ORCHID: Climate Risk Screening in DFID India. Technical Appendix

Sreeja Nair, Souvik Bhattacharjya, Sangeet Kumar Srivastava, Pradhan Parth Sarthi, Meena Sehgal, Thomas Tanner, Daniel Kull, and Unmesh Patnaik

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ORCHID
Opportunities and Risks from Climate Change and Disasters

ORCHID:
Climate Risk Screening in DFID India

Technical Appendix

Sreeja Nair[1], Souvik Bhattacharjya[1], Sangeet Kumar Srivastava[1], Pradhan Parth Sarthi[1], Meena Sehgal[1], Thomas Tanner[2], Daniel Kull[3], and Unmesh Patnaik[4]

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Overview

The screening process by researchers and programme staff was facilitated by a set of technical inputs relating to climate vulnerability, historic and future climate impacts, and economic consequences of impacts. These inputs are shown in Parts A-D respectively of this **technical appendix** accompanying this report.

Part A summarises **recent climate variability and future climate change** in India related to primary climate variables of temperature and rainfall.

Part B then examines the implications of these changes for **secondary impacts** on natural and human systems across India.

Part C introduces the concept of **climate vulnerability** and summarises existing work to identify the indicators and distribution of vulnerability in India.

Part D presents evidence of the **economic impacts** of past climate shocks and stresses in India. This gives an indication of the key regions and sectors where climate change damages may be most economically severe.

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Cover image: India. A portrait of Anita Devi, the president of the Musahar Vikas Manch (Musahar Development Forum), standing at a water pump in front of her collapsed house following the 2007 South Asian floods.
Photographer: Jacob Silberberg / Panos Pictures

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Part A: Recent Climate Variability and Future Climate Change in India

A1. Introduction and overview

This report reviews past trends and presents future climate scenarios of temperature and rainfall in India at national, and regional level (the four DFID partner states of Andhra Pradesh, Orissa, West Bengal and Madhya Pradesh). We use the historical observed data from the India Meteorological Department (IMD) to analyze climate variability. Our analysis of future climate scenarios is based on the simulations of regional climate models. These models represent the complex interactions of the ocean, land and atmosphere within the global climate system.

The main results of the analysis are summarized in two tables below. Table A1 shows recent climate trends in India and Table A2 shows future projections of climate based on the commonly used 'A2' [1] scenario of future greenhouse gas emissions. The report then outlines in greater detail the past variations in temperature and rainfall and future climate scenarios at national and regional levels.

Some key points that emerge from the analysis are as follows:

- Surface temperatures in India show a warming of about 0.3^{o}C between 1901 and 2000 with considerable regional variation
- The All-India rainfall series for the monsoon season shows no clear trend between 1901 and 2000. Regional differences exist with some areas experiencing moderate increases and other decrease in rainfall.

Climate change scenarios (future changes in temperature and rainfall) are presented using three different sources of information: recent IPCC results and two spatially detailed regional climate models. The results show:

- Warming occurs in all four seasons.[1,2,3]
- 2–3^{o}C rise by 2100 (with A2 greenhouse gas emission scenario).[1,2]
- Warming is highest for post-monsoon (October–November) and winter seasons (December–January–February) over northern India.[2]
- High confidence exists for temperature changes as climate models show good agreement.
- Most climate models indicate wetter monsoon conditions. These are likely to be associated with higher rainfall intensities causing higher peak flows in rivers and increases in flood magnitude/frequency.[2,3]
- There are no clear indications at this time regarding future changes in El Niño amplitude in a warmer climate and its influence on monsoon rainfall.[14]
- A recent study shows only small influences on the wet and dry (active/break) phases of monsoon, although variability of the magnitude and frequency around the average would be increased by 2100.[15]
- There is medium confidence in future rainfall scenarios and changes in the frequency of extreme events because climate models still show considerable differences in their ability to simulate these phenomena and how they will behave in a warmer climate.

[1] Various scenarios of development as defined by the IPCC Report on Emission Scenarios include A1 (A1B, A1T, A1F), A2 and B1, B2. The A2 scenario has been used to elaborate in the results in the context of the study. A2 storyline and scenario family: a very heterogeneous world with continuously increasing global population and regionally oriented economic growth that is more fragmented and slower than in other storylines. A2 scenario falls in the category of 'Medium-High' emissions. The cumulative global carbon emissions between 2000 and 2100 for this scenario is taken to be 1862 Gt C (1GtC = 1 giga or Bt of Carbon; 1 tone of Carbon = 3.67 tones of CO2).

Table A1: Recent observed variability and trends in temperature and rainfall, all India and four states

Geographical coverage	Seasonal distribution	Historic variability / trend
Temperature		
All India	Annual	Rise in temp is 0.3°C for 1901–2000 Considerable regional variations in rate of warming
	Winter	Rise in temp at the rate of 0.4°C per 100 years
	Pre-monsoon	0.2°C rise during 1901–2000
	Monsoon	0.1°C rise during 1901–2000
	Post-monsoon	0.5°C rise during 1901–2000
West Bengal	Annual	Warming trend for 1901–2000[2]
Orissa	Annual	Warming trend during 1901–2000
Andhra Pradesh	Annual	Warming trend in 1901–2000
Madhya Pradesh	Annual	Significant warming trend in 1901–20003
Rainfall		
All India	Annual	The All-India rainfall series for the monsoon season shows no clear trend between 1901 and 2000. Annual average rainfall is 1200 mm, with a variance of 109 mm for 1901–2000
West Bengal	Summer Monsoon	Decreasing rainfall trend during 1901–2000
Orissa	Summer Monsoon	Decreasing rainfall trend during 1901–2000
Andhra Pradesh	Summer Monsoon	Increasing trend during 1901–2000
Madhya Pradesh	Summer Monsoon	Increasing over east MP Decreasing over west MP
El Nino Southern Oscillation – Monsoon links	Summer Monsoon	Historically, El Nino linked to drier monsoon, and La Nina to wetter monsoon Studies show weakening of this relationship in the last 10 years, e.g. above-normal rainfall of 1997 despite being a strong El Nino year and below-normal of 1999 despite being a La Nina year
Breaks/timing in Monsoon	Summer Monsoon	The break period signifies the mid-monsoon dry period. Its resident time varies from 15 to 30 days.

2 Warming trend: spatial trend values lies in between 0.1-0.6,

3 Significant warming trend: spatial trend values more than 0.6

Table A2. Summary of climate change scenarios for India

Climate parameter	**Future climate scenarios[1]**	**Confidence in projection[2]**
Increasing temperatures[1]		
All India	Warming occurs in all four seasons. 2–3°C rise by 2100s (A2 Scenario). Warming trend is most for post-monsoon and winter seasons over northern India.	**High confidence** Good agreement between climate models.
West Bengal	2020s: 0.33–0.55°C; 2050s: 1.60–2.38°C; 2080s: 2.48–4.78°C	
Orissa	2020s: 0.70–2.35°C; 2050s: 2.38–3.7°C; 2080s: 4.43–4.85°C	
Andhra Pradesh	2020s: 1.28–2.75°C; 2050s: 2.60–3.65°C; 2080s: 4.75–4.95°C	
Madhya Pradesh	2020s: 0.75–4.30°C; 2050s: 2.80–5.38°C; 2080s: 4.40–6.70°C	
Change in rainfall amounts/distribution[1]		
All India	All India annual rainfall – increase of 150–250 mm by 2100 Regional in 2080s: Except east Andhra Pradesh, all the other states would receive ~50% increase in rainfall Spatially speaking, south Andhra Pradesh would be drier and the other states wetter by ~30%	**Medium confidence** Less agreement between climate models in the direction and magnitude of change.
West Bengal	Wetter, mostly in winter, pre-monsoon, and post-monsoon seasons	
Orissa	Wetter, mostly in winter and pre-monsoon seasons	
Andhra Pradesh	Wetter, mostly in winter and pre-monsoon seasons East AP will be drier by 2100	
Madhya Pradesh	Wetter by 2100, mostly during pre-monsoon season	
Changing rainfall intensities[1]	Most models indicate wetter monsoon conditions. Likely to be associated with higher rainfall intensities causing higher peak flows in rivers and increases in flood magnitude/frequency. Increased frequency of intense rainfall episodes No clear signal of changes in the variability of monsoon rainfall.	**Medium confidence** Models differ in projecting the quantity and distribution of rainfall
Monsoon breaks	Reduced residence time of monsoon break	**Medium-High confidence**
El Nino Southern Oscillation	No clear indications at this time regarding future changes in El Niño amplitude in a warmer climate. (Van Oldenborgh et al. 2005, Merryfield 2006)	**Low-Medium confidence**

Notes: [1]= Based on results from recent climate model experiments presented here. [2]= Considers inherent uncertainty of different variables produced by climate models and differences between climate models.

A2. Temperature: Past trends and future projections

Average surface temperature, subsequently referred to simply as temperature, is a crucial variable to describe changes in the climate and a primary driver of impacts. Temperature varies significantly across regions of India, and national and regional trends in temperature are presented separately in the following sections.

The historical records demonstrate that there is significant variation year-on-year around the long term average temperature. Trends must therefore be examined in relation to this variability, both the long term trends and more recent shifts in the trend that have occurred in both temperature (and rainfall) across many parts of India since the 1960s.

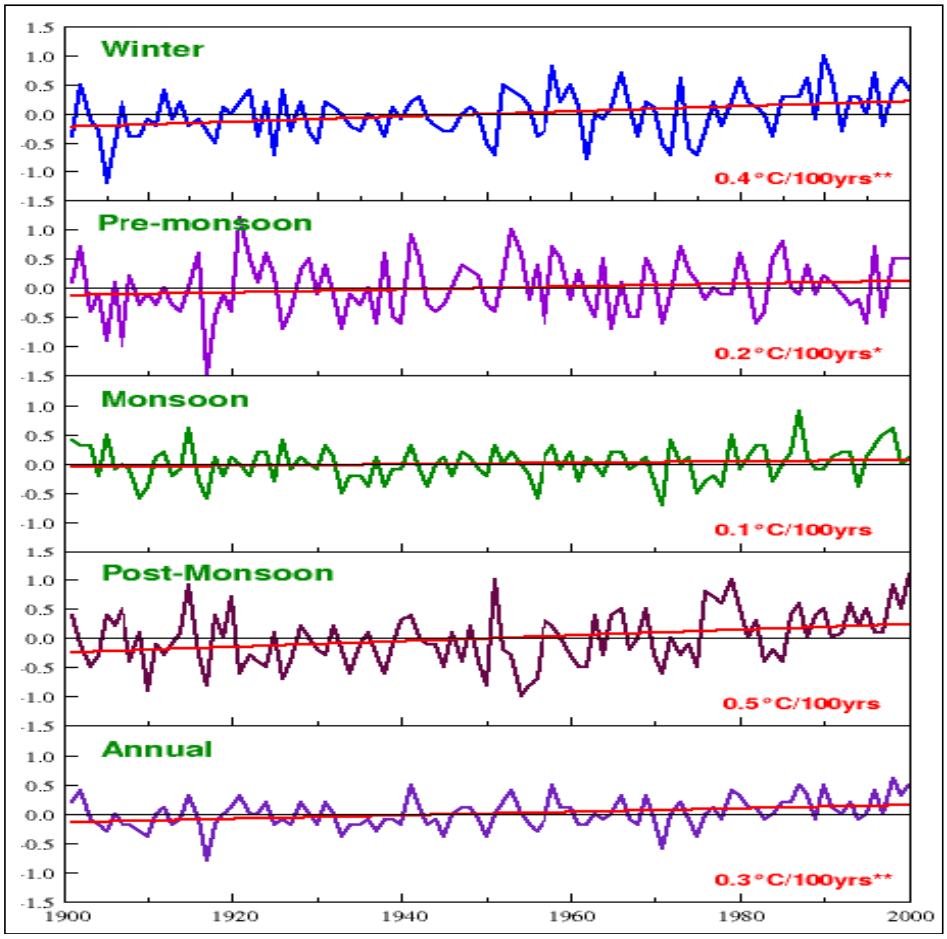


Fig.A1 Seasonal variation in all-India temperature during the 20th century with linear trends to represent the rate of warming (Source: IMD)

A2.1 Historic temperature trends

Figure A1 shows the temperature distribution across India since 1901. Analysis of the data series demonstrates that:

- The warming trend is more conspicuous during winter, pre-monsoon and post-monsoon seasons. No significant temperature trend is present during the monsoon season nationally.
- The warming is relatively more pronounced in winter and post-monsoon seasons than in pre-monsoon.

Analysis of the linear trend in temperature across India (Fig.A2) shows:

- A significant warming trend is observed along most of the west coast, the central peninsula and northeast India.
- A cooling trend is observed over northwest India.
- In terms of statistical significance, most prominent warming trends are observed over Andhra Pradesh and Madhya Pradesh.
- Statistically, West Bengal and north Orissa do not show any significant trend (neither cooling nor warming).

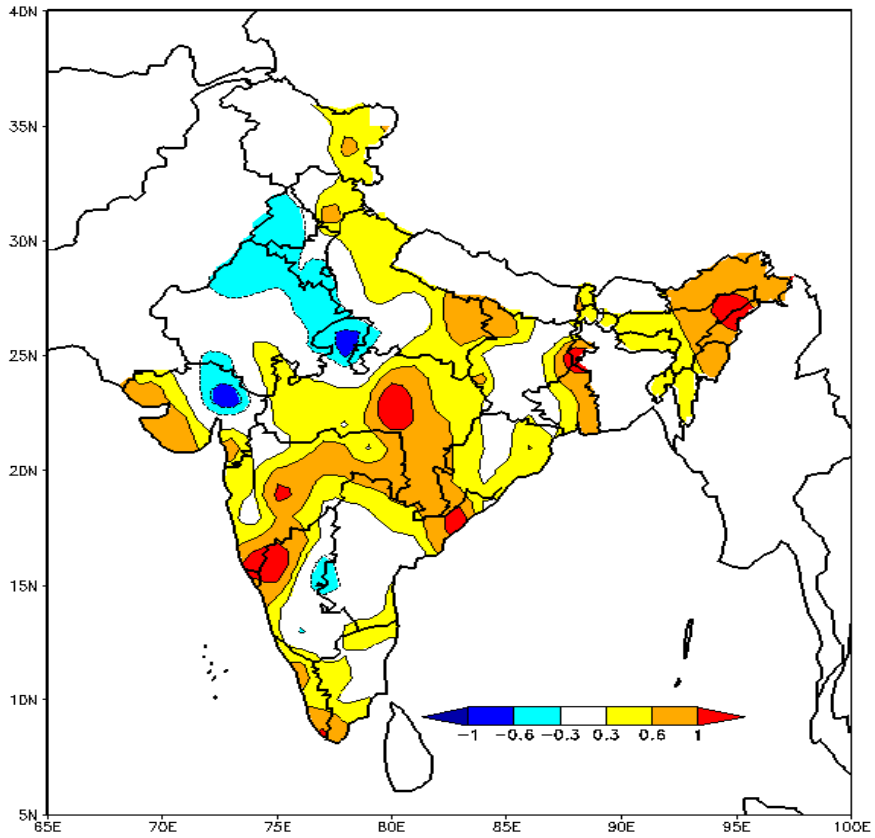


Fig.A2 Spatial patterns of linear trends in temperature over India for 1901-2000. (Source: IMD)

A2.2 Future temperature projections

The analysis of climate models outputs (from AR4, HadRM2 and PRECIS models) (shown in Fig.A3, A4 & A5) suggests that

- The projected increase in annual temperature varies between 2.0 to 3.0°C by the end of the 21st century.
- By 2050, the highest warming trend (6–7°C) occurs in western Utter Pradesh (UP) in every season.
- By 2080, the highest warming trends occur in the post-monsoon and winter seasons over most of northern India.
- For both 2050s and 2080s, during pre-monsoon months, warming trend is relatively more over the north-west sector of India and is least over the west coast during all seasons.

Analysis of simulated future temperature in DFID partner states illustrates that:

- All of the four states show similar warming trend in pre-monsoon and monsoon seasons.
- A warming of 4–6°C is observed over parts of Madhya Pradesh, Andhra Pradesh and Orissa. The warming trend for West Bengal during the same seasons is of magnitude of 4–5°C.

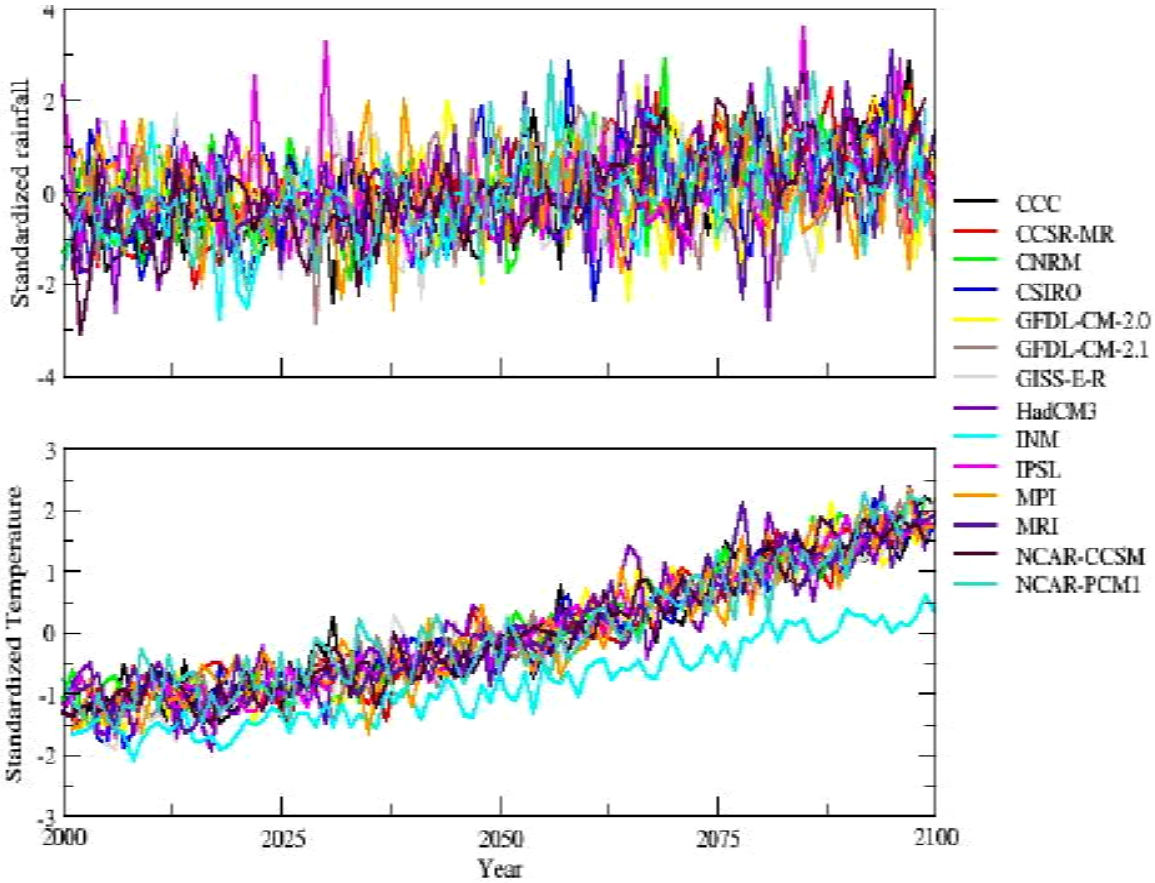
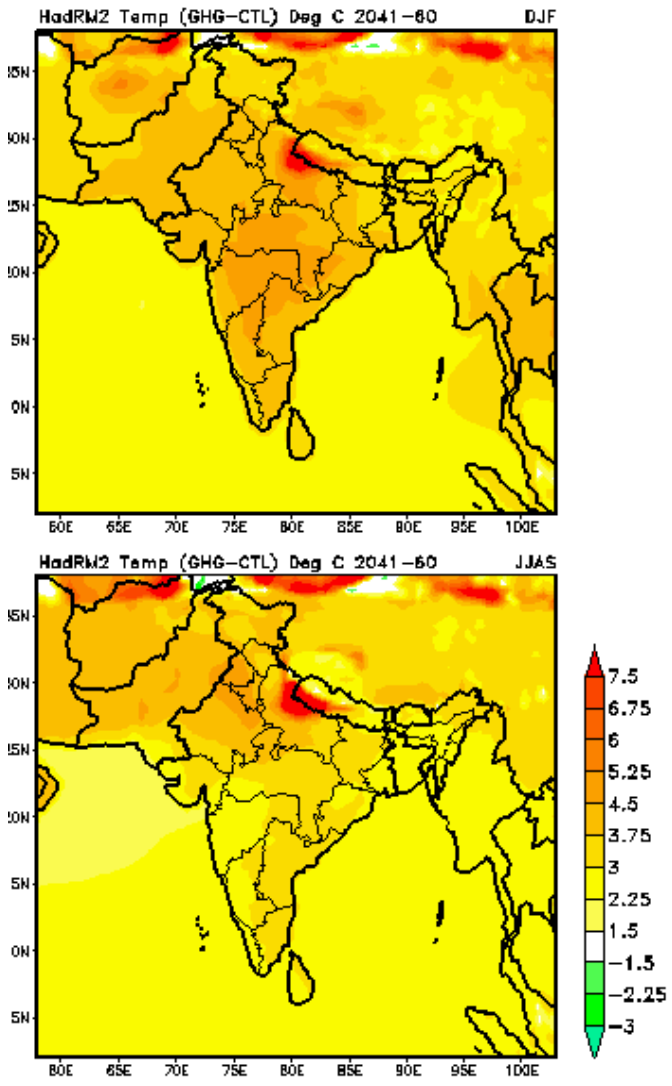


Fig.A3 21st century future scenarios over India based on 14 IPCC models (AR4) for rainfall (top) and temperature (bottom).

