

The Economics of Climate Change

*A Review of Studies in the Context of South Asia
with a Special Focus on India.*

Prepared by

Joyashree Roy
Professor of Economics
Coordinator- Global Change Programme-JU
Jadavpur University
Kolkata. India

Assisted by

Anupa Ghosh (Ph.D Student , Department of Economics, JU)
Gopa Barua (Research Assistant, Global Change Programme , JU)

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Summary

Lack of response and action to climate change in South Asian Region is limited by the availability of information about the balance between economic costs of damage and benefits of reductions of damages in the short run. Climate variability and its impact will unfold in the longer run so the real challenge is how to integrate it to the short run development agenda which is of top priority for developing countries both economically and politically. The purpose of this summary is to come up with a review of the existing studies on direct impact assessment of climate variability predictions on income, human development and the environment in the context of countries in South Asia and/or the region as a whole. This is expected to highlight the gap in the literature and need for prioritization of future research agenda.

Over almost a decade a fast growing literature is adding value to the growing knowledge on climate variability and its impacts in the context of South Asian Region. However, in preparation of this review we have tried to concentrate only on those literature which helps us in making assessment of damage costs (adaptation cost) of climate variability and the abatement cost (Mitigation cost) assessment. In the process we have not only concentrated on climate research reports rather natural calamity and disaster related reports have also been consulted.

The text below provides the summary of the potential direct impact of climate change/variability on income, human development and the environments.

- **Regional Climate Model results** for India (more accurate than GCM results¹) predict² :
 - 3-5° C rise in mean surface temperature under A2 scenario and 2.5-4 C under B2 scenario.
 - 20% rise in summer monsoon rainfall
 - Extreme temperatures and precipitations are expected to increase
 - Both day and night temperature are going to increase. But nights are going to be warmer.
 - Regionally within India
 - northern India will be warmer.
 - All states will have increased rainfall except Punjab, Rajasthan, Tamil Nadu where it will decrease.
 - Extreme precipitations will increase particularly in west coast and west central India
 - Wetter Forest types in NE and drier in NW predicted to increase

- **Hydrological cycle** is likely to be altered. Drought and flood intensity will increase. Over all run off will decline. Krishna, Narmada, Cauvery, Tapi river basin will experience severe water stress and drought condition

¹ All assessment statements within the brackets show level of confidence. The assessment statements are in IPCC format and based on assessment by the authors of the report.

² About models:

RCM: based on PRECIS developed by Hadley Centre for climate predictions. It takes care of features at finer scale, takes better care of summer monsoon. The horizontal resolution is (1.24 D latitude x 1.88 D longitude in the driving GCM) .44 D x .44 D nominal resolution is 50 km. X 50 km (for GCM 150x 150). The results from RCM with high resolution for SA region are more reliable than other global models (detailed discussion are in Rupa Kumar et al. 2006) and can predict extremes better.

Distributed hydrological Model **SWAT** (soil and water Assessment Tool) has been used to simulate hydrological conditions for twelve river systems in India. It does take natural parameters like soil characteristics and current land use but do not consider man made interventions like dams/diversions, predictions of land use pattern change. So the results provide limited evidence.

BIOME 4 Model is successor of BIOME 3 and uses data on temperature, precipitation and sunshine hours. It has been customized to accept location specific data. Model is sensitive to CO2 concentration. It also uses water holding capacity and depth of the top soil. The model results will be biased by the level of uncertainty in climate predictions models.

For agricultural impact analysis Controlled environment facilities, such as open top chambers, phytotron, & greenhouses (Free Air CO2 Enrichment (FACE) is being used to understand the impact of temperature, humidity & CO2 on crop growth & productivity by the Indian Agricultural Research Institute, New Delhi. Interactive effects of CO2, rainfall & temperature is studied through the use of crop growth simulation models. Models of various crops : for rice, the ORYZA series of models have been effectively used. For wheat, Indian models such as the Wheat Grown Simulator (WTGROWS) have been the basis of a large number of studies. InfoCrop a decision support system has been developed. These models are not rich in defining social economic parameters.

For economic welfare impact assessment both econometric as well as CGE kind of models have been used but mostly they are regional and global with adjustments for agriculture sector. Even if they are developed for Indian economy have not considered either trade sector or price adjustments properly. For some of the models details are not in the public domain. Most of the studies have tried to include CO2 fertilisation effect and have found positive response if taken partially.

For Malaria study no specific mathematical or computer simulation model have been used. Climate change projections have been linked to spatial distribution of malaria and transmission windows based on the analysis of interdependence of temperature, precipitation, humidity and growth pattern of vector species and current incidence of malaria.

and Mahanadi, Godavari, Brahmani will experience enhanced flood. (limited evidence³).

- Temperature rise scenario upto 3 degree C shifts the sowing season onwards. Shifting in sowing season appropriately is suggested adaptation strategy (Kalra et al, 2003)(High agreement) .
- Crop yield decrease with temperature and rise with precipitation. (high agreement). Prediction of loss of wheat is more. *Rabi* crops will be worse hit which threatens food security. In India kharif accounts for 78% cereal production and Rabi 72% of food production.
- Increased CO₂ levels tend to decrease the adverse impacts of climate change. CO₂ increase will raise yield with moderate to high temperature i.e under optimistic scenario (medium information, high agreement).
- The magnitude of beneficial effect of elevated CO₂ is significantly reduced under water stress conditions. Net predictions for Indian agriculture is decrease in yield i.e, overall effect of temperature, rainfall and CO₂ is expected to be negative (High agreement).
- Warming increases pest attacks and reduces activities of natural enemies and causes loss of yield. (limited evidence, high agreement) .
- Overall offset effect in crop productivity decline induced by decline in crop duration under pessimistic scenario. (high agreement, medium evidence).
- Economic loss (revenue loss) despite farm level adaptation due to temperature rise between 2-3.5 ° C may be between 9-25% . (limited agreement and limited evidence). GNP loss may be to the tune of even if trade effects are considered 0.67%. (limited evidence) Coastal agriculture suffers most (Gujrat, Maharashtra, Karnataka), Punjab, Haryana, Western UP will face reduction in yield, West Bengal, Orissa, Andhra Pradesh gains marginally (limited evidence). 100 cm sea level rise can lead to welfare loss of US\$ 1259 million in India equivalent to 0.36% of GNP. (limited evidence)
- Under A2 and B2 scenarios there will be shifts towards wetter forest types. Due to CO₂ increase and warming NPP will double under A2 and 70% under B2 scenario (high agreement).
- Frequencies and intensities of tropical cyclones in Bay of Bengal will increase particularly in post monsoon period and increased flooding in low lying coastal areas. (much evidence) . Sea level rise predicted of

³ 'Limited' evidence means either the studies existing have limitations in underlying models or data coverage say: small sample/case studies which may not be generalised. 'Medium' evidence means there is till scope for improvement. Degree of (Low, medium , High) agreement means various studies maybe with comparable or non comparable models have similar findings or the perceptions of stake holders are dissimilar/similar.

less than 1mm/yr for Mumbai Visakhapatnam and Kochi (much evidence) but decrease in Chennai (limited evidence).

- Malaria will continue to be endemic in current Malaria-prone states (Orissa, West Bengal and Southern Parts of Assam ordering north of West Bengal). It may shift from the central Indian region to the south western coastal states of Maharashtra, Karnataka, Kerala. New regions (States like Himachal Pradesh, Arunachal Pradesh, Nagaland, Manipur and Mizoram) will become malaria prone and transmission duration window will widen in northern and western states and shorten in southern states. (limited evidence). Transmission window is open only for 4 months if both temperature & relative humidity are considered, while it is open for 8 months if only temperature is considered. Due to climate change in developing countries malaria incidence will increase by 5-15% (limited evidence).
- Besides malaria other vector borne diseases like kal –a zar, dengue, etc will be on rise . Extreme weather related health effects like diarrhea, cholera, heat stroke etc will be more and malnutrition due to threat to food security will be higher.
- Desertification will increase (limited evidence).
- Increased bleaching and mortality of coral reefs predicted.(limited evidence).
- Carbon mitigation cost curve for India for 2005-2035 has been estimated as upward rising non linear (limited Evidence).
- Annual total outlay for natural disaster related relief fund of GOI accounts for 0.3% of GDP. (Conservative estimates) This is in actual much bigger if other allocation of private and NGO's are taken. 80% of this can be taken as transfer of investible fund as it leads to dissaving, comes under revenue account (high agreement, limited evidence).
- Average flood causes death of 0.11% cattle population (major asset of Rural India) , 0.0015% human life. (Conservative numbers). Under climate change condition this will increase.
- Average drought affects 25% of population and 33% of India is drought prone. (Conservative numbers)
- Flood and drought increases
 - Indebtedness of households (high agreement, limited evidence).
 - Dissaving (high agreement, limited evidence)
 - Migration (high agreement, limited evidence)
 - Inflation (high agreement, limited evidence)
 - Water borne disease especially in flood (high agreement, limited evidence). Currently 70% of epidemic emergencies are due to water borne diseases. Cost burden to avoid water borne

disease per household ranges between Rs 187-1457/- per month. (high agreement, limited evidence).

- Evidence from Bangladesh flood and Pakistan drought shows GDP growth declines (limited evidence) 1%-5%
 - Vulnerability of the marginal farmers. 59% (2001) of land holdings in India are Marginal (below 1 hectare of land) farm holdings.
- Incidence of loss are shared by (medium evidence and high agreement)
 - Government (by way of loan, wage labour days creation, relief operation, budgetary provision for calamity, infrastructure construction)
 - NGOs through relief operation for (food, clothings, health services)
 - Communities (food, clothings)
 - Individual households
 - Both Reactive and pro active actions work but proactive actions helps through creation of adaptive capacity and reduction in the incidence of loss (medium evidence).
 - Actions with high priority to enhancement Adaptive capacity (to cope with extreme events in the short run and simultaneously help achieve development objectives). Among many others (mentioned in the text) highest priority needs to be on investment in infrastructure creation like (wide agreement, much evidence)
 - good quality all weather roads both urban as well as rural,
 - access to drinking quality water in both urban and rural areas,
 - strengthening of public distribution network/system especially in rural areas,
 - alternative occupation opportunity creation in rural areas.

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Introduction

South Asia (SA) includes the Indian sub continent (India, Pakistan, Bangladesh and Nepal) as well as Sri Lanka, Maldives and Bhutan. It is argued that SA region is particularly vulnerable to predicted climate change impacts because of its population load, low adaptive capacity, several unique and valuable ecosystems (coral reef, large deltaic region with rich biodiversity) and vast low altitude agricultural activities. Although SA region comprises of 3% of land area globally it houses more than 20% of the global population. India alone accounts for almost 75% of the landmass. IPCC –TAR among other regions have identified SA region as critical area of water stress.

Prioritisation and actions towards reduction of climate change is much less than desired. Among other reasons globally, sometimes actions in SA region is limited by the lack of enough information on the balance between economic costs and benefits of reductions. Knowledge on 'damage avoided' can only induce optimum or near optimum actions. Since cost of reduction of climate change effects are measured in monetary units and investment decisions are based on monetary valuation damage assessment also needs to be done in monetary units. Actions get deferred due to uncertainty of magnitude of impacts and non-uniformity of impacts across regions and within the region also across economic agents and micro level stake holders. Climate prediction are in longer term perspective but in developing countries short to medium term objectives over ride the longer term objectives and climate change related issues are pushed back in terms of prioritisation.

Aim and Scope

Aim of the present report is to produce an assessment of monetary valuation of impacts (primarily damages) -mainly the monetary valuation- due to climate change trend and extremes. Focus is on South Asian region and India in particular. With its huge and growing population, a 7500-km long densely populated (DOD. 2002) and low-lying coastline and an economy that is closely tied to its natural resource base, India is considerably vulnerable to the impacts of climate change.

Literature

The past decade has produced vast literature on study of climate variability, and impacts. However, the literature covered in this assessment are selected keeping in view the aim and scope of this assessment. Text that follows is heavily based on the review of the literature listed in Table 1 and the list in the Bibliography. Over almost a decade a fast growing literature is adding value to the growing knowledge on climate variability and its impacts in the context of South Asian Region. However, in preparation of this review we have tried to concentrate only on those literature which helps us in making assessment of damage costs (adaptation cost) of climate variability and the abatement cost (Mitigation cost) assessment. In the process we have not only concentrated on climate research reports rather natural calamity and disaster related reports have also been consulted.

Table 1. List of Literature

Reference	Region	Country coverage	Climate factor	Sector of study
Mendelsohn (2005)	South and South East Asia	India, Bangladesh, Nepal, Pakistan, Sri Lanka	Climate warming scenarios,	Impact on agricultural GDP
Okamoto et al (2005)	South and South East Asia	India, Bangladesh	NPP	Impact on agricultural productivity
GOI (2004)	India	India	Temperature, precipitation	Impact on agricultural productivity
Shukla, P.R., Sharma, S. K., Ramana, P. V. and Bhattacharya, S (2002)	India	India	Temperature, precipitation, CO ₂	GDP
Saseendran et al (1999)	India	India	Temperature	productivity
Lal et al (1995)	India	India	Temperature	productivity
Kumar and Parikh (1998)	India	India	Temperature	Revenue, price, yield
Sanghi et al, (1998)	India	India		revenue
Lonergan S (1998)	India	India	Temperature, CO ₂	Climate variability
Shukla, P.R., et al (2002)	India	India	Climate parameters	Macro
Roy et al 2005	India	India	Extreme events	Households
Sharma et al 2004	India	India	India	Households
Ghosh and Roy 2006			India	Households
Muhammed 2004	South Asia	India, Bangladesh, Nepal, Pakistan	India	Households
Mitra 2004	South Asia	India, Bangladesh, Nepal, Pakistan	India	Households
Gosain (2006)	India	India	hydrology	12 river basins
Ravindranath (2006)	India	India	Forestry	India
Unnikrishnan (2006)	India	India	Sea level	Indian coast
Rupa Kumar (2006)	India	India	Climate predictions	India
Bhattacharya (2006)	India	India	Malaria	India

Observed Climate variability

Temperature

1. There has been a general rising **trend** in surface temperature in the order of $0.5^{\circ}\text{C} \pm 0.1^{\circ}\text{C}$ over the entire SA region during the past century.
2. For India warming of $0.4^{\circ}\text{C}/100$ years in mean annual temperature has been observed during 1901-1982. But this is not spatially uniform.
3. Winter is becoming milder.
4. Warming has been observed in Bangladesh, Nepal and Pakistan also.
5. In Nepal trend is higher in higher latitudes 0.6°C to 1.2°C per decade
6. Pakistan has experienced cooling -0.4°C to -2.6°C and warming 0.1°C to 4.0°C both.
7. Bangladesh experiencing moderate increase in post monsoon and strong warming (0.1°C - 0.3°C / per decade) in monsoon seasons
8. For India, Bangladesh and Pakistan rise in temperature is attributed to increase in maximum temperature while in Nepal amplitude of variation in minimum temperature is significantly more than maximum temperature .

Rainfall

1. No significant trend exists in all-India rainfall over the period of record (since 1871).
2. Changes are observed in smaller spatial scales.
3. Inter annual variability is SA feature
4. Weak Monsoon, negative Southern oscillation Index, El nino over a century
5. Strong monsoon and La nina
6. Dry regions getting Drier by 10% in last 100 years.
7. Vulnerable areas are areas are IGP, Bangladesh, Assam, Sabarmati

Extreme events

1. Extreme hydro meteorological events frequently occur in south asia.
2. GLOFFs are common
3. Instrumental records over 130 years do not show any significant long term trend on frequency in large scale drought or flood.
4. Over Bay of Bengal, Arabian Sea significant and consistent warming of sea surface has occurred during twentieth century.
5. More cyclones occur in Bay of Bengal than in Arabian sea.
6. Bangladesh has suffered from more storm surges.

Climatic Variability Predictions: trends and extremes

Temperature

Loneragan S (1998) estimates that India's climate could become warmer under conditions of increased atmospheric carbon dioxide. The average temperature change is predicted to be in the range of 2.33°C to 4.78°C with a doubling in CO_2 concentrations.

Lal M, Cubasch U, Voss R, Waszkewitz J (1995) present a climate change scenario for the Indian subcontinent, taking projected emissions of greenhouse gases and sulphate aerosols into account. It predicts an increase in annual mean maximum and minimum surface air temperatures of 0.7° C and 1.0° C over land in the 2040s with respect to the 1980s. Since the warming over land is projected to be lower in magnitude than that over the adjoining ocean, the land-sea thermal contrast that drives the monsoon mechanism could possibly decline. However, there continues to be considerable uncertainty about the impacts of aerosols on the monsoon. So the scientific information on possible impact of decline in monsoon is uncertain.

Results (Rupa Kumar et al. 2006, Sathaye et al. 2006) from Regional climate model (RCM) which is realistically designed for South Asian Region, applied for India under A2 and B2 scenario shows, by the end of century :

- 3-5 C rise in mean surface temperature under A2 scenario and 2.5-4 C under B2 scenario.
- Extreme temperatures and precipitations are expected to increase .
- Both night and day temperature are going to increase but nights will be warmer in future scenario.

- Regionally
 - northern India will be warmer.
 - Wetter Forest types in NE and drier in NW predicted to increase

Rainfall

There will be an increase in the frequency of heavy rainfall events in South and Southeast Asia (IPCC 1998).

By the year 2050, the average annual runoff in the river Brahmaputra will decline by 14 %. Studies have indicated that the impact of snow melting in the high Himalayas will lead to flood disasters in Himalayan catchments. Impacts will be observed more in the western Himalayas as the contribution of snow to the runoff of major rivers on the western side is about 60 % compared to 10 % on the eastern side (IPCC. 2001). Singh (1998) suggests that an increase in surface temperatures will lead to a rise in the snowline, increasing the risk of floods in North India during the wet season. In longer run rivers that are dependent on snow melt will have less water.

Rupa Kumar et al 2006 predicts 20% rise in summer monsoon rainfall in Indian sub continent. All states will have increased rainfall except Punjab, Rajasthan, Tamil Nadu where it will decrease. Extreme precipitations will increase particularly in west coast and west central India.

Extreme events

More frequent and record extremes (droughts, flood, storms, cyclone) are expected to occur even at 2° C rise in Global mean temperature. Increasing susceptibility to droughts in western parts of Indo Gangetic Plains (IGP) while increased monsoon activity in eastern part are predicted.

