, and Tamil Nadu) are relatively more vulnerable than those on the Western coast. The study also highlighted the importance of cyclonic storms for Indian coastal resources and attempted developing a relationship between cyclone induced damages and storm characteristics – the rationale being to develop a tool for forecasting potential future risks. The study argued for developing and/or strengthening strategies to address present day climate extremes (such as cyclonic storms) as a part of broader adaptation strategies for climate change. The adaptation options for climate change should also be placed within the broader framework of integrated coastal zone management. The roles of insurance – especially micro-insurance – to help people guard themselves from the impacts of cyclones, and reinsurance to help the government in spreading the risk are also discussed.

5.2 Cost of Adaptation

Even though a number of adaptation options have been used across different sectors and regions, it may not be appropriate to conclude that adaptation would be feasible across the board. The adaptation options may not be universally or equally available and even more importantly, those options may not be implementable due to variety of reasons. For example, the viability of crop insurance depends heavily on the degree of information, organization, and subsidy available to support it. Similarly, the option of changing location in the face of hazard depends on the resources and mobility of the affected part and on the availability and conditions in potential destination areas. Individual cultivator response to climate risk in India has long relied on a diverse mix of strategies, from land use to outside employment (sometimes requiring temporary migration); many of these strategies have been undermined by changes such as population pressure and government policy, without being fully replaced by others (Gadgil *et al.*, 1988; Johda, 1989).

Rayner and Malone (1998) observe “rarely do people choose the best responses—the ones among those available that would most effectively reduce losses—often because of an established preference for, or aversion to, certain options”. There are other factors that constrain the choice of ‘best’ option and these include, lack of knowledge of risks or alternative adaptation strategies, other priorities, limited resources, and institutional barriers. Recurrent vulnerabilities, in many cases with increasing damages, illustrate less-than-perfect adaptation of systems to climatic variations and risks. Societal responses to large environmental challenges tend to be incremental and ad hoc rather than fundamental (Rayner and Malone, 1998). These findings suggest that problems that demand early or long-term attention often fail to receive it, and the most efficient responses are not taken. There is little evidence that efficient and effective adaptations to climate change risks will be undertaken autonomously.

Would societies adapt autonomously to avoid climate change impacts? While some studies (including the analysis presented in Chapter 3) assume that market mechanisms help in autonomous adaptation (Mendelsohn and Neumann, 1999;

Yohe *et al.*, 1996), some other studies highlight the constraints on autonomous adaptation, such as limited information, lack of financial resources etc. (Reilly, 1999; Fankhauser *et al.*, 1999). The second set of studies argue for planned adaptations facilitated by public agencies.

The underlying issue of concern for adaptation options – autonomous or otherwise – is the costs associated with them. For example, as mentioned above autonomous choice may not lead to selection of efficient strategy due to resource constraints among other things. Moreover, autonomous adaptation options may not be desirable sometimes from fairness and equity point of view. In such circumstances facilitating choice of appropriate option by relaxing the resource constraints could lead to desirable outcomes.

5.3 Financing Adaptation

UNFCCC and Adaptation

The UNFCCC itself does not define the world 'adaptation' but relevancy and references are drawn from the words such as 'adverse effects' in the Convention and subsequent IPCC documents. Article 4.8 of the Convention clearly asks Parties to give full considerations to the adverse effects:

"In the implementation of the commitments in this Article, the Parties shall give full consideration to what actions are necessary under the Convention, including actions related to funding, insurance and the transfer of technology, to meet the specific needs and concerns of developing country Parties arising from the adverse effects of climate change and/or the impact of implementation of response measures, especially on – (a) small island countries; (b) countries with low-lying coastal areas; (c) countries with arid and semi-arid areas, forested areas and areas liable to forest decay; (d) countries with areas prone to natural disasters; (e) countries with areas liable to drought and desertification; (f) countries with areas of high urban atmospheric pollution; (g) countries with areas with fragile ecosystems, including mountainous ecosystems; (h) countries whose economies are highly dependent on income generated from the production, processing and export, and/or on consumption of fossil fuels and associated energy-intensive products; (i) land-locked and transit countries. Further, the Conference of the Parties may take actions, as appropriate, with respect to this paragraph" (UNFCCC, 1992).