(Winter) **(Pre-monsoon)**



(Monsoon) **(Post-monsoon)**

Fig.A4 Projected seasonal temperature changes (in °C) **for 2050s** relative to 1990s baseline scenario, under increased greenhouse gas concentrations (A2 emission scenario), for the seasons of winter, pre-monsoon, post-monsoon and monsoon (clockwise from top left) from HadRM2 model (Source: IITM).

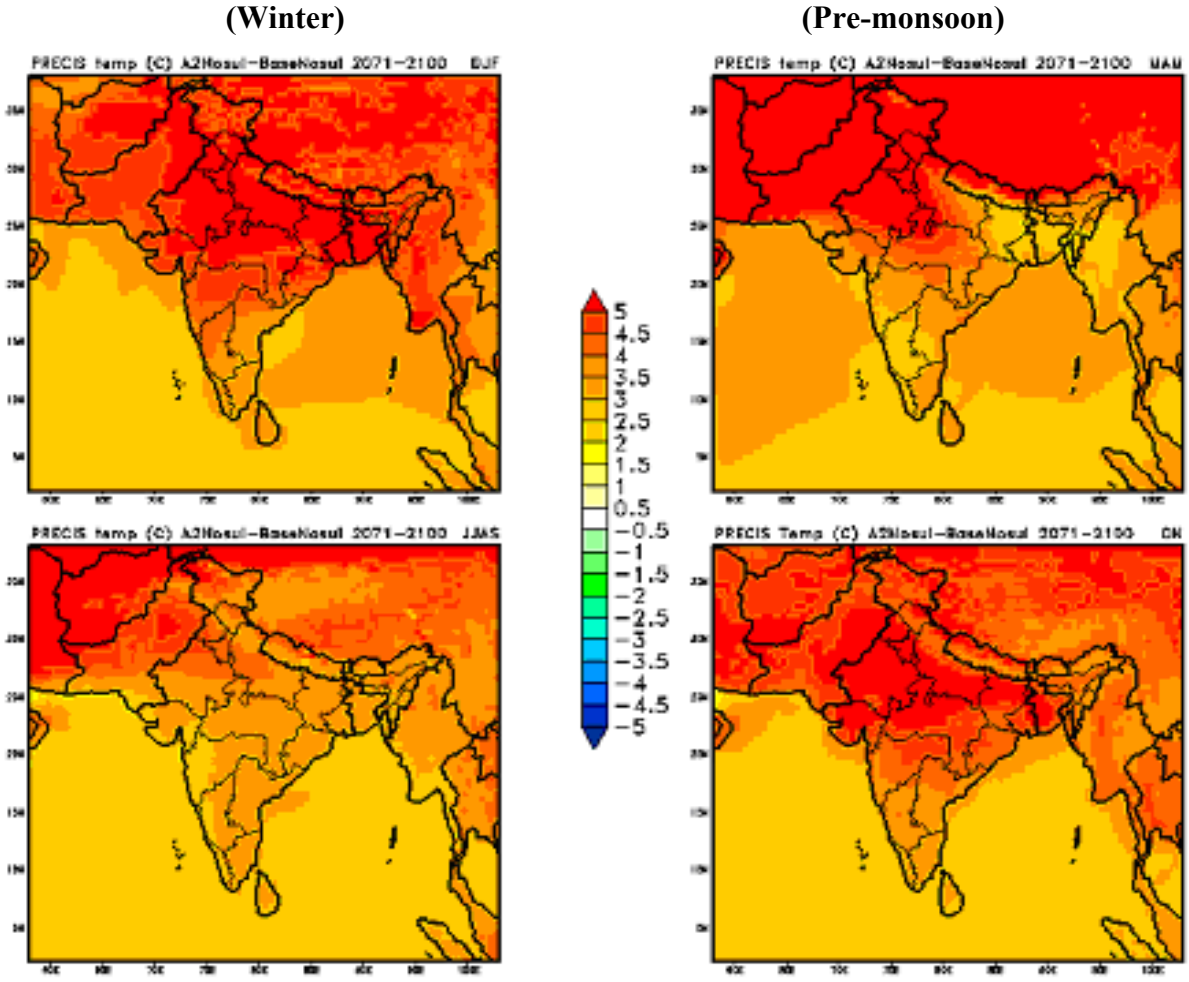


Fig.A5 Projected seasonal temperature changes (in °C) **for 2080s** relative to 1990s baseline scenario, under increased greenhouse gas concentrations (A2 emission scenario), for the seasons of winter, pre-monsoon, post-monsoon and monsoon (clockwise from top left) from PRECIS model (Source: IITM).

A3. Rainfall: Monsoon influences, past and future trends

A3.1 Monsoon rainfall characteristics

Rainfall, especially in the monsoon period, is an important indicator of climate change. Spatial and temporal changes in the monsoon patterns are more conspicuous in recent years. Summer monsoon season (June–July–August–September, JJAS) is the principal rainy season in India except for Jammu & Kashmir and Tamilnadu. The rainfall of Indian subcontinent during monsoon season is almost 75-90% of its annual rainfall. This section briefly introduces the characteristics of the monsoon phases and their variability over time before looking at rainfall trends and future projections across India.

Monsoon starts with the **onset** phase and its arrival is determined by the amount of rainfall and wind conditions near the Kerala coast. In middle of July the monsoon affected regions experience a dry spell of about 15–30 days, known as the **break** phase of the monsoon, during which most of the country receives limited rainfall but there is heavy rainfall along the foothills of the Himalaya, parts of north east and southern peninsula of India. The long intense breaks are often associated with poor monsoon seasons, and have a major impact on Indian agriculture. The **withdrawal**

phase of the monsoon normally starts from western sector of Rajasthan by 1st September and moves south, normally leaving Tamil Nadu and Kerala by 15th October (figure A5).

A recent study of Mandke *et al*. (2007) on global warming influences on the break phase of monsoon concludes that global warming will have only small influences on the wet and dry (active / break) phases of monsoon, although variability of the magnitude and frequency around the average would be increased by 2100.

A3.2 ENSO and the Indian summer monsoon

For the past century (except the last decade – after 1980s) El Niño and La Niña (simultaneously known as **El Niño Southern Oscillation** (ENSO)) have had major influences on the summer monsoon. There is a general tendency for reduced Indian summer monsoon rainfall in El Niño years and above normal rainfall in La Niña years. However, recent analyses have revealed that the strength of this relationship has decreased recently (for example, 1997 – a strong El Niño year – was a wetter monsoon and 1999 – a La Niña – spelt in a drier monsoon), while the influence of global warming on ENSO remains unclear[4].

A3.3 Historic rainfall variability in India

It is crucial to situate past and future average rainfall trends in the context of the year-on-year variation around the long term average of 880 mm yearly. The variability around this mean averages to ± 9.5% (equal to 109 mm per year). Fig. A6 illustrates the variation around the long term average, highlighting both 'drought' and 'flood' years where variability is greater than this average, and the relation with ENSO. 10% greater than normal monsoon rainfall is categorized as meteorological 'flood' rainfall year whereas less than 10% is defined as a meteorological 'drought' year (Parthasarathy & Mooley, 1978). Fig. 6 shows that monsoons have been within the normal conditions in recent years except the severe drought year in 2002.

The running rainfall average for the previous 5 years window is inlaid in fig A6. This illustrates wetter and drier multi-year phases, showing the recent trend of drier than average weather conditions.

[4] The MPI and ARPEGE/OPA models (Ashrit et al., 2001, 2003) show no global-warming related change in the ENSO-monsoon relationship. The weakening of the ENSO-Monsoon relationship in India might be part of natural variability in the cliamte (Krishna Kumar et al., 1999).

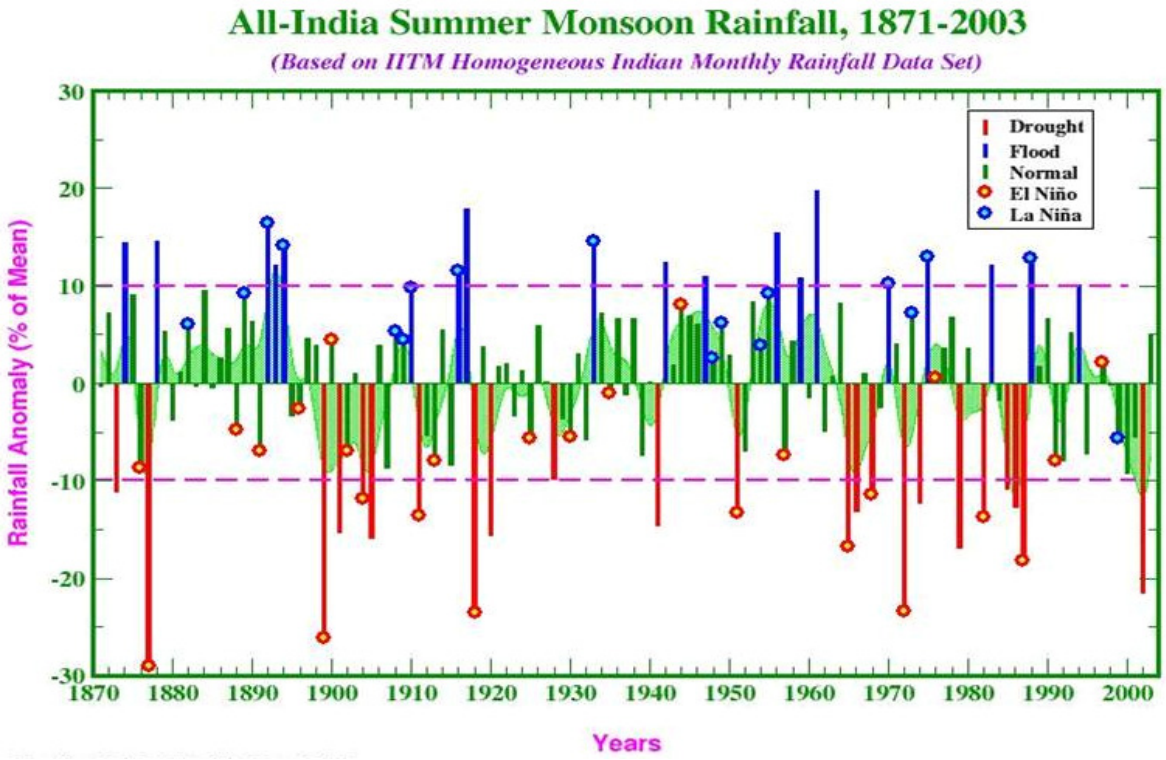


Fig.A6 All-India Summer Monsoon Rainfall trends for the period 1871-2003. A running mean of 5-years is imposed on the time series. (Source: IITM)

A3.4 Historic rainfall trends

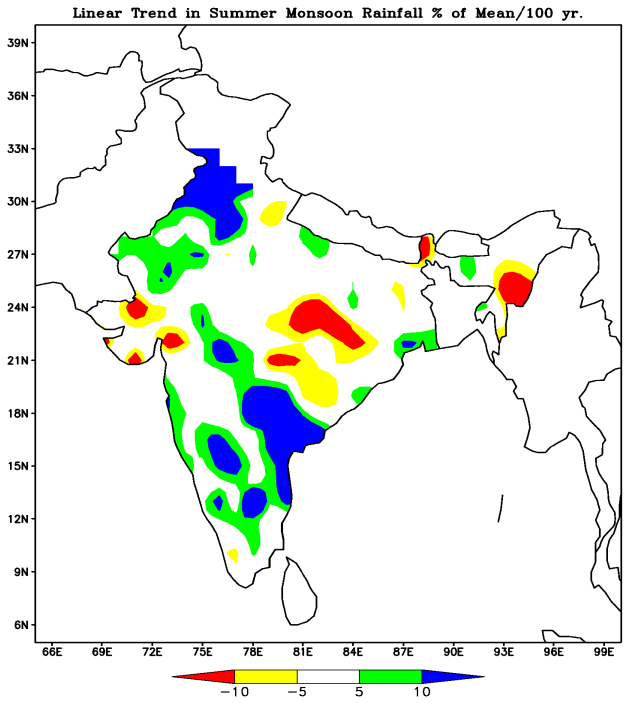


Fig.A7 Linear trend in observed monsoon rainfall over India (in % of mean for 100 years) for the period 1871-1990

At the national level, analysis of rainfall trends for the last 100 years and for the last four decades suggests that (Fig.A7):

- For both time periods, the monsoon rainfall shows no clear trend. Trend is somewhat random over the 100 year period, particularly on country scale.
- However, an increasing rainfall trend is mainly confined to the east coast of India, Delhi, Haryana and Punjab.
- A decreasing rainfall trend is observed over Gujarat, parts of Madhya Pradesh, Chhattisgarh, Jharkhand and Manipur.

Based on all-India observed monsoon rainfall data of IMD for the period 1871–2005 the past and present climate patterns are indicated below and summarised for the DFID states, although large regional disparities within the states have not been captured:

- **West Bengal**: Starting 1991 the monsoon rainfall follows a continuously decreasing trend.
- **Orissa:** 1961 onwards, the rainfall patterns are below the normal, suggesting a drier spell over the region.
- **Andhra Pradesh:** Increasing trends over coastal regions and Rayalseema regions. A sharp decrease in rainfall during monsoon season has been observed in the recent years (starting 1981) over the Telangana region.
- **Madhya Pradesh:** The rainfall pattern does not show significant changes over east of Madhya Pradesh. Over west MP, the sharp decrease of rainfall is observed for the last two decades.

A3.5 Future rainfall projections

Analysis of Indian rainfall changes for the period 2071–2100 from the IPCC models (Fig A3, A8a) suggests that

- The projected increase in monsoon rainfall is about 1–2 mm per day (an increase of about 150–250 mm by 2100).
- Pre-monsoon and winter seasons would be ~50% wetter for almost all India.
- Eastern Andhra Pradesh would be drier in monsoon season.

For the 2050s, with A2 emission scenario, it is projected that:

- There would be an increase of rainfall between 10–30% during monsoon months over West Bengal, Orissa, Andhra Pradesh and Madhya Pradesh.
- There are some pockets in Andhra Pradesh that may experience change in rainfall of -5 to +5%.
- During drier winter season the percentage increase of rainfall would be in the range of 30–50 %.

For the 2080s, the model outputs suggest following:

- 15–25% increase in monsoon rainfall is expected over West Bengal, Orissa, Madhya Pradesh and north-west Andhra Pradesh.
- The eastern and southern regions of Andhra Pradesh show decrease in monsoon rainfall.

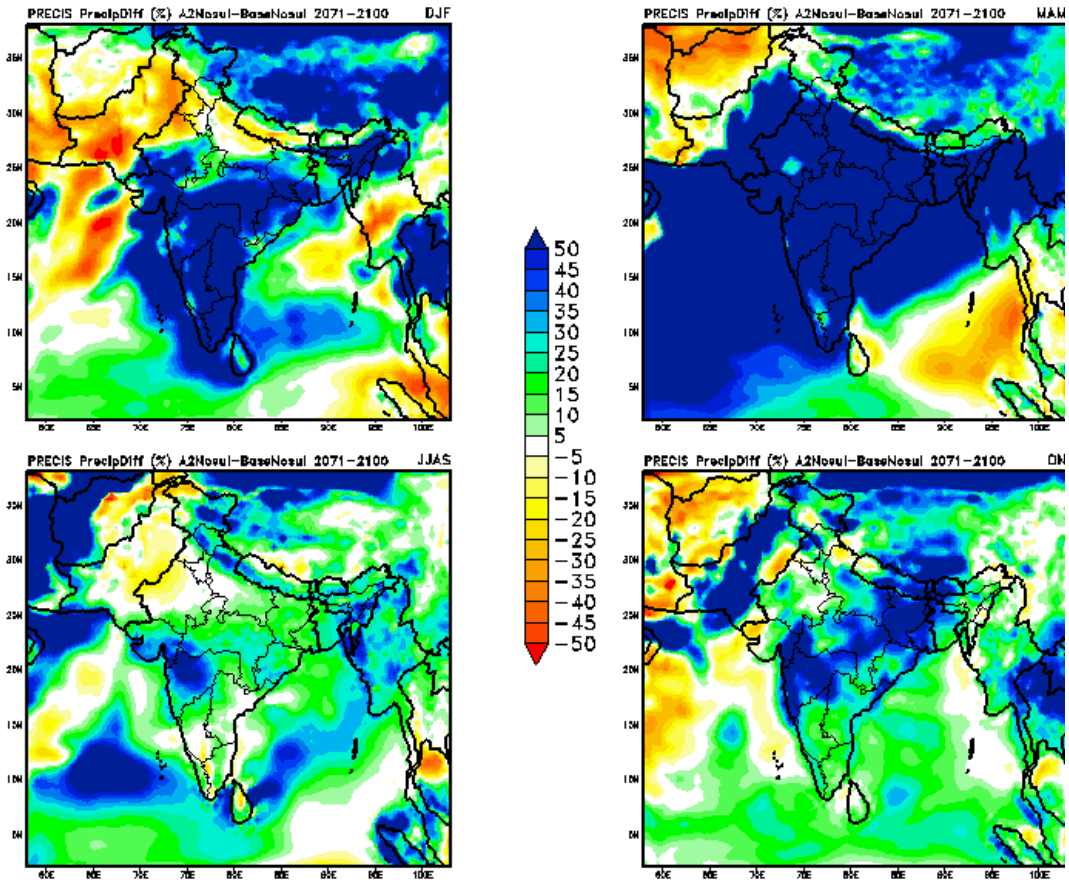


Fig. A8 Percentage difference in simulated rainfall between A2 and baseline by PRECIS for the period 2071-2100, for the seasons of winter, pre-monsoon, post-monsoon and monsoon (clockwise from top left).Source: IITM.