Major concerns

1. Monsoon governs the hydrological system of the South Asian region.
2. Low latitude regions of the world will be vulnerable to climate change because of agricultural density and already hot temperature. South Asian agriculture amounts to over 50% of all low altitude agriculture.
 1. Crop agriculture will be severely constrained
 2. Extreme rainfall events of 1-day, 2-day, 3-day events will increase
 3. Indo-gangetic plain identified as the most vulnerable area with highest population density.
 4. Region is characterised by many large river systems
 5. Cross border river, mountain and glacial systems and easy migration potential of people adds a special dimension
 6. Monsoon dependent agriculture still the single most contributor to the economy, livelihoods, and is the most vulnerable activity.
 7. Rising stress on water resources due to population growth and urbanisation
 8. Residential sector continues to show rising energy intensity trend.
 9. Due to low coping capacity of poor people, they are the most vulnerable.
 10. The mean temperature in India is projected to increase by 0.10 C to 0.30C in *kharif* (summer) and 0.30C to 0.70C in *rabi* (winter) by 2010 and to 0.40C to 2.00C in *kharif* and 1.10C to 4.50C in *rabi* by 2070 (IPCC, 1996). Mean rainfall is projected not to change by 2010 but may increase by 10% during *rabi* by 2070.
 11. The cereal yield of 2050 is estimated to increase to 4.1 times than in 1961 and 1.7 times than in 1999. But population growth is expected to balance out the per capita availability if food trade and arable land remain unchanged.
 12. Uneven distribution of NPP in South Asian Countries will possibly cause regional differences in predicted cereal yields and socio economic impacts.

Economic Impact Assessment: Market and Non Market Sectors

Ideally economic impact assessment is expected to cover monetary valuation of the impacts (damaging as well as beneficial) of climate variability covering both market (agriculture, forest, fishery) and non market sectors (health, biodiversity, ecosystems). The economic indicators range from income, employment, expenditure and extended to poverty indices. Over past one decade vast literature has emerged discussing the possible impacts of climate variability. Methodology for economic assessment of externality is also taking a mature shape in the environmental economics literature (appendix I). However, despite all these almost none of the studies have attempted to

study the impact of climate change through economic assessment exclusively for South Asian Region. Only a handful of studies have covered south-east Asian countries (Table 1) that covers south Asian countries partially or have extrapolated the results obtained for India to SA region. Most of the studies available are for India. That too are limited so far economic assessment is concerned. Productivity loss studies due to climate variability and extremes have been attempted by a number of researchers (Table 1). Only a few studies Kumar and Parikh, Shukla et. al. (various references), Roy et al. have tried to estimate economic damages taking a number of economic indicators like GDP, revenue, price, yield, expenditure. These studies cover both macro level impact assessment as well as micro impact assessment. Some of the micro level studies have been done in the context of a number of countries either applying same methodology (Roy et. al, Ghosh and Roy, 2003, Sharma et al. 2003, Muhammed 2003) or different methodologies. Micro level studies are mostly extreme event related studies through analysis of past damages or based on peoples perception survey or stakeholder interview method. These studies cover mostly rural areas. Several indicators like livelihood, income, adaptive actions, livestock loss, health etc. have been tried out. Macro studies are based on varying climate scenarios and based on alternative socio economic scenarios and try to assess the impacts on either the aggregate economy or sectoral impacts.

Methodologies adopted differ across studies leaving rare scope for comparison. The two groups of literature: climate change studies and disaster related damage studies have used macro models and micro analytical study models. Macro studies have tried Top down approaches as well as bottom up approaches.

I. Climate Change Literature: South Asian Region with Special Reference to India

Climate change associated variables such as CO₂ & temperature can influence food availability through their direct effects on growth processes & yield of crops and through indirect effects. A number of studies have focused on impacts on agriculture and food security of predicted changes in climate parameters.

For South East Asian Region, Mendelsohn (2005) has applied Global Impact Model (GIM). The model has been developed to measure country level impacts of climate change with two types of climate response functions: Ricardian analysis of Indian agriculture and Experimental Crop Simulation models. He has extrapolated the Indian results for all the countries in the region. The model computes economic impacts. The model is based on baseline agricultural net revenues determination. The Ricardian function assumes quadratic combination of seasonal temperature and precipitation variables estimated from district level data which includes soil and other control variables. Welfare is a simple function of climate. Simulation models makes crop simulation results more climate sensitive as local adaptation is not included in this model as in the former based on cross section data. Carbon fertilisation effects are included in the crop simulation models which is

not there in cross section models. Latter has been adjusted by the assumption that 30% rise in productivity due to doubling of carbon fertilisation. Three climate scenarios (temperature and precipitation) for 2100 have been tested: PCM, CCSR and CCC. Besides India this study through extrapolation provides Agricultural GDP measures for Bangladesh, Nepal, Pakistan, Sri Lanka. Estimates show that Indian agriculture can lose up to \$87 billion in the CCC scenario. With the experimental response function GDP loss is expected to be over half.

Okamoto et al (2005) uses Climatological methods to study past and present Net Primary Productivity (NPP) or carbon biofixation of locations with major cereals. For India and Bangladesh in South Asian region. Difference between present and mid 21st century NPP is used as climate index to predict trend cereal productivity in the 21st century. The present NPP is calculated using IIASA climate data. NPP in mid 21st century is from GCM.s. For India NPP is predicted to rise 0.8-1.2 times and for Bangladesh it is expected to decline by 0.4-1.0 times due to uneven rainfall.

The NPPs of the cropland and the total land areas were generally estimated to be lower than the present NPPs for South Asian countries, viz, India and Bangladesh. This is considered to be due to the uneven distribution of rainfall. Three possible scenarios for projecting changes in NPPs: first an optimistic scenario in which maximum of GCM outputs used as NPPs second a moderate scenario in which mean outputs of GCMs are used as NPPs and pessimistic scenario in which minimum output of GCMs are used as NPPs. The cereal yield of 2050 is estimated to increase to 4.1 times than in 1961 and 1.7 times than in 1999. But population growth is expected to balance out the per capita availability if food trade and arable land remain unchanged. For Bangladesh cereal production will rise 2.1 times than 1961 and 1.3 times than 1999 as against population growth of 4.1 times and 1.7 times. Consequently Bangladesh will need to depend more on cereals import. Uneven distribution of NPP in South Asian Countries will possibly cause regional differences in predicted cereal yields and socio economic impacts.

Carbon fertilization continues to be a source of controversy in the literature, however, as some researcher finds that carbon-di-oxide field experiments yield lower return (Mendelsohn, 2005). Positive effect of CO₂ fertilisation has been shown by a number of studies (Kalra et al 2003, Dawin Kennedy 2000, Pohit 1997) in Indian context but the net effect on yield due to temperature rise has been shown to be negative.

The regional wheat yields shows a considerable relation with temperature beyond 2°C increase in temperature, the decrease in grain yield of wheat was very high. A 2°C increase in temperature resulted in 15%-17% decrease in the grain yield of both crops. the loss in farm-level revenue may range between 9% & 25% for a temperature rise of 2°C -3.5°C.

India specific studies

Impacts (GOI 2004) : The results uses climate scenarios predicted from RCM⁴ (Rupa Kumar et al) and are derived from) SWAT model (Gosain et al. 2006), Biome4 (Ravindranath et al. 2006), simulations for mean sea level (Unnikrishnan et al. 2006), Malaria Transmission window analysis (Bhattacharya et al 2006) and simulations based on dynamic crop models (GOI 2004)

- Hydrological cycle is likely to be altered. Drought and flood intensity will increase. Over all run off will decline. Krishna river basin will experience severe drought condition and Mahanadi flood.
- Crop yield decrease with temperature.
- CO2 increase will raise yield with moderate to high temperature
- **[Overall offset effect is crop productivity decline induced by decline in crop duration.**
- **Under A2 and B2 scenarios there will be shifts towards wetter forest types. Due to CO2 increase and warming NPP will double under A2 and 70% under B2 scenario for the forestry sector**
- Frequencies and intensities of tropical cyclones in Bay of Bengal will increase particularly in post monsoon period and increased flooding in low lying coastal areas. Sea level rise predicted of less than 1mm/yr for Mumbai Visakhapatnam and Kochi (much evidence) but decrease in Chennai .

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- Malaria prone states will continue to be so (Orissa, West Bengal and Southern Parts of Assam ordering north of west Bengal). It may shift from the central Indian region to the south western coastal states of Maharashtra, Karnataka, Kerala. New regions (States like Himachal Pradesh, Arunachal Pradesh, Nagaland, Manipur and Mizoram) will become malaria prone and transmission duration window will widen in northern and western states and shorten in southern states.
- Desertification will increase
- Carbon mitigation curve (Sathaye et. Al. 2006) for India for 2005-2035 has been estimated as upward rising non linear.

Agriculture

Agriculture and allied activities constitute the single largest component of India's economy, contributing nearly 27% of the total Gross Domestic Product (GDP) in the year 1999-2000 (TERI. 2002). Agriculture exports accounts for 13 to 18% of total annual exports of the country (Ministry of Finance. 2002). However, given that 62% of the cropped area is still dependent on rainfall (MOEF. 2002), Indian agriculture continues to be fundamentally dependent on the weather. The impacts of climate change on agriculture are critical in India. Despite rapid industrialization, India is still predominantly dependent on agriculture. Not only does this sector provide food for India's large population, but it also accounts for more than 30 percent of gross national product. As some 75 percent of the population lives in rural areas, agricultural performance is closely related to poverty levels. The focus is on India's two main cereal crops—rice and wheat—in terms of the effects of climate change on crop yields, overall food production, and welfare.

Shukla, P.R et al predicts that either direct effects due to changes in temperature, precipitation or CO₂ concentrations or indirect effects through changes in soils, distributions and frequency of infestation of pests, water stress, etc. there will be decline in GDP for India. The adaptability of farmers in India are severely restricted by the heavy reliance on natural factors and the lack of complementary inputs and institutional support systems which adds to the worsening of the scenarios.

A major source of literature is National communication of the Government of India (2004) where most of the results focus on productivity loss estimates but very little on economic valuation associated with those productivity loss estimates.

Methodology

- 1) Controlled environment facilities, such as open top chambers, phytotron, & greenhouses, are now increasingly being used to understand the impact of temperature, humidity & CO₂ on crop growth & productivity. One such facility is Free Air CO₂ Enrichment (FACE) facility which has recently been set up at the Indian Agricultural Research Institute, New Delhi to study the effect of increased CO₂ on crop photosynthesis & yield.
- 2) Interactive effects of CO₂, rainfall & temperature can be studied through the use of crop growth simulation models.

- 3) Models of various crops included in the Decision support system for Agro-technology Transfer (DSSAT) shell have been the most popular.
- a) for rice, the ORYZA series of models have been effectively used.
 - b) For wheat, Indian models such as the Wheat Grown Simulator (WTGROWS) have been the basis of a large number of studies.
 - c) InfoCrop is an indigenous decision support system, based on crop models that have been developed recently at the Indian Agricultural Research Institute.

Impacts predicted: Agriculture sector

The mean temperature in India is projected to increase by 0.10 C to 0.30C in *kharif* (summer) and 0.30C to 0.70C in *rabi* (winter) by 2010 and to 0.40C to 2.00C in *kharif* and 1.10C to 4.50C in *rabi* by 2070 (IPCC, 1996). Mean rainfall is projected not to change by 2010 but may increase by 10% during *rabi* by 2070. At the same time, there is an increased possibility of climate extremes, such as the timing of onset of monsoon and intensities and frequencies of droughts and floods. Agricultural productivity can be affected by climate change in two ways: first, directly, due to changes in temperature, precipitation and/or CO₂ levels and second, indirectly, through changes in soil, distribution and frequency of infestation by pests, insects, diseases or weeds. Acute water shortage conditions, combined with thermal stress, could adversely affect wheat and, more severely, rice productivity in India even under the positive effects of elevated CO₂ in the future.

Simulation of four different sites (Kalra et al 2003, GOI 2004) under various climate change scenarios for each crop suggest (a) that the yields of both crops –rice and wheat- would decrease with a rise in temperature levels and increase with a rise in precipitation; (b) that higher CO₂ concentrations in the atmosphere would have beneficial effects for both crops by increasing the rate of photosynthesis, radiation use efficiency, and water use efficiency and (c) that increased CO₂ levels would be more favourable for wheat than for rice. Overall, the simulation suggests the following:

- Both rice & wheat showed a small positive effect with an increase in yield between 1% & 5%. The effect remained positive (5% to 20%) in the case of rice, even by 2070, due to the effect of a large increase in CO₂ compared to a relatively small reduction in *kharif* temperature. By comparison, the effect on wheat could be positive (up to 25%) or negative (up to 30%), depending upon the magnitude of the change in CO₂ & temperature. Since there is greater probability of increase in temperature in *rabi* , it is likely that the productivity of wheat & other *rabi* crops would be significantly reduced.
- That wheat, which is generally grown in the winter, is more likely to be affected than rice
- That increased CO₂ levels tend to decrease the adverse impacts of climate change
- That the net yield losses in rice under irrigation could be some 13–22 percent, compared with losses of 16–34 percent for wheat. This is the overall net effect.

- An increase in temperature may have significant effect on the quality of cotton, fruits, vegetables, tea, coffee, aromatic & medicinal plants etc. the nutritional quality of cereals & pulses may also be moderately affected by this change in temperature.
- The reductions in grain yield of crops due to increase in temperature can be offset by the rise in CO₂, the magnitude of this response varied with crop, region & climate change scenario. This is possible due to the fertilizing effect of CO₂ on crop growth.
- The decline in grain protein content in cereals could partly be related to increasing CO₂ concentrations.
- The highest increase in temperature & lowest increase in CO₂ are detrimental to crop growth & hence, is known as a **pessimistic scenario**.
- **Aphid** is a major pest of wheat & its occurrence is highly influenced by weather conditions. In case the weather limits their growth, the production losses could get further magnified.
- The appearance of **black rust** in northern India in the 1960's & 1970's was related to the **temperature-dependent movement of spores** from southern to northern India.
- Several pathogens such as the **phytophthora & puccinia group** produce an abundance of propagules from the infected lesion or spot. Such pathogens & pests are highly sensitive to even minor changes in temperature, humidity & sunlight. Any change in weather conditions reduce the incubation period.

Some crop specific results :

The impact analysis was extended for various cereal crops in different regions for the climate change scenarios of 2010. The results showed that

- (a) Irrigated **rice** yields register a small gain irrespective of the scenario at all places in India.
- (b) **Sorghum**, being C4 plant, does not show any significant response to increase in CO₂ & hence the different scenarios do not affect its yield.

However, if the temperature increases are higher, western India may experience some negative effect on productivity due to reduced crop durations. This effect can be mitigated easily by using varieties that are of relatively longer duration.

- The magnitude of beneficial effect of elevated CO₂ was significantly reduced under water stress conditions. Global warming will push the snow line higher & dense vegetation will shift upwards.

Atmospheric CO₂ concentration has to rise to 450 ppm to nullify the negative effect of a 1°C increase in temperature, & to 550 ppm to nullify the 2°C increase in temperature.

- (c) **Wheat** yields in central India are likely to suffer by up to 2% in the pessimistic scenario but there is also a possibility that these might improve by 6% if the global change is optimistic (note: pessimistic

are those that uses GCM's lowest output and optimistic are those that uses highest output.

- (d) Increased climatic variability may affect our rainfed crops, such as pulses, significantly. Considering the response of **soybean**, an increase 3°C in temperature nullified the positive effect of doubled CO₂ on yield.
- (e) With small changes, the virulence of different of pests changes. For example, at 16°C the length of the latent period is small for yellow rust. Once the temperature goes beyond 18°C, this latent period increases but that of **yellow & stem rusts** decreases.
- (f) Changes even to the extent of 1°C in maximum or minimum temperature will make a great deal of difference between moderate & severe terminal disease development.
- (g) **The swarms of locust** produced in the middle east usually fly eastward into Pakistan & India during the summer & they lay eggs during the monsoon. Changes in rainfall, temperature & wind speed pattern may influence the migratory behaviour of the locust.
- (h) Most crops have C₃ photosynthesis (responsive to CO₂), while many weeds are C₄ plants (non-responsive to CO₂). The climate change characterized by higher CO₂ concentration will favour crop growth over weeds, although temperature increase may further accelerate crop-weed competition depending upon the threshold temperatures in different locations.
- (i) Temperature increase associated with global warming will increase the rate of **snow melting** & consequently snow cover will decrease. In the short term, this may increase water flow in many rivers that, in turn, may increase lead to increased frequency of floods, especially in those systems where water carrying capacity has decreased due to sedimentation.
- (j) In the long run, however, a receding snow line would result in **reduced water flow in rivers**.
- (k) Changes in **soil water** induced by global climate change may affect all soil processes & ultimately, crop growth.
- (l) An increase in temperature would also lead to increased evapotranspiration, which may result in the **lowering of the groundwater table** at some places.
- (m) Increased temperature coupled with reduced rainfall may lead to upward water movement, leading to **accumulation of salts in upper soil layers**.
- (n) A **rise in sea level** associated with increased temperature may lead to salt-water ingression in the coastal lands, making them unsuitable for conventional agriculture.
- (o) An increase of 1°C in the soil temperature may lead to **higher mineralization**.
- (p) **N availability** for crop growth may still decrease due to increased gaseous losses.
- (q) **Biological nitrogen fixation** under elevated CO₂ may show an increase, provided other nutrients are not strongly limiting.