The decisions made in the COP-1 (Decision 11) provided the initial guidance on policies, programme priorities, and eligibility criteria to the operating entity of the financial mechanism for adaptation. Short-term, medium-term, and long-term strategies for adaptation to the climate change were proposed in COP-1. Such strategies were envisaged to be implemented in a stage-by-stage basis in the developing countries. The three stages dealing with short, medium and long-term adaptation measures, respectively.

Stage-I: This includes studies of possible impacts of climate change, to identify particularly vulnerable countries or regions and policy options for adaptation and capacity building.

Stage-II: This includes the measure which may be taken to prepare for adaptation as stipulated by Article 4.1 (e) of the Convention including further capacity building. Article 4.1 (e) address the adaptation measures to develop and elaborate appropriate and integrated plans for coastal zone management, water resources and agriculture, and for the protection and rehabilitation of areas, particularly in Africa, affected by drought and desertification, as well as floods.

Stage-III: This includes the measures to facilitate adequate adaptation, including insurance, and other adaptation measures as envisaged by Article 4.1 (b) and 4.4. Article 4.1 (b) asks the Parties to formulate, implement, publish and regularly update national and regional programmes containing measures to mitigate climate change by addressing anthropogenic emissions by sources and removals by sinks of all GHGs not controlled by the Montreal Protocol, and measures to facilitate adequate adaptation to climate change. Article 4.4 deals with 'particularly vulnerable developing countries' and asks the Parties to assist these countries in adapting to the climate change.

According to the Convention Article 4.3, the Annex-II developed country parties are obliged to provide the financial resources to the convention's financial mechanism to cover the agreed *full incremental costs*, incurred by the developing country parties.

Global Environment Facility (GEF) was designated, as an interim entity, to oversee the financial matters by COP-1 for stage-I adaptation measures. GEF was established in 1991 as a pilot trust fund of US$ 1.3 billion to support the developing countries with the projects to protect the global environment and sustainable development. GEF is entrusted the task of meeting the agreed full costs of the activities (basically stage-I measures only) such as, formulation of national communication, studies on the possible impacts of climate change, vulnerability assessment, studies to identify the options for implementing the adaptation measures.

So far, only stage-I adaptation measures have been supported at full cost basis. Based on the stage-I assessments and the results of the scientific and technical studies, COP is empowered to decide to implement the stage-II and III measures. If COP decides that it has become necessary to implement the stage-II and III measures, Parties included in Annex-II are obliged to provide funding. After COP-1 there were no significant decisions regarding adaptation till COP-4, where it was decided that GEF should provide funding to developing country parties to implement stage-II adaptation measures and emphasis was given to countries vulnerable to climate related natural disasters. As a result, a few Stage II studies (for example in the Caribbean, Pacific and Bangladesh) have been initiated.

Adaptation Funding and Kyoto Protocol

Apart from the provisions in the Artcile 4.3 and 4.4 of the Convention, Artilce 12.8 of the Kyoto Protocol has opened a new prospect for funding the adaptation measures. According to this article, a share of Clean Development Mechanism (CDM) is to be used to cover the administrative costs of CDM as well as to meet the costs of adaptation needed in 'particularly vulnerable' developing countries. However, many questions, including the size of the potential CDM market and determination of the share of CDM, remain unanswered. These unanswered questions impose uncertainty in the quantity of financial resources that CDM can deliver to meet the adaptation costs. Some have argued that there is no specific rationale for creating adaptation fund only through the proceeds of CDM and similar contributions from joint implementation and emission trading should also go towards adaptation fund.

The COP-7 meeting in Marrakech in 2001 agreed the setting up of a number of funds including a Climate Change Fund to support the developing countries on adaptation, technology transfer and capacity building with respect to climate change as well as a separate LDC (Least Developed Countries) Fund to help the LDCs to develop National Adaptation Plans of Action (NAPAs). Contributions to funds were to be voluntary and a number of developed countries pledged to make contributions at the level of over $400 million a year that would be channeled to the developing countries through the GEF.

Despite the availability of financing mechanisms for adaptation one should keep in mind that almost all the developing countries would be competing for these scarce funds. Potential barriers for funding the adaptation measures include:

- 'Global environmental benefit' is the principle key word in the constitutional mandate of GEF, which is not met by financing adaptation projects for the simple reason that adaptation projects would be local in effect. However, at COP8 a decision was taken to overcome this barrier.