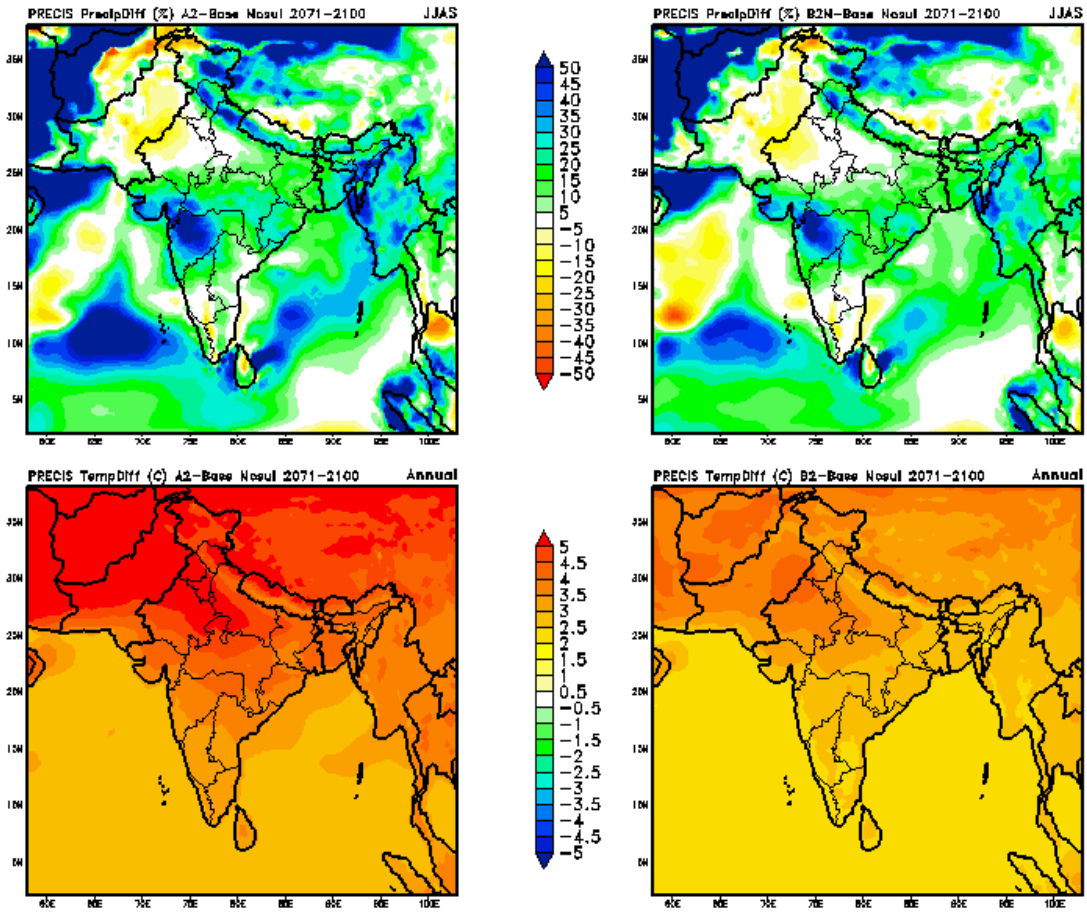


Fig.A9 Spatial patterns of the changes in summer monsoon rainfall (%) and annual mean temperature (°C) for the period 2071-2100 w.r.t the baseline (1961-1990) (a) A2-baseline monsoon rainfall, (b) B2-baseline monsoon rainfall, (c) A2-baseline annual temperature, and (d) B2-baseline annual temperature. Source: IITM.

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Part B: Secondary Impacts of Climate Change on Biophysical and Socio-economic Systems in India

Summary Table

Secondary effects	Impacts	Confidence/severity
Rainfall Intensity	• Increased frequency of heavy rainfall spells in the recent decade. • An overall increase in frequency and redistribution of heavy rainfall spells over the DFID partner states in India as suggested by the future projections of 2030s, 2050s, 2080s. • Increase in 1-day and 5-day extreme rainfall intensity, in general, over India. • Increase in the severe rainfall activities along Western Ghats and northwestern peninsular India including Maharashtra and the adjoining parts of Andhra Pradesh, Madhya Pradesh and Karnataka by the end of 2100 (HadRM2[5] projection).	Medium confidence (Goswami et al., 2006; AR4, 2007; Rupa Kumar et al., 2006)
Floods	• Intense rain occurring over fewer days in future warmer climate implying increased frequency of floods	Medium confidence (AR4, 2007)
Droughts[6]	• With IS92a[7] scenario, severity of hydrological droughts in various parts of India is likely to increase. • An increase in severe drought conditions in some parts of the Sabarmati and Mahi river basins but less severe in areas covering parts of the Mahanadi and Brahmani basins	High confidence (National Communication, 2004)
Heat Waves	• It is very likely that heat waves or hot spells in summer will be of longer duration, more intense and more frequent. • In Multi-model ensemble simulation, heat waves are more frequent in India over the later part of 20th century, and are projected to increase globally in a warmer climate scenario.	High confidence (Chaudhury et al., 2000; AR4, 2007)
Cold Waves	• The cold episodes are projected to decrease significantly in a future warmer climate	High confidence (De et al., 2005)

[5] Hadley Centre's HadRM2 is a regional climate model with horizontal resolution of 50 km.

[6] On a meteorological sub-divisional level, rainfall between -19 and +19% of Long Period Average (LPA) is regarded as normal. A rainfall deficit/surplus of more than 25 (50)% of LPA is defined as a moderate (severe) meteorological drought/flood.

[7] IS92a is the reference ("Business As Usual") global energy scenario of the Intergovernmental Panel on Climate Change (IPCC, 1994)

Water Resources	• Reduction in runoff under the IS92a scenario over India and water scarcity in different river basins in future projections • River basins of Gujarat and Rajasthan are likely to experience acute water scarce conditions where some other parts are likely to experience constant water scarcity and shortage. • Cauvery, Ganga, Narmada and Krishna basins are likely to experience seasonal or regular water stressed conditions. • Godavari, Brahmani and Mahanadi basins are projected to experience water shortages only in a few locations	Medium confidence (National Communication, 2004; AR4, 2007)
Cyclone	• It is likely [>66%] that future tropical cyclones will become more intense, with larger peak wind speeds and more intense precipitation associated with the ongoing warming of tropical sea surface temperature. However, it has been projected that formation of cyclones will be lesser in number. • The cyclone intensity would possibly be increased by 10–20% for a rise of 2–4^{o}C rises in the sea surface temperature • By using HadRM2, no significant change in the number of tropical disturbances in the increased GHG run in 2050s.However, the occurrence of intense cyclones will be more frequent • An increase in the number of intense cyclone in the Bay of Bengal during the post-monsoon season • A possible increase in cyclone intensity of 10–20% for a rise in sea surface temperature of 2 to 4°C relative to the threshold temperature of 28°C is very likely.	Medium confidence (AR4, 2007; Lal, 2001; Unnikrishnan et al., 2006)
Storm Surges	• High storm surges will likely to occur more frequently under an increased GHG scenario by 2050s (HadRM2)	Medium confidence (Lal, 2001)
Agriculture	• Increase in rice grain yield due to increase in CO_2 concentration. • 2^{o}C increase in mean air temperature could decrease rice yield by about 0.75 ton/hectare in the high yield areas and by about 0.06 ton/hectare in the low yield in coastal regions. • By 2050s in Central and South India, an increase in rice yield is likely under the projected climate change scenarios (CERES-rice model)	Low confidence (Uprety et al, 2003; Kalra et al., 2003; Rathore et al. 2001)

Health (Malaria)	• Transition window (TW) will get changed under the changing climate patterns • With 3.8^{o}C rise in temperature and 7% increase in relative humidity by 2050s, TW will be open for whole year in Andhra Pradesh, Chattisgarh, Karnataka, Kerala, Maharashtra, Orissa, Tamil Nadu and West Bengal. • For Orissa and some southern states, with a mean temperature of 32^{o}C, a further increase in temperature may likely to reduce the TW by 2–3 months.	High Confidence (Rupa Kumar et al., 2006; National Communication, 2004)

A level of confidence: It is based on expert judgment as to the correctness of a model, an analysis or a statement. The last two terms in this scale should be reserved for areas of major concern that need to be considered from a risk or opportunity perspective, and the reason for their use should be carefully explained.

Table 1. Quantitatively calibrated levels of confidence Terminology Degree of confidence in being correct (Source: IPCC AR4)

Terminology	Degree of confidence in being correct
Very High confidence	At least 9 out of 10 chance of being correct
High confidence	About 8 out of 10 chance
Medium confidence	About 5 out of 10 chance
Low confidence	About 2 out of 10 chance
Very low confidence	Less than 1 out of 10 chance

Executive Summary

Part A has analysed the primary climate parameters of rainfall and temperature. This summary draws on these data to detail the main secondary impacts of climate change in India outlined in Part B.

Rainfall intensity

- **Present**: The changing patterns, both spatial and temporal, of atmospheric hydrological cycle ensues a redistribution of Indian summer monsoon patterns as evident from changes over the last decade (2006, IMD Met. Monograph).
- **Future**: It is very likely [>90%][8] that an increase will be observed in the frequency of intense precipitation events under an enhanced climatic simulation for the periods 2020s, 2050s, and 2080s.

Floods

- **Past**: Past observations do not indicate any definite long-term trend in the frequencies of large-scale floods in the summer monsoon season over India.
- **Recent**: However, the vicinity of major river-systems of northern India is found to be more flood-prone in recent years. The other high flood-prone areas are northern Andhra Pradesh, West Bengal and Orissa. No specific trend was found over Madhya Pradesh.
- **Future**: Intense rain in fewer days in the future warmer climate (i.e., in the three future time slices). This implies increased frequency of floods in absence of a proper drainage system or runoff to the river systems.

Droughts[9]

- **Past:** No significantly conclusive trend. The most drought-affected region in India is Andhra Pradesh, and the trend is increasing over the recent years.
- **Recent**: The regions with high probability of occurrences of drought are primarily Tamilnadu, Maharashtra, Andhra Pradesh, Rajasthan and parts of Gujarat. Some parts of southern Orissa are also drought-affected regions. No specific trend is observed for West Bengal, Madhya Pradesh and north Orissa.
- **Future**: Based on the 15 climate-models used for AR4, it can be inferred that the models are consistent in predicting drier soil in Asian monsoon region during December–January–February.

Cyclone and storm surges

- The tropical storms over north Indian Ocean show a significant decreasing trend after the 1980s. In particular, during the monsoon season, there is a decreasing trend in the number of cyclonic events.
- Region specific trends have been observed in cyclone or storm surges (Table 1).

[8] '**Very likely'** reflects a probability of more than 90% associated with the event, whereas '**likely**' suggests a probability of 60% or more.

[9] Meteorological definition of flood and drought (source: IMD): On a meteorological sub- divisional level, rainfall between -19 and +19% of Long Period Average (LPA) is regarded as normal. A rainfall deficit/surplus of more than 25 (50)% of LPA is defined as a moderate (severe) meteorological drought/flood.

- It is likely [>66%] that future tropical cyclones will become more intense, with greater peak wind speeds and heavier precipitation associated with ongoing increases in tropical SSTs.
- Based on regional HadRM2 simulations, increases in the frequency as well as intensities of tropical cyclones in the 2050s in the Bay of Bengal is reported under the IS92a[10] scenario (with baseline emission), which will eventually cause more heavy precipitation in the surrounding coastal regions of South Asia, during both southwest and northeast monsoon seasons (Unnikrishnan et al. 2006).

Sea level rise

- A long-term rising trend of about 0.1 mm per year in the sea-level has been observed, which has increased after 1950s to about 0.25 mm per year.
- The sea level rise is greater along the east coast than along west coast of India.
- The recent trend in sea level rise is less that 1 mm per year for the Indian coast except for Chennai and Vishakapatnam in Andhra Prasdesh.
- Possible increases in sea level result in more extreme sea-level events.
- Southern peninsular coast will be the most vulnerable to sea-level rise in the warmer climate scenarios.
- AR4 report concluded that its very likely that sea level will be about 40cm higher than today by 2100.

Heat waves

- Frequency of hot days and multiple-day heat waves has increased in India.
- In particular, El Nino years are more prone to get longer and frequent heat waves, whereas these occurrences are rather less during La Nino years.
- The maximum number of heat waves (during 1901–1999) is over Bihar followed by West Bengal (Chaudhury et al., 2000).
- The other heat-wave-prone regions are Rajasthan, Maharastra and Uttar Pradesh.
- Among the four DFID partner states considered here, maximum number of heat waves occurred in Orissa followed by Andhra Pradesh during the 20th century, however recently Andhra Pradesh has experienced many severe heat wave spells.
- It is very likely [>90%] that heat waves/hot spells in summer will be of longer duration, more intense and more frequent (AR4).

Cold waves

- The cold waves mainly affect the areas to the north of 20^{o}N with few exceptions over states like Maharashtra and Karnataka.
- The major cold wave prone regions are Jammu & Kashmir, Rajasthan, Utter Pradesh and Bihar.
- Among the four DFID partner states, the maximum number of cold waves is observed over Madhya Pradesh and West Bengal (De et al, 2005).
- Its very likely [>90%] that cold episodes will decrease significantly in a future warmer climate (AR4)

Water resources

- The atmospheric hydrological cycle is very likely [>90%] to be altered in significant ways due to climate change as early as by 2020s.

[10] **IS92a** is the reference ("Business As Usual") global energy scenario of the Intergovernmental Panel on Climate Change.

- There is a general reduction in the quantity of available runoff under the IS92a (with 1996 IPCC emission rates) scenario.
- River basins of Sabarmati and Luni of Gujarat and Rajasthan, are likely [>60% probability] to experience acute water scarce conditions.
- River basins of Mahi, Pennar, Sabarmati and Tapi are likely [>60% probability] to experience constant water scarcity and shortage.
- River basins of the Cauvery, Ganga, Narmada and Krishna are likely to experience seasonal or regular water stressed conditions (National Communications, 2004).
- River basins of the Godavari, Brahmani and Mahanadi are projected to experience water shortages only in a few locations (National Communications, 2004).

Agriculture

The impacts of climate change on agriculture in India are uncertain. Depending on temperature rise (2^0C, 3^0C, 4^0C), and increase in CO_2, the average impact may be positive and negative.

- The rabi crops (winter season crop) in central and southern India will be more risky in future.

Human health

- For a 3.8°C increase in temperature and 7 % increase in relative humidity by the 2050s (in relative to the base line), nine states of India may have transmission windows open for all 12 months.
- Orissa, Andhra Pradesh and some southern states, where the mean temperature is more than 32°C during 4–5 months in a year, a further increase in temperature may reduce the transmission window by 2–3 months.

B1. Introduction

This report presents a review of published studies on the impacts of climate change in India. The report covers rainfall intensity, flood, drought, cyclone and storm surges, sea level rise, heat waves, cold waves, water resources, agriculture, and human health sectors under climate change scenarios. Each section highlights the evidence of past, current and future impacts at the national and regional scale in India, with focus on the four DFID partner states- West Bengal, Orissa, Andhra Pradesh, Madhya Pradesh. The results of these impacts studies will be conditional upon the climate model scenarios, which have been used, and the reliability of the impacts models. Most results therefore have only medium confidence, for example, there remain important uncertainties about crop responses to changing climate and their interaction with higher levels of CO_2. Some caution should therefore be used in the interpretation of the main results. It is important that a greater range of climate models is used to simulate impacts in India to give a better representation of these uncertainties. See the report in scenarios for a description of these uncertainties. The work is based on papers, reports and some key findings from IPCC AR4 (2007).

B2. Rainfall intensity

Indian monsoon rainfall has shown remarkable stability over the past century even though the global mean surface temperature has risen steadily. The amount of annual monsoon rainfall has some short-term variability but it has no specific and significant long-term trend. However, there is evidence of increasing heavy rainfall spells in recent years (Goswami et al., 2006). The intensity and frequency of rainfall can lead to more hazardous impacts over a region, namely, flash floods, landslide, damages to crops and infrastructure as well as loss of lives. With the changing patterns of Indian summer monsoon, both spatial and temporal, rainfall intensities and frequencies are increasing. It has been projected in model simulations that there would be an increase in many extreme events, including heavy rainfall spells (IPCC Fourth Assessment report, hereafter, AR4). Based on the daily-observed rainfall data of IMD (1901–90), the spatial pattern of mean intensity of rainfall for a rainy day is shown in Fig B1(a). Fig. B1(b-d) shows the control simulation, increased greenhouse gas simulation and difference between the two, respectively.

National

- Intensity varies between 10–40 mm per rainy day across India.
- Lowest values of less than 10 mm per day are observed over the extreme northern parts of the country and northwestern India, and over the rain-shadow regions of east Western Ghats, the intensity is about 10–15 mm per rainy day.
- Highest magnitude of 40 mm/day is seen along the west coast and over some parts of northeast India.
- Over rest of the country, the intensity of rainfall is of the order of 15–25 mm per day.

Regional

- For monsoon season, the increasing trend of rainfall intensity is observed only over north-west Andhra Pradesh. Rainfall patterns over the other three states indicate a decreasing trend (Fig.B1(a)).
- Over Andhra Pradesh and West Bengal, the rainfall intensity is in the range of 14–20 mm per day.
- The rainfall intensity is about 20–24 mm per day over central Madhya Pradesh and north-west Orissa.

Future

- ❖ Heavy rainfall events will be increased in future climate scenario. There is very likely to be an increase in the frequency of intense precipitation events in parts of India (AR4).
- ❖ There is a predicted increase in intensity and frequency of extreme rainfall events in the three major river basins of India, viz. Krishna, Ganga and Godavari, by 2100.

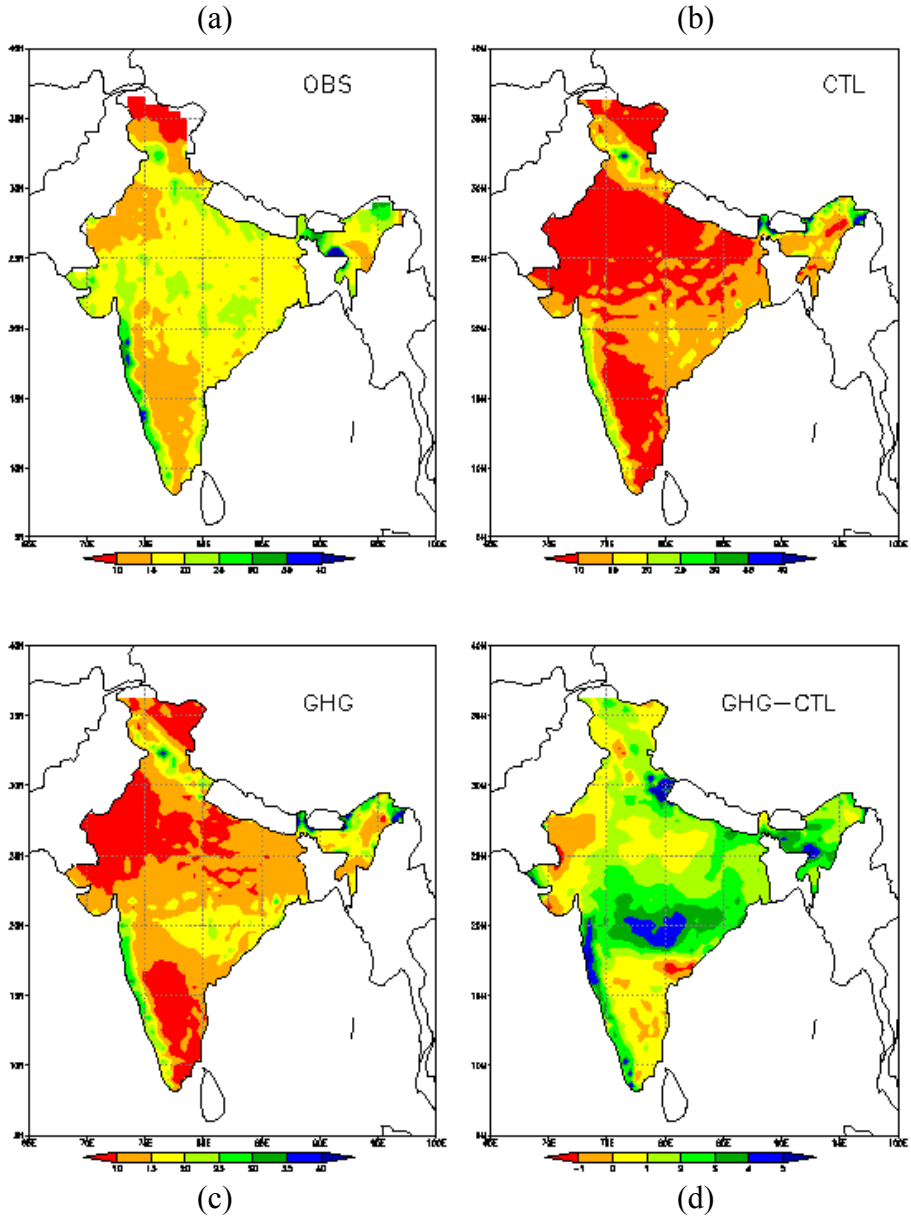

Fig.B1 Mean intensity of rainfall per rainy day (in mm/day): (a) Observed and HadRM2 simulated (b) CTL (control), (c) GHG (with emission scenarios), (d) GHG-CTL (anomaly to the control)). (Source: 1(a) National Communication, 2004)

B3. Floods

The changing patterns of rainfall regime and extreme events are leading to frequent occurrences of flood and drought at varying rates in different regions. It has been suggested by various studies that the global atmospheric hydrological cycle is intensifying with the increase in global surface temperature and extreme events are becoming more frequent, leading to more frequent and intensified floods and droughts. Observations from the past and current flood scenarios in India suggest the following.