Damage Predictions: Physical/qualitative/relative/monetary

Table 3. Climate models and predictions of Impacts for India

sector	Assumptions	Impact	Source	Region	Strength /weakness
Agriculture					
Aggregate agriculture	Temperature change from 2.7 –5.4 Cross section data used Local adaptation included	Loss upto \$87 billion, loss of half of agricultural GDP	Mendelsohn (2005)	India	Price change effect ignored, CO2 fertilisation effect not included
Rice and wheat yield	A2, B2 scenario	decline	Shukla, P.R., Sharma, S. K., Ramana, P. V. and Bhattacharya, S (2002)	India	
rice yields	1.5°C rise in temperature and a 2 mm day ⁻¹ increase in precipitation	decrease by 3 to 15 %	Saseendran et al (1999)		CO2 fertilisation ignored
yields of soyabean	+2 and +4 °C change in temperature; ± 20 and ± 40 % change in precipitation.	- 22 to 18 %	Lal et al		CO2 fertilisation ignored
farm level net revenue	Temperature rise 2.0-3.5° C , farm-level adaptation	loss 9-25%	Kumar and Parikh (1998)	India	Considers imperfect land market and administered price
Yield of Rice wheat	Temperature rise 2.5°C to 4.9°C	loss between 15%-42% and 25 %-55%	Kumar and Parikh (1998)	India	without considering the carbon fertilization effect
GDP		drop between 1.8 to 3.4%	Kumar and Parikh (1998)	India	without considering the carbon fertilization effect
agricultural relative to		increase by 7 to 18%;	Kumar and Parikh (1998)	India	without considering the carbon fertilization effect

nonagricultural prices					
		losses in the same direction but somewhat smaller	Kumar and Parikh (1998)	India	with carbon fertilization effects
farm level total net- revenue	+ 2°C and an accompanying precipitation change of +7% With adaptation by farmers of cropping patterns and inputs	fall by 9%	Kumar and Parikh (1998)	India	With adaptation by farmers of cropping patterns and inputs
farm level total net revenue	+3.5°C and precipitation change of + 15%,	fall nearly 25%		India	
Agricultural net revenues	2° C rise in mean temperature and a 7% increase in mean precipitation	reduce by 12.3%	Sanghi et al, 1998)	India	Includes adap-tation options
agriculture in the coastal regions		most negatively affected	„	Gujarat, Maharashtra and Karnataka	
..		Small losses	„	Punjab, Haryana and western UP	
..	warming	benefit a small extent	„	West Bengal, Orissa and Andhra Pradesh	
Agriculture, coastal infrastructure, tourist activities and onshore explorations		high risk	„	India	

Rice	2 ^{0C} rise 1.5 ^{0C} rise + 2 mm rainfall rise + 460 ppm CO ₂	-0.06 - 0.075 ton / hec +12%	Sinha & Swaminathan (1991) Saseendran et al (1999)	South India	
Wheat	2 ^{0C} rise + 425 ppm CO ₂	-1.5 - 5.8% -17-18% -10%	Aggarwal & Kalra (1994) Kumar & Parikh (1998)	in sub tropical India in tropical India in Punjab, Haryana	
Maize	2 ^{0C} rise + 425 ppm CO ₂	-7-12%	Chatterjee (1998)	in North India	
aggregate	1.5° -2.5° C,	-2% of GDP	Mendelsohn 1996	India	baseline development trend, Adaptation included
aggregate	Catasprohic impact factored in	-4.9% of GDP	Nordhaus and Boyer (2000)	India	
Aggregate	Carbon Fertilisation	Gain	Pohit (1997)	10 sector 10 region, India	Global CGE
Aggregate /crop wise	2° C rise in mean temperature and a 7% increase in mean precipitation	0.617% fall in GNP. crop wise production falls 1.9- 8.3%	Pohit (2005)	10 sector 10 region, India	GTAP model, trade effects smoothes price change
Aggregate	100 cm sea level rise	US\$ 1259 million Welfare loss	Pohit et al (2005)	Indian coastal area	Same producti-ve use of land and no adaptation
aggregate	Carbon fertilisation factored in	gain	Darwin and Kennedy (2000)	World	Over estimates gain
Country specific and regional	Difference between present and mid 21 st century NPP considered to predict productivity	Gain in cereal production but balanced if socio economic factors are considered	Okamoto et al (2005)	South Asia/ and Countries	Over estimates gain

Forest: India

The area under forests is estimated to be about 67 Mha according to the state of forest reports. Forests contribute 1.7% to the GDP of the country (MoEF, 1999). Moreover, non-timber forest products provide about 40% of total official forest revenues and 55% of forest-based employment. In India about 200 million people depend on forests directly or indirectly for their livelihoods. Indian forests support more than 5150 species of plant, 16214 species of insects, 44 mammals, 42 birds, 164 reptiles, 121 amphibians and 435 fish species. Forests meet nearly 40% of India's energy needs and 30% of fodder needs. In India, out of 15000 plant species, 3000 species yield non timber forest products (**NTFP**) such as fruits, nuts, edible flower, medicinal plants, rattan and bamboo, honey and gum. All forests sector activities are labour intensive and generate rural employment. Value of goods and services provided by the forests sector – approx Rs 25984 crore. Of the GDP of Rs 23000 crore, fuelwood – approx 54%, extraction from industrial wood – 9%, NTFPs – 16%, eco tourism- 14%, carbon sequestration – 7% (planning commission, 2002).

Climate is an important determinant of the geographical distribution, composition and productivity of forests. Therefore, changes in climate could alter the configuration and productivity of forest ecosystems.

Impact assessment (GOI 2004) was carried out using the **BIOME-3** model by predicting the equilibrium composition of different vegetation types under the CTL & GHG scenarios. It combines the screening of biomes through the application of climatic constraints with the computation of net primary productivity (NPP) & leaf area index (LAI), both based on fully coupled photosynthesis & water balance calculations. The model uses nine Plant Functional Type (PFTs), such as Tropical Evergreen, Tropical Rain green, Temperate Broadleaved Evergreen, Conifer, Boreal Evergreen, Boreal Deciduous, Temperate Grass & Tropical/warm-temperate Grass. Based on the climatic parameters, the model computes the viability & wherever applicable, the productivity-related parameters of the PFTs, such as the LAI & the NPP. ECHAM 3 model has also been applied to derive impacts for India (Table 4).

Table: 4. List of climate change literature for forestry impact study.

Source	Climate change scenario	Climate parameters	Impacts	Scope
Ravindranath N H and Sukumar R (1998)	greenhouse gas forcing	(i.e increased temperature and rainfall)	increased productivity, migration of forest types to higher elevations, and transformation of drier forest types to moister types	India
	incorporating the effects of sulphate aerosols	modest increase in temperature and a decrease in precipitation	adverse effects on forests	central and northern India
Achanta A and Kanetkar R (1996)	climate scenarios generated by the ECHAM3		soil moisture is likely to decline and, in turn reduce teak productivity from 5.40 m ³ /ha to 5.07 m ³ /ha	
			productivity of moist deciduous forests could decline from 1.8 m ³ /ha to 1.5 m ³ /ha.	
Deshingkar P, Bradley P N, Chadwick M J, Leach G (1996)	BIOME model			
Ravindranath et al (2006)	BIOME4	A2, B2 scenarios	Forest shifts	India

Projected change in area under different forests types in Uttar Kannada, Western Ghats

Forest type	Baseline area in sq km	Most likely scenario (2020) Temp + 0.3° C, rainfall + 3%	Most likely scenario (2050) Temp + 0.7° C, rainfall + 7%	Worst case scenario (2050) Temp +1° C, rainfall - 7%
Evergreen	1089	+17.9%	+45.4%	+61.8%
Semi evergreen	2092	+5.4%	+8.13%	-24.3%
Moist deciduous	2265	-9.27%	-21.5%	-9.71%
Dry deciduous	478	-20.5%	-36.8%	+11.9%

Projected change in area under different forests types in Nilgiris, Western Ghats

Forest type	Baseline area in sq km	Most likely scenario (2020) Temp + 0.3° C, rainfall + 2%	Most likely scenario (2050) Temp + 0.6° C, rainfall + 4%	Worst case scenario (2050) Temp +0.9° C, rainfall -8%
Evergreen	585	+13.4%	+22%	-3.7%
Dry thorn	2083	+12.8%	+12.3%	+32.9%
Moist deciduous	895	+14%	+26.9%	+16.8%
Dry deciduous	1624	-27.4%	-36.4%	-47.7%
Montane/grassland	289	-3.1%	-7.3%	-9.1%

Ravindranath (1997)

In Uttar Kannada, under the most likely scenario, the aggregate quantity of non-timber forest products (NTFPs), potentially available for extraction is likely to increase in the evergreen and semi evergreen forest areas with projected increase in area under these forest types. For the district as a whole, the financial value of potentially extractable NTFPs is projected to increase marginally with increase in area under high income yielding moister forest types and decline in area under comparatively low income yielding dry forest types. The aggregate quantity of potentially extractable NTFPs is projected to:

- Increase in expanding evergreen and moist deciduous forest types, and
- Decline in the dry deciduous, dry thorn and montane forest areas.

Therefore, there will be an increase in income from potentially extractable NTFPs with the income per hectare likely to increase by about 22%. However, there is uncertainty regarding the transient response of vegetation to climate change and this could lead to forest dieback and loss of vegetation. Conversely, fuelwood and timber production may increase due to increased productivity as a result of increased CO₂ fertilization and nitrogen deposition.

Under moderate climate projections, the total area under tree covers in all biomes except the tundra and xerophytic woods in Himachal Pradesh is projected to increase by 11%. The tundra forests a uniform downward trend with sharp reduction in area by early 2020. By 2080, more than 70% of the area under tundra forests is projected to decline under the moderate scenario.

Eco systems

Coral reefs: India

Coral reefs are distributed in six major regions along the Indian coastline.

These are

- the Gulf of Kutch in Gujarat
- the Malwan coast in Maharashtra
- the Lakshadweep islands
- Gulf of Mannar
- Palk Bay in Tamil Nadu
- the Andaman & Nicobar islands.

The coral reefs in the Indian region (GOI 2004) are already under threat from several anthropogenic & natural factors, including destructive fishing, mining, sedimentation, & invasion by alien species. To this the possible impacts of future climate change. The increased sea surface temperature (SST) results

in 'bleaching' of corals. While bleaching is a normal event & is reversible, a prolonged increase in SSTs &/or intense bleaching may result in the death of the corals. In recent decades, the most widespread & intense bleaching of corals (mass bleaching), including in the Indian Ocean, occurred during the years 1997-1998 associated with *El Nino* when SSTs were enhanced by over 3°C, the warmest in modern record.

- The corals of the Lakshadweep islands were significantly affected by this event with bleaching of over 80% of coral cover & mortality of over 25% of corals.
- The corals of the Gulf of Mannar were similarly affected. The most affected were shallow water corals, such as the branching *Acopora* & *Pocillopora* that were almost completely wiped out.
- The least affected coral reefs were those in the Gulf of Kutch with an average of about 10% bleaching & little mortality.

Inland or freshwater wetlands : India

The inland wetlands include a large number of natural lakes & swamps or marshes, as well as man-made reservoirs & tanks. Shallow water marshes & swamps would be even more vulnerable to increased temperatures & lower precipitation as projected for central & north-western India by the HADCM2 (GOI 2004).

Grasslands: India

There are five major grassland types recognized in India (GOI 2004), on the basis of species associations, geographical location & climatic factors:

- Alpine grasslands of the Himalayas
 - Moist fluvial grasslands of the Himalayan foothills
 - Arid grasslands of northwestern India
 - Montane grasslands of the Western Ghats
- 1) The anthropogenic factors such as livestock grazing & fire that were for creating many of the grassland types in the country are also involved in their degradation.
 - 2) While moderate levels of grazing could be sustainable & even promote plant species diversity, heavy grazing reduces the plant cover & eliminates palatable grasses & herbs while promoting the growth of unpalatable plants.

When considering the likely impact of future climate change on natural grasslands, several factors that need to be considered are direct response of grasses to enhanced atmospheric CO₂, as well as changes in temperature, precipitation & soil measure.

- The plants with the C₃ & the C₄ pathways of photosynthesis respond differently to atmospheric CO₂ levels & also 2

temperature & soil moisture levels. The C3 plants include the cool, temperate grasses & practically all woody dicots, while the C4 plants include the warm, tropical grasses, many sedges & some dicots.

- The C4 plants that constitute much of the biomass of tropical grasslands, including the arid, semi-arid & moist grasslands in India, thrive well under conditions of lower atmospheric CO₂ levels, higher temperatures & lower soil moisture, while C3 plants exhibit the opposing traits.
- Increasing atmospheric CO₂ levels should, therefore, favour C3 plants over C4 grasses, but the projected increases in temperature would favour the C4 plants.

The outcome of climate change would thus be region-specific & involve a complex interaction of factors.

- 3) GCM model projections (for example, the HADCM2) for India indicate an increase in precipitation by up to 30% for the north-eastern region in addition to a relatively moderate increase in temperature of about 2°C by the period 2041-2060. This could increase the incidence of flooding in the Brahmaputra basin & thus favour the maintenance of the moist grasslands in the regions.
- 4) the HADCM2 projections for the rest of the country (southern, central & north-western India) are a steep increase in temperature of 3°C in the south (except along the coast) to over 4°C in the north-west, & a decrease in precipitation of over 30% in the north-west though little change in parts of the south. This combination of temperature increase & rainfall decrease would cause major changes in the composition of present-day vegetation in these regions, with an overall shift to a more arid type.
- 5) Increased atmospheric CO₂ levels & temperatures, resulting in lowered incidence of frost, would favour C3 plants including exotic weeds such as wattle that could invade the montane grasslands of the Western Ghats.
- 6) The cool, temperate grasslands of the Himalayas could also be impacted by rising temperature that would promote the upward migration of woody plants from lower elevations.

Mountain eco system: India

In the hills, the low temperature & shorter growing period limit the productivity of crops. These restrictions become conspicuous with increase in altitude. Global warming is likely to prolong the growing season & this could result in potentially higher crop yields, provided water remains available.

Infrastructure and Energy

Infrastructure includes road, rail and airways, river systems, electric power systems, and all the different types of communication and service lines. It also includes the built and engineered entities, the factories, buildings, dams, and all that comprise the cities and towns. Infrastructures are manmade life-long assets. Climate change can affect long life assets. The incidents of cyclones on the east and west coast of India and landslides caused by heavy rainfall in the Konkan region indicate that the infrastructures are vulnerable to extreme climatic changes. Tables below present a qualitative comparison of the authors assessment of the extent of magnitude, possibility of occurrence, sensitivity, adaptability and vulnerability of the two sectors (Kapse et al. 2003).

Sensitivity, vulnerability, adaptability – infrastructure sector

CC Criteria	Magnitude	Occurrence	sensitivity	Vulnerability	adaptability
Temp rise	Medium	High	Medium	Low	High
Precipitation rise	medium	medium	medium	medium	Medium
Sealevel rise	medium	medium	medium	medium	Low
Extreme events	High	Low	Medium	High	low

Sensitivity, vulnerability, adaptability – energy sector

CC Criteria	Magnitude	Occurrence	sensitivity	Vulnerability	adaptability
Temp rise	High	High	High	Medium	High
Precipitation rise	medium	medium	medium	Low	Medium
Sealevel rise	medium	medium	medium	medium	Low
Extreme events	High	Low	Medium	High	medium

Health: India

Predictions

Current climate trends have shown an increase in maximum temperatures, heavy intense rainfall in some areas & emergence of intense cyclones.

In the summer of 1994, western India experienced temperatures as high as 50°C, providing favourable conditions for disease-carrying vectors to breed.

In 1994, as summer gave way to the monsoon & western India was flooded with rains for three months, the western state of Gujarat was hit by a malaria epidemic. Weather conditions determine malaria transmission to a considerable extent. Heavy rainfall results in puddles, which provide good breeding conditions for mosquitoes. In arid areas of western Rajasthan & Gujarat, malaria epidemics have often followed excessive rainfall. In very humid climates, drought may also turn rivers into puddles. Bhattacharya et al (2006) is of the view that rainfall per se may not lead to malaria. It is temperature and relative humidity which widens the transmission window.

Malaria Under Climate Change Scenario

When the temperature & relative humidity are considered together for determining the transmission window, it is observed that less than 60% relative humidity; the transmission window is open only for 4 months if both temperature & relative humidity are considered, while it is open for 8 months if only temperature is considered. Therefore, it appears that transmission may take place at less than 60% relative humidity.

Changes in climate may alter the distribution of important vector species & may increase the spread of disease to new areas that lack a strong public health infrastructure.

- High altitude populations that fall outside areas of stable endemic malaria transmission may be particularly vulnerable to increases in malaria, due to climate warming.
- The seasonal transmission & distribution of many other diseases transmitted by mosquitoes & by ticks, may also be affected by climate change.

Table 5. Health

Health Concerns	Vulnerabilities due to climate change
Temperature-related morbidity	(a) Heat- & cold-related illnesses. (b) Cardiovascular illnesses. (GOI)
Vector-borne diseases	(a) Changed patterns of diseases. (b) Malaria, filarial, kala-azar, Japanese encephalitis, & dengue caused by bacteria, viruses & other pathogens carried by mosquitoes, ticks, & other vectors. (c) Spatial distribution (Bhattacharya 2006)
Health effects of flood and drought	(a) Diarrhea, cholera & poisoning caused by biological & chemical contaminants in the water (even today about 70% of the epidemic emergencies in India are water-borne). Avoided cost of water borne disease and/or welfare loss per household per month amounts within the range of Rs 187/- 1457/- (Roy et al 2004, Roy et al 2004, Roy 2006) (b) Damaged public health infrastructure due to cyclones/floods. (Ghosh and Roy 2006., Roy et al 2005) (c) Injuries & illnesses. (Muhammad 2004) (d) Social & mental health stress due to disasters & displacement. (Muhammad 2004)
Health effects due to crop damages from flood and drought	(e) Malnutrition & hunger, Human as well as livestock. (Muhammad 2004)

The Present Scenario

Malaria is endemic in all parts of India (Bhattacharya et al. 2006), except at elevations above 1800 metres & in some coastal areas. The principal malaria-prone areas are Orissa, Madhya Pradesh, Chhattisgarh, & the north-eastern parts of the country. Periodic epidemics of malaria occur every 5 to 7 years. According to the World Bank, in 1998 about 577000 Disability Adjusted Life Years (DALYs) were lost to malaria. Among all the states, Orissa has the highest Annual Parasite Index (API) which is greater than 10, followed by

Madhya Pradesh & Chattisgarh (API between 6-10). The occurrence is high in Jharkhand, which is mainly inhabited by a tribal population. Here, the incidence increased from 35000 to more than 40000 between 1995 & 2000. Subsequently, there was a resurgence of malaria. In 1976, over 6.7 million cases were reported. From 1977, the National Malaria Eradication Programme (NMEP) began implementing a modified plan of operation for the control malaria. Despite these efforts, the number of reported cases of malaria has remained around two million in the 1990s. The increase in malaria incidences are attributed to the resistance of mosquitoes to pesticides, & the resistance of parasites to anti-malaria drugs, thus, limiting the effectiveness of malaria control attempts through the NMEP. Climate parameters: For most vectors of malaria, the temperature range 20°C-30°C is optimal for development & transmission. Relative humidity higher than 55% is optimal for vector longevity, enabling the successful completion of sporogony. Malaria transmission requires a minimum average temperature higher than 15°C for *P.vivax* & 19°C for *P.falciparum*, & this temperature should sustain over a period of time for the completion of sporogony. For example, when average temperature, humidity, precipitation & incidences have been plotted for Gujarat, the maximum incidences are seen to occur in the months of June, July & August when relative humidity is highest, i.e., greater than 60% & less than 80%, at temperatures ranging between 25°C to 30°C.

II. Disaster Literature

Under climate variability scenarios given the predictions of more frequent flood, drought, cyclone, storm surges we have reviewed two types of literature: First secondary data based studies, reports that concentrate on assessment through physical loss of assets, livelihood etc. Secondly, case studies based on primary level data collected from direct interview of the stake holders to understand more closely the actual losses faced by the households and to understand the adaptive behaviour and technological and institutional issues involved in the adaptation process or vulnerability assessment. The goal is to assess both damage as well adaptive actions : reactive as well as proactive. Vulnerability is directly linked to adaptive capacity. More the adaptive capacity is less will be vulnerability. Case study based damage assessment was done for rural areas for four countries –Bangladesh, India, Nepal, Pakistan (Ref Table 1. Muhammed, Mitra 2003) to assess the impact of flood and drought by analysing peoples' responses and perception through Household survey and community response through PRA. Same survey instruments were used to keep the comparability. For India further analysis was done to assess impact through LIFE approach (Ghosh and Roy, 2006) . Predicted increase in frequent and intensive floods and droughts are likely to have unfavorable impacts on the livelihood options, food security, health, social infrastructure etc. of the hotspots (Roy and Ghosh 2003, Roy et al 2004, Roy et al 2005, Ghosh and Roy 2004, 2006). The bottom up approach to adaptation strategy assessment starts from the identification of hotspots, understanding vulnerability and identifying coping mechanism for the households and communities based on current level of climate variability. The framework adopted here starts from the premise that adaptive actions from both the vulnerable groups with private motive as well as government and

non-government external agencies with social welfare motive generate both private and public goods and services. Careful analysis of these provide with a portfolio of actions. It is useful to characterize the adaptation strategies by the nature of action: public or private and the time scale to phase out the action profile based on the stated response of the vulnerable groups. General observation is these effects usually put additional burden on the poverty alleviation policies of the government.