- Divergent views as to what constitutes adaptation and the role of development, particularly sustainable development. The nature of uncertainty concerning the scope and magnitude of climate changes suggests that some adaptation strategies may turn out to be redundant. In the worst scenarios, investments in adaptation may be offset by maladaptive policies in other sectors. Hence, as argued in previous chapter in the context of coastal resources, there is an emerging view that adaptation to climate change should be seen within the context of adaptations to present day weather related hazards[14]. However, the mechanisms of UNFCCC and Kyoto Protocol have authority only to focus on environmental impacts and adaptation provoked by a narrowly defined *human-induced climate change*. This could lead to wasteful efforts on 'identifying' the climate change component of impacts, rather than seeing climate change as another dimension of threats to development.

[14] But others argue that the climate threat and the need for adaptation is a not a continuation of what has gone before and that climate change brings new and urgent dimensions to sustainable development.

5.4 Policy Implications

The scope of the study does not warrant policy suggestions that feed directly into climate negotiations. However, a number of policy relevant conclusions can be made on the basis of results obtained from this study.

- For India (and other developing countries) there are a number of more demanding development priorities that need immediate attention compared to climate change. Hence the issues related to climate change should be placed in the sustainable development framework to gain wider acceptability.
- Adaptation to climate change is an issue of considerable interest to India, given its high vulnerability to climate change. The results of this study for two climate sensitive sectors, agriculture and coastal resources, highlight this. Equal emphasis, if not more, should be placed on adaptation policies in the climate change negotiations.
- Vulnerability indices such as those developed for the coastal districts of India in this study could provide insights on prioritizing adaptation strategies for specifically vulnerable regions.
- Understanding vulnerability to present day climate extremes such as cyclones would provide useful insight about the adaptive capacity of a region. Such knowledge could be useful in formulating adaptation strategies.
- Immediate benefits can be gained from better adaptation to climate variability and extreme atmospheric events. Immediate benefits also can be gained by removing maladaptive policies and practices.
- Anticipatory and precautionary adaptation could be more effective and less costly than forced, last minute, emergency adaptation or retrofitting.
- India could benefit by ensuring that its legal and economic structures and price signals encourage the private sector to take adaptive measures. Insurance, and more specifically micro-insurance, should be encouraged to help people adapt to the climate change conditions.

- India and other developing countries could also benefit by encouraging research that fosters identification of new and cost-effective adaptation strategies. The global community also has a significant role to play in this endeavor.

- The global community should address and resolve on priority basis the barriers mentioned above with regard to financing the adaptation options in developing countries.

- Even though the impacts and hence the adaptation needs are local in nature, given the global nature of the climate change problem responsibility rests on all the countries. Moreover, the principle of ‘common but differentiated responsibilities’ should be applied here also. The developed countries should shoulder bulk of the cost of adaptation in developing countries on the basis of fairness principles such as equality and vulnerability.

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Annexure A1

November 1996 Cyclone in Andhra Pradesh

On 5-6 November 1996, the state of Andhra Pradesh was hit a severe cyclonic storm. The maximum wind velocity recorded was 217 kmph and the storm induced surge height was about 5 meters. The districts of Prakasam, Guntur, Krishna, East and West Godavari were affected by the storm and sea surge has led to inundation of Krishna estuary and coasts south of Machilipatnam. The official estimate of human loss caused by the cyclone was placed at 2000, of which more than half were fishermen. Table A1.1 shows detailed estimation of both physical and monetary losses caused by the cyclone. It may be noted that these estimates were gathered from various independent sources. The study hopes to acquire more disaggregated estimates of damages at district and taluk level from the government records and cross compare the same with the aggregate assessments presented below.