National

- Instrumental records (IMD observations) over the past 130 years do not indicate any marked long-term trend in the frequencies of large-scale floods in the summer monsoon season over Indian region.
- The vicinity of major river-systems of northern India is found to be more flood-prone in recent years.

Regional

- It is observed that high frequency of floods has occurred in northeast and north Indian rivers. The other high flood-prone areas include northern Andhra Pradesh, West Bengal and Orissa (Fig.B2). No specific trend was found over Madhya Pradesh.

Future

- Intense rain occurrences over fewer days in future warmer climate implies increased frequency of floods.

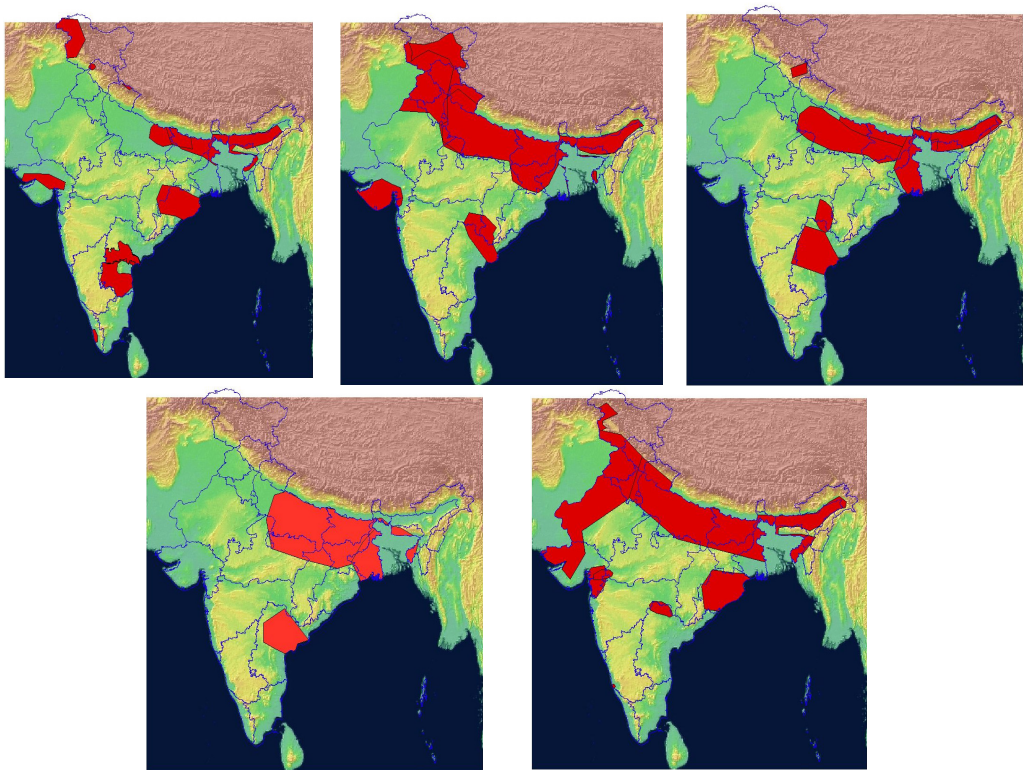

Fig. B2 Flooded regions (red sheds) in recent years over India (a) 1986, (b)1988, (c) 2000, (d) 2001, (e) 2003. (Source: IMD)

B3.1 Urban flood

Due to changing rainfall regimes, India's urban and semi urban regions are getting more vulnerable to extreme rainfall events such as flash floods (Mumbai Flash Flood in 2005) in absence of properly planned drainage systems. However, such cases are quite recent and yet to be studied heuristically.

B4. Droughts

Drought may be thought of as an associated phenomenon to the disturbed atmospheric hydrological cycle, and increasing number of floods also reflects an increasing number of droughts, though over some other regions. In fact, the fast changing global as well as regional hydrological imbalances due to changes in the evaporation and convection patterns consequently result in floods in some areas and droughts over other areas. The trends on national and regional scales are as follows.

National

- The regions with a high probability of occurrences of drought are primarily Tamilnadu, Maharashtra, Andhra Pradesh, Rajasthan and part of Gujarat (FigB3)

Regional

- The most drought-affected region is Andhra Pradesh, and the trend is increasing over the recent years. (Fig. B4)
- Some parts of southern Orissa are also drought-affected regions (Fig.B4).
- No specific trend is observed for West Bengal, Madhya Pradesh and north Orissa.

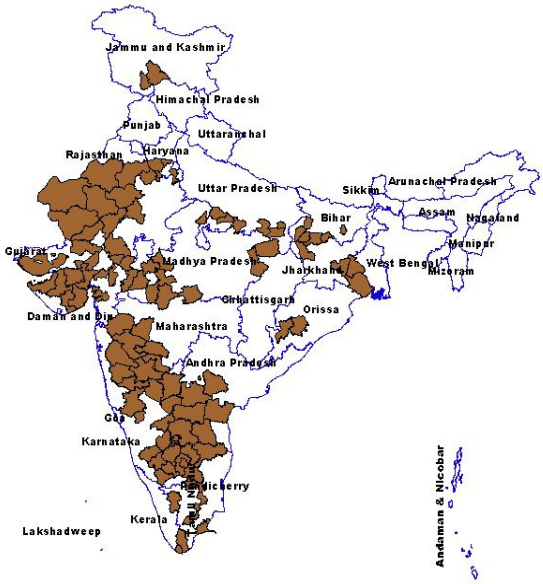

Fig.B3 The probability of occurrence of droughts (shaded area) based on the rainfall deficiency for the last 100 years

Future

Based on SWAT (Soil and Water Assessment Tool) water balance model for hydrologic modeling of different river basins in the country and outputs of the HadRM2 regional climate model, preliminary assessments showed that under the IS92a scenario, the severity of hydrological droughts and intensity of floods in various parts of India is likely to increase.

In some parts of the vicinities of Sabarmati and Mahi rivers, the climate scenarios suggest an increase in severe drought conditions. In areas covering parts of the Mahanadi and Brahmani, the drought conditions are likely to be less severe under the climate scenarios (National Communication, 2004).

The agricultural drought is lined with drier soil. Based on the 15 climate model used in the AR4, it is concluded that the models are consistent in predicting drier soil in Asian monsoon region (including central India) during December–January–February (winter) (Kripalani et al., 2003).

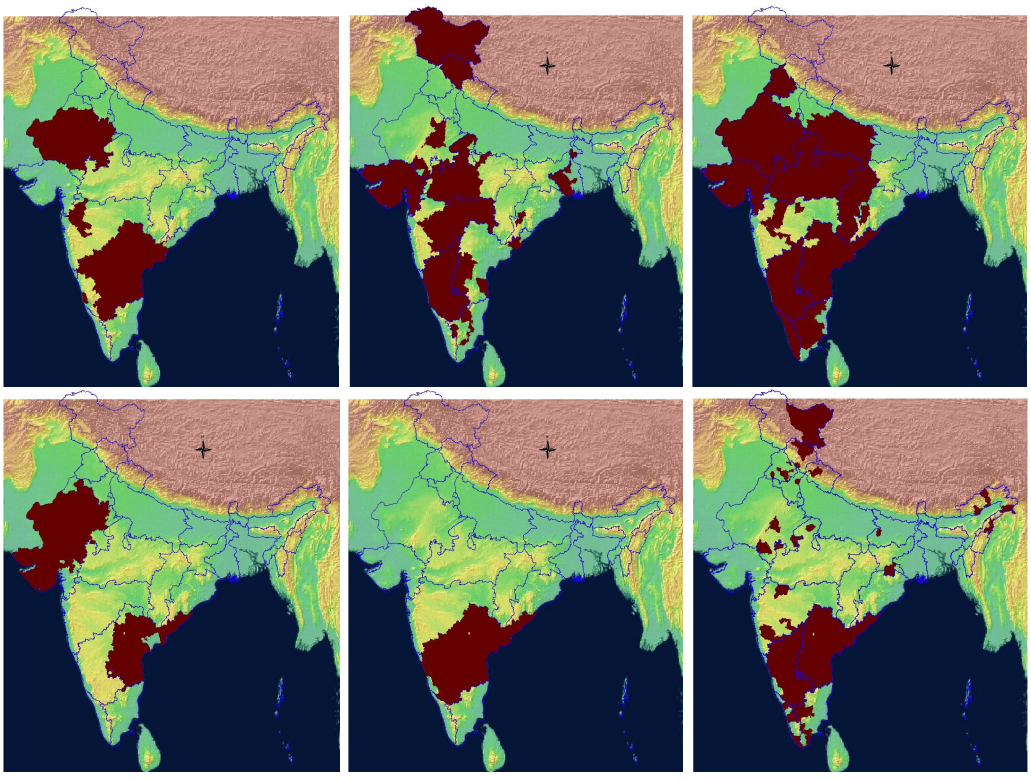

Fig.B4 Temporal and spatial spread of drought (red shad) in the recent years (a) 1984, (b) 1986, (c) 1997, (d) 2000, (e) 2001, and (f) 2002. (Source: IMD)

B5. Cyclone and storm surges

Cyclogenesis and its evolution depend on certain favorable atmospheric and oceanic conditions; with the most important factor being ocean surface temperature. There are marked seasonal variations in origin, tracks and intensities of cyclones, both in the Arabian Sea and Bay of Bengal. Cyclones are rare in Bay of Bengal from January to March. During this period, isolated cyclones forming in the South Bay of Bengal normally move west north westwards and hit coastal regions of Tamilnadu and Sri Lanka. In April and May, cyclones form in the south and adjoining central

Bay and move initially northwest, north and then turn to the northeast striking the Arakan coasts in April and coasts of Andhra Pradesh, Orissa, West Bengal, and Bangladesh in May. Most of the monsoon (June – September) storms develop in the central and in the North Bay and move west-north-westwards affecting coasts of Andhra Pradesh, Orissa, and West Bengal. Post monsoon (October–December) storms form mostly in the south and the central Bay, turn between 15^{o}N and 18^{o}N affecting Tamilnadu, Andhra Pradesh, Orissa, West Bengal, and Bangladesh coasts. (IMD)

About 80 tropical cyclones (with wind speed ≥65 km per hour) form globally in a year. Of these about 6.5% (~5 cyclones) develop in the Bay of Bengal (~4) and Arabian Sea (~1) (WMO). During ENSO, a cyclone in tropical oceans has more than 40% chance of being a sever one.

Storm surges: Cyclones are associated with high- and low-pressure differences and consequently with strong winds. These strong winds, in turn, generate storm surges. A storm surge is an abnormal rise of sea level near the coast caused by a severe tropical cyclone; as a result, sea water inundates low lying areas of coastal regions drowning human beings and live-stock, eroding beaches and embankments, destroying vegetation and reducing soil fertility.

National

- Overall, the tropical storms over north Indian Sea show a significant decreasing trend after the 1980s.
- Overall, during the monsoon season, there is a decreasing trend in the number of cyclonic events.
- For 2001–2005, the number of total cyclones dissipating in sea is more than the total cyclones that crosses the coasts (Fig.6). This trend is based on only 5 years data.
- Severe storms show an increasing trend.
- Frequency of severe cyclonic storms in the Bay of Bengal has increased in recent decades (Unnikrishnan et al. 2006)

Regional

- There is a trend of increasing frequency of severe cyclones over West Bengal.
- For Orissa, the trend is decreasing.
- The number of cyclones during the period of 1891–2006 is more for Orissa, followed by Andhra Pradesh and West Bengal (Fig.B5)

Future

Various studies suggest that cyclone intensity would possibly be increased by 10–20% for a rise of 2–4^{o}C rises in the sea surface temperature (with the threshold temperature taken as 28^{o}C) (M Lal, 2001). Given the Bay of Bengal geophysical location, being at low-latitude and partly land-locked the projected rise in sea surface temperature may lead to greater convective activities over the region. This suggests increased cyclonic intensity in Bay of Bengal and consequently increased storm surges in the region, together with the increasing sea level.

The table B1 in the following summarizes the frequency of cyclones over some stations in the three coastal DFID-partner states of India.

Table B1: Number of cyclones during 1891–1989 in some parts West Bengal, Orissa, and Andhra Pradesh (Source: IMD)

State	Coastal districts	No of cyclones (1891–1989)
West Bengal	24 Parganas	23
	Medinapur	12
Orissa	Balasore	19
	Cuttack, Puri	17
	Ganjam#	10
Andhra Pradesh	Srikakulam	7
	Visakapatnam	14
	East Godavari	8

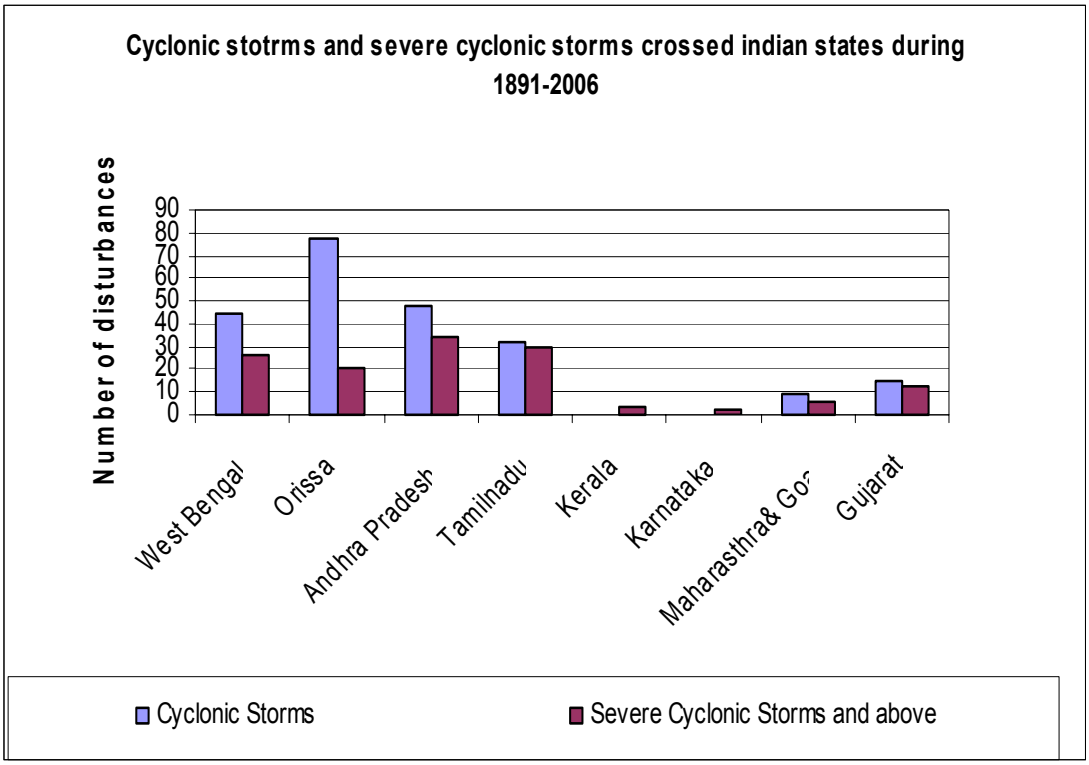

Fig.B5 Cyclonic storms over Indian States during 1891–2006 (Source: IMD)

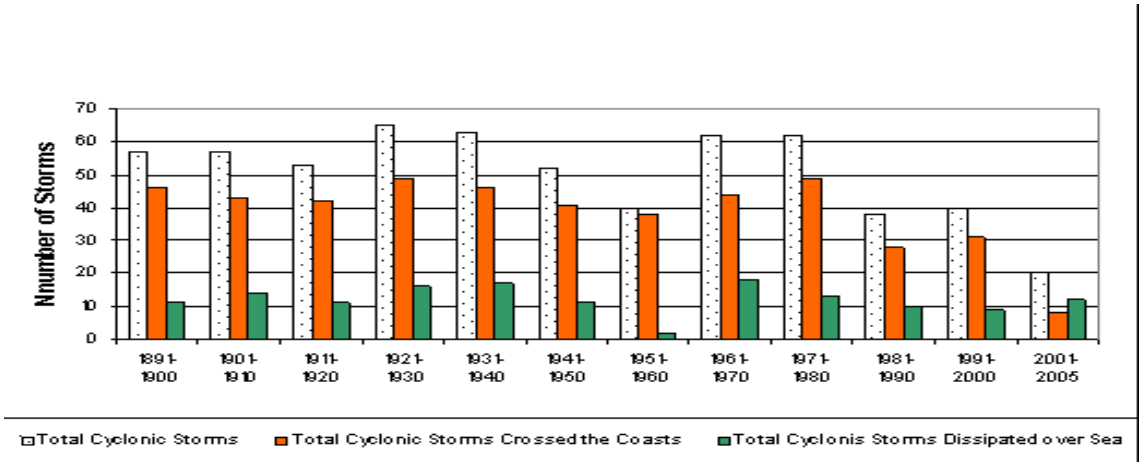

Fig.B6 Cyclonic storms over North Indian Ocean during 1891–2005 (Source: IMD)

Super cyclone of Orissa (1999): Two tropical cyclones crossed Orissa in the month of October 1999 (17 and 29 October). The second one was quite vigorous in nature (wind speed ~260 kmph and heavy rainfall), and strong surges (> 8 meter high) were associated with it. This cyclone was more or less stationary (with slight southward drift) over the region after making landfall[11] and this led to large scale loss and damage to infrastructure and livelihoods. More than 10,000 lives were lost and over a million were rendered homeless.

Future

- It is likely [>66%] that future tropical cyclones will become more intense, with larger peak wind speeds and more intense precipitation as a consequence to the ongoing increases in tropical sea surface temperatures.
- Based on regional HadRM2 simulations, increases in the frequency as well as intensities of tropical cyclones in the 2050s under the IS92a scenario in the Bay of Bengal is reported, which will cause more heavy precipitation in the surrounding coastal regions of South Asia, during both southwest and northeast monsoon seasons (Unnikrishnan et al. 2006).

B6. Sea level rise

Sea level rise is an increase in the sea level leading to inundation of low-lying land. The causes of this rise may include expansion of seawater as the oceans warm, and melting of glaciers. Because of it geophysical topography India is more vulnerable to sea level rise. The Indian coastline stretches about 5700 km on the mainland and about 7500 km including the two island territories. Since the measurement of sea level change is difficult, mainly because sea level is measured relative to a land-based tide-gauge benchmark, the observational reports are sporadic. However, recently reported intrusion by seawater and inland movement of saline water in the Sunderbans has caused greater concerns and emphasizes the need to assess the rise and its impacts with more certainty. The major findings are:

[11] Landfall: arrival of cyclone at the land part

National

- A long-term rising trend of about 0.1 mm per year has been observed.
- 1950s onwards, the rate of sea level rise is about 0.25 mm per year.
- The sea level rise is greater along the east coast than along west coast of India due to frequent cyclogenesis and thermal expansion related seawater rise in Bay of Bengal.
- The recent sea level rise trend is less that 1 mm per year for the Indian coast except for Chennai.

Regional

- Based on the data from selected stations over Indian coasts, there may be sea level rise of less than 1mm per year over coastal Andhra Pradesh.

Future

- Possible increases in the intensity of cyclonic storms may lead to more extreme sea-level events.
- Case studies of expected sea-level changes for few locations suggest that the southern peninsular coast will be the most vulnerable to sea-level rise.
- In AR4, under the most conservative scenario, sea level is projected to be about 40cm higher than today by 2100.

B7. Heat waves

A heat wave is an extended time interval of abnormally and uncomfortably hot and unusually humid weather. To be a "heat wave" such a period should last at least for one day, but usually it lasts from several days to several weeks. In India, certain regions often get heat waves during March to July (see Table 3). However, the impacts due to heat waves are different in different regions, mostly due to the geographical locations. Heat waves are more fatal when humidity ratios are higher. Based on past studies, the major findings for these phenomena are as follows (Chaudhury et al., 2000).

National

- Frequency of hot days and multiple-day heat waves has increased in India in the past century (AR4).
- Table 3 indicates the loss of life and number of spells of heat wave. The number of deaths was more in 1998 with 33 occurrences of heat wave.
- In particular, El Nino years are more prone to get longer and frequent heat waves, whereas these occurrences are fewer during La Nino years.

Regional

- The maximum number of heat waves is over Bihar followed by West Bengal (see Table B2) in the recent decades.
- The other major heat-wave-prone regions are Maharastra and Utter Pradesh.
- During the 20^{th} century the reported number of heat waves is 51 for Orissa and 24 for Andhra Pradesh, however, in recent years Andhra Pradesh experienced many severe heat wave spells.

TableB 2 Numbers of Heat wave in India (De et al., 2005)

State	Epochs				
	1901-10	1911-67	1968-77	1978-99	1901-99
West Bengal		76	9	28	113
Bihar		105	6	23	134
Uttar Pradesh		27	3	42	72
Rajasthan		43	1	7	51
Gujarat, Saurashtra & Kutch		-	2	-	2
Punjab		-	1	-	1
Himachal Pradesh		-	-	-	-
Jammu & Kashmir		26	5	35	66
Maharashtra		82	4	13	99
Madhya Pradesh		32	4	15	51
Orissa		25	8	18	51
Andhra Pradesh		21	-	3	24
Assam		-	4	19	23
Haryana, Delhi & Chandigarh		-	1	2	3
Tamil Nadu		5	-	2	7
Karnataka		-	-	-	-
Telangana		-	-	-	-
Rayalaseema		31	2	28	61

Table B3 Total no. of heat waves associated with loss of Human lives (1978-99) (Chaudhury et al., 2000)

State	Month*					
	March	April	May	June	July	Total*
Andhra Pradesh	–	7(21)	8(447)	3(7)	–	18(475)
Assam	–	1(–)	1(–)	1(26)	–	3(26)
Bihar	–	5(112)	9(182)	14(477)	–	28(771)
Gujarat	2(–)	1(10)	4(24)	–	–	7(34)
Haryana	1(–)	1(–)	1(5)	7(31)	2(1)	12(37)
Himachal Pradesh	–	–	1(–)	–	–	1(–)
Karnataka	–	1(2)	1(3)	–	–	2(5)
Madhya Pradesh	1(–)	1(–)	5(121)	6(44)	–	13(165)
Maharashtra	2(–)	6(12)	23(110)	4(121)	–	35(243)
Orissa	–	1(7)	10(430)	4(92)	–	15(529)
Punjab	–	1(–)	7(22)	7(92)	2(–)	17(114)
Rajasthan	1(–)	5(8)	16(733)	19(882)	1(2)	42(1625)
Tamil Nadu	–	–	1(20)	1(3)	–	2(23)
Uttar Pradesh	1(–)	3(23)	8(167)	10(496)	1(–)	23(686)
West Bengal	–	10(51)	12(24)	6(83)	–	28(158)
Delhi	–	–	1(24)	3(25)	–	4(49)
Chandigarh	–	–	2(1)	1(1)	–	3(2)

Future

It is very likely [>90% probability] that heat waves or hot spells in summer will be of longer duration, more intense and more frequent (AR4).

B8. Cold waves

A cold wave, in general, is a prolonged period of excessively cold weather. The excessive cooling of air becomes more fatal when it is accompanied by high winds that cause excessive wind chills. Due to its diverse topography (plains), mostly northern, central and eastern Indian regions are more prone to cold waves, which occur mostly during November–February. However, cold waves may also affect regions to the south of 20°N due to large amplitude troughs as observed in states like Maharashtra and Karnataka as well. The national and region-specific trends are discussed in the following (De et al, 2005).

Table B4 Numbers of cold waves in India (De et al., 2005)

State	Epochs				
	1901-10	1911-67	1968-77	1978-99	1901-99
West Bengal	2	14	3	28	47
Bihar	7	27	8	67	109
Uttar Pradesh	21	51	8	47	127
Rajasthan	11	124	7	53	195
Gujarat, Saurashtra & Kutch	2	85	6	6	99
Punjab	3	34	4	19	60
Himachal Pradesh	-	-	4	18	22
Jammu & Kashmir	1	189	6	15	211
Maharashtra	-	60	4	18	82
Madhya Pradesh	9	88	7	12	116
Orissa	4	5	-	-	9
Andhra Pradesh	2	-	-	-	2
Assam	1	1	-	-	2
Haryana, Delhi & Chandigarh	-	-	4	15	19
Tamil Nadu	-	-	-	-	-
Karnataka	-	10	-	-	10
Telangana	-	5	1	-	6
Rayalaseema	-	3	-	-	3

National

- The cold waves mainly affect the areas to the north of 20^{0}N but cold wave conditions are sometimes reported at states like Maharashtra and Karnataka as well.
- The major cold wave areas, apart from Jammu & Kashmir, are Rajasthan, Utter Pradesh and Bihar.

Regional

- The maximum numbers of cold waves occur across Madhya Pradesh and West Bengal.

Future

Cold episodes are projected to decrease significantly in a future warmer climate (AR4) with the projected increase in minimum temperature range.

B9. Water resources

The per capita annual water resource (AWR) has been used to classify countries with respect to the water scarcity. Countries with an AWR per capita of 1700 cubic meter and above have been termed as countries where shortage will be rare; those with an AWR per capita of less than 1000 cubic meter as water-stressed countries; and those with an AWR per capita of 500 cubic meter

and below as countries where availability of water is a primary constraint to life. In 1955, only seven countries were found to be with water stressed conditions. In 1990 this number rose to 20 and it is expected that by 2025 another 10 to 15 countries shall be added to this list. It is further predicted that by 2050, two-thirds of the world population may face water-stressed conditions. It is worth noting that this assessment has been made without taking into account the possible impact due to predicted changes in global climate. Such consideration may aggravate the situation of AWR further (Gosain *et al*., 2006).

In India, groundwater has been the mainstay for meeting the domestic needs of more than 80% of rural and 50% of urban population, besides fulfilling the irrigation needs of around 50% of irrigated agriculture. It has been estimated that 70–80% of the value of irrigated production in India comes from groundwater irrigation. Contribution from groundwater to India's Gross Domestic Product (GDP) has been estimated as about 9% (Bijuria and Romani, 2003).

National

There are 12 major river systems in India. The hydrological cycle is likely to be altered in significant ways due to climate change as early as by 2020s, thus, together with recession of Himalayan glaciers, affecting the river systems and availability of fresh water. The future scenarios suggest (based on National Communications, 2004):

- There is a general reduction in the quantity of available runoff under the IS92a scenario.
- River basins of Sabarmati and Luni of Gujarat and Rajasthan, are likely to experience acute water scarce conditions.
- River basins of Mahi, Pennar, Sabarmati and Tapi are likely to experience constant water scarcity and shortage.
- River basins of the Cauvery, Ganga, Narmada and Krishna are likely to experience seasonal or regular water stressed conditions.
- River basins of the Godavari, Brahmani and Mahanadi are projected to experience water shortages only in a few locations (National Communication, 2004).

It must be noted that further work is necessary to run these river basin models with more climate model scenarios to get a better measure of the uncertainty associated with the runoff scenarios. Different climate models may produce different changes in rainfall and evaporation thus affecting the impacts on river flows.

Implications of climate change for water availability

The control and climate scenarios for the 12 river basins depict the comparison of water balance components expressed as percentage of rainfall. It is observed that the impacts are different in different catchments. The increase in rainfall due to climate change does not result in an increase in the surface run-off as may be generally predicted. It may be observed that even though an increase in precipitation is projected for the Mahanadi, Brahmani, Ganga, Godavari, and Cauvery basins for the climate scenario, the corresponding total run-off for all these basins has not necessarily increased

Regional

Madhya Pradesh

Seasonal or regular water stresses conditions is projected in Narmada river basin

Andhra Pradesh
The river basin of the Godavari is projected to experience water shortages only at few locations.

Overall impact
There is a general reduction in the quantity of the available run-off under the future climate scenario. The river basins of Cauvery, Ganga, Narmada and Krishna are likely to experience seasonal or regular water-stressed conditions. The river basins of the Godavari, Brahmani and Mahanadi are projected to experience water shortages only at few locations (National Communication, 2004).

B10. Agriculture (wheat and rice)

India has two major crop seasons, Kharif and Rabi. *Kharif* crops are sown in May-June and harvested in September– October. The important *Kharif* crops are cotton, rice, sugarcane, maize, jowar and bajra. *Rabi* crops are sown in October–November and harvested in February–March. The important *Rabi* crops are wheat, grams,barley, rapeseed and mustard.

Based on Wheat Growth Simulator (WTGROWS) model, the optimal dates of sowing of wheat crop suggest that variability in the amounts of winter rains received could influence the rainfed wheat yields under normal weather as well as rising temperature (1–3^{0}C) situations. However, the results are found to be different for different agro-ecological regions in terms of yields.

Based on different reports, it can be concluded (Mall et al. 2006):

- The impacts of climate change on agriculture productivity in India are still uncertain and need to be studied elaborately.
- Depending on temperature rise (2^{0}C, 3^{0}C, 4^{0}C), increase in CO_2 and interaction of increase in temperature and CO_2, the average impact may be positive and negative.
- The rabi crops (winter season crop) in central and southern India will likely to be more risky in future.
- Up to 2050s, climate change will have either no or a positive impact on Indian agriculture.

By the end of 2080s, Indian agriculture will suffer worst when projected temperature rise is higher.

The impact of rainfall and temperature on wheat

Many of earlier studies have shown that

- The food production for the monsoon season (*kharif*) has a positive relationship with the seasonal rainfall
- In the post-monsoon season, the rainfall is scanty, and wheat is largely irrigated. Hence, such crops do not show any relation with the seasonal rainfall. The regional wheat yields, however, do show a considerable relation with temperature.

In recent years, crop models have been used in India to study the impact of climate change on crop production. Most of the simulation studies show that:

- As temperature increases, there is a decrease in the duration and yield of crops (Aggarwal et al. 2001).
- Wheat crop is quite sensitive to temperature rise, even a 0.5^{o}C increase in the mean winter temperature would reduce wheat yield by 0.45 ton per hectare considering the potential yield of 8 ton per hectare. However, the actual yield of wheat at present is 2.6 ton per hectare (Kalra et al., 2003).
- As it has been projected in AR4 that winter season would be drier in India, wheat crop may again go down, if irrigation is not done.

Future projection with respect to CO_2:
The reduction in yield is affected by increase in CO_2 – “the fertilization effect”. The magnitude of the reduction in grain yield varies with crops, regions and climate change scenario. The result of these studies suggests that

- For rice and wheat, yields decrease as temperature increases
- About $2^{o}C$ increase in temperature decreases 15–17% in the grain yield of both crops.

Based on different reports, it can be concluded (Mall et al. 2006):

- The impacts of climate change on agriculture productivity in India are still uncertain and need to be studied elaborately as studies carried out presently assume other factors as constants and therefore do not present the realistic picture of impacts.
- Depending on temperature rise ($2^{0}C$, $3^{0}C$, $4^{0}C$), increase in CO_2 and interaction of increase in temperature and CO_2, the average impact may be positive and negative.
- The rabi crops (winter season crop) in central and southern India will likely to be more risky in future.
- Up to 2050s, climate change will have either no or a positive impact on Indian agriculture.
- By the end of 2080s, Indian agriculture will suffer worst when projected temperature rise is more.

B11. Human health

From model simulations, based on the minimum required conditions for malaria transmission, it is projected that the transmission window remains open for 12 months in eight states of India in the future warmer climate. These include Andhra Pradesh, Chhattisgarh, Karnataka, Kerala, Maharashtra, Orissa, Tamil Nadu and West Bengal. In the next level, that is, the 9–11 months transmission windows will be open for the north-eastern states (Gujarat, Haryana, Madhya Pradesh, Punjab, Rajasthan, Uttar Pradesh and Uttaranchal). The 5–7 months transmission windows for malaria will remain open for the states of Himachal Pradesh and Jammu and Kashmir. (National Communications, 2004 and Rupa Kumar et al., 2006)

- The transmission window is reduced by one to five months under conditions of relative humidity values being less than 60%.
- With 3.8°C increase in temperature and 7 % increase in relative humidity by the 2050s (in relative to the base line), nine states of India may have transmission windows open for all 12 months.
- States like Orissa and some southern states, where the mean temperature is more than 32°C for 4–5 months, a further increase in temperature may reduce the transmission window by 2–3 months.

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Part C: Assessing vulnerability to climate change – insights from case studies in India

Summary

- Vulnerability of physical and human systems to climate variability and change is a composite of the ability of the system to cope with current climatic shocks and stresses and the ability to adapt to the long-term changes in the climate.
- Climate change can add to the existing vulnerabilities of populations having a low coping capacity and high dependence on climate-sensitive sectors such as agriculture, water and forests for livelihoods and sustenance
- A range of structural and non-structural measures can contribute towards decreasing the vulnerability associated with changes in the climate; either by reducing the risks directly or indirectly by enhancing the resilience of the communities to cope with these risks.
- More integrated efforts are needed towards sectoral and regional assessments on the impact and vulnerability analysis of the risks posed by short-term and long-term changes in the climate.

Key terms

(Source: IPCC, 2001)

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

Climate change in IPCC usage refers to any change in climate over time, whether due to natural variability or as a result of human activity. This usage differs from that in the Framework Convention on Climate Change, where climate change refers to a change of climate that is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and that is in addition to natural climate variability observed over comparable time periods.

Sensitivity is the degree to which a system is affected, either adversely or beneficially, by climate-related stimuli. Climate-related stimuli encompass all the elements of climate change, including mean climate characteristics, climate variability, and frequency and magnitude of extremes. The effect may be direct (e.g. a change in crop yield in response to a change in the mean, range or variability of temperature) or indirect (e.g. damages caused by an increase in the frequency of coastal flooding due to sea- level rise).

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

C1. Introduction

C1.1 Vulnerability: concept and assessment

Despite its various facets and definitions, vulnerability to climatic hazards represents a crucial element of climate risk assessment. Hence, identification of regions that are exposed to shocks and stresses posed by the current climate and by future climate change, and their ability to cope or respond (*adaptive capacity*) can enable the development of suitable intervention strategies for support.

Inter-governmental Panel on Climate Change (IPCC, 2001) defines vulnerability as:

''***the degree to which a system is susceptible to, or unable to cope with adverse effects of climate change***.''

IPCC (2001) also mentions that vulnerability is a function of the character, magnitude and rate of climate variation to which a system is exposed, its sensitivity, and its adaptive capacity.

Vulnerability = f (Exposure, Sensitivity, Adaptive capacity)

Human activities in most regions face *multiple stresses* that influence their ability to respond to specific climate stresses. The most vulnerable are considered to be those who are most exposed to hazard, who have limited resources to cope, are heavily dependent on subsistence activities involving extraction of natural resources, and who have least resilience to climatic shocks (Bohle et al 1994). Hence, measures to improve adaptive capacity in response to specific climatic stresses need to be integrated within other aspects of development such as livelihood enhancement, water resource management, coastal protection and disaster risk reduction (IPCC, 2007).

C2. Insights from existing vulnerability studies

Several national, regional and local case studies indicate that fluctuations in climatic patterns have already affected physical and biological systems to varying degrees and further threaten to have effects that would only increase in case of inaction. India's Initial National Communication (NATCOM, 2004) to the United Nations Framework Convention on Climate Change (UNFCCC) highlights the major threats that India faces in the context of climate change, which include:

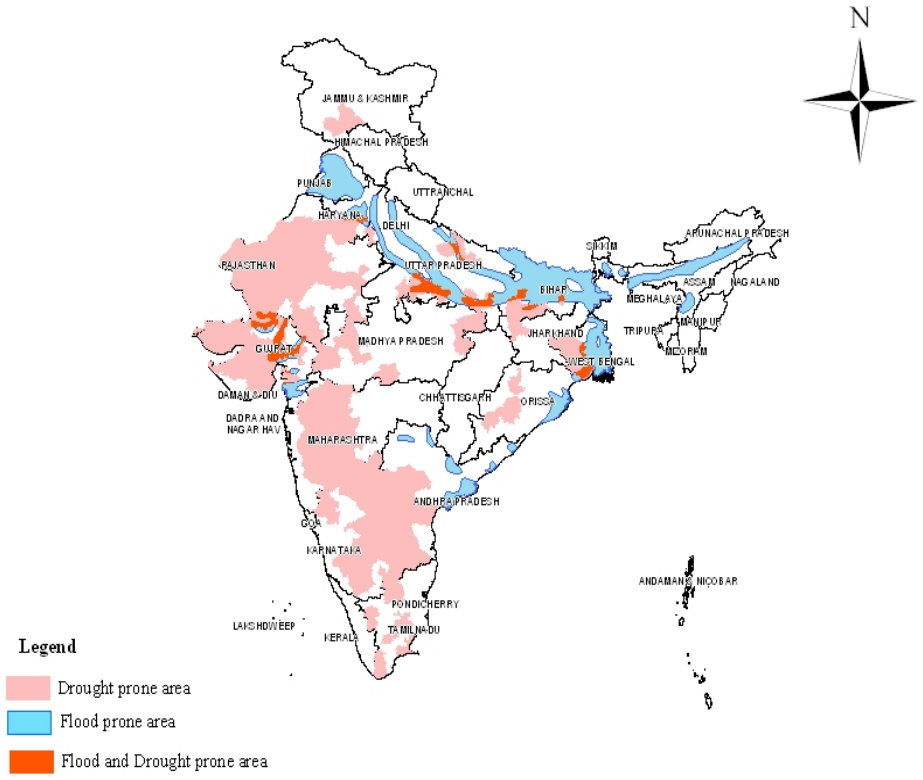
i. Sensitivity of agricultural yields to changes in climatic variables (precipitation, temperature, humidity), associated shifts in occurrence of crop pests and diseases and implications for food security
ii. Reduction in the fresh water availability
iii. Boundary shifts for different forest types, with consequent implications for species diversity and forest-dependent communities
iv. Adverse impacts on natural ecosystems such as wetlands, mangroves and coral reefs and mountain ecosystems
v. Threat of sea-level rise along coastal zones
vi. Changes in virulence and disease patterns especially vector borne diseases due to prevalence of conducive environments
vii. Increased energy demands, and
viii. Impacts on climate-sensitive infrastructure

The sections ahead discuss the sector- wise climate vulnerability in the Indian subcontinent.

C2.1 Vulnerability to climate change: Water resources

India is highly vulnerable to extreme events due to both, scarcity as well as excess of water resources, with the pattern being highly variable across the country. About two-thirds of the total sown area in the country is drought prone with about 40 million hectares of land being flood prone (NCDM and NDMD. 1999). While majority of Rajasthan, Andhra Pradesh, Gujarat and Maharashtra and comparatively smaller areas in Karnataka, Orissa, Madhya Pradesh, Tamil Nadu, Bihar, West Bengal, and Uttar Pradesh are affected by drought; most of the river basins in north and northeastern belt of India are prone to flood hazards (Figure C1).

Figure C1: Drought and flood prone regions in India (Source: CWC[12])



Extensive river systems such as the Brahmaputra, Ganga and Indus are expected to be more vulnerable because of the large contribution of snow and glaciers into these river systems. The glaciers within the Himalayan mountain system have already started retreating and this phenomenon is expected to increase as the temperature rises. Though glacial melt would lead to increase in river- flows and floods initially, it would be followed by a drastic reduction in flows in the long run (DFID, 2006).

Under an Indo-UK project (initiated in 2001) on the impacts of climate change in India, the Department for Environment, Forests and Rural Affairs (DEFRA) funded a collaborative project with the Ministry of Environment and Forests (MOEF), India. The analysis was based on daily – observed precipitation data record analysis at the country level, between 1901–1995. The regional climate model HadRM2 was then used to study the impacts of climate change on water resources. The results of this study suggest that the hydrological cycle may become more intense, with higher annual average rainfall as well as increased drought (due to increased run-off leading to less recharge). The results also show a predicted increase in extreme rainfall and

[12] Map prepared by overlaying flood hazard map, CWC (1981) and map prepared using data on drought prone districts in India accessible at http://mospi.nic.in/comenv2000tab5.3.3.htm, last accessed on 20th May 2007

rainfall intensity in three major river basins of India viz.- Krishna, Ganga and Godavari towards the end of the 21st century.

The NATCOM also assesses vulnerability of the water resources with respect to changes in the river flows. Results from HadRM 2 projected climate change GHG scenario (with the assumption that land use remains constant over time), overall there is a reduction in the available run-off. This could be attributed to changes in temperature, changes in rainfall distribution and evapo-transpiration. Hence, despite predictions of increased rainfall, some river basins might still face water scarcities. For example, river basins of Cauvery, Ganga, Narmada and Krishna are likely to experience seasonal or regular water-stressed conditions. Also, the river basins of Mahi, Pennar, Sabarmati and Tapi are likely to experience constant water scarcities and shortage, while the Godavari, Brahmani and Mahanadi river basins are projected to face water shortages in only a few parts. (Figure C2, NATCOM, 2004).

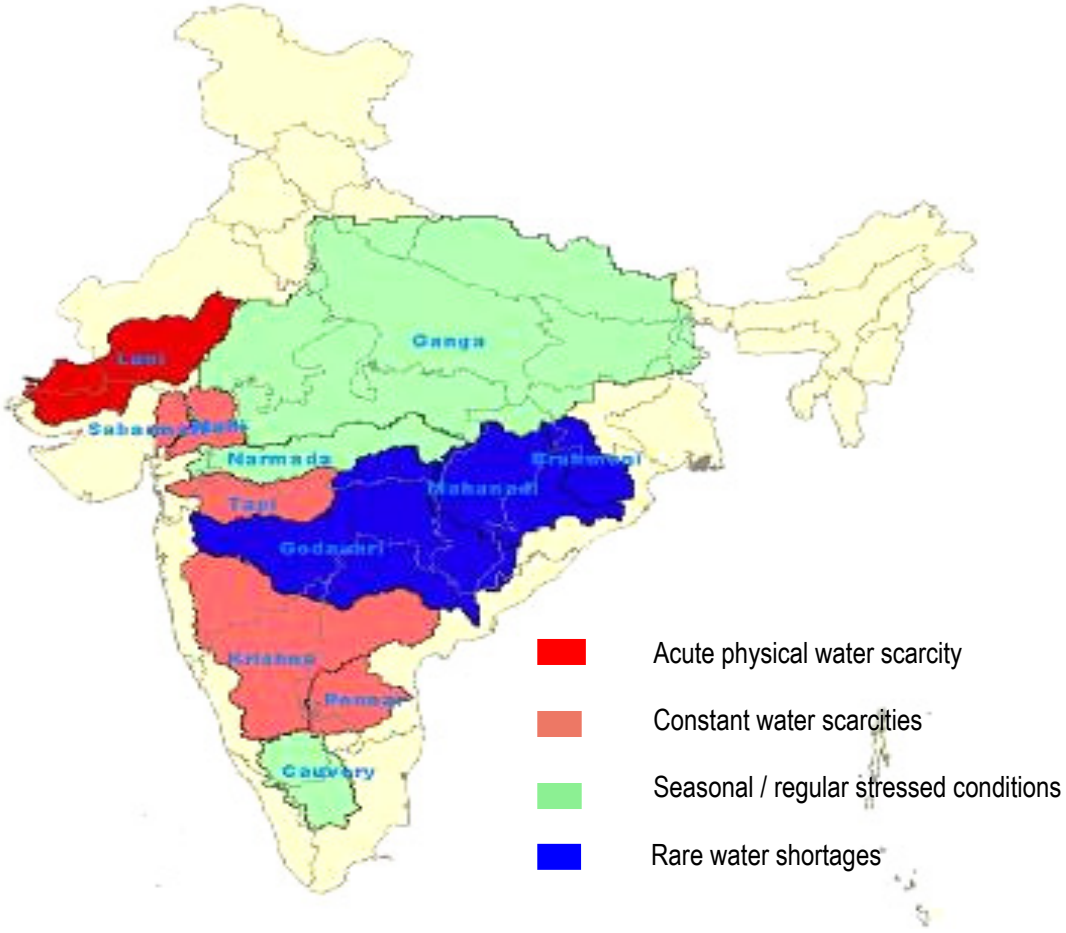


Figure C2: Regions vulnerable to changes in water availability due to projected climate change

(Source: NATCOM, 2004)

C2.2 Vulnerability to climate change: Agricultural sector

The agricultural sector contributes about 18.5 % to the country's GDP[13] and has over 600 million-people dependent[14] on the sector. Hence, impacts on the agricultural sector threaten to have a multi-fold implication across all socio-economic classes within the country. Furthermore, as about

[13] www.indiainbusiness.nic.in/economy/agriculture.htm as accessed on 18 October 2007
[14] www.ficci.com/media-room/speeches-presentations/2007/sep/agri/SessionV/MukundAnnigeri.pdf

68 percent of the net sown area in India is rainfed[15]; hence changes in precipitation patterns are form a regular risk factor for agricultural yields and agriculture-based incomes. In addition, over 80% of the agricultural holdings in India are less than 2 hectares in size and over 60% are less than 1 hectare area each[16], thereby limiting the opportunities for growth and development in this sector. Apart from climatic factors however, the vulnerability of the agricultural sector is also determined by socio-economic conditions of the farmers, market factors, infrastructure development and availability of technologies inter alia.

Insights from some case studies on the vulnerability of agricultural sector in India are detailed below.

Case study 1- Impacts of climate change and economic changes on Indian agriculture: a collaborative study by TERI, CICERO and IISD.

This study explored the vulnerability of the Indian agriculture to the dual challenge of climatic changes as well as economic changes. It was assumed that certain biophysical, social and technological factors (Table C1, Figure C3a, C3b, C3c) contribute towards strengthening the adaptive capacity of the farmers to respond to these changes effectively. Three indices[17] were created representing biophysical, social and technological factors based on the average value of a set of normalized variables assisting in the identification of high and low vulnerable regions.

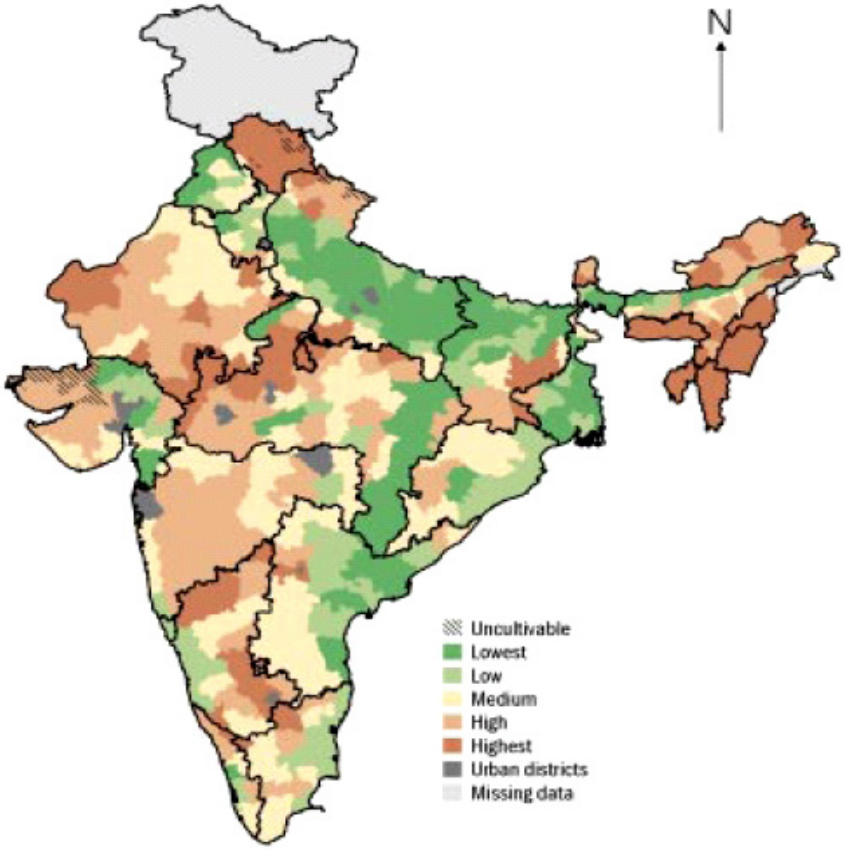


Figure C3 (a) Biophysical vulnerability

[15] www.dhan.org/rainfed/index.htm
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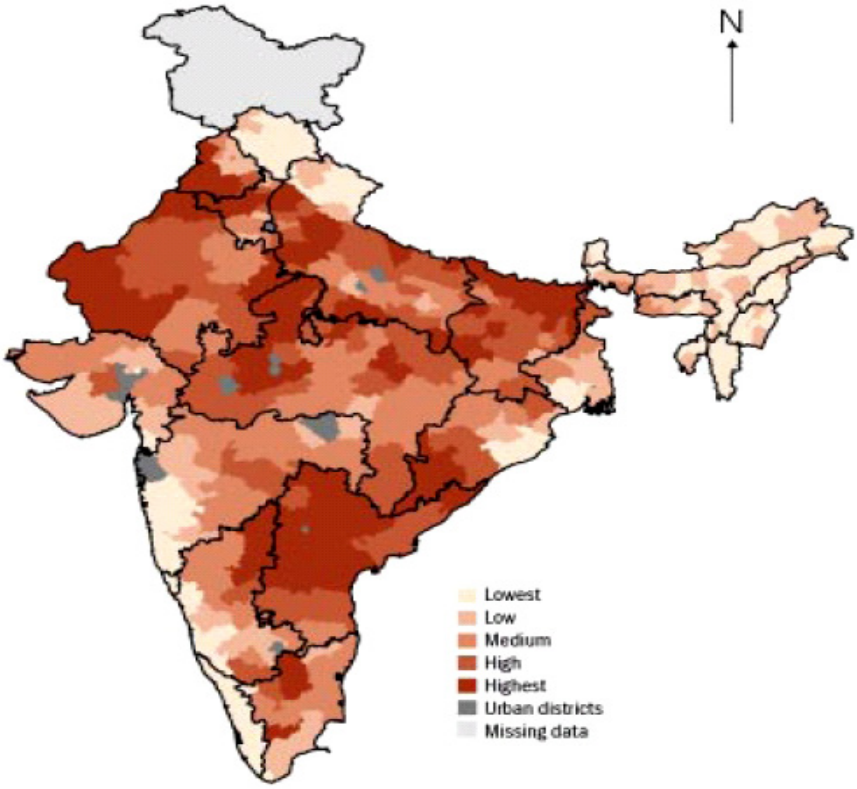


Figure C3 (b) Social vulnerability

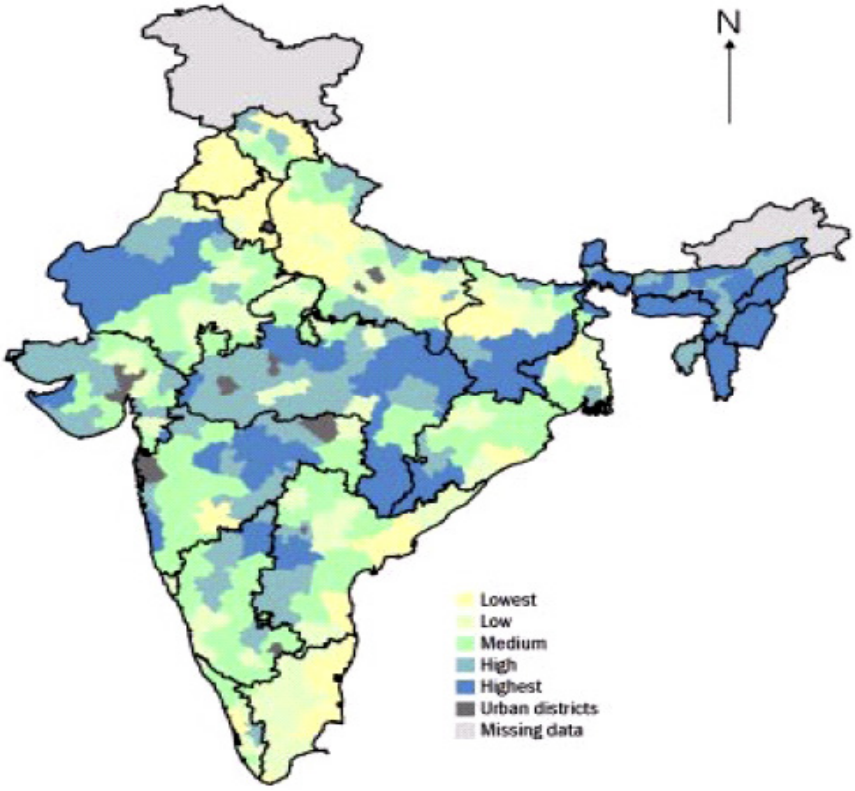


Figure C3 (c) Technological vulnerability

The biophysical, social, and technological vulnerability maps were combined to produce a profile of adaptive capacity (Figure C4).

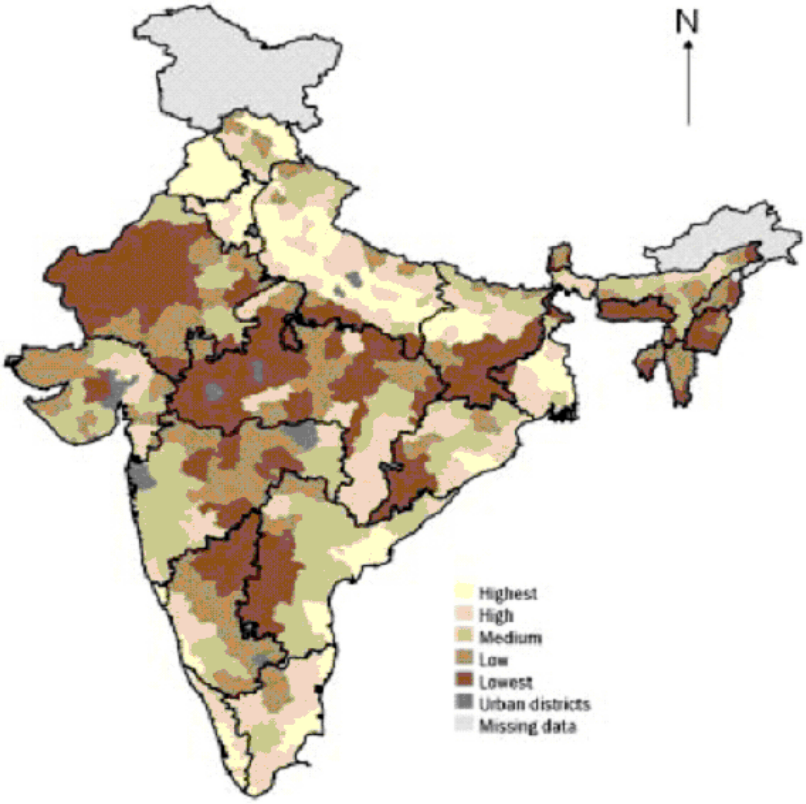


Figure C4: Adaptive capacity profile for the agricultural sector generated by integration of biophysical, social and technological profiles

The adaptive capacity profile was then combined with climate change profile generated by studying sensitivity to change using HADRM2 outputs to create a composite map of climate change vulnerability (Figure C5) (Table C1).

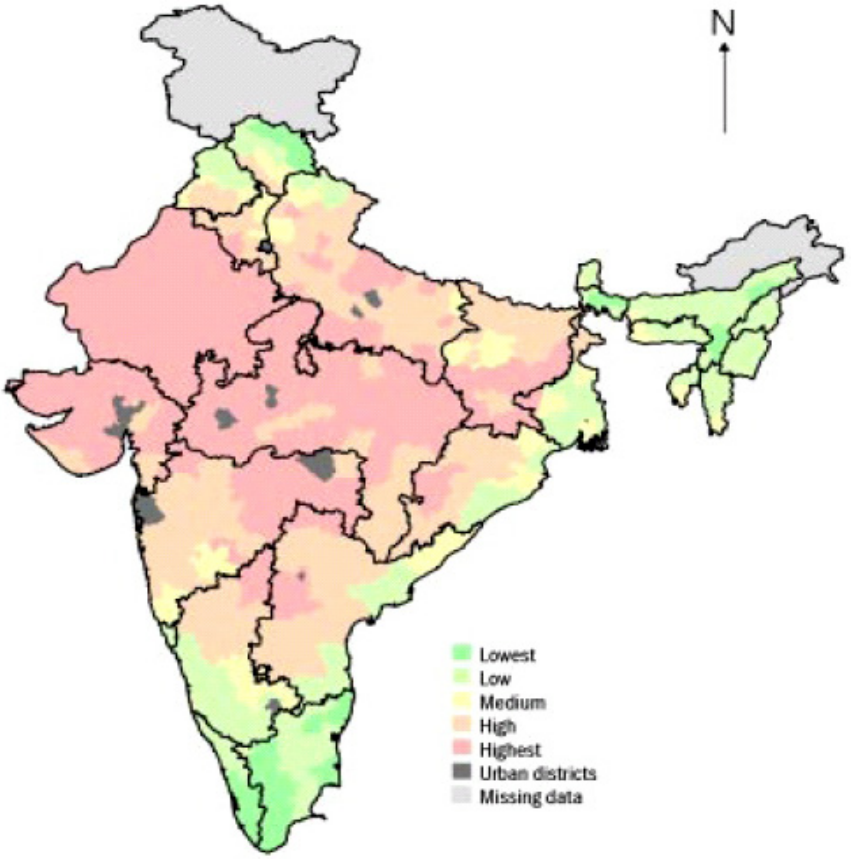


Figure C5: Climate change vulnerability profile generated by integration of adaptive capacity (Figure 4) and climate sensitivity profiles[18]

Table C1: Vulnerability factors that influence adaptive capacity factors and distribution in India

Factors considered to determine agricultural vulnerability	***Vulnerable areas***
Biophysical factors: Soil conditions and groundwater availability	*Semi-arid districts and the northeastern districts of India*
Social factors: % of workers employed in agriculture, landless labourers, literacy levels etc.	*Districts in Punjab, Rajasthan, Haryana, Andhra Pradesh, Madhya Pradesh, Bihar, and Uttar Pradesh*
Technological factors Communications, education, health, transport, irrigation, banking, and energy infrastructure	*Districts of western Rajasthan, Madhya Pradesh, central Maharashtra, Bihar, and the northeastern states*

[18] A macro-level exercise on hotspot mapping was attempted to identify vulnerable regions that were taken up for detailed case studies in order to study the micro- scale dimensions of vulnerability. The indicators for this study have been chosen with focus on the agricultural sector only. The study excludes climate sensitivities associated with sea level rise, depressions and storm surges; a major reason for the coastal regions falling in the low vulnerability categories. However the study sought to include exposure of coastal regions to cyclones through a separate mapping exercise. For details please refer to TERI, 2003. Coping with global change: Vulnerability and adaptation in Indian agriculture. TERI, Delhi.

The results of the study highlighted that the districts with the highest climate sensitivity under exposure to climate change are not necessarily the most vulnerable, and vice versa, thereby reinforcing IPCCs definition of vulnerability as an outcome of factors that influence exposure, sensitivity and adaptive capacity.

Case study 2- Study on household vulnerability to extreme events and observed coping behaviour

An assessment of the vulnerability and observed coping measures of rural households in response to extreme events (droughts and floods) was carried out by TERI and RMSI as part of a World Bank-funded study. The study was conducted in two drought- prone basins (Pennar in Andhra Pradesh and the Godavari in Maharashtra) and one flood- prone basin (the Mahanadi in Orissa) in India. To quantitatively assess the vulnerability of households to droughts and floods an Income Impact Index (III) was constructed *to measure the differential vulnerability across various landholding categories and villages in terms of the changes in household income between a normal year and drought/ flood affected year*.

Given that agriculture formed a prime source of livelihood for a majority of the sample households, the impact of climatic stresses on household income levels was found to be high. Critical factors that can increase or reduce vulnerability at the household level were highlighted. These factors included *presence of social safety nets (savings, insurance), livelihood and income diversification, local institutional mechanisms and community structures and infrastructure facilities (irrigation facilities, roads, communication facilities, education, hospitals etc).*

In sum, the factors influencing the vulnerability of rural populations exposed to droughts/ floods included:

1. **Presence of social safety nets**[19] such as savings at household level (often with the help of self-help groups) as well as credit/ loan mechanisms enables individuals and households to tide through the affected (drought/ flood) year, without resorting to the sale of their liquid assets.
2. **Livelihood diversification** into non-farm sector provides opportunities to reduce risks associated with high levels of dependence on climate- sensitive sectors such as agriculture, forestry and fishery activities. Higher levels of education/ acquisition of skill sets enable diversification of income within a range of avenues assisting in supporting livelihoods.
3. In many regions, **strong local institutions** were found to play a major role in enhancing the capacities of communities in dealing effectively with climatic shocks.
4. Regions with good **infrastructure development** (in the form of better roads, presence of banks, healthcare facilities, schools within close proximity, availability of efficient irrigation facilities) are found to be more resilient to risks associated with climatic variability and exposure to extreme climatic conditions. Better connectivity and communication facilitates the flow of information, goods and services into and out of the affected areas.

[19] Social safety nets are designed to help individuals and households cope with the consequences of economic shocks and provide support to the poor. They are directed primarily to those poor who are most adversely affected by temporary shocks to income and well-being in general. A typology of the major social safety net programs includes cash and in-kind aid, price subsidies, food for work programs, public works programs, microfinance and insurance programs that can also reach the poor. *Source:* Social Safety Nets in Response to Crisis: Lessons and Guidelines from Asia and Latin America, 2001

C2.3 Vulnerability to climate change: coastal zones

Coastal ecosystems harbour some of the most diverse and productive habitats by forming an active interface between land and water. However they are currently reeling under immense pressure from a medley of stressors such as rapid population growth, urbanization and development activities that alter the structure and function of these ecosystems. The extent of vulnerability of the coast depends not only on the exposure to hazards, but also on the level of human activities prevalent in and around the coastal zone and the ability to cope with the impacts. Impacts include loss of land due to inundation and erosion, increased flooding, and salt-water intrusion with implications on coastal agriculture, tourism, freshwater resources, fisheries, aquaculture, human settlements, and health (Noronha et al, 2003). While some natural resource-based activities are especially sensitive to climate shocks and stresses, others, such as land reclamation, mining, construction, and groundwater extraction contribute towards increasing vulnerability.

A large share of the coastal population in India is dependant on coastal and marine resources like mangroves for their livelihood. Climatic factors like changes in temperature, humidity, precipitation, wind flow, radiation and fresh water flow in the region are crucial factors for the natural growth, development and succession of mangroves. It is also expected that rise in sea-level would submerge the mangroves as well as increase the salinity of the wetlands. This could have serious implications in the Sunderbans region where there is rich diversity of vegetation in the mangrove systems.

There are a few studies carried out by TERI, National Institute of Oceanography (NIO), Goa and IIT Bombay on the vulnerability of coastal districts to SLR and cyclones. A mean SLR of 15– 38 cm (attributed to thermal expansion) along India's coast by the mid- 21st century and 46– 59 cm by the end of the century has been projected based on simulation outputs of a four AOGCM model ensemble. In addition, a projected increase in intensity of tropical cyclones by 15% has been estimated and poses a high threat to populations living in cyclone prone coastal regions of India. Studies of which areas of the coastline are most exposed to SLR and their ability to cope remain extremely limited to date. However, studies have shown that much of India's coastline is already highly dynamic, with historical trends showing both erosion and deposition (NATCOM, 2004).

The vulnerability of Indian coastal zones to tropical cyclones was assessed under the NATCOM by creating three indices to represent hazard, exposure and impacts (Table C2). These indices were developed to represent cyclone hazard and to identify coastal districts that face the maximum cyclone occurrences.

Based on the results of these indices the districts were classified into high and somewhat vulnerable categories (Table C3). Coastal districts in DFID partner states of Orissa, West Bengal and Andhra Pradesh are predominant in the highly and somewhat vulnerable categories.

Table C2: Creation of cyclone vulnerability indices (adapted from NATCOM, 2004)

Index	Indicators used
Hazard index	Frequency of events (by cyclone type, i.e., depressions, storms and severe storms) in a particular district.
Exposure[20] index Determined by normalizing the number of events in a district by the coastline length of the districts;	Distribution of housing stock across the different categories of houses (based on the wall material) and the knowledge of susceptibility of a particular category of house to storm and flood damage); and the density of population.
Impact index Determined by normalizing the number of events in a district by area of that coastal district.	Data on human mortality, livestock mortality, damage to houses, damage to crop area, loss in monetary terms and population affected.

Table C3: Classification of Indian coastal districts on the basis of vulnerability to cyclones[21] (NATCOM, 2004)

Vulnerability	Districts
Highly vulnerable	Jagatsinghpur and Kendrapara in Orissa; Nellore in Andhra Pradesh; Nagapattinam in Tamil Nadu; Junagadh and Porbandar in Gujarat
Somewhat vulnerable	North 24 Parganas, and South 24 Parganas in West Bengal; Baleshwar and Bhadrak in Orissa; Srikakulam, East Godavari, Guntur, and Krishna in Andhra Pradesh; Thiruvallur, Cuddalore, and Ramnathpuram in Tamil Nadu.

C2.4 Human health

The impacts of climate change on health (Table C4) could be direct via increasing mortality from extreme temperature and weather events such as transmission of vector-borne diseases, or/ and indirect via changes in ecological and socio- economic systems (NATCOM, 2004).

A study by the National Physical Laboratory (NPL), Delhi reviewed the current malaria scenario in India (with the base year 2000) along with climatic variables such as temperature, precipitation and humidity (using outputs from the HadRM2 model). The study also projected malarial prevalence in India under projected climate change scenario for 2050s and predicted an increase in the transmission windows (TWs) for malaria (Figure C6).

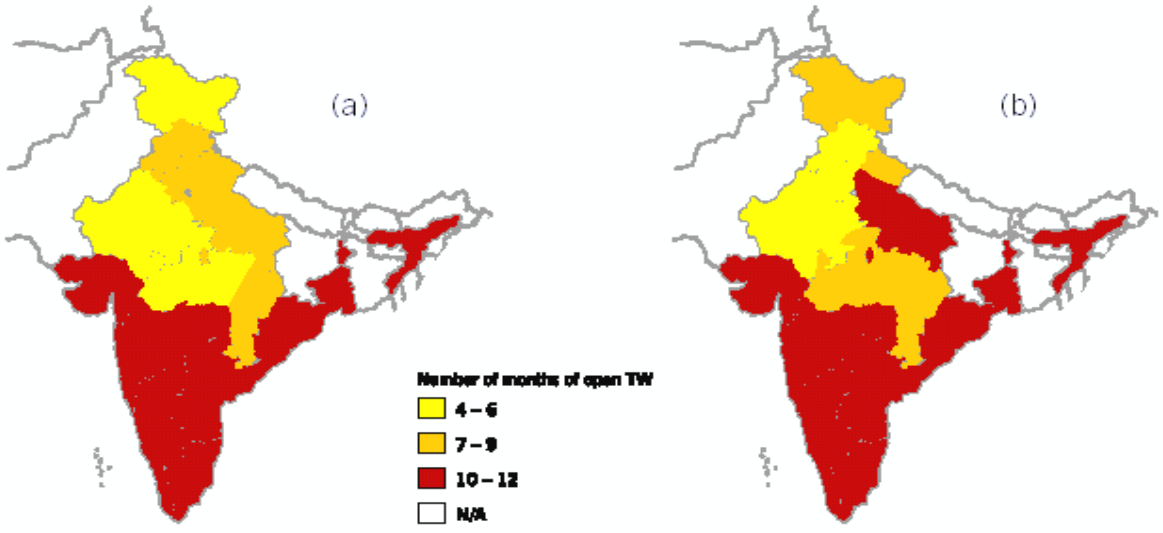
[20] The term "Exposure" in the NATCOM study refers to the extent to which the human systems are unprotected from climate-related natural hazards. Data for the years 1971, 1981, 1991 and 2001 have been used.

[21] The indices have been developed for the districts, rather than a continuous and a uniform metric like per 100 km of coastline length. Thus, there are differences in rankings for districts on the basis of different indices.

Table C4: Impact of climate change on human health (Source: NATCOM, 2004)

Health concern	Vulnerability due to climate change
Temperature related morbidity	▪ Heat and cold related illness ▪ Cardio vascular illnesses
Vector borne diseases	▪ Changed patterns of diseases by region and by climate parameter ▪ Malaria, Filaria, Kala-azar, Japanese Encephalitis, and Dengue caused by bacteria, viruses and other pathogens carried by mosquitoes, ticks, and other vectors
Health effects of extreme weather	▪ Diarrhoea, Cholera and intoxication caused by biological and chemical contaminants in water. ▪ Damaged public health infrastructure due to cyclones / floods ▪ Injuries and illness ▪ Social and mental health stress due to disasters and displacement
Health effects due to food insecurity	▪ Malnutrition, hunger, particularly in children

Figure C6: Changes in transmission window of malaria, from the base case to the projected climate scenario case (NATCOM, 2004)



C3. Conclusion

Given the vulnerability of different sectors and regions in India to climatic variability and change, it can be concluded that there is a further need for targeted studies. There are few sectoral studies exploring the impact of climate change using scenario-based modelling approaches, however very few studies combine climate model outputs with the concept of vulnerability and adaptive capacity. There is hence a need for an integrated approach for a holistic view on vulnerability analysis and identification of suitable strategies for intervention to strengthen adaptation. Furthermore, given the varying scales of vulnerability there is a need to draw linkages between local and national-scale programmes for an integrated case- study based research. This is also essential in order to identify necessary adaptation interventions at all scales and foster efforts that link to the country's overall developmental aspirations and poverty alleviation goals.

C4. Part C References

The principle studies summarised here include:

i. The Initial National Communication (NATCOM, 2004) of India to the United Nations Framework Convention on Climate Change (UNFCCC) in which a national scale climate change impact assessment was undertaken.

ii. A study conducted by TERI, with funding from World Bank (2005), with the objective of addressing vulnerability to climate variability and change through assessment of adaptation issues and options.

iii. A collaborative three year study (2001–2004) by TERI (The Energy and Resources Institute), India; CICERO (Centre for International Climate and Environmental Research – Oslo), Norway; and IISD (International Institute for Sustainable Development) funded by the Government of Canada through the Canadian International Development Agency (CIDA) and the Ministry of Foreign Affairs, Norway. This study analysed the combined effect of both climate change and globalisation on Indian agriculture.

iv. A joint research venture spanning three years was initiated in 2001 by the Department for Environment, Food and Rural Affairs (DEFRA) and the Ministry of Environment and Forests (MoEF) of India in order to assess the current expertise and undertake further capacity building on the impact assessment in various climate- sensitive sectors in India.

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Noronha, L., Choudri, B. S., and Nairy, K. S. 2003. *Relative vulnerability of districts to a potential sea-level rise along the coastline of India*. In Environmental threats, vulnerability and adaptation-case studies from India. TERI, India

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Part D: Economic Impacts of Climate Variability and Change

D1. Economic burden of disaster events in India

India, the second largest inhabited nation in the world, has a history marked with extensive damage from natural disasters. That vulnerability to disaster events is heightened by its low lying coastline that extends 7,500 kilometres, a growing population estimated at 1.1 billion people, and an economy historically linked closely to its natural resource base.

Table 1: Major Categories of Natural Disasters in India 1900-2007

Category	No of Events	People Killed	People Affected (Million)	Damage (US$M)
Drought	11	4,250,300	711.84	942
Extreme Temperatures	41	13,148	--	544
Flood	198	55,243	747.93	21,355
Wind Storm	141	163,318	87.67	12,719
Wave/Surge	2	16,789	0.65	1,022
Earthquake	25	61,705	27.26	4,147

Source: The OFDA/CRED International Disaster Database

Climatic changes further raise the country's exposure to natural disasters and threaten considerable economic and financial risk. The IPCC report[i] projects sectors such as food and fibre and human health to be highly vulnerable to the impacts of climate changes in India and other countries in South Asia.

This paper studies the impact of climatic change as manifested in extreme events such as flooding, cyclones, drought and heat- waves.

Table 2: Top Ten Natural Disasters in India

By People Affected

DISASTER	DATE	PEOPLE AFFECTED
Drought	May 1987	300,000,000
Drought	1972	200,000,000
Flood	July 1993	128,000,000
Drought	June 1982	100,000,000
Drought	1965	100,000,000
Flood	June 2002	42,000,000
Flood	June 1975	34,000,000
Flood	Aug 1982	33,500,000
Flood	June 2004	33,000,000
Flood	Sep 1995	32,704,000

By Total Damages

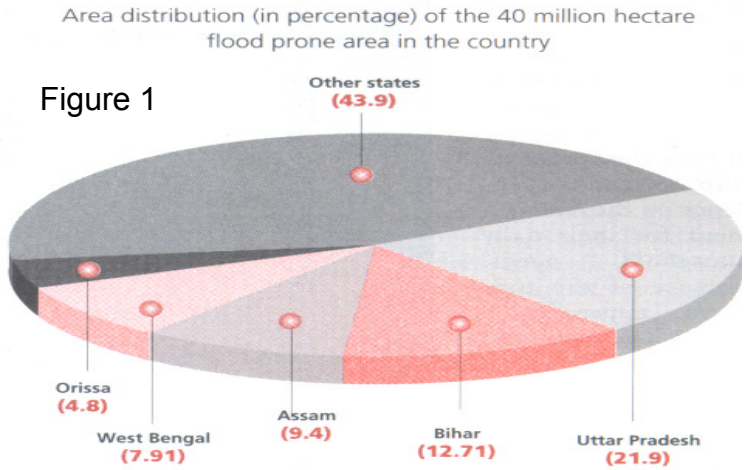
DISASTER	DATE	DAMAGE (US$ 000's)
Flood	July 2006	3,390,000
Flood	July 2005	3,330,000
Earthquake	Jan 2001	2,623,000
Wind Storm	Oct 1999	2,500,000
Flood	June 2004	2,500,000
Flood	June 2005	2,300,000
Wind Storm	Aug 1990	2,200,000
Wind Storm	Nov 1996	1,500,000
Wind Storm	May 1990	1,300,000
Wave/Surge	Dec 2004	1,022,800

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

Estimates of the magnitude and scope of the challenge vary due to differences in frameworks, assumptions and metrics, which complicate comparison. Nevertheless, this report summarises estimates, based on secondary research, of the current and future economic costs of climate impacts. Much of this data necessarily focuses on extreme events.

According to the OFDA/CRED disasters database[ii], over 1.5 billion people have been affected by major disaster events since 1900, more than 4.5 million human lives have been lost, and damage in excess of $40 billion suffered over this period. The National Institute of Disaster Management (NIDM), GOI's apex body dealing with disaster control, reports an average disaster leads to an annual loss of 4,350 human lives, 1.42 million hectare of crop loss, and 2.36 million damaged houses[iii].

Figure 1



While the NIDM review of disasters includes both *events of nature and man-made events* that lead to disruption in normal life, a study of data collected by different government and non-governmental sources shows that climate related categories such as floods, droughts, windstorms, and extreme temperatures account for majority of the impact.

Floods cause the bulk of the damage to property and infrastructure, with OFDA/CRED placing estimates in excess of US$ 21 billion over the last century or so.

Of India's annual rainfall of 400 million-hectare meters, 75% is received in just four months.[iv]

Nearly 40 million hectares of land is vulnerable to floods, with about eight million hectares flooded annually. In the last four decades, the country has lost about INR 9,720 million in damages to crops, public utilities and houses.[v]

In more recent times, during the period 1982–2002 *(see chart)*, floods affected nearly 41 million people annually on average and claimed on average 1,813 human lives each year.

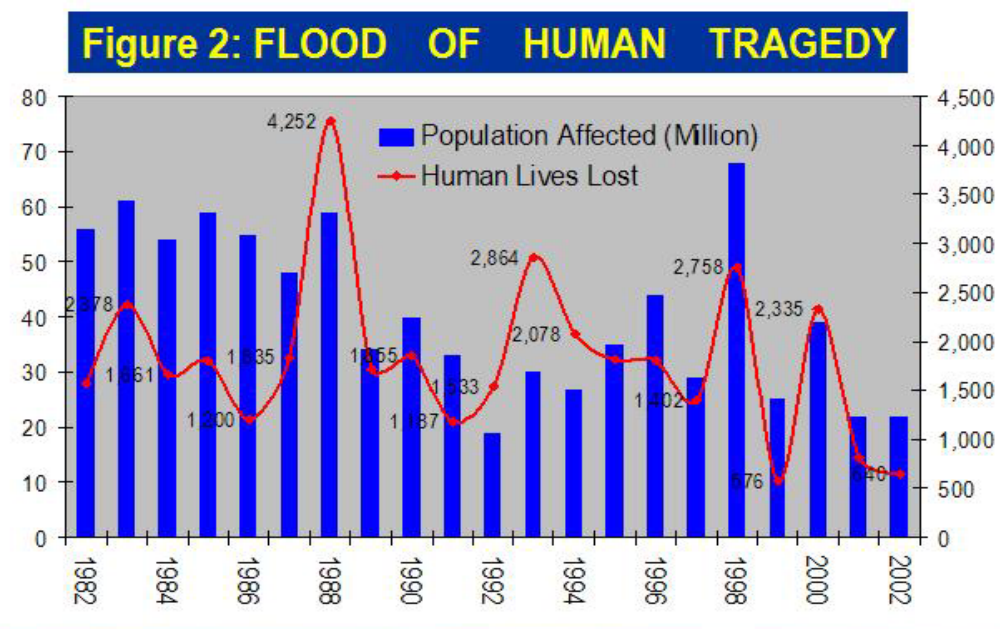
Of all Indian states (Figure 1), five, namely Uttar Pradesh, Bihar, Assam, West Bengal, and Orissa collectively comprise majority (55.1%) of the flood prone area in the country. All other states account for the remaining 43.9% of the 40 million hectare that is identified as vulnerable to floods. In Uttar Pradesh, the lead state, flooding is the main hazard in the Ganges River basin. The Ganges has a consistent history with major flooding in 1954, 1962, 1966, 1972, 1974, 1978, 1983, 1986, 1988, 1996, 1998, and 2000.

Among all natural hazard-related disasters, droughts have been the single largest claimant of human lives in India. NIDM data suggests that of the net area sown in the country, 68% is prone to drought. 33% is chronically drought-prone, receiving rainfall of less than 750 mm per annum while 35% receives rainfall between 750–1125 mm per annum.[vi]

Researchers have also studied the effects of climate change manifested in sea-level shifts. A 1994 study[vii] showed that in the absence of any protection, a one-meter sea level rise would

affect an area of 5,763 sq km and put 7.1 million people at risk. 83% of all damages will be because of land loss.

TERI, in a report[viii] prepared for the Ford Foundation, used a weighted index method to develop a district-level ranking of vulnerability, to a one-meter sea level rise. The estimated economic costs of this rise ranged from INR 2,287 billion in the case of Mumbai to INR 3.6 billion in the case of Balasore district of Orissa.

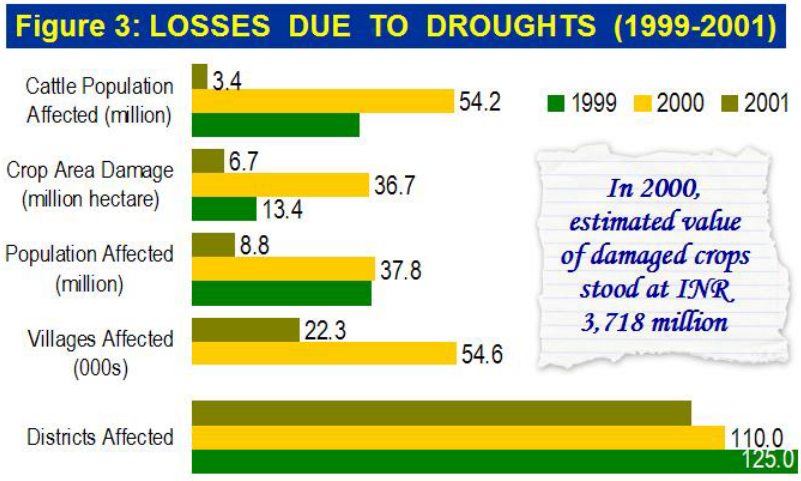


The government budget allocation and response to disasters parallels the rise in economic damage from disasters and provides testimony to the gravity of the situation. Government agencies rely on federal relief funds and the states also allocate resources depending on their exposure and vulnerability. The Calamity Relief Fund (CRF) has almost doubled in the last decade: compared to INR 63 billion (US$1.5 billion at Sep 2007 exchange rates) for 1995–2000, the allocation rose to INR 110 billion for 2000–05 (US$2.71 billion at Sep 2007 exchange rates).

The government's perspective for the next five year planning cycle points to the serious attention being paid to disaster management. Unlike in the past, the GOI Planning Commission's Report of *The Working Group On Disaster Management* for the XI Five Year Plan (2007–2012) indicates that the planners favour the suggestion that 0.5% of the total plan allocation of each Ministry/Department be earmarked for National Disaster Mitigation Fund. Considering that the Tenth Plan had a total allocation of INR 4,874 billion under the central sector, this would equate to a potential INR 24.37 billion for National Disaster Mitigation Fund for a five-year period, a huge increase over previous budgets.

D2. Sectoral economic impacts in India

D2.1 Impacts on agriculture



Agriculture and allied activities constitute the largest component of India's economy, contributing nearly 27% of the total GDP in the 1990s. More recently, due to the faster growth in other sectors of the economy, especially services, the contribution of agriculture has steadily declined to 18.6% by 2005. Nevertheless, agriculture remains the mainstay for the majority of rural and semi-urban population in India.

Despite all the advances in farming technologies, the performance of the agriculture sector is still highly dependent on the climate, given that 62% of the cropped area is still dependent on rainfall for primary irrigation. Any type of climatic shock or stress such as a flood, a drought, or a cyclone can adversely impact the agriculture production. For example, the super cyclone in Orissa in 1999 killed nearly 15,000 people and destroyed more than one million hectares of crops. The damage to homes, buildings, property, crops and infrastructure was estimated at INR 100 billion.[ix] Besides the direct and immediate damage, saline incursion of agricultural fields would affect yield and crop patterns in the future years.

Data from GOI's National Disaster Management Division (Figure 3) highlights the adverse impact of drought on the country. In 2000 alone, drought conditions affected 37.8 million people, 54.2 million cattle, damaged 36.7 million hectare of crop area and the estimated value of damaged crops stood at INR 3,718 million.[x]

More recently, the drought in 2002 exposed India's reliance on rain-fed agriculture. The steep fall in food grain production was unprecedented, to the extent of 29 million tonnes; cropped area left unsown during Kharif season, due to drought, was around 18.53 million hectares and 47 million hectares of the cropped area was damaged. The fall in Rabi output was around 8%, which is one of the largest reductions during Rabi in comparison to major earlier drought years. Around 150 million cattle were affected due to lack of fodder and water. The total loss in rural employment due to the shrinkage of agricultural operations was estimated at 1,250 million man-days. The GDP in agriculture shrank by 3.1% and the loss in agriculture income was estimated to be around INR 390 billion.[xi]

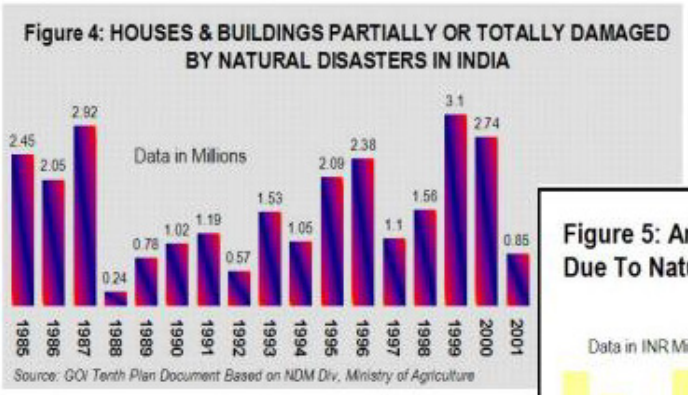
Extract from Document Prepared by Working Group on Risk Management in Agriculture for XI Five Year Plan (2007-2012)

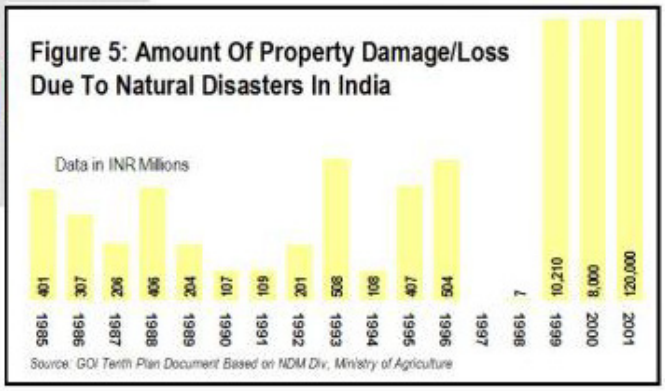
…From an economic perspective, 'agricultural drought' may be viewed as an exogenous, supply-side shock, which is widely recognized as resulting directly in sharp reductions in agricultural production and employment apart from other losses associated with declines in rural income. In addition, meterological drought, may result in hydrological conditions that have a direct impact on non-agricultural production, including hydro-electric power generation and drinking water supply….

A World Bank study[xii] of sample villages of Rajasthan shows that during drought years, the level of debt rose to much higher levels as a percentage of annual income for lower income groups (71% of maximum annual income) than for the wealthy (20–35%). The study also points out that drought impacts on human and livestock population are present in most years even when there is no official drought.

D2.2 Impacts on infrastructure

The pressures of rising population, increasing urbanization and high cost of real estate in major metropolitan areas have combined to force people to live on marginal lands where they are at greater risk to disasters and their consequential damage. In addition to large-scale displacement and loss of life, these events also result in the loss of property worth millions of dollars annually. The loss to property is generally high partly because many of the buildings are either not engineered or partially engineered to withstand climatic catastrophes.





A 2003 World Bank study[xiii] reported that estimated losses to property and infrastructure from climate and seismic related disaster events over the last 35 years amounted to US$30 billion, but actual losses would have been substantially more.

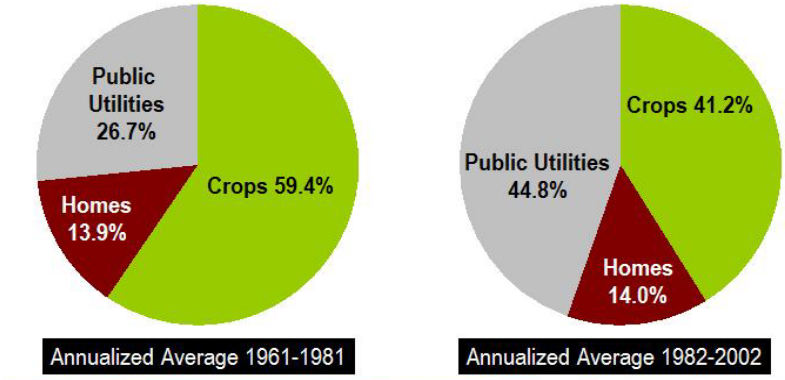
The study also pointed out that the loss of infrastructure has a more far-reaching impact on the impoverished sections of the society. As the poor are dependent on agriculture/horticulture sectors, delays in rebuilding and restoration of rural infrastructure such as roads, water supply and electricity directly affects those people, who often have no or limited other source of income and minimal assets and savings on which to fall back.

Our analysis of data[xiv] pertaining to flood damage shows significant shifts that are consistent with the phase of India's economic and industrial development. During 1961–1981, the agricultural sector bore the brunt of the damage, with crops accounting for 59.4% of the damage by value. That was congruent with India's focus on agriculture during that time period and the central role in played the economy then. In the decade of the eighties and nineties, the Indian economic base shifted appreciably towards manufacturing and services and the country simultaneously made large expenditures in building public infrastructure. Data from flood damage for the period 1982–2002 (Figure 6) corroborates this shift with crops declining to 41.2% of the damage and public utilities accounting for 44.8% of the value damage from floods and heavy rains.

Table 3: Damage Due to Floods/Heavy Rains (INR Tens Millions)
Source: NIDM Data

Year	Crop Value	House Value	Damage Public Utilities	Year	Crop Value	House Value	Damage Public Utilities
1961	24.0	0.9	6.4	1981	524.0	159.6	512.3
1962	83.1	10.6	1.0	1982	589.0	383.8	671.6
1963	30.1	3.7	2.7	1983	1,285.8	32.3	873.4
1964	56.8	4.6	5.1	1984	906.0	181.3	818.1
1965	5.8	0.19	1.0	1985	1,425.0	583.8	2,050.0
1966	80.1	2.5	5.7	1986	1,231.5	534.4	1,982.0
1967	133.3	14.2	7.8	1987	1,154.6	464.4	950.5
1968	144.6	41.1	25.3	1988	2,510.9	741.6	1,377.8
1969	281.9	54.4	68.1	1989	956.7	149.8	1,298.7
1970	162.7	48.6	76.4	1990	695.6	213.7	455.2
1971	423.1	80.2	129.1	1991	579.0	180.4	728.8
1972	98.5	12.4	47.1	1992	1,027.5	306.2	2,010.6
1973	428.0	52.4	88.4	1993	1,308.6	528.3	1,445.5
1974	411.6	72.4	84.9	1994	888.6	165.2	740.7
1975	271.4	34.0	166.0	1995	1,714.7	1,307.8	679.6
1976	595.0	92.1	201.4	1996	1,124.4	176.5	861.3
1977	720.6	152.2	328.9	1997	692.7	152.5	1,985.9
1978	911.0	167.5	376.1	1998	2,372.5	302.0	3,171.4
1979	169.9	210.6	233.6	1999	1,663.2	174.4	268.6
1980	366.3	170.8	303.3	2000	446.6	301.6	911.7

Figure 6: VALUE DAMAGE DUE TO FLOODS/HEAVY RAINS



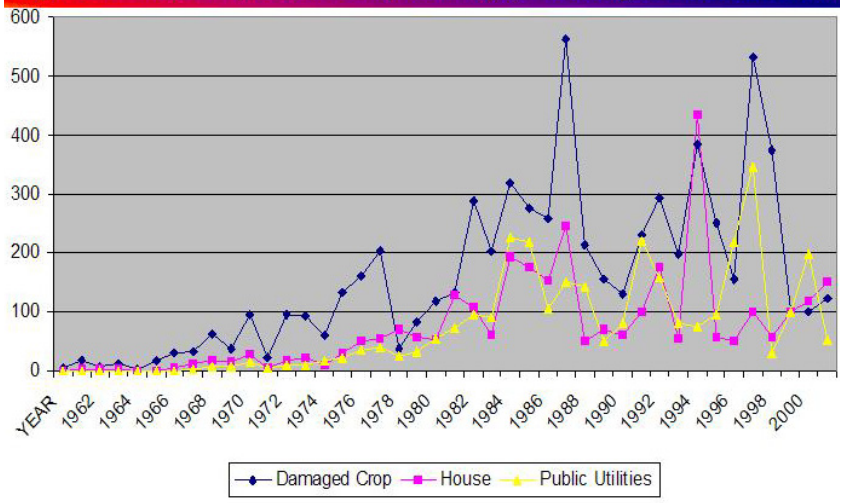
Analysis of flood damage data (Figure 7) from 1961 to 2000 also shows that the economic losses have increased over the years when prices are held constant at 2000; this increase is most distinctly seen for crop damage, although losses have a wide range between different categories.

Close to 10% of the flood prone area (3.58 million hectare) lies in the northeast region alone. Maximum flood related damages that have occurred in various states of this region are Assam INR 7,530 million (2000), Arunachal Pradesh INR 5,055 million (2004), Manipur INR 718 million (1986), Tripura INR 800 million (1993), Meghalaya INR 210 million (2004), Nagaland INR 195 million (1993), and Mizoram INR 193 million (1997).[xv]

Any large disaster causes direct and collateral damage that is hard to numerically assess accurately. For instance, the July 2004 floods in India's commercial capital, Mumbai, not only brought life to a standstill but also resulted in estimated losses of over INR 90 billion. Losses extended to motor vehicles, homes, offices, and inventories in warehouses and stores. The state

power system suffered massive losses: 5,667 of its transformers were affected, 12 high-tension towers fell and 14 small distribution stations were flooded. Mumbai's industry association, The Indian Merchants Chamber, estimated the losses at INR 50 billion.

Figure 7: Flood Impact On Crop Damage, Housing & Public Utilities



The super-cyclone that hit Orissa on October 29, 1999, was one of the most destructive climate-related disasters in India with wind speeds of nearly 300 km/hour and incessant rains that lasted for about 48 hours. Over 15 million people in 12 state districts were affected. Over 15,000 human fatalities were reported. Infrastructure was badly hit: about 1,650,086 houses were damaged from the cyclone and ensuing flood; around 14,901 primary schools, 3,425 high school buildings and 66 colleges were damaged; communication systems was severely affected as 12,000 km of roads and 1,447 bridges were damaged; electricity supply to most villages was disrupted and the total estimated damages were INR 39,680 million.[xvi]

Table 4: Average Annual Loss Summary (US$ Million)

State	Cyclone: Housing	Flood: Housing	Cyclone: Public Infrastructure	Flood: Public Infrastructure
Andhra Pradesh	**44.1**	**16.2**	**17.1**	**5.5**
Gujarat	**21.9**	**16.1**	**4.1**	**5.9**
Orissa	**22.6**	**4.0**	**12.6**	**4.0**

Table 5: Average Annual Loss Due To Extreme Events

STATE	LOSS (US$M)	% OF STATE GDP
ANDHRA PRADESH	82.9	3.3
GUJARAT	64.9	4.4
MAHARASHTRA	2.8	0.1
ORISSA	43.2	6.5

Source: World Bank August 2003

The effect of disasters on individual states varies notably. Other studies too have investigated in detail the impact on infrastructure. A report by the World Bank[xvii] focussing on states vulnerable to natural disaster shows (Table 4) that infrastructure losses from floods across four different states highlights that losses are highest to the housing sector followed by roads and bridges, education and medical institutions. This trend emerged consistently across the four states, except in Orissa (Table 5). In Orissa, its lower density of population and a lower level of economic development can explain the low values of housing and infrastructure exposure, compared to other states. Maharashtra had high damage values for all asset classes particularly housing and infrastructure as it is the commercial capital of India with very high per capita income.

Table 6: Major Cyclones With Landfall on the Indian Coast

When	Location	Human Casualty Estimated	Damage (US$M)
November 1977	Andhra Coast	10,000	77.8
May 1979	Andhra Coast	700	37.8
June 1982	Orissa Coast	243	111.1
November 1984	Andhra Coast	604	88.9
May 1990	Andhra Coast	967	499.6
October 1999	Orissa Coast	15,000	4,444

Source: Performance of Built Environment In the October 1999 Orissa Super Cyclone by Simon Francis, Prasad VSK Gunturi, Munish Arora, March 2001

Orissa, partly due to its coastal geography and relatively lower economic output, suffers annual losses that approximate 6.5% of the state's total GDP. Other states show much less impact on their GDP. Experts estimate that overall, the country bears the brunt by incurring an overall 2% drop in GDP due to damage from disaster events.[xviii]

The top ten CRF beneficiary states during 2000–2005 also rate high on their vulnerability to climatic risk. Maharashtra, Andhra Pradesh, Rajasthan and Gujarat count as regions with a high likelihood of drought. As shown in the chart, cyclones have historically targeted Orissa and Andhra Pradesh with parts of West Bengal also bearing the brunt. In recent decades, maximum number of heat waves has been over Bihar, followed by West Bengal. Although floods are generally known to occur in major rivers of the north and northeastern parts in India, northern Andhra Pradesh, West Bengal and Orissa are identified among high flood-prone areas.

Impact of cyclones has been acutely felt in the states of Andhra Pradesh, Orissa and Gujarat. As the chart shows, private housing accounted for very large losses with cyclones causing more damage than floods. Similarly losses to public infrastructure were brought about more by cyclones than by floods.[xix] Cyclone related damages (Table 6) are influenced largely by wind speed at landfall. As examples, the 1999 Orissa cyclone incurred US$ 4,444 million in losses when hit with 259 kmph wind and Andhra coast in 1984 was hit by cyclone of 112 kmph bringing losses of US4 88.9 million.[xx] Andhra Pradesh, Gujarat, and Orissa have historically had a high probability of natural disaster and in future are predicted to show high impact of climatic changes.

D3. Economic impacts due to climatic change induced impacts

It is important to recognize here that in India, a developing nation with high exposure to natural hazards, basic life essentials such as *food, shelter and clothing* remain major priorities even today for governments and citizens alike. Against such a backdrop, much of the governmental data collection, monitoring, and planning effort is targeted at preventing, preparing for and coping with disasters, rather than economic quantifications of the damage attributed purely to climatic changes.

Any study to measure the effects of climatic change in India can either rely on qualitative, anecdotal trends or use surrogate data that at best points to the scale and magnitude of the impact. The use of disaster data is based on the indirect linkage that shifts in climatic factors such as temperature and precipitation, influence and eventually manifest in events such as droughts, floods, storms, and cyclones. However, slow onset changes and other aspects of the economic impacts on human productivity, energy consumption, or transportation shifts are not assessed in this report.

Agriculture

Agricultural productivity is directly impacted by changes in temperature, precipitation, and carbon dioxide concentrations. Changes in soil moisture and infestations by pests and disease also indirectly influence crop yields and efficiency. Although the effect of climatic change on agriculture output cannot always be explained in monetary terms, the economic impact is just as much measured by reduction in crop yields or volumes of production and any shifts in supply curves.

Many scientists have analysed the effect of climatic changes on the agriculture sector in India. The Stern Review on the Economics of Climate Change[xxi] reported some major qualitative and quantitative findings that include:

- Kumar and Parikh (1998) studied cross-sectional data to estimate the relationship between farm level net revenue and climate variables. Their research showed that economic impacts would be significant even after accounting for farm level adaptation. The loss in farm level net revenue is estimated to range between 7% for a temperature rise of 2°C with 7% precipitation, and 25% for a rise of 3.5°C with 15% precipitation. The researchers also projected a 30–35% reduction in rice yields for India given a temperature increase of 2°C–3.5°C or losses in the range of US$3–4 billion.
- Sinha and Swaminathan (1991) showed that an increase of 2ºC in mean temperature could decrease rice yields by about 0.75 ton/hectare in the high yield areas and about 0.06 ton/hectare in the low yield coastal regions. On the other hand, a 0.5ºC increase in winter temperature would reduce wheat yield by 0.45 ton/hectare, which translates to a 10% reduction in high yield states of Punjab, Haryana and Uttar Pradesh.
- Lal et al (1999) report that if the minimum and maximum temperatures rise by 3ºC and 3.5ºC respectively, then soya bean yields will decrease by 5% compared to 1998.
- In a 2005 article,[xxii] Mendelsohn tested different climate scenarios for 2100 from the Atmospheric Oceanic General Circulation Models (AOGCM)—the CCSR model and the CCC model. With variations in temperature and precipitation, the models captured future climate scenarios. The study then determined the impact on agricultural GDP in 2100 for different countries. In the case of India, the researchers estimated a loss range of $1.1–86.7 billion (in the case of CCC where the temperature scenario was 28.1ºC and precipitation of 13.6 mm/month). In the CCSR model (temperature scenario was 27ºC and precipitation of 16.4 mm/month), the loss range was $1.5–47.8 billion.

A TERI study[xxiii] of villages in climatically vulnerable states highlights the risk exposure of small land category farmers during adversity periods of flood and drought. Data shows that even in normal years, the per capita monthly incomes of small land category farmers are closer to the poverty line. In Maharashtra and Andhra Pradesh, for both small-farm and mid-size farm holders, the incomes correspond to poverty status during conditions of drought and floods. In landless category however, incomes are found close to the poverty line in all states during a normal year, with fall observed during an impact year. Though the comparative drop in latter categories is insignificant, their sustenance even in a normal year is at stake.

Overall, the drop in income is large and widespread among the mid-sized farm holders, which constitute 40–50% of the households. Programs designed to strengthen the ability of these households to obtain credit or access agricultural technology and infrastructure can possibly boost the economic situation and bring much needed buoyancy during adverse events.

This study bears out the ability of large-land category farmers to cope effectively due to availability of safety nets such as insurance, access to credit/loans and infrastructure facilities like irrigation. On the other hand, small-land and land-less categories need government and non-governmental support to improve their economic status.

In summary, climatic changes in temperature and precipitation result in losses in agriculture yields and revenues. Some of the adaptation options to offset vulnerabilities of the agriculture sector include the following:

- Development of hardy variety of seeds and crops;
- Promotion of horticultural crops;
- Development of saline water resistant crops; and
- Grain storage technologies and structures

Health

Climate changes also impact the spread and onset of diseases. For example, health scientists have shown that an increase in the global mean temperature of 1–2 degrees would enable mosquitoes to extend their range to new geographical areas leading to increase in malaria and other diseases.

Recent research has projected that the number of people in developing countries at risk of malaria infection will increase by 5–15% because of climate change. Areas that are currently free of malaria, like Himachal Pradesh where altitude is above 1800 meters, may become malaria prone under the changed climate conditions in the 2050s. In a counter-effect, eastern states like West Bengal and Orissa where average temperature is around 32–34°C may experience reduction in transmission windows by few months, due to increase in the upper limits of temperature.[xxiv]

Floods and rains bring a surge in water borne diseases like typhoid and hepatitis. The Mumbai floods of 2005 damaged 437 primary health centres, rural hospitals and residential premises of health personnel, besides spreading *leptospirosis,* a disease contracted on wading through flood waters infected with animal waste.[xxv]

The 1994 outbreak of plague in Surat, Gujarat, in the wake of floods, is yet another example of the impact of disaster events on the health of local population. Surat, an industrial centre for fine gold work and diamond cutting, saw flood waters from the river Tapi dislodge rats from their burrows into human habitats. The city's medical and public health functionaries