Extreme Events: Flood

Damage to crop, life.

India- 40 million hectare of the country experiences periodic floods. The average area affected by floods annually in India is about 7.5m ha of which crop area affected is 3.5 m ha. Every year, on an average, floods claim about 1529 human lives and 94000 heads of cattle. Outspread of water borne diseases and severe food shortages are some of the severe impacts of flood. Traditionally UP, Bihar, West Bengal, Orissa and Assam have been the most flood prone states. Currently the situation is also worsening in Andhra Pradesh, Karnataka, Tamil Nadu, Maharashtra, Gujarat, Himachal Pradesh, Rajasthan and Jammu & Kashmir. In 2000 the monsoon rainfall led to severe flood in 11 Indian states. Over 30 million people were affected. The worst affected states were Assam, Bihar and West Bengal. Similarly, the super-cyclone in 1999 caused at least 10,000 deaths in Orissa & the total number of people affected was estimated at 10-15 million. The 2000 floods, caused by severe monsoon activities, was spread over 9 districts of West Bengal. The floodwater submerged more than 50% area of the districts of Murshidabad, Burdwan, Birbhum, Hoogly, North 24 Parganas, Nadia, Midnapore, Malda and Howrah. Around 70 to 80% land in these districts is used for primary activities. The floods caused extensive damage to standing crops like kharif rice, kharif vegetables, jute, pulses, oilseeds, fruits, flowers and sugarcane. Almost 2.3 mha of cropland was affected. The floods during 2000 damaged 1345 health facilities in the flood-affected districts of West Bengal. It led to the outbreak of water borne diseases like diarrhoea, skin infections and worm infestations.

Bangladesh – On current predictions, a fifth of Bangladesh will be drowned entirely and the rest regularly experience floods on the scale of 1998 by 2100. Flooding will be exacerbated by exaggeration of the world's rainfall patterns. Water scarcity for drinking and industry is already a problem for 1.7 billion people. By 2050, it is likely to be a problem for up to 3.6 billion. Due to its special topographic condition – the majority of the landmass being the flat delta of the Ganga-Brahmaputra-Meghna river systems, the country experiences floods almost every year. Four types of flood occur in Bangladesh: (i) flash floods caused by the overflowing of the hilly rivers of eastern and northern Bangladesh (in April-May and September-November), (ii) rain floods caused by heavy rainfall and drainage congestion, (iii) monsoon floods in the flood plains of the major rivers (June-September) and (iv) coastal floods due to storm surges. Past data on floods suggest that normal floods occur every 2.25 years, while moderate floods are reported every 4 years. On an average, severe floods occur every 7 years while catastrophic floods

occur once in every 40-50 years. Since 1974 the frequency and duration of occurrence of high intensity floods has increased. One of the severest floods occurred in 1998. The flood which began in July and ended in September, inundated 100.3 thousand acres of area i.e. almost 68% of Bangladesh. Almost 1000 people died in the flood that affected more than 30 million people. The 1998 flood damage was in the range of US\$ 2– 2.8 billion. During 1998-99 GDP growth declined to 4.6% from 5.2% the previous year due to the devastating floods of 1998. The industrial sector growth decreased by 3.4% during the same period. Flash floods occur suddenly and have the potential to drown unprepared people. Thus every year some lives are lost to flash floods. As the water level rises above the danger mark and the duration of the flood increases, deaths occur due to drowning, snakebites, electrocution or by being crushed to death by falling walls. In Bangladesh 1988 floods damaged or completely destroyed 12.8 million houses. An estimated 916660 houses were totally destroyed and another 1.3 million houses were partially damaged during the 1998 floods. The latter caused an estimated loss of about US\$1.7 – 1.9 billion. The Government of Bangladesh and some NGOs launched a programme to provide building material as relief. According to unofficial estimates only about 4 to 5% of the total requirements could be met through these relief operations.

Nepal - Apart from loss of lives and livestock, every year floods and landslides affect about 30000 families, destroy about 7000 houses and 5400 ha of land. The damage to the monsoon crops – paddy and maize, was extremely high during the 1995 disaster. It was about 12% less than the average production during normal years. Floods are specific to the flood plains of Inner Terai, the Outer Terai i.e. the northern extension of the Indo-Gangetic plain, and the flood plains of river valleys in mountains. But in the mountains and hills, particularly in small basins and in the upper Terai, due to steep terrain and river gradient and fractured geology, the floods usually occur in the form of bank erosion, channel shift, debris flow during rainstorm causing huge damage to life and property. Erosion and landslides and channel diversion in upstream areas trigger these phenomena. Similarly the landslide-damming flood and the glacial lake outburst floods are also another hazards in the mountains. The loss from flood and landslides was highest in 1993. The devastating floods, landslides and debris flow in July 1993 had socio-economic impacts. Human deaths rendered by landslides and floods during the period between 1983-2001 were 6052 with an annual average of 317. It is about 29% of the deaths caused by all types of natural disaster. The toll on human population due to flood in the Terai during 1992-2001 is 1002 which is 36% of the total deaths. The worst flood and landslide occurred in 1993 when 1170 people died, which is 60% of the total loss during the period 1983-2001. It is estimated that about 81% of the population has access to safe drinking water. Only 3% of the population has access to sanitary facilities.

Damage to Infrastructure

Severe floods damage existing infrastructure like rail and road communication. Absence of communication retards the success of relief operations carried out by government and non-government organizations

thereby aggravating the distress of the affected region. During the 2000 floods in West Bengal, infrastructure and farm inputs like sheds, veterinary hospitals, and dispensaries, farm buildings, equipment and machinery, fodder and seed were damaged. Around 1.8 million houses were damaged or destroyed. Communication links were affected. 450kms of rail track and at least 30 bridges and culverts were destroyed. 328kms of national highway, 1173kms of state highway and 1739 km of district roads were adversely affected. The floodwaters damaged a large number of primary education centers. Field survey reports that in India floods cut off transport and communication links and obstruct the movement of relief and staples to the affected zones. In Bangladesh drainage infrastructures on the metallic roads are also subject to erosion due to passage of high velocity water especially during the recession of floodwaters. Educational institutions, shops in rural marketplaces and other local government institutions like health centers made of easily perishable building materials are often damaged during floods. Apart from houses a significant proportion of the rural roads and flood protection embankments are made of mud and can be easily washed away. In 1998 over 22590 km of rural earthen roads, 15000 km of highways and roads, and 2000 km of embankment were damaged. The 1998 flood also damaged 1204 bridges and culverts. Some 54 ferry stations suffered moderate to severe forms of damages. The national railway suffered colossal losses – 496 km of rail tracks and 117 bridges were washed away or damaged, many signaling and other equipment also became inoperative. 11000 industrial units and 24000 educational institutions were affected. Floodwaters ravaged 155 growth centers, huge number of small-scale water infrastructure, offices, silos, pump houses for irrigation, irrigation canals, etc. The estimated total damage to physical infrastructure was between US\$ 720 – 1530 million. In Nepal every year damage to public properties like road, bridges, canals, hydropower, public buildings, etc. due to floods and landslides amount to hundreds and million of rupees. During the period 1983 – 2001 floods and landslides destroyed 124429 houses, damaged 86527.27 ha of land, damaged 1968 units of public infrastructure. The total estimated loss to property is about NRs 13732. The loss is generally higher in the Terai region than in the hills and mountains. In Nepal the floods of July 1993 completely destroyed the water supply system of Hetauda Municipality, causing safe drinking water scarcity for 5 days.

Damage to Livestock

During floods lack of fodder and the floodwater lead to a rapid fall in the livestock population. Damage to livestock adversely affects the income of the people dependent on the agrarian structure for livelihood. During the 2000 floods in India over 8.9 million heads of livestock were affected. This included cattle & buffalo, goat & sheep, and poultry.

Losses to the livestock during floods is often due to incidences of snakebites and electrocution. During high intensity floods loss of fodder causes malnutrition and increased pathogen activities threaten animal health. During the 1998 floods in Bangladesh 64000 bovines and 57000 goats were reported lost. In Nepal the average annual toll on livestock due to floods and landslides is about 2288. The loss of livestock population in the Terai for the

period 1992-2001 is 22233, which is 71% of the total deaths due to natural calamities in the same period. In 1993 the loss of livestock was as high as 24785 heads.

Impact on Food security

An important indicator of sustainability and poverty status is food security. Household responses based on past experiences strengthen the hypothesis that future increase in extreme weather events will deteriorate the poverty situation unless addressed with due consideration. Due to damage to transport and communication links from flood movement of relief and staples to the affected zones get affected. Loss in agricultural output, livestock and disrupted supply of basic amenities exposes the community to inflationary pressures. The presence of government operated fair price shops in **India** which provide basic staples at subsidized rates fail to control the ripple effect of agricultural productivity loss on inflationary tendencies. During and after severe floods individual households have to depend on aid/loans from relatives, friends, local moneylenders and non-government organizations (NGOs) to cope with the adverse impacts of flood.

During high intensity floods **Bangladeshi** farmers face colossal losses in agricultural production, which put national food security at risk. During the flood of 1974 national food supply was mainly dependent on Aman. A loss of about 1.4 million tons of rice led to price hike and consequently to famine. Flash floods as opposed to rain induced riverine floods, often maul the standing crop and causes heavy losses. Floods generally facilitate open water fisheries. But high intensity floods can be hazardous to pisciculture. Floodwaters inundate the entire landscape including the water bodies used in fisheries and set free the fishes from captivity. During the 1998 floods a large number of hatcheries and fish farms had to close down and requested for compensation from the authorities. Access to food during floods is further limited by the breakdown of the transportation system. This hampers the food supply logistics and drive up the price of essential commodities.

Effect of Natural Disaster on Bangladesh

Resources worth an estimated US\$25 billion have been destroyed by natural calamities in Bangladesh from 1947 to 1991 (Rahman, 1989). According to the Disaster Management Bureau, the loss of standing crops, including paddy, was estimated at Taka 33.05 billion. BIDS studies revealed that the loss to the agriculture sector was Taka 50.52 billion, of which the losses from rice and other crops were Taka 43.77 billion; and Taka 6.75 billion for fisheries, livestock, etc.

Damage: Health

Floods affect the water bodies used for consumption and other domestic purposes. Natural water bodies and open wells are also extensively used for drinking water in rural areas. Floodwater contaminates all open water bodies. Water purification techniques are not widely practiced because of lack of knowledge and techniques. A large portion of the community is therefore exposed to health risks through the consumption of contaminated water. In

India during field survey almost 59% of the respondents have indicated floodwater as their potable water source during floods. Only 2% of the total sample employs any filtration measures to sterilize this water. 24% have reported lack of potable water while the remaining depends on other normal water sources to meet their daily needs. Almost 97.96% households reported difficulty in obtaining drinking water during floods. Almost 59% of the respondents have indicated floodwater as their potable water source during floods. Only 2% of the total sample employs any filtration measures to sterilize this water. 24% have reported lack of potable water while the remaining depends on other normal water sources to meet their daily needs. In **Bangladesh** majority of the population use tube wells for domestic purposes. During floods these tube wells become inoperable and inaccessible to the village community. The people are forced to drink pathogen laden surface water and hence suffer from diarrhoea and cholera. With the availability of cheap dehydration therapy the death toll through epidemic outbreak has declined nowadays. Unfortunately floodwaters are the breeding ground for mosquitoes and people fall victim to malaria, dengue and typhoid that can often be fatal. In **Nepal** due to poor sanitation and waste disposal measures, pathogen laden human and animal wastes, food and garbage pile up near homes or drain into waterways to infect drinking water supplies. This has a severe implication during monsoon, with high incidence of epidemics in the flood and landslides affected areas. Increased incidences of such diseases like encephalitis, typhoid, dysentery, meningitis, kala-azar and influenza have been reported from flood affected areas. Most vulnerable are the children, women and the poorest sections of the community.

Extreme Events: Drought

Like floods droughts are also common to **India**. In the past 50 years, there have been around 15 major droughts, due to which the productivity of rain crops in those years was affected. There is shown a decrease in the duration & yield of crops as temperature increased in different parts of India. Yields of both crops (rice & wheat) decreased due to the increase in temperature. Recently, the incidence and severity of droughts seem to have increased. Approximately 263 million Indians live in drought prone area spanning over 108 million hectares. Thus about $\frac{1}{4}$ th of the population live under the shadow of droughts covering $\frac{1}{3}$ rd of the geographical area of India. The effects of drought in India can be well understood if one analyses the recent drought in the western state of Gujarat. During the year 2002, the state of Gujarat, received deficient rainfall in 24 out of its 25 districts. Monsoon entered Gujarat in the 4th week of June 2002. The second spell of rains that were expected between mid-July to the last week of August failed, resulting in severe loss of crop and scarcity of drinking water and fodder in most parts of the state. The failure of the second spell of rains, damaged 40% of the crops sown after the first rains. Out of the total average crop sown area (average over 1997 to 2001) of 8 million ha, only 7.3 million ha was sown till August 12, 2002.

Pakistan. The land area of Pakistan is 87.98 million hectares. About 59.3 per cent of the total area is classified as rangelands. Most of this area receives less than 200mm rainfall annually and is, therefore, considered as arid. In

addition to the climatic factors limitation are also imposed by poor and rocky soils, deserts and rough topography. These arid rangelands support 93.5 million heads of livestock and a very large number of pastoral people. However, continuous shortage of fodder and water due to the current drought has caused heavy losses of livestock and adversely affected the life of the pastoral communities. Besides the drought conditions in the arid rangelands, non-availability of water in the Indus river system has made the situation even worse. The pastoral people have particularly been hit hard due to unfavorable changes in prices of grains and livestock during the drought period. The main arid rangelands are Thar, Cholistan, Dera Ghazi Khan, Tharparkar, Kohistan, and western Balochistan. Except Balochistan all of these areas are within the range of monsoon rainfall, which, however, is erratic and scattered. Hence, 2 to 3 years in every 10 years in these areas are drought years.

The FAO/WFP Joint Mission to Pakistan conducted assessment for the impact on livestock in Balochistan during 2000-01. Total livestock population (cattle, buffalo, sheep, goats, camels, horses, asses and mules) is estimated as 55 million heads. Out of this, about 23, 15, 12 and 5 millions of livestock population is in Balochistan, NWFP, Punjab and Sindh provinces, respectively. Furthermore it was estimated that the drought had affected about 43, 40, 40 and 66% population of livestock in Punjab, Balochistan, NWFP and Sindh provinces, respectively. The cumulative loss, in the drought-affected years, was estimated as 43 % of the country's livestock population. Heavy direct losses due to animal mortality, production losses and distress sales of animals have been widely reported. A prolonged drought had seriously affected crop and livestock production in Pakistan. During the year 1999-2001, the large segment of the population of the drought-affected areas (Balochistan and parts of Sindh and Cholistan desert in Punjab province) has suffered serious consequences in relation to food security. However, continued drought conditions in the first half of the year have increased the scale and severity of the problem raising humanitarian concerns that require urgent attention.

UN conducted assessment for the impacts of drought on livestock for 2001-02, where they reported that despite low monsoon and winter rains; there have been no reports of livestock casualties from any part of the country. However, productivity losses have been observed in the regions under severe drought stress, which are estimated to be within the range of about 10 %. Some movement of livestock to irrigated zones in search of water and feed has been reported in the Cholistan desert.

During droughts the decline in agricultural productivity is aggravated by extreme water stress that adds to the effects of the already inadequate irrigation facilities in the surveyed region in India. The impact of the drought on the surveyed villages is worsened by the fact that majority of the households depend on agriculture and related activities like animal husbandry and agricultural labour work for livelihood. Only 12% of the total cultivated area in the surveyed region (India) has access to irrigation. Despite the choice for appropriate crop variety the fact remains that persistent drought for three consecutive years (2000-01 to 2002-03) has significantly undermined the

existing coping capacity of the farmers leaving no time for recovery as the minimum time for recovery is considered to be 2 to 3 years. Almost 18% of surveyed households have reported major outstanding debts. The average annual debt value due to drought is approximately Rs 26,000 /- payable at an annual interest that varies between 15 to 30%. On an average each household reported 89% land damage and a 96% loss in agricultural output. Although almost 51% of the households have reported damage to the jowar crop, the maximum loss in output (94.44%) has been for pulses. The drought also drastically affected the livestock count. Almost 59% of the households reported damage to livestock. The most affected species were cows, bulls and goats. Approximately 280 cattle heads were affected by the water stress and fall in fodder supply. Scope for alternative sources of occupation are also limited as more than 90% of the population are either illiterate or have minimum primary education. Though agriculture is the primary occupation, 31.33% of the farmers in the surveyed area are either landless or marginal farmers. A meager 6% fall in the category of small and semi-medium farmers, while the remaining 63% are medium sized farmers. Low-income classes face the worst impacts of drought, as they do not have adequate resources to invest in infrastructure that would improve their coping capacities. In most areas only one annual crop, either Kharif (summer crop) or Rabi (winter crop), was cultivated instead of the normal two crops. On an average each household reported 89% land damage and a 96% loss in agricultural output. The maximum percentage of households (50.7%) has reported damage to the jowar crop. However, the maximum loss in output (94.44%) has been witnessed in the cultivation of pulses. The loss in the productivity of paddy (86%), jowar (90%), cotton (88%), maize (76%) and bajra (71%) has also been very high. All crops recorded a more than 50% reduction in output during the drought period.

In **Pakistan** in 2000-01 the production of all the major crops like wheat, rice, maize, barley, sugarcane, cotton and chickpea were affected. The reduction in wheat production was around 10%. The production of chickpea and barley were reduced to the extent of 30 and 27%, respectively, primarily due to the reason that these crops are normally grown in the dry regions, which were severely affected by drought. The production of horticultural crops like vegetables and fruits was also adversely affected. Productions of pomegranate, apples and garlic were badly affected. The Balochistan province was severely affected during the prolonged drought 1998-2002. The production of field crops for the years 1997-98 was taken as a reference year prior to the drought. The production of the three years affected by drought (1998-2001) was averaged and compared with pre-drought year of 1997-98. The average reduction in production during the period of drought affected years (1998-2001) was 28, 30, 55, 34, 19 and 37 % per annum for wheat, maize, barley, millets, pulses and fodders, respectively. The production of horticultural crops for the years 1997-98 was taken as a reference year prior to the drought. The production of drought-affected years (1998-2001) was averaged and compared with the pre-drought year of 1997-98. The average reduction in production during the period of drought-affected years (1998-2001) was 26, 26, 33, 32, 27, 37, 27 and 24 % per annum for apples, apricot, peach, plums, grapes, pomegranate, dates and almonds, respectively.

Apples, apricot and dates are the major fruits grown in the province. The reduction in production of all fruits was to the tune of 27% per annum during the last three years of drought, which is a significant reduction for the agricultural economy of the province.

Damage to Livestock

In **India** survey reports from the eight villages in the drought prone of Sabarmati basin suggest that agriculture is supplemented with the raising of livestock. The drought drastically affected the livestock of the region. Almost 59% of the surveyed households reported damage to livestock. The most affected species were cows, bulls and goats. Almost 280 cattle heads suffered due to water stress and fall in fodder supply. In **Pakistan** livestock production plays important role both in contributing to the national economy and livelihood for a large number of people living in rural and urban areas. In normal years, livestock production contributes nearly 9% to GDP, about 37% to the agriculture sector output and about 10 % of total export earnings of the country. Available estimates indicate that, for the country as a whole, animals provide around 20 kg of meat and nearly 160 kg of milk products per capita annually. The dietary contributions in the agro-pastoral regions are much larger. In addition, vast remote pastoral areas have little or no access to alternative food sources and animals play a vital role in household food security, providing essential nutritional needs through meat and milk. Large losses, therefore, will have direct and severe impact on household food security, especially for those in remote and inaccessible areas.

The most affected districts of the Balochistan province account for 35 and 45% of the provincial population of goat and sheep, respectively, during 1999-00. During the year the meagre production of palatable biomass dried up earlier due to lack of rainfall and thus the carrying capacity was reduced considerably. Heavy losses in term of higher mortality and forced culling rates were 45 to 55% for sheep and 30 to 40% for goats. In the drought-affected districts, there have been a smaller number of newborns and these have been sold, died or transported to other provinces depriving the flocks by not having the replacement stock. Economic losses in terms of mortality and forced culling in the worse affected districts of the Sindh province were 10% for cattle, 30% for sheep and 20% for goats. Domestic production of sheep and goat milk is estimated to have been reduced by 70-80% in the worse affected. The prices of livestock have declined by 80, 75 and 70% for cattle, sheep and goats, respectively. The ruminants in Sindh are very weak and have limited resistance to incidence of disease. The prolonged droughts resulted in gradual vanishing- of water and vegetation in the Cholistan desert, which generally inflicted heavy economic losses to the herders because they were stuck deeper in the desert due to higher mortality of their herds. Among the adult animals, the mortality rate was 6.4 and 6.9%, for cattle and sheep respectively. Young stock of small ruminants suffered proportionately higher casualties than the young stock of large ruminants. Mortality of young stock of sheep and goats was 6.8 and 10.3% respectively. The camel and its young stock suffered least casualties due to drought. Considering drought mortality differences between farm types, casualties of large ruminants were relatively

higher on pastoral farms while that for small ruminants were higher on agro-pastoral farms. Small-size herders, as compared with farmers of medium or large herd-size categories, reported proportionately more casualties of adult cattle and sheep. In case of goats, mortality of both adult and young stock was relatively higher among large-size herds.

Impact on Food security

In **India** the state government is the major relief provider during droughts. Non-governmental institutions also provide some support in the form of loans or by organizing cattle camps. All the surveyed villages reported the existence of fair price shops. The government provides basic necessities like wheat, sugar, kerosene, etc at subsidized rates through these shops. However, direct government support during extreme climatic events is only forthcoming once the region is officially declared drought affected. The government also carries out relief operations to supplement the income of the drought-affected people. Government relief work comprises of construction of social infrastructure like roads, dams, etc. These provide employment opportunities to the affected communities for 2 to 3 months. Generally wages are paid in both kind and cash. The average wage per worker was reported to be Rs 25 to 30 and Rs 25 worth of food grain per day.

Pakistan Slightly more than half of the human population in the worst affected districts of Balochistan during the drought period of 1999-00 was affected badly affected in terms of food: milk, butter and Kharroot availability. The livestock herders left only one option of eating dry "Rooti" with water if it is available. More than half of the affected population in the Chaghi and Kharan districts reported eating simple boiled rice without milk and butter, which occurred due to non-availability of wheat flour. About 5% families in Kharan district even reported nothing to eat. These families are awaiting their elders to bring food for them after earning wages. This situation leads to the undernourishment and weakening of the human population. Drought affected population represented around 16 % of the total population of 4.6 million of the drought-affected districts of Sindh province during the year 1999-00. The diet of majority of affected population in Sindh had reduced to wheat bread, which is usually taken with onions and/or chilies. Permitting the resources they also take potatoes and pulses. Traditionally, the families eat together including women and children. Reduction in the in-take of "buttermilk (Lassi)", other milk products and locally produced vegetables resulted in the intake of low nutritional food materials.

The impact of drought on social conditions may be estimated by the evidence that calorie based poverty index has increased significantly in the 1999, rising from 17.3% in 1988 to 31% in 1997 (Gap 2002). Recent estimates suggest that poverty has further increased to 33.5% in 2000, which accounts for drought as well as other socio-economic factors and natural calamities responsible for high incidence of poverty. It was estimated that around 349000 people were affected by drought, which comprise of smallholders, pastoral and landless rural households living under adverse living conditions,

particularly in parts of Balochistan, Sindh and Cholistan desert in Punjab province.

Damage to Health

In **Pakistan** as a result of drought, the decline in consumption of important food items like milk, meat and vegetables was a major nutritional concern for women and children who already have high malnutrition and anemia in Balochistan and Sindh provinces. Rural households have higher levels of malnutrition and anemia than urban households. The lack of water was the most severe problem faced by communities of these provinces. This has resulted in increased workload for women and children in parts of Sindh and Balochistan provinces. Many women are now covering longer distances to fetch water as groundwater sources have receded and surface water sources have dried up. Due to extremely low recharge and excessive abstraction of groundwater, water table has been continuously falling in the drought-affected districts by up to 3 meters annually. Every year tubewells have been sunk deeper and deeper. In some places, water is available only at depths of 200-300 m. As a consequence of deepening of the tubewells, a large proportion of the traditional water sources, the Karazes, in the most affected districts of Balochistan have dried up during 1999-00. In Sindh province before the onset of rains, people normally construct small ponds, which are either mud plastered or cemented to store and conserve rainwater for domestic and stock water use. The stored water is normally available for a period of 4 to 6. At deeper depth, water is available but it is highly brackish. In places, springs and wells have dried up due to the continued drought. Due to prolonged drought, people in Kohistan region have been forced to migrate out of the areas and shifted to places where water is available. Failure of rainfall along with poor quality groundwater has affected crop production.

Some Highlights of Impacts of Flood and Drought

Flood	Cost of damage during each event	Population affected in million in each event	Persons died in each event	Extent of affect
Bangladesh (1954-1998)	Taka 1200-100000	20-47 millions	87-2379	
	GDP growth decline by 1%-5%			
India- West Bengal 2000			1429	2.3 million crop area affected, 1.8 m houses damaged
Nepal (1983-2001)	Total 21-4904 M NRs.		49-1336	Total 43038 families affected
Drought				
Pakistan	GDP growth			

	decline by 1-3%			
Bangladesh (1951-1997)		53% of population		47% of the country
	GDP growth decline by 1%-5%			
El Nino-La nina	GDP growth decline by 1%-5%			

Vulnerable groups : flood vs drought

Survey results show that the economic hardships of an agrarian society dominated by small and marginal farmers, are compounded by loss of output and property damage during floods. Table 6 shows the vulnerability assessment in flood prone area of Mahanadi basin in comparison to drought prone area of Sabarmati through reduction in food security and impoverishment.

Table 6. Vulnerability Assessment through Indices in the Hotspots

Category	Sabarmati Hotspot	Mahanadi Hotspot
Percentage of households showing a more than 10% fall in monthly expenditure during extreme events	84	100
Percentage of households showing a more than 10% fall in monthly food expenditure during extreme events	28	84
Percentage rise in the price of staple food during extreme events	10 to 50	85 to 150

Source: Ghosh and Roy 2006

Poor are forced to live in flood vulnerable marginal lands. These houses are totally susceptible to all kinds of flood. During high intensity floods even those houses built on flood free land are damaged.

Special Reference to Coastal Zone Methods and Models for Assessing Vulnerability

Assessment of coastal zones to projected climate impacts & development of adaptation strategies include

- (a) a description & analysis of present vulnerability, including representative vulnerable groups (for instance, specific livelihoods at the risk of climatic hazards).
- (b) Descriptions of potential vulnerabilities in the future, including an analysis of pathways that relate the present to the future.
- (c) Comparison of vulnerability under different socio-economic conditions, climatic changes & adaptive responses.
- (d) Identification of points & options for intervention, which would lead to formulation of adaptation responses.

- (e) Relating the range of outputs to stakeholder decision making, public awareness & further assessments.

Projected variability and impacts

Future climate change in the coastal zones is likely to be manifested through the worsening of some of the existing coastal zone problems such as (in the context of Indian coastal zones)

- erosion
- flooding
- subsistence
- deterioration of coastal ecosystems such as mangroves
 - salinization.
 -

In many cases, these problems are either caused by or exacerbated by

- sea-level rise
- tropical cyclones
- changes in temperature

India

India's coastal zones are not only densely populated, but also the location of a number of oil exploration projects. To separate the influences due to global climatic changes the available mean sea-level historical data from 1920 to 1999 at 10 locations were evaluated. There is a large contrast in the observed sea level changes. The sea level rise along Gulf to Kutchh & the coast of West Bengal is the highest. Along the Karnataka coast, however, there is a relative decrease in the sea-level.

Sea level rise

India

A recent Asian Development Bank study reports that the effects of a 1-meter rise in sea level in India in the absence of protection would be as follows:

- Approximately 7 million people would be displaced
- Around 5,764 square kilometers of land would be lost because of inundation
- Some 4,200 kilometers of roads would be destroyed.

A rise in sea-level has significant implications on the coastal population & agricultural performance of India. A variety of impacts are expected which include :

- (a) land loss & population displacement
- (b) increased flooding of low-lying coastal areas
- (c) agricultural impacts (like, loss of yield & employment) resulting from inundation, salinization, & land loss
- (d) impacts of coastal aquaculture
- (e) impacts on coastal tourism, particularly the erosion of sandy beaches.

Bangladesh

The population is already severely affected by storm surges. Catastrophic events in the past have caused damage up to 100 km inland. Digital terrain modeling techniques have been used to display the Bangladesh scenarios. A three dimensional view of the country has been overlaid with the current coastline and major rivers and potential future sea levels at 1.5 meters. Since this scenario was calculated in 1989, the expected rate of sea level rise has been modified. At present expected rates, this stage will occur in about 150 years from now.

Scenario	Land area '000km ²	Population 1989 '000'000 est.	Population 2030 '000'000 est.
150 cm	22 (16%)	17 (15%)	34 (15%)
Bangladesh total	134 (100%)	112 (100%)	224 (100%)

The data given here are coarse estimates, using the same parameters as Delft Hydraulics. (UNEP/Delft 1989).

Disaster related Damage Predictions: Coastal : Physical/Qualitative/Relative/ Monetary

UNEP (1989) identifies **India** among the 27 countries that are most vulnerable to sea level rise. Most of the coastal regions are agriculturally fertile, with paddy fields that are highly vulnerable to inundation and salinization. Coastal infrastructure, tourist activities, and onshore oil exploration are also at risk. The impacts of any increase in the frequency and intensity of extreme events, such as storm surges, could be disproportionately large, not just in heavily developed coastal areas, but also in terms of the paralyzing devastation in low-income rural areas. Agricultural production in India is strongly influenced by cyclones, which devastate standing or ripening crops in the fertile coastal areas. Cyclonic storms from the Bay of Bengal and the Arabian Sea affect some 7,000 kilometers of coastline. Inundation by the tidal saline water reduces crop yield. The problem is usually observed in the coastal plains. An estimated 0.83 mha of prime agricultural land in the coastal zone of Bangladesh suffer from high soil salinity.

Author	Assumptions	Impact	Country
ADB (1994)	in the absence of protection, 1m rise in sea level	affect a total area of 1563 sq kms. and put 7.1 million people at risk. Dominant cost is due to land loss 5764 km ² , which accounts for 83% of all damages.	India
TERI 1996		in present value terms, the losses would range from 2287 billion rupees to 3.6 billion rupees	in the case of Mumbai and Balasore respectively
	submergence of coastline due to sea level rise	Large-scale out-migration	India
	intrusion of seawater in the groundwater	Fall in fishery and agricultural income	India
Yohe, 1990	1 meter sea level rise	35%of the land submergence	Bangladesh
		Out migration to India	
Mitra 2004	Storm surges, 2.5-6.7 m surge	Deaths upto 14000, max cattle killed 70, 000, 1.74 hect crop damaged, 3000 houses destroyed	Bangladesh, India
	Tropical cyclone (1990-99)	Loss of human life in the range of 451-140000 and economic loss in the range of 20-2500 US\$	

Adaptation

Past Actions and Costs

The severity of the threat of climate change and rapid economic progress to the water resources is well understood by the governments of these four countries. Individual Governments have already undertaken several measures to mitigate the undesirable socio-economic impacts that are confronting these nations.

India

The Indian government has budgetary allocation for natural calamities: like floods, droughts, cyclones, earthquakes, landslides, etc. Budget allocation on flood control projects is increasing over the years. On an average the Union Government is presently spending about Rs 4.5 crores per annum on flood control projects. These capital account expenditures are intended to reduce the country's vulnerability to such future catastrophes. Under the revenue account approximately Rs 20 crores is allocated for flood control. The total outlay for natural disaster relief has been about 0.3% of the country's GDP. Since water is a state related subject in India, as a result the role of the Ministry of Water Resources, Government of India, is essentially catalytic in nature. One of the Ministry's activities is to provide technical guidance and to monitor flood control projects of the states. The Central Water Commission (CWC) on behalf of the Ministry performs these activities. The important activities of the flood management sector are:

- Examination of Master Plans for Flood Management and Drainage
- Techno-economic Appraisal of Flood Management Schemes
- Compilation of Flood Management Data
- Studies on river morphology and river mechanics
- Flood forecasting for not only rivers in the Indian territory but also for rivers common to India and Nepal.

One of the major objectives of the above activities is to reduce future flood damages also to ensure better planning of rescue and relief operations.

Apart from the broad plans undertaken by the Indian government, at the local level also individual stakeholders and local institutions undertake various practices to cope with the effects of flood. In the surveyed region of the Mahanadi floodplains in Orissa the farmers usually cultivate Champeswar – a local variety of paddy in order to reduce agricultural output loss. The crop is tolerant to water stagnation and can sustain almost seven days submergence. In this case only 50% of the crop is generally damaged. If however, the water stands for more than ten days, the entire crop is lost. The seeds are generally available from Government depots or have been individually stored using traditional means of storage. Despite the seed supply from the government, HYV seeds are not available. In the absence of any HYV seeds, Champeswar is therefore the best alternative available to cope with flood damage.

As a short-term strategy to cope with flood impacts the community do labour work in unaffected villages or migrate in order to supplement their incomes. However, the most popular individual initiative coping methods followed is storage dry foodstuff and medicine during normal times to use during floods. Some report on crop insurance (reported by almost 18% of the respondents) was also obtained. Institutional support in the form of government support and NGO aid is also forthcoming during floods. These aids generally complement the support received from the informal sector. Food relief constitutes the major share of all forms of institutional relief. Aid in the form of clothes and seeds are also forthcoming. While the contribution of the NGOs in providing clothes to the victim was high, the seed aid from the government to support future agricultural activities is high. However, monetary loans are not much forthcoming. Thus the institutions fail to give the long-term financial aid that can be productively used and hence provide long-term benefit to the community. A possible explanation for lack of monetary aid can be the inability of the villagers to repay such loans. These debts are generally taken to reconstruct dwelling places and for other consumption purposes. Thus the financial organizations do not find it profitable to provide such non-productive loans. National Flood Commission (*rashtriya barh ayog*) was set up in 1976 by the Govt. of India to review & evaluate the flood protection measures undertaken since 1954 & to evolve a comprehensive approach to the problems of floods. In 1996, govt. of India set up a task force to review the impact of recommendations of the *rashtriya barh ayog* & analyze the strategies evolved so far 4 mitigating flood problems & suggest both short-term & long-term measures.

Health

India

India started using the pesticide DDT to control malaria beginning in 1946. In 1953, the National Malaria Control Programme was started. This programme was renamed the National Malaria Eradication Program (NMEP) in 1958 due to the success of DDT & the commitment to malaria eradication in India at that time.

It was believed that it could eradicate malaria in 7 to 9 years, but the disease began to re-emerge in 1965. After 1965, malaria rates in India rose gradually & consistently, with a peak of 6.47 million cases in 1976 (NMEP, 1996). This resurgence of malaria caused India to begin attempt to control rather than eradicate malaria in 1977 with a Modified Plan of Operation (MPO).

By 1985, it seemed as though the NMEP would succeed in controlling malaria, because there were only 2 million cases of malaria & the incidence rate had stabilized.

India has, however, experienced more epidemics & deaths from malaria in the 1990s, along with the creation of a new malaria phenomenon. In 1994, there were large-scale epidemics of malaria throughout the country, & since then malaria mortality has increased.

Financial assistance also has been received from the World Bank for the Enhanced Malaria Control Programme (EMCP) to cover a 100 predominantly *P.falaciparum* malaria endemic tribal-dominated districts in AP, Bihar, Jharkhand, Gujarat, Madhya Pradesh, Chhattisgarh, Maharashtra, Orissa & Rajasthan & 19 other cities.

In other areas, the NMAP continues to be implemented as a centrally sponsored scheme on a 50:50 cost-sharing basis between the centre & states in urban & rural areas.

The central government provides drugs, insecticides & larvicides & also technical assistance/ guidance as & when the state government require. In view of the high incidence of malaria (particularly of falciparum malaria) & high mortality, a 100% central assistance under the NMAP is being provided to the north-eastern states since 1994.

Since the Ninth Plan goal for reduction in API & morbidity rate reduction by 25% in 2007 & 50% in 2010.

Parameter	To achieve
Annual Blood Examination Rate (ABER)	Over 10%
API	1.3 or less
Morbidity & Mortality	Reduce by 25% by 2007 & 50% by 2010

Bangladesh – The traditional cropping practices of the farmers are well adapted to cope with the normal seasonal inundations. During normal inundation farmers select their crops based on flooding characteristics of the region. Before the introduction of HYV seeds, farmers tend to grow a host of late planting Aman cultivars in uplands, deepwater (DW) broadcast Aman with considerable low yield and jute in deeply flooded lands. The latter two crops suited most of the low-lying lands, while both were capable of growing taller along with the water column on the land. As a result, the adverse impact of normal inundation on crops grown in relatively deeply flooded lands has been minimal. A rise in water column by a few centimeters above 'normal flood level' can transform a moderately flooded land into a deeply flooded land. So, the prospect of producing transplanted Aman with a higher yield compared to that of DW Aman is considerably reduced.

In the flood susceptible areas of rural Bangladesh, people's homesteads are located usually on raised lands. In the floodplains, every homestead is found to have an adjacent pond testifying that earth excavation had been carried out in the past in order to raise the land level above flood risk levels. Similarly, local religious centers, educational institutions, and markets are usually built on raised lands in the floodplains. Where flood vulnerability is higher, people tend to build houses on stilts, as observed in Srinagar and Louhajang sub-districts of Munshiganj district, allowing floodwaters to pass through the homestead. In those areas, the well-to-do families even build their *bathan* on sufficiently raised lands.

Since the 1960s the perceived threat has been greatly modified in a number of flood vulnerable areas by building flood protection embankments. A public funded organization, Bangladesh Water Development Board (BWDB), has been facilitating such a coping capacity. Although there have been criticisms regarding the fact that such structures actually increase flood vulnerability outside the protected areas, it is undeniable that such an adaptation to climate variability enabled farmers to grow HYV Arnan varieties, increasing the food production significantly. At the same time, however, these have been giving a false sense of security: the embankments cannot keep the 'protected' areas dry during the high intensity floods due to the fact that the structures are only meant to withstand moderate flooding.

Most of the communication network including national railways and highways are built on raised lands, suggesting a coping strategy taken by the peers. The Local Government Engineering Department (LGED) has taken a coping strategy for any future infrastructure to be built on floodplains. Over the years, the BWDB have developed a commendable capacity to forecast floods and issue flood warning. It houses a Flood Forecasting and Warning Centre (FFWC) that is capable of analyzing data collected from a number of stations spreading across the country. But the effectiveness of its activities are of little significance due to two reasons: (a) forecast is disseminated poorly which often fails to reach flood vulnerable people, and (b) the lead time for the forecasts are so short that, even if it reach the people at the grassroots, they do not find any substantial time to take precautionary measures.

Within a flood-affected community, people often help each other to cope with a flood. Most of the assistance is offered in terms of meeting food and energy demands, supply of potable water, rendering storage facilities for household belongings etc. The rich donate dearly to arrange free food for the flood victims, especially the poor ones.

The poor contribute their free labour to transform an educational institute into a flood-shelter. The youth often help neighbours to relocate in flood shelters, provide free (boat) ride to local hospitals, prepare and distribute food for the local destitute, voluntarily take charge of all types of operations of flood-shelters, etc. During the flood of 1998, all the public universities in and around Dhaka were transformed into flood-shelters: the people used the classrooms as shelters while the students staying in the halls (hostels) prepared and distributed food among the affected ones. Youth generally plays very constructive voluntary role towards community based flood management operations in Bangladesh.

Local-level public administration organizations, local youth clubs and other community-based organizations (CBO) also play vital roles by facilitating local-level activities. Based on the experiences of the past three high intensity floods, the Government of Bangladesh (GOB) issued a Standing Order towards implementation of Disaster management activities, including those meant for flood management. NGOs play a significant role towards supplying food, clothing, medicines, and other items including water purifying tablets, oral rehydration saline etc. They also commission medical teams to provide health care services. Both the Government organizations and NGOs continue to offer services during the post-flood rehabilitation. Restoration and reconstruction of damaged houses, decontamination and re-sinking of tube wells, restoration of physical infrastructure, continuation of health care services - all require gigantic efforts on the part of both government agencies and NGOs. Continuation of relief operations by the then government following the deluge of 1998, especially giving the poor food grains as relief successfully averted an anticipated famine - it is now regarded as a major example of post-disaster adaptation.

Government can consider policy-level adaptation as well. In the case of flood 1998, a policy was devised to procure food grains following each harvest to create storage towards minimizing food insecurity instigated by natural disasters. It was also decided to distribute a large sum as soft-term loan among poor farming communities to boost post-flood agriculture that resulted in a record production of food grain in the following crop season. Through the operations of the national agencies dealing with agriculture, seeds were also distributed following the recession of floodwaters in 1998. The floods and droughts are being adapted to some extent in the agricultural practices by the expert prescriptions, which are disseminated by the government to the farmers. The farmers are provided necessary guidelines for timely and appropriate action in case of special circumstances such as floods and droughts on plantation, irrigation, and fertilizer application, types of crops to be planted, etc. To avoid the flood risk on agriculture, stress has been given to the extensive rice cultivation using irrigation during the winter and pre-monsoon period. The crops like maize, wheat, pulses and potatoes, which do

not need much of irrigation, are gradually being cultivated in an increased intensity during the dry winter period.

Besides, the weather and flood monitoring, predicting and warning systems have been strengthened and improved in BMD, FFWC of BWDB, and SPARRSO and in a few NGOs engaged in the water sector planning and flood forecasting. Studies have been conducted on the predictions of floods and droughts based on the ENSO activities. The findings of such studies have been successfully applied for predicting the droughts of 1997 and floods of 1998. This helped the government to take necessary preventive measures. In Bangladesh, a comprehensive and effective disaster management system where government, NGOs and peoples would play active role is under development.

Steps taken towards improvement:

The Department of Forest, under the Ministry of Environment and Forest has undertaken a project titled "The Coastal Greenbelt Project" for the period 1995- 96 to 2001-2002. The project will cover 12 coastal districts of Bangladesh such as Barisal, Jhalkati, Patuakhali, Borguna, Bhola, Bagerhat, Pirojpur, Lakshmipur, Noakhali, Feni, Chittagong, and Cox's Bazar. The main objectives of the project are to:

- Prevent loss of life and damage to property by cyclone, storms, and associated tidal surges;
- Protect and improve the coastal environment through increased vegetative cover in the project areas;
- Help poverty alleviation of the local rural population by generating supplementary income opportunities by augmenting tree cover in the coastal region;
- Contribute to the government objectives for increasing the country's forest resources;
- Help increase the stability of the coastal embankments;
- Help establish cottage industries based on forest products to be grown in plantation;
- Find multiple uses for land along the roadsides, railways, feeder roads, and embankments, rather than keeping the land fallow;
- Enrich homesteads of the coastal region with trees that produce timber, fuel-wood, and fruits; and
- Impart training to youth and elderly regarding raising nurseries and growing trees, and create awareness among people with regard to forest management that leads to income generation, and self-reliance.

The Government of Bangladesh has drawn up a Five-Year Strategic Plan for the Comprehensive Disaster Management Programme (2004-2008). During the last flood affecting Dhaka City in 1998, 70 percent of the city area was inundated for as long as 90 days. Natural disasters like cyclones, floods and tidal surges claimed approximately 153,000 lives in Bangladesh during the last 10 years affected at least 50 million people and caused damages to property worth more than US\$ 7 billion. Measures undertaken to protect the

people and their property from such disasters have been very inadequate so far. A panel of experts has finalized the Bangladesh National Building Code (BNBC, 1996), which, if properly followed, should minimize losses due to disasters. The government has taken action to enforce BNBC to construct high rise building to prevent disasters. Another government programme is the Fund for Mitigating Risks for Natural Disasters. This has a total budgetary allocation of Tk 1.5 billion. The programme is intended to respond to natural disasters such as drought, rain from the hills, floods, river erosion, cyclones and tidal waves. It covers about 22,000 beneficiaries each year. Victims of disasters are eligible for interest-free loans from Tk 5,000 to Tk 25,000, with a one to three years' period for loan repayment and a one-time 5 percent service charge. PKSF is also implementing a pilot programme titled "Disaster Fund for the Poorest" specifically to protect those who have borrowed micro-credit under the programme.

Nepal - Relief and rescue operations, temporary rehabilitation, diseases (epidemic) control measures as immediate response are the most common type that characterize the autonomous adaptation in Nepal wherein most sectors of the civil society as well as government agencies are involved. Besides several institutions at government, political, non-government and local level have emerged to facilitate the management of 1993 disaster.

In spite of scarce physical resources, the active participation demonstrated by institutions and community to deal with the disaster seems to be highly appreciable. Reconstruction and restoration of vital infrastructures such as highway, motor roads, bridges, hydropower plants, irrigation projects by government with public and international cooperation was another immediate response to the disaster. Some research efforts of policy implication on understanding the nature, cause and impact of extreme events, and hazard and risk assessment, were also carried out by the institutions like ICIMOD, DPTC, JICA, UNDP, Department of Hydrology and Meteorology, Department of Mines and Geology, and Tribhuvan University. Similarly, several workshops and seminars were held in both national and international forum to recommend policy measures and action plan (ICIMOD, 1993; DPTC, 1993). The government has developed better capabilities in emergency response especially after 1993-flood and landslide incidence in central Nepal. The Central Natural Disaster Relief Committee (CNDRC) and District Natural Disaster Relief Committee (DNDRC) formed under the provision of the Natural Disaster Relief Act 1982 work in close cooperation and coordination with Nepal Red Cross Society and with various agencies involved in providing cash, material and technical assistance for rescue and relief operations. These include Japan International Co-operation Agency (JICA); United States Agency for International Development (USAID); Lutheran World Service (LWS); Technical Co-operation of the Federal Republic of Germany (GTZ); OXFAM, CARE Nepal, United Mission to Nepal (UMN); United Nations Development Program (UNDP); Save the Children Fund; Red Barna etc. Although the capabilities in emergency response has increased, but the lessons so far learnt, shows that post disaster assessment of damage is still weak, and lacks trained personnel to be mobilized during the disaster and also there is a dearth of local institutional arrangement at VDC level for proper

distribution relief and rehabilitation materials). It was also learnt that early warning system and post disaster effective communication and transportation system could play an effective role in disaster management.

The above-discussed adaptations refer to active type; mostly characterize the sharing loss from disaster by means of government, social institutions, community and individual effort. The share of loss is only a small portion, and kind of temporary relief and rehabilitation, however very crucial, to the total loss. Hence bearing the losses and accepting the cost is the most prevalent method of adaptation to disaster, particularly for poor and marginal families. A large number of people lose their livelihood asset, mainly land, or become marginalized and pose additional challenge to sustainable development. In a study conducted by the Central Department of Geography in 1999 found that the strategies adopted by household to adapt to flood and other geomorphic hazards include:

- reclaiming the reclaimable land by self or hired labor,
- evacuation and from flood prone area to other areas within or outside the locality,
- migration of some economically active household members to India, or cities and other parts within the
- country, some even to Middle East countries mostly for unskilled and semi skilled jobs;
- construction of small structure to control river bank cutting,
- tree plantation and afforestation,
- resorting full time or seasonal wage labor for livelihood,
- farming on rented land on share crop basis,
- collecting firewood for selling or doing petty trade/hawking in nearby bus -stations/towns, and
- cultivation of cash crops such as water melons on limited scale that can be grown on sandy waste land.

Government activities until the 1980s were mainly directed towards post disaster activities viz. rescue, relief and rehabilitation only as voluntary social work. There was no well-structured disaster policy. In 1982 the Natural Disaster Relief Act came into existence, which was amended twice, in 1989 and 1992 enunciating the significance of the predisaster and post -disaster activities. The Act has made provisions for the Disaster Relief Committees at the central, regional, district and local levels. As stated earlier, only the central level and district level committees are functioning; the others are to be executed only during big natural disaster. The CNDRC is the apex committee that is responsible for formulating policies and plans regarding overall aspects of disaster management in coordination with about 22 national government agencies and 14 non-governmental agencies that are involved in disaster management. Although the institutional arrangement for disaster management provided by the NDRA has strengthen the logistic capacity for emergency response (rescue, relief, rehabilitate, medication) to disaster; it still lacked broader perspective of disaster and it management. No single comprehensive action plan existed for addressing multifold issues of disaster such as disaster preparedness, early warning system, disaster information system; hazard and

risk analysis, impact vulnerability and adaptation assessment; training's and simulations. It was only after the advent of National Action Plan on Disaster Management in 1996, broad spectrum of disaster prevention and mitigation activities were considered. The Plan specified the priority activities to be undertaken in the field of disaster management (including flood and landslide mitigation) by responsible government agencies. The disaster management activities envisaged by the NAPDM are as follows:

- Measures related to national policy and planning for making institutional arrangement, providing legal framework, adopting national policy and plans on disaster management;
- Measures related to geological hydrological and meteorological hazard and risk assessment and environmental engineering studies;
- National land use /land cover plan for effective land use zoning;
- Measures related to awareness raising, training, rehearsal, and simulation activities;
- Measures related to establishment of disaster management information system and stocks piling of emergency supply materials;
- Risk assessment for development planning;
- Policies on the role of NGOs, local communities, private sector and people's participation;
- Promotion of regional and sub regional cooperation between countries experiencing same types of hazard;
- Establishment of documentation center on disaster activities

Prior to ninth plan (1997-2002) no specific program was planned for disaster prevention issues. Some programs related to disaster prevention were planned to implement in the forest sector. These include soil conservation and watershed management, gully and landslide and flood control projects by encouraging public participation and awareness. In the Ninth Plan, the need to strengthen the disaster management capability was recognized. The Ninth Plan envisages that efforts should be made for prevention, mitigation, and reduction of natural disaster through advanced geological, hydrological, and meteorological technology.

The plan emphasizes the importance of hazard mapping, vulnerability assessment, risk analysis and early warning systems, for which efficient manpower should be made available. It also emphasized the need national and international assistance. With regard to flood mitigation, the Ninth Plan outlines the following activities:

- River Control program shall be coordinated with agriculture, forestry, and soil conservation programs to make it more effective and its scope of work shall gradually be expanded.
- Emergency flood control work will be carried out using the available resources and means; and also mobilizing the local public participation.

- Master Plan will be formulated by studying through internal and external resources various rivers of the kingdom, which cause maximum loss annually with the assistance of friendly nations and internal resources; programs of river control will be launched.

River control work will be conducted in a planned way with grant assistance received in kind from the friendly nations. People's participation and environment conservation policy will be compulsorily implemented in river control work.

Urban centers are usually located, although in most cases along rivers, on raised lands. Urban areas are, therefore, by commonest of definitions, free from flooding. Only floods of 'higher than normal' intensity are capable of causing problems in urban lives. Occasional breach in the embankment also catches people unprepared and floodwaters can drown everything inside the breached embankment within hours. People of Dhaka protected lives of millions and potential damage worth billions of dollars by ceasing a breach on the Dhaka-Narayanganj-Demra embankment during 1988. Examples of flood in Mumbai (2005) and cities like Calcutta in 1998 are some such examples.

Sea level rise

Pakistan

The Indus basin irrigation system (IBIS) is the world's largest contiguous irrigation system commanding an area of 16.4 million hectares. During 60s and 70s, the two large dams were constructed in the Indus basin with a live storage capacity of around 20 billion m³. This includes Tarbela on the river Indus and Mangla on the river Jhelum. These dams are under continued sedimentation and around 24% of the live storage capacity has been lost. Thus there is an urgent need to provide additional storages of around 10 to 12 billion m³ in the system, with or without climate change. Such reservoirs can provide incremental benefits in case climate change impacts are significant. Government of Pakistan has already included construction of number of storage dams in the 10 years Perspective Plan prepared for the current decade. This includes Kalabagh and Bhasha dams on the Indus river, raising Mangla on the river Jhelum, Gomal dam on Gomal river, storage dams on the Mirani and the Hangol rivers in the province of Balochistan, and Sehwan in the province of Sindh. The investment plan for the next decade also reflects the required investment.

Punjab Irrigation and Power Department implemented a comprehensive strategy by closing canals in the fresh groundwater zone through diversion of water into canals of the brackish groundwater zone. National Drainage Programme (NDP) of WAPDA financed a research project that helped develop technology for skimming of thin to medium depth layers of fresh groundwater and application of the skimmed water using pressurized irrigation systems i.e. sprinkler and drip irrigation systems to address the issue of smaller discharges. Government has launched programmes to install tubewells to provide water to meet shortfalls, especially in the areas where domestic water availability is a major concern. Government has provided

policy support for the availability of concessional rates of energy for pumping of groundwater for agriculture. The public tubewells installed by WAPDA were transferred to the provincial governments for the O&M purposes. Most of the public tubewells were not in operation due to the deferred maintenance or lack of payment of the energy bills by the provincial governments. These tubewells were transitioned and communities were encouraged to install shallow tubewells using diesel operated pumping systems, because communities were not ready to pay the electricity tariffs. Diesel fuel was much cheaper than the electric tariff. Small and resource-poor farmers were able to purchase water from the community tubewells and they were able to meet the shortfall in canal water supplies.

Rain fed farming systems and human settlements in the Barani lands are being seriously affected due to dry spells and prolonged droughts because dependence of rural people for agriculture and domestic water use is solely from rainfall and runoff. Government of Punjab had established a Special Commission for the development of Barani lands and based on the recommendations of the Commission, the Government of Punjab has established Agency for Barani Areas Development (ABAD) with mandate to provide coordination among the nation building departments for the implementation of the Barani Area Development Programmes

Government of Punjab has established Small Dams Organization with its headquarters located in Rawalpindi. They have been constructed 34 small dams with designed command area of around 25,000 hectares. Stored water is now being used for irrigating the command area. Fisheries Department has also introduced freshwater fisheries in these dams. Pondered area also contributed significantly in recharging the groundwater, which is being exploited by farmers and rural communities. ABAD has also sponsored construction of mini dams, where farmers are contributing 50% of the cost. Rod-Kohi is one of the potential ecosystems of the country, where floodwater of hill-torrents is diverted to irrigate large fields. Fields are over 3 hectares in size. With one deep watering of 2 m depth, farmers can grow successful crop of wheat. One additional watering can help to have bumper harvest. Deep-rooted crops are recommended for this ecology. Water management of this ecology is crucial and different from irrigated and Barani farming systems.

Government of Punjab has established the Cholistan Development Authority to coordinate activities of the nation-building departments. The major intervention introduced in desert was development of earthen ponds to store the runoff emerged from rainfall. The availability of pond's water for domestic and stock water use is the essential element for maintaining life in the desert. They have also installed tubewells in areas where usable groundwater is available. PCRWR and PARC have also established their field research outfits in the Cholistan desert for rainwater harvesting and storage, range management and forest plantation on sand dunes, supplemental irrigation techniques and cultivation of oil seeds like Jojoba, rape and mustard, castor seed, etc.

Thar Desert was badly affected by severe drought, which was prolonged for over five years (1995- 00). Government of Pakistan has approved a project to divert water through a lined canal to meet the domestic and stock water needs. The nation-building departments have also provided installation of tubewells in areas where groundwater of usable quality is available.

Key Lessons from the past

1. **Adoption of ‘no regrets’ policies** have been successful in decoupling growth and energy consumption and consequent emissions (Dasgupta and Roy 2000, Ganguli 2006, Das 2005).
 - a. Adoption of Energy efficient technologies
 - i. in industry sector has helped in showing downward trend in energy intensity since
 - ii. in transport sector
 - iii. in agriculture sector
 - b. Environmental policy, capital investment and fuel prices have played positive role in generating behavioural response to reduce energy intensity (Dasgupta and Roy).

Key messages

The messages summarized are based on the literature available and subsequently research gaps are also highlighted. It is important to integrate development policy options with climate policy options.

Vulnerable{ XE "Vulnerable" } groups

As concerns socioeconomic effects, the model indicated that the effects of climate change would be greater for poorer sections of the population. A large number of resource-poor farmers in India are not able to apply desired levels

Vulnerable groups	Degree of vulnerability	Literature
Small and marginal farmers	Very high	Disaster
Farmer with no irrigation facility	Very high	Disaster/trend
Poor households	Very high	Disaster
Farmers with no secondary source of livelihood	High	Disaster
Coastal Fishermen	Very high	Storm surge, tropical cyclone

Vulnerable sectors/activities

Agriculture	High	Trend
Coastal agriculture	Very high	Extreme events
Marine and Coastal Fishery	Very High	Extreme events
Forestry	High	Extreme events
	Medium	Trend
Infrastructure	Very High	Extreme Events
Health	Very high/high	Extreme events/trend

Additional burden on local and national economy

Both the literature confirm that additional burden on the economies are going to be very high. The situation will be worse depending on the level of poverty and coping capacity. Further worsening will occur in case of extreme events.

Adaptation Prospects

The survey reveals that both reactive and proactive measures work. The challenge is to endogenise the reactive adaptation measures through appropriate institutional arrangement and local capacity building in order to enhance the rate of coping capacity. This will help not only to reduce the vulnerability through proactive adaptation systems but would lead to sustainable livelihood provisions also. The survey further emphasizes the requirement for such strategies to simultaneously address the problems of adaptation and development. Coping capacity building policies when developed in the context of traditional welfare issues like poverty, low level of economic activity, starvation, health risks, etc. has a positive cumulative effect on the adaptation strengths of the affected stakeholders. The above analysis establishes that the capacity to adapt to climate change goes beyond income generation to other pre-requisites of innovative development planning, institutions, economic management and technology. Based on local scale climate impact and adaptation needs in consultation with stakeholders, the following portfolio of future actions may be suggested.

Time Scale, Coverage & Actor	Technical	Institutional
<i>Policies Common to Flood & Drought Prone Areas</i>		
Short –term Local Measures	<ul style="list-style-type: none"> • Early detection systems of extreme weather events 	<ul style="list-style-type: none"> • Communication of early warning systems • Emergency relief • Public distribution systems. & Food banks • Purchase/mortgage scheme for livestock
Medium –term Community/state level Measures	<ul style="list-style-type: none"> • Diversification of livelihoods through skill formation 	<ul style="list-style-type: none"> • Low interest credit systems • Better education • Yearly joint scientific meetings
Long –term National Measures	<ul style="list-style-type: none"> • Capacity building that transforms livelihood option set • R&D to develop disaster resistant crop strains • R&D to develop alternative cropping patterns • Investments in studying “the diverse” impacts of floods /droughts including impacts on water quality • Investments in rainfall & river monitoring & their modeling 	<ul style="list-style-type: none"> • Media- radio/T.V. programme disseminating information on adaptation measures

<i>Policies Specific to Flood Prone Areas</i>		
Short –term Local Measures	<ul style="list-style-type: none"> • Safe places • Flood proofing (structural & non-structural) • Water management through appropriate storage and distribution systems to accelerate access to safe water • Food preservation 	<ul style="list-style-type: none"> • Resources to address disease outbreak
Medium –term Community/state level Measures	<ul style="list-style-type: none"> • Phasing out high-risk land use practices • Assessing redistribution of risks from structural measures including dams, diversions and dykes 	<ul style="list-style-type: none"> • Recognising both positive & negative aspects of “floods” • Fostering institutional learning • Investment in public health • Policies to encourage efficient water use
Long –term National Measures	<ul style="list-style-type: none"> • Building for current & future regimes 	<ul style="list-style-type: none"> • Enforcing land-use zoning & building restrictions in flood plains or removing perverse incentives for inappropriate risk-taking or redistributing involuntary risks likely to help for current & future variability • Inter-governmental cooperation on information systems including those related to assessing changes in flood regime due to climate interacting with land-use – residential & agricultural.
<i>Policies Specific to Drought Prone Areas</i>		
Short –term Local Measures	<ul style="list-style-type: none"> • Small storage ponds • Low cost irrigation 	<ul style="list-style-type: none"> • Early purchase schemes for livestock at good prices
Medium –term Community/state level Measures	<ul style="list-style-type: none"> • Data dissemination 	<ul style="list-style-type: none"> • Ensuring technological gains are not over-run by increases in intensity of activities (enforced caps on crops/year, land receiving water) • Employing people during drought • Information systems and monitoring to ensure “fair compliance” & allocation at times of scarcity. “Managers” can then do their jobs • Water rights
Long –term National Measures	<ul style="list-style-type: none"> • Improving scientific knowledge, data capability • Investments in R&D in water saving practices and varieties 	<ul style="list-style-type: none"> • Regional water sharing agreements • Water resource development strategies that “take-into-account” variability • Structural changes • Shift towards demand management rather than never-ending strategies of augmenting supply

Source: Ghosh and Roy (2006)

Adaptation: options

One option would be to ***advance the sowing date***, which may be effective in the case of wheat. However, given the relatively high temperature regime that prevails throughout most of the year, the benefits may be limited. A feasible

strategy for the long run is **to develop cultivars** that **can resist the higher temperatures** expected under future climate change scenarios.

The consensus is that protecting and rehabilitating the global environment for food security does not pose significant technical challenges. Nevertheless, continued coordination of efforts to mitigate the effects of climate change and to improve food security for the world's population is of paramount importance. Such efforts require the implementation of legal and institutional reforms; the introduction of incentives to enable land users to manage their land on a sustainable basis and the provision of sufficient information, know-how, and technical support for them to be able to adapt to climate change. Climate change is likely to have widespread and adverse impacts for India. Because these impacts will only be realized in full over a period of 60–70 years, the incentive to act now is weak. However, consensus for action must be reached today so that mitigating measures can be undertaken immediately. Negligence or delay in generating the necessary political will and international cooperation could manifest itself in the form of unacceptable costs to countries and communities in the form of continued environmental degradation, hunger, and malnutrition.

Health

In addition to disease specific measures, the following actions might be taken (GOI 2004) to develop adaptation strategies for the future:

- Improved surveillance & monitoring systems.
- Develop vector specific regional maps.
- Technological engineering strategies.
- Improved infrastructure to avoid artificial breeding.
- Medical interventions.
- Develop predictive models linking climate & incidence.
- Develop integrated environmental management plans.
- Public education.

A combination of these options can be used in addition to the ongoing efforts of the government to control malaria. The appropriateness of these measures will of course be decided by the local experts according to the health care needs of the public in the region & some of them may be temporary in their effectiveness.

No regret Options

Developing adaptation strategies exclusively for minimizing the negative impact of climatic changes may be risky in view of large uncertainties associated with its spatial & temporal magnitude. Proposal for identification of 'no-regrets' adaptation strategies that may be needed for sustainable development of agriculture. These adaptations can be at the level of the individual farmer, society, farm, village, watershed, or at the national level.

Some possible adaptation options are

1) Altered agronomy of crops

- (a) Small changes in climatic parameters can often be managed reasonably well by altering the dates of planting, spacing & input management.
- (b) Alternate crops or cultivators more adapted to the changed environment can further ease the pressure. For example, in the case of wheat, early planting or the use of longer duration cultivators may offset most of the losses associated with increased temperatures.
- (c) Available germplasm of various crops needs to be evaluated for heat & drought tolerance.

2) Watershed management

These types of programmes yield multiple benefits such as

- sustainable production
- resource conservation
- ground water recharge
- drought moderation
- employment generation
- social equity.

3) Development of resource conserving technologies

Surface seeding or zero-tillage establishment of upland crops after rice give similar yields as when planted under normal conventional tillage over a diverse set of soil conditions.

- this reduces the cost of production
- this allows earlier planting.

Thus both combined results in

- (a) higher yields
- (b) less weed growth
- (c) reduced use of natural resources such as fuel & steel for tractor parts
- (d) improvements in efficiency of water & fertilizers.

In addition, such resource conserving technologies

- restrict the release of soil carbon, thus mitigating the increase of CO₂.
- zero-tillage saves at least 30 litres of diesel as compared to the conventional tillage. This leads to 80kg/ha/year reduction in CO₂ production. if these savings could be translated even partially to large arable areas, substantial carbon dioxide emissions to the atmosphere could be reduced.

4) Increasing income from agricultural enterprises

Global environmental changes, including climatic variability, may further increase the costs of production of crops, due to its associated

- increases in nutrient losses
- evapotranspiration
- crop-weed interactions.

Suitable actions such as

- accelerated evolution of location-specific fertilizer practices
- improvement in extension services
- fertilizer supply & distribution
- development of physical & institutional infrastructure.

Can improve efficiency of fertilizer use.

5) Improved land use & natural resource management policies & institutions

- (a) adaptation to environmental change could be in the form of social cover such as a crop insurance, subsidies, & pricing policies related to water & energy.
- (b) Necessary provisions need to be included in the development plans to address the issues of attaining the twin objectives of containing environmental changes & improving resource use productivity.
- (c) Policies such as financial compensation or incentive for green manuring should be evolved that would encourage farmers to enrich organic matter in the soil & thus, improve soil health.

6) Improved risk management through early warning system & crop insurance

- (a) Policies that encourage crop-insurance can provide protection to farmers in the event their farm production is reduced due to natural calamities.
- (b) It will be very useful to have an early warning system of environmental changes & their spatial & temporal magnitude. Such a system could help in determining the potential food insecure areas & communities, given the type of risk.
- (c) Modern tools of information technology could greatly facilitate this.

7) Recycling waste water & solid wastes in agriculture

- (a) The effluents such as industrial & sewage waste water, once properly treated, can also be a source of nutrients for crops.
- (b) Effective inter-departmental coordination within the government is needed to develop the location-specific framework of sustainable water management & optimum recycling of water.

8) Reducing dependence on agriculture

The share of agriculture has declined to 24% of the GDP, but 64% of the population continues to remain dependent on agriculture for its livelihood. That, in turn, results in low volume of marketable surplus & therefore, increased vulnerability to global change.

Institutional arrangements, such as cooperatives & contract farming, that can bring small & marginal farmers together for increasing production & marketing efficiencies are needed.

Some of the initiatives taken by the government of India includes

- National Watershed Development Project for Rainfed Areas
- Improved access to credit for farmers (through *Kisan Credit Card*)
- creation of a Watershed Development Fund implementation of the National Agriculture Insurance Scheme.

more emphasis on the efficient management of flood plains, flood proofing, including disaster preparedness & response planning, flood forecasting & warning, & many other non-structural measures.

Gaps in the literature

More research is needed to refine estimates of impacts in this region and to identify potential adaptation options for farmers and governments (Mandelsohn 2005). The assessment of research gaps keeping in mind the objective of this study are summarized in tables 20 through 23..

Table 20. Economic sectors

Sectors	Impacts studied	Economic valuation
Agriculture	Decline in productivity crop wise	Limited availability in both kinds of literature
Forest product	increased productivity	NA
	migration of forest types to higher elevations	NA
	transformation of drier forest types to moister types	NA
	reduce teak productivity from 5.40 m ³ /ha to	NA

	5.07	
	productivity of moist deciduous forests could decline from 1.8 m ³ /ha to 1.5 m ³ /ha.	NA
	Loss due to extremes	Quantification NA
NTFP	Gain as well as loss	NA. (Limited availability in non climate literature)
Infrastructure	Damage to road, public health , coastal areas	Very limited availability in disaster literature

Table 21: Non economic sectors

Sector	Observed and predicted Physical Impact	country	Economic valuation
Grass land	favourable impact on moist grass land	India	NA
	shift in arid grass lands	India	NA
	migration of woody plantation to high elevations	India, Nepal	NA
Inland or freshwater wetlands	Increased temperatures & lower precipitation as projected for central & north-western India	India	NA(Limited availability in non climate literature)
Coral reefs	with bleaching of over 80% of coral cover & mortality of over 25%	Lakshadweep	NA
	Acopora & Pocillopora that were almost completely wiped out	Gulf of Mannar India	NA
	Loss of Shallow water corals	Gulf of Mannar India	NA
	10% bleaching	Gulf of Kutch	NA

Health

In addition to uncertainties about health outcomes, it is very difficult to anticipate what future adaptive measures (for example, vaccines & the improved use of weather forecasting to further reduce exposure to severe conditions) might be taken to reduce the risks of adverse health outcomes. Malaria is one of the important climate-change related diseases that have been extensively studied since the early 1960s in India. However, Records of incidences & mortality due to the same are inadequate.

An integrated approach is required to evaluate the impacts of climate change on malaria in India, which will include not only the future climate & land-use pattern parameters but also would integrate the projected socio-economics which need to include access to medical intervention in the region/ state/ district.

Table 22 Health sector

Health Concerns	Vulnerabilities due to climate change	Economic valuation of damage
Temperature-related morbidity	(c) Heat- & cold-related illnesses. (d) Cardiovascular illnesses.	NA
Vector-borne diseases	(d) Changed patterns of diseases. (e) Malaria, filarial, kala-azar, Japanese encephalitis, & dengue caused by bacteria, viruses & other pathogens carried by mosquitoes, ticks, & other vectors.	(a)NA (b)Limited information based on Disability Adjusted Life Years (WB 1998)
Health effects of extreme weather	(f) Diarrhea, cholera & poisoning caused by biological & chemical contaminants in the water (even today about 70% of the epidemic emergencies in India are water-borne). (g) Damaged public health infrastructure due to cyclones/floods. (h) Injuries & illnesses. (i) Social & mental health stress due to disasters & displacement.	(a)Limited literature available (b, c,d)NA
Health effects due to insecurity in food production	Malnutrition & hunger, especially in children.	NA

BIBLIOGRAPHY

Achanta A and Kanetkar R. (1996). Impact of climate change on forest productivity: a case study of Kerala, India. Paper presented at the Asian and Pacific Workshop on Climate Change Vulnerability And Adaptation Assessment. [Manila, Philippines, 15-19 January 1996]

Aggarwal, P.K. and Kalra, N. (1994). Analyzing the limitations set by climatic factors, genotype, and water and nitrogen availability on productivity of wheat. II. Climatically potential yields and optimal management strategies. *Field Crops Res.*, 38, 93-103.

Aggarwal, P.K. and Sinha, S.K., (1994). Effect of probable increase in carbon dioxide and temperature on the wheat yields in India. *Journal of Agriculture Meteorology* 48(5), 811-814.

Agriculture, Environment, Climate and Health (1994): Sustainable Development in the 21st Century, edited by V. W. Ruttan. University of Minnesota Press, Minneapolis.

Asian Development Bank. (2001). Water for All: The Water Policy of the Asian Development Bank, <http://www.adb.org/documents/policies/water>

Asthana, V., (1994). Impacts of greenhouse-induced sea level rise on the islands and coasts of India. Jawaharlal Nehru University of India, New Delhi.

Bhattacharya, S., Sharma, C, R.C.Dhiman and A.P Mitra(2006), Climate Change and Malaria in India, *Current Science*, Vol 90. No 3, pp 369-375.

Briscoe J, Usman Qamar, Pervaiz Amir, Manuel Contijoch and Don Blackmore. (2005). Pakistan's Water Economy: Running Dry. Water CAS. World Bank. Washington, D.C USA.

Central Pollution Control Board, (1989), Basin Sub-basin Inventory of Water Pollution: The Mahanadi Basin, Assessment and Development Study of the River Basin Series: ADSORBS/23/1993-94.

Central Pollution Control Board, (1989), Basin Sub-basin Inventory of Water Pollution: The Sabarmati Basin, Assessment and Development Study of the River Basin Series: ADSORBS/20/1988-89.

Central Pollution Control Board, Basin Sub-basin Inventory of Water Pollution.(1985-86) The Subarnarekha Basin, Assessment and Development Study of the River Basin Series: ADSORBS/15/1985-86.

Change, World Meteorological Organization, and United Nations Environment Programme, Geneva.

Changnon, S.A. and D. Changnon. (1998). Climatological relevance of major USA weather losses during 1991–1994. *International Journal of Climatology*, 18, 37–48.

Chatterjee, A. (1998). Simulating the impact of increase in Carbon Dioxide and temperature on growth and yield of Maize and Sorghum. M.Sc. thesis, Division of Environmental Sciences, Indian Agricultural Research Institute, New Delhi.

Das Gupta M and Roy J (2000): "Manufacturing Sector's Energy Use in India: A Decomposition Analysis". The Asian Journal of Energy and Environment, Volume 1, Issue.3. September 2000.

Das Gupta M and Roy J (2001): "Estimation and Analysis of Carbon Dioxide Emissions from Energy Intensive Manufacturing Industries in India". International Journal of Energy Environment and Economics. Vol. 11. No.3.

Deshingkar P, Bradley P N, Chadwick M J, Leach G. (1996). Adapting to Climate Change in a Forest-Based Land Use System: a case study of Himachal Pradesh, India, Stockholm: Stockholm Environment Institute.

District Statistical Handbook Nayagarh, (1999), Directorate of Economics and Statistics, Government of Orissa. 2000.

DOD. (2002). Annual Report 2001/02, New Delhi: Department of Ocean Development.

Ghosh, Anupa, (2005), A Survey of Literature on Adaptation and Vulnerability: Socio –Economic Perspective, Working Paper no. GCP-JU-APN –1. Global Change Programme, Jadavpur University, Kolkata, India.

Ghosh, A and J, Roy (2006), Coping with Extreme Climatic Events: analysis of Household and Community Responses from selected Hotspots in India, Science and Culture, Special issue on Flood Disaster risk Reduction in Asia, Vol 72, No 1-2, January-February, pp 23-31

Gosain, A. K. & Rao, S.; Impacts of Climate Change on Water Sector in Shukla, P. R., Sharma, S. K., Ravindranath, N. H., Garg, A. & Bhattacharya, S. (ed).(2003). Climate Change and India: Vulnerability Assessment and Adaptation, Universities Press (India) Pvt Ltd, Hyderabad.

Gosain , A.K. , Sandhya, Rao., D Basuray (2006), Climate Change Impact Assessment on hydrology of Indian River Basins. Current Science, Vol 90. No 3, pp 346-353.

Government of India, Reassessment of Water Resources Potential of India- Ministry of Water Resources.(2000).

GOI (Government of India), 2004: India's Initial National Communication to the UN Framework Convention on Climate Change, Ministry of the Environment and Forest, New Delhi.

Government of Orissa, District Statistical Handbook Nayagarh.(1999), Directorate of Economics and Statistics, Orissa, Bhubaneswar.

Grasty S. (1999). Agriculture and Climate Change. Published in TDRI Quarterly Review Vol. 14 No. 2 June 1999, pp. 12-16

Haughton, G., (1998), Private profits—public drought: the creation of a crisis in water management for West Yorkshire. Transactions of the Institute of British Geographers, NS 23, 410–435.

Hewitt, K., (1997), Regions of Risk: A Geographical Introduction to Disasters. Addison-Wesley Longman, Essex, United Kingdom.

IPCC (1996). Climate Change 1995: Impacts, Adaptations and Mitigation of climate change: Scientific-Technical Analysis. Report of the Working Group II of the Intergovernmental Panel on Climate change, Cambridge University Press, London and New York.

Intergovernmental Panel on Climate Change (IPCC). (2001). Climate Change Scientific Basis, Summary for the Policy Makers. (Intergovernmental Panel on Climate Change, WMO-UNEP, Geneva, Switzerland)2001.

IPCC, (2001), Climate Change 2001: Impacts, Adaptation and Vulnerability, Contributions of Working Group II to the third assessment Report of the IPCC, Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Intergovernmental Panel for Climate Change (2001), Third Assessment Report, Climate Change 2001: Impact, Adaptation and Vulnerability, Working Group II.

IPCC. (1998), The Regional Impacts of Climate Change: an assessment of vulnerability, Cambridge: Cambridge University Press.

IPCC. (1996). Climate Change 1995: Impacts, Adaptations and Mitigation of Climate Change: Scientific-Technical Analyses. Contribution of Working Group II to the Second Assessment Report of the Intergovernmental Panel on Climate Change.

IPCC, (1996). The science of climate change, vol 1 of climate change 1995: IPCC Second Assessment Report. Cambridge University Press, Cambridge.

IPCC. (1992), Global Climate Change and the Rising Challenge of the Sea, Supporting document for the Intergovernmental Panel on Climate Change, World Meteorological Organization, and United Nations Environment Programme, Geneva.

IPCC. (1990). W. J. McG. Tegart, G. W. Sheldon and D. C. Griffiths. (editors). Australian Government Publishing Service. Canberra.

JNU. (1993). Impacts of greenhouse induced sea-level rise on the Islands and coasts of India, New Delhi: School of Environmental Sciences, Jawaharlal Nehru University

Kalra, N. and Aggarwal, P. K.. (1996). Evaluating the growth response for wheat under varying inputs and climate options using wheat growth simulator –WTGROWS. Abrol, Y.P., Gadgil, S., Pant, G.B., (Editors), Climate variability and agriculture. Narosa Publishing House, New Delhi.

Katsuo O Kamoto <http://www.terrapub.co.jp/e-library/kawahata/pdf/391.pdf>

Kohli, R.K., *et al*; Future Climate Scenarios in Shukla, P. R., Sharma, S. K., Ravindranath, N. H., Garg, A. & Bhattacharya, S. (ed). (2003). Climate Change and India: Vulnerability Assessment and Adaptation, Universities Press (India) Pvt Ltd, Hyderabad.

Kumar, K.S.K. and Parikh, J. (1998). Climate change impacts on Indian agriculture: The Ricardian approach. In: Measuring the impacts of climate change on Indian agriculture, Technical Paper No. 402. World Bank, Washington, D.C.

Kumar K and Parikh J. (1998). Climate change impacts on Indian agriculture: the Ricardian approach, In Measuring the Impact of Climate Change on Indian Agriculture, edited by A Dinar, R Mendelsohn, Everson, J Parikh, A Sanghi, K Kumar, J Mckinsey and S Lonergan, Washington, DC: The World Bank [World Bank Technical Paper No 402]

Kumar, K.S.K. and Parikh, J. (1997). Potential impacts of global climate change on ndian agriculture. Presented at the workshop on Measuring the impacts of climate change on Indian and Brazilian agriculture, 5-7 May, 1997. The World Bank, Washington D.C.

Kumar & Parikh
<http://siteresources.worldbank.org/WBI/Resources/wbi37151.pdf>

Kumar K.S.K and J. Parikh (2001), Indian agriculture and climate sensitivity, Global Environmental Change, vol 11(2), pp 147-154.

Kumar, M.D. (2001). Institutional and Policy Framework for Integrated Water Management in Sabarmati River Basin, Monograph 4, Anand: India Natural Resource Economics and Management Foundation.

Kumar, M.D., and Nagar, R.K. (2001). Institutions and Policies Governing Water Development and Use in Sabarmati River Basin, Monograph 3, Anand: India Natural Resource Economics and Management Foundation.

Kumar, M. D. and Singh, O.P. (2001). Rationed Supply and Irrational Use: Analysing Water Accounts of Sabarmati Basin, Monograph 1, Anand: India Natural Resource Economics and Management Foundation.

Kumar, M.D., Singh, O.P. and Singh, K. (2001). Integrated Water Resources Management in Sabarmati Basin: Some Issues and Options, Anand: India Natural Resource Economics and Management Foundation.

Kumar, M.D., Singh, O.P. and Singh, K. (2001). Groundwater Depletion and its Socio-economic and Ecological Consequences in Sabarmati River Basin, Monograph 2, Anand: India Natural Resource Economics and Management Foundation.

Kunkel, K.E., R.A. Pielke Jr., and S.A. Changnon, (1999), Temporal fluctuations in weather and climate extremes that cause economic and human health impacts: a review. *Bulletin of the American Meteorological Society*, 80, 1077–1098.

Kydland, Finn E. and Prescott, Edward C., (1977), “Rules Rather than Discretion: The Inconsistency of Optimal Plans,” *Journal of Political Economy*, 85, June :473-91.

Lal M, Cubasch U, Voss R, Waszkewitz J. (1995). Effect of transient increase in greenhouse gases and sulphate aerosols on monsoon climate, *Current Science* **69**(9): 752-763.

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

La Red, (1999): La Red de Estudios Sociedades en Prevencion de Desastres. International Non-Governmental Organization, Lima, Peru.

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

Marsden, T.K., (1997): Reshaping environments: agriculture and water interactions and the creation of vulnerability. *Transactions of the Institute of British Geographers*, 22, 321–337.

Mendelsohn R (2005) Climate Change Impacts on South Asian Agriculture, Yale university, website.

Miller, K.A., S.L. Rhodes, and L.J. MacDonnell. (1997). Water allocation in a changing climate: institutions and adaptation. *Climatic Change*, 35, 157–177.

Mileti, D., (1999). *Disasters by Design: A Reassessment of Natural Hazards in the United States*. The Joseph Henry Press, Washington, DC, USA, 250 pp.

Ministry of Finance. (2002) Economic Survey 2001-2002, New Delhi: Ministry of Finance, Economic Division, Government of India

Ministry of Environment. (2005). Survey to assess wood vegetation and wood volume on Non-Forest Areas in Pakistan. Report to Inspector General of Forest and the Asian Development Bank. Government of Pakistan. Islamabad, Pakistan

Mitra A.P (2004), Climate In south Asia and Water Resources –Introductory Note in Climate Change and Water Resources in South Asia, Proceedings of Year End Workshop, ed Muhammed AmirKathamandu 2003, Asianics Agro Dev International, Islamabad, Pakistan.

Mitra, A.P., Bhattacharya S., Dhiman, R.C., Kumar, K.K., Sharma, C. (2003), Impact of Climate Change on Health: A Case Study of Malaria in India, in Climate Change and India Vulnerability Assessment and Adaptation Ed. by Shukla P.R., Sharma K. S., Ravindranath N.H., Bhattacharya. S. , Universities Press, Hyderabad.

MoEF. (2002) Agenda 21: an assessment, New Delhi: Ministry of Environment and Forests, Government of India

MoEF. (1999). National Forestry Action Plan, New Delhi: Ministry of Environment and Forests, Government of India

Muhammed A (2004). Climate Change and Water Resources in South Asia, Proceedings of Year End Workshop, Kathamandu 2003, Asianics Agro Dev International, Islamabad, Pakistan.

Munasinghe, M. and C. Clarke (eds.). (1995). Disaster Prevention for Sustainable Development: Economic and Policy Issues; A Report from the Yokohama World Conference on Natural Disaster Reduction, May 1994. World Bank, Washington, DC, USA.

Murthy, N.S., Panda, M. and Parikh, K. (2000). CO₂ emissions reduction strategies and economic development of India. IGIDR Discussion Paper, Indira Gandhi Institute of Development Research, Mumbai.

Okamoto, K, M, Yokozawai, H. Kawashima (2006), Changes in Productivity of east and South asian Countries in the 21st Century, Regional trends according to Climate Change, Nationa; Institute for Agro-Environmental Sciences, Website.

Parikh, J. (1992). IPCC response strategies unfair to the South. Nature 360, 507-508

Parikh, J. (1994). North-South issues for climate change. Economic and Political Weekly, 2940-2943

Parikh, J.K. and Parikh, K. (2002). Integrating Climate and Sustainable Development Issues, Opportunities and Strategies, in Climate Change in India: Issues, Concerns and Opportunities, (ed) Shukla, P. R., Sharma, S. K. and Ramana, P. V., Tata McGraw-Hill Publishing Company Ltd, New Delhi, pp 220-225.

Patwardhan, Anand; Narayanan, K.; Parthasarathy, K.; Sharma, Upasana. (2003). "Impacts of climate change on coastal zones", Climate Change and

India: Vulnerability Assessment and adaptation (Edited by P.R. Shukla, Subodh K. Ravindranath, Amit Garg, Sumana Bhattacharya); University Press. pp. 326 to 359.

Pielke, R.A. Jr. and C.W. Landsea. (1998). Normalized hurricane damages in the United States: 1925–95. *Weather and Forecasting*, 13, 621–631.

Pohit, S (1997) "The Impact of Climate Change on India's Agriculture: Some Preliminary Observations," Proceeding of the 20th International Conference of the International Association for Energy Economics, 22-24th January, Delhi, India.

Pohit, s., and S Srinivasan (2005), Impact of Climate Change on Indian agriculture: Study of Selected Issues. Draft Project of National Council of Applied Economic Research, submitted to SANEL.

Pulwarty, R.S. and W.E. Riebsame, (1997), The political ecology of vulnerability to hurricane-related hazards. In: *Hurricanes: Climate and Socioeconomic Impacts* [Diaz, H. and R. Pulwarty (eds.)]. Springer-Verlag, New York, NY, USA.

Ravindranath, N.H.; Joshi, N.V.; Sukumar, R.; Murthy, Indu K.; Suresh, H.S. (2003). "Vulnerability and adaptation to climate change in the forest sector", *Climate Change and India: Vulnerability Assessment and adaptation* (Edited by P.R. Shukla, Subodh K. Sharma, N.H. Ravindranath, Amit Garg, Sumana Bhattacharya); University Press. pp. 227 to 265.

Ravindranath N H and Sukumar R. (1998). Climate change and tropical forests in India, *Climatic change* **39**(2-3): 563-581

Ravindranath n.H., N.V. Joshi, R. Sukumar and A saxena (2006), Impact of Climate Change on Forest in India , *Current Science*, Vol 90. No 3, pp 354-361.

Ravindranath N.H., Joshi, N.V., Sukumar, R., Murthy, I.K., Suresh, H.S. (2003), Vulnerability and Adaptation to Climate Change in the Forest Sector, in *Climate Change and India Vulnerability Assessment and Adaptation* Ed. by Shukla P.R., Sharma K. S., Ravindranath N.H., Bhattacharya. S. , Universities Press, Hyderabad.

Rupa Kumar, K., A.K. Sahai, K. Krishna Kumar, S.K. Patwardhan, P.K. Mishra, J.V. Revadekar, K. Kama and G.B. Pant (2006), High Resolution Climate Change scenarios for India for the 21st century. *Current Science*, Vol 90. No 3, pp 334-345.

Mendelsohn

Robert

http://www.aeaweb.org/annual_mtg_papers/2006/0107_1430_1601.pdf

Rosenzweig, C., Hillel, D. (1993). Agriculture in a Greenhouse World: Potential Consequences of Climate Change. *National Geographic Research and Exploration* vol. 9, pp. 208-221.

Rosenzweig, C. and Parry, M.L. (1994). Potential impact of climate change on world food supply. *Nature* vol. 367, pp. 133- 138.

Roy, J. and Ghosh, A. (2003). Socio-economic Scenario in South Asia. Amir Muhammed (Editor). *Climate Change and Water Resources in South Asia: Proceedings of Year End Workshop: Kathmandu, Nepal, 7-9 January, 2003*, Asianics Agro Dev International, Islamabad, Pakistan, November.

Roy J, Ghosh A, Majumdar A, Roy P, Mitra A. P, Sharma C. (2005). Socio-economic and Physical Perspectives of Water Related Vulnerability to Climate Change: Results of Field Study in India, *Science and Culture, Special Issue*, vol 71 . No 7-8 pp 239-259.

Roy, J., Mitra A.P, Sharma C, Majumdar, A, Ghosh, A. (2004). Climate Prediction, Adaptation and Coping Mechanism: Micro Analysis of SHUs in India; Second Year APN Report.

Roy Joyashree, Subhorup Chattopadhyay, Sabyasachi Mukherjee, Manikarnika Kanjilala, Sreejata Samajpati, Sanghamitra Roy (2004), An economic Analysis of Demand for Water Quality: A Case from Kolkata City, *Economic and Political Weekly*, vol XXXIX No 2, January 10-16, pp 186-192.

Roy Joyashree and Sohini Sahu (2004), "Willingness to pay studies: a policy tool", paper presented at Conference on Market Development of Water and Waste Technologies through Environmental Economics, May, Paris.
<http://www.cerna.ensmp.fr>

Roy Joyashree (2006) , Estimating Economic Benefits from Arsenic Removal in India:A Case Study of West Bengal. Research Report submitted to SANDEE.

Sanghi, A., Mendelsohn, R., Dinar, A. (1998). The climate sensitivity of Indian agriculture. In: Dinar, A. et al (eds), *Measuring the impacts of climate change on Indian agriculture*. World Bank Technical Paper No. 402. The World Bank, Washington, D.C.

Saseendran, S.A., Singh, K.K., Rathore, L.S., Singh, S.K. (1999). Effects of climate change on rice production in the tropical humid climate of Kerala, India. *Climate Change* 12:1-20.

Sathaye, J., P.R Shukla, N.H. Ravindranath (2006), Climate Change, sustainable development and India: Global and National Concerns. *Current Science*, Vol 90. No 3, pp 314-325.

Shah, A. (2001). Water Scarcity Induced Migration: Can Watershed Projects Help?; *Economic and Political Weekly*, 36(35): 3405-3410.

Sharma, C., Roy, J., Kolli, R.K., Singh, R.N., Pentu Saheb, S., Mitra, A.P. (2003). Impacts of Climate Change on Water Resources in India in Amir Muhammed (Editors). *Climate Change and Water Resources in South Asia*:

Proceedings of Year End Workshop, Kathmandu, Nepal, 7-9 January, 2003, Asianics Agro Dev International, Islamabad, Pakistan.

Shukla, P. R., Sharma, S. K. & Venkata Ramana, P. (Editors). (2002). *Climate Change and India: Issues, Concerns and Opportunities*, Tata McGraw-Hill Publishing Company Ltd, New Delhi.

Shukla, P.R., Sharma, S. K., Ramana, P. V. and Bhattacharya, S. (2002). Introduction, in *Climate Change in India: Issues, Concerns and Opportunities*, (ed) Shukla, P. R., Sharma, S. K. and Ramana, P. V., Tata McGraw-Hill Publishing Company Ltd, New Delhi, pp 14-15.

Shukla, P.R., Garg, A., Kapshe M. (2003) , *Greenhouse Gas Emission Scenarios*, in *Climate Change and India Vulnerability Assessment and Adaptation* Ed. by Shukla P.R., Sharma K. S., Ravindranath N.H., Bhattacharya. S. , Universities Press, Hyderabad.

Shukla, P.R., Sharma, S.K., Garg, A., Bhattacharya S., Ravindranath N.H (2003), *Vulnerability and Adaptation: Challenges Ahead*, in *Climate Change and India Vulnerability Assessment and Adaptation* Ed. by Shukla P.R., Sharma K. S., Ravindranath N.H., Bhattacharya. S. , Universities Press, Hyderabad.

Shukla, P.R., Sharma, S.K., Garg, A., Bhattacharya S., Ravindranath N.H. (2003), *Climate Change Vulnerability Assessment and Adaptation: The Context*, in *Climate Change and India Vulnerability Assessment and Adaptation* Ed. by Shukla P.R., Sharma K. S., Ravindranath N.H., Bhattacharya. S. , Universities Press, Hyderabad.

Sukumar, R., Saxena, K.G., Untawale, A. (2003), *Climate Change Impacts on Natural Ecosystems*, in *Climate Change and India Vulnerability Assessment and Adaptation* Ed. by Shukla P.R., Sharma K. S., Ravindranath N.H., Bhattacharya. S. , Universities Press, Hyderabad.

Shukla, P.R., Sharma, S.K., Garg, A., Bhattacharya S., Ravindranath N.H (2003), *Vulnerability and Adaptation: Challenges Ahead*, in *Climate Change and India Vulnerability Assessment and Adaptation* Ed. by Shukla P.R., Sharma K. S., Ravindranath N.H., Bhattacharya. S. , Universities Press, Hyderabad.

Singh. (1998). Effect of global warming on the streamflow of high altitude Spiti River. In *Enhydrology of High Mountain Areas*, pp. 103-114, edited by S R Chalise, A Hermann, N R Khanal, H Lang, L Molnar and A P Pokhrel. Kathmandu: International Centre for Integrated Mountain Development

Sinha S K and Swaminathan M S. (1991). Deforestation, climate change and sustainable nutrition security: a case study of India. *Climatic Change* 19: 201-209.

Smith, J., Tirpak, D. (editors). (1988). The Potential Effects of Global Climate Change on the United States. Report to Congress. U.S. Environmental Protection Agency. Washington, D.C.

TERI. (1996). The Economic Impact of a One Metre Sea Level Rise on the Indian Coastline: method and case studies, Report submitted to the Ford Foundation

TERI. (1999). TERI Energy Data Directory and Yearbook 1999/2000, New Delhi: Tata Energy Research Institute

TERI. (2002). TERI Energy Data Directory and Yearbook 2001/2002, New Delhi.

TERI (2003), Coping with Global Change, Vulnerability and Adaptation in Indian Agriculture. New Delhi.

Tobin, G.A. and B. Montz, (1997), Natural Hazards: Explanation and Integration. Guilford Press, New York, NY, USA.

Tol, S.J. Richard. (2001). "Estimates of the Damage Costs of Climate Change (Part 1: Benchmark Estimates)", Environmental and Resource Economics 2002 (Volume 21, Number 1). Kluwer Academic Publishers, Netherlands. pp. 47 to 73.

United Nations. (1992). Framework convention on Climate Change (UNFCCC). United Nations, New York.

Unnikrishnan, A.S., K. Rupa Kumar, Sharon E, Fernandes, G.S Michael, S.K Patwardhan (2006), Sea level Changes along the Indian Coast : Observations and Projections. Current Science, Vol 90. No 3, pp 362-368.

U.S. Congress, Office of Technology Assessment. (1993). Preparing for an Uncertain Climate. Vol. 1. OTA-O-567. U.S. Government Printing Office. Washington, D.C.

Water Resources in South Asia: Proceedings of Year End Workshop: Kathmandu, Nepal, 7-9 January, Asianics Agro Dev International, Islamabad, Pakistan, November .

Wiener, J.D. (1996). Research opportunities in search of federal flood policy. Policy Sciences, 29, 321–344.

World Resources Institute. (1999). World Resources 1998-1999. A Guide to the Global Environment, Oxford University Press.

World Resources Institute. (2001). World Resources 2000-2001, People and Eco systems: The Fraying Web of Life, Oxford University Press.

Yohe, G. (1990). The cost of not holding back the Sea. Coast Management 18, 403-431.

www.censusindia.net

www.reliefweb.int/library/documents/2002/undmt-ind-20aug.pdf

www.un.org.in/dmt/orissa/WHOorissareport.htm

www.undp.org.in/Programme/undpini/factsheet/Orissa.pdf

www.undp.org.in/DMVR.htm

<http://www.peopleandplanet.org/climatechange/briefing.impact.php>

<http://www.grida.no/climate/vital/33.htm>

http://www.rrcap.unep.org/reports/soe/bangladesh_disasters.pdf

<http://www.sdnbd.org/sdi/international>

[days/wed/2005/bangladesh/disaster/index.htm](http://www.sdnbd.org/sdi/international/days/wed/2005/bangladesh/disaster/index.htm)

Appendix I