Table A1.1: Damages Caused by 1996 Cyclone in Andhra Pradesh

Particulars	Losses
Physical Damages	
Paddy crop (Lakh Ha.)	3.47
Other crops (Lakh Ha.)	0.53
Coconut (Lakh Ha.)	0.30
Horticulture (Lakh Ha.)	0.81
Total crops (Lakh Ha.)	5.11
Houses – fully damaged (Lakh)	3.33
Houses – partially damaged (Lakh)	31.14
Livestock (Lakh)	0.20
Monetary Damages (Rs. Cr.)	
Agriculture	4443.00
Housing	642.00
State Electricity Board	100.00
Municipal Admn. and Urban Development	90.00
Panchayat and Rural Development	39.27
Fisheries	26.77
Animal Husbandry	13.68

Roads and Buildings	7.50
Irrigation	7.32
Others	5.18

October 1999 Super Cyclone in Orissa

During 25-29 October 1999, the state of Orissa was devastated by super cyclone. The super cyclone hit the coast of Orissa on 29th morning around 10:00 hours, near Saharabedi, a village about 1.5 km from the seacoast in Ersama Block, Jagatsinghpur district with a wind speed around 260 kmph, and a storm surge of about 10 m. After crossing the coast, the system moved northwestward and remained stationary as a super cyclone for about six hours. The storm travelled more than 250 km inland and within a period of 36 hrs ravaged about 200 lakh hectares of land. The storm also brought in heavy rainfall averaging 600 mm in six days causing flash floods that breached highways, railway track embankments, culverts etc. and submerged and inundated vast tracts of land in many districts. The districts of Balasore, Bhadrak, Jajpur, Kendrapara, Jagatsinghpur, Khurda, Puri, Cuttack, Nayagarh, Keonjhar, Mayurbhanj, Dhenkanal (partially) were affected by the storm.

About 130 lakh people in around 15000 villages were affected by the storm. As many as 10000 people died in the devastation caused by the storm – out of which in Jagatsinghpur district alone about 8000 casualties were reported. In the aftermath of the storm more than 4.44 lakh livestock perished, 16 lakh houses were damaged, and about 9000 fishing boats were lost. Table A1.2 and Table A1.3 present the estimated damages for the agricultural sector. The estimates are based on a study conducted by Food and Agriculture Organization (FAO). Table A1.2 shows crop-wise production losses and the corresponding financial losses incurred in the thirteen districts of the state. The cost calculations reported are based on the farm gate prices of the crops. The estimated overall losses in the agricultural sector are Rs. 2090 crores (Table A1.3).

Table A1.2: District-wise Agricultural Damages Caused by 1999 Super Cyclone

District	Winter rice		Millet (Ragi)		Pulses		Onion		Chilli		Oilseeds	
	Prod. (000t)	Cost (000 Rs.)	Prod. (000t)	Cost (000 Rs.)	Prod. (000t)	Cost (000 Rs.)	Prod. (000t)	Cost (000 Rs.)	Prod. (000t)	Cost (000 Rs.)	Prod. (000t)	Cost (000 Rs.)
Balasore	73.8	442800	0.005	18	0.077	1147.5	2.147	10732.5	0.214	2137.5	0.056	843.75
Bhadrak	181.8	1090800	0.000	0	0.054	810	4.104	20520	0.234	2340	0.012	180
Cuttack	117	702000	0.432	1728	0.696	10440	3.696	18480	0.876	8760	1.410	21150
Jagatsinghpur	99	594000	0.504	2016	0.126	1890	2.448	12240	0.441	4410	0.117	1755
Jajpur	126.9	761400	0.036	144	2.223	33345	3.231	16155	0.423	4230	2.169	32535
Kendrapara	136.8	820800	0.018	72	0.054	810	3.303	16515	0.333	3330	0.000	0
Dhenkanal	45.6	273600	0.051	204	2.643	39645	2.280	11400	0.378	3780	4.578	68670
Ganjam	119.7	718200	9.810	39240	4.074	61110	1.860	9300	0.189	1890	3.762	56430
Keonjhar	9.9	59400	0.027	106.2	0.902	13533.75	0.190	951.75	0.077	774	0.692	10381.5
Mayurbanj	35.73	214380	0.007	28.8	1.206	18090	1.003	5013	0.204	2043	0.497	7452
Puri	85.8	514800	0.186	744	0.030	450	1.104	5520	0.390	3900	0.066	990
Khurda	33.98	203850	0.128	513	0.108	1620	0.709	3543.75	0.162	1620	0.124	1856.25
Nayagarh	14.48	86880	0.101	403.2	0.117	1752	0.224	1120	0.031	312	0.285	4272
Total		6482910		45217.2		184643.25		131491		39526.5		206515.5

Note: The cost calculations are based on per ton farm gate price of Rs. 6000, Rs. 4000, Rs. 15,000, Rs. 5000, Rs. 10000 and Rs. 15000 for rice, millet, pulse, onion, chilli and oil seeds, respectively.

Table A1.3: Total Financial Cost of Agricultural Loss due to 1999 Super Cyclone

PARTICULARS	LOSSES (RS. CR.)
Agriculture	709.03
Horticulture	1083.74
Animal Husbandry	156.01
Fisheries	141.03
Total	2089.82

Annexure A2

Table A2.1: Wind Speed and Storm Surge of Cyclones along Indian Coast

Date	State	**District(s)**	**Max Wind Speed (Kmph)**	**Min Wind Speed (Kmph)**	**Storm Surge (metres)**
1952 Nov. 30	Tamil Nadu	Thanjavur	NA	NA	3
1955 Dec. 1	Tamil Nadu	Thanjavur	NA	NA	5
1964 Dec. 23	Tamil Nadu	Ramanathapuram	193	NA	6
1967 Dec. 8	Tamil Nadu	Thanjavur	130	NA	NA
1969 Nov. 7	Andhra Pradesh	East Godavari	NA	176	2.6
1971 Oct. 30	Orissa	Cuttack	167	150	4
1971 Oct. 1	West Bengal	North 24 Parganas	NA	NA	NA
1971 Sep. 10	Orissa	Ganjam, Puri & Cuttack	NA	NA	NA
1972 Dec.1 to 8	Tamil Nadu	South Arcot	148	111	NA
1972 Nov. 15 to 23	Andhra Pradesh	Nellore	148	111	NA
1972 Sep. 7 to14	Orissa	Ganjam	204	NA	3.4
1974 Aug. 20	West Bengal	Medinipur	139	NA	NA
1975 Oct. 22	Gujarat	Junagarh	NA	NA	6
1976 May 29 to Jun. 5	Gujarat	Bhavnagar	NA	NA	NA
1976 Nov. 15 to 17	Andhra Pradesh	Nellore	259	222	NA
1976 Nov. 3 to 6	Andhra Pradesh	Krishna	NA	NA	NA
1976 Sep. 11	West Bengal	Medinipur	148	NA	2.5
1977 Nov. 19	Andhra Pradesh	Nellore	259	NA	5
1977 Nov. 8 to 12	Tamil Nadu	Thanjavur	120	NA	NA
1978 Nov. 24	Tamil Nadu	Ramanathapuram	212	NA	4
1979 May 12 & 13	Andhra Pradesh	Nellore	189	100	12
1981 Dec. 4 to 11	West Bengal	North 24 Parganas	NA	NA	NA
1982 May 31 to Jun. 5	Orissa	Cuttack	NA	NA	2
1982 Nov.	Gujarat	Junagarh	NA	NA	3.5
1982 Oct. 16 to 21	Andhra Pradesh	Nellore	NA	NA	NA
1984 Nov. 9 to 14	Andhra Pradesh	Nellore	NA	NA	NA
1987 Oct. 14 to 19	Andhra Pradesh	Nellore	NA	NA	NA
1987 Oct. 31 to Nov. 3	Andhra Pradesh	Nellore	NA	NA	NA
1989 May 23 to 27	Orissa	Baleshwar	NA	NA	NA

1989 Nov. 4 to 7	Andhra Pradesh	Nellore	NA	NA	NA
1991 Nov. 11 to 15	Tamil Nadu	Thanjavur	NA	NA	NA
1992 Nov. 11 to 17	Tamil Nadu	Chidambaranar	NA	NA	NA
1993 Dec. 1 to 4	Tamil Nadu	Thanjavur	NA	NA	1.5
1994 Oct. 29 to 31	Tamil Nadu	Madras	NA	NA	2
1995 Nov. 7 to 10	Orissa	Puri	NA	NA	1.5
1995 Nov. 7 to 10	Andhra Pradesh	Srikakulam	NA	NA	NA
1996 Jun. 17 to 20	Gujarat	Amreli & Junagarh	NA	NA	6
1996 Jun. 12 to 16	Andhra Pradesh	Visakhapatnam	NA	NA	NA
1996 Nov. 5 to 7	Andhra Pradesh	East Godavari	NA	NA	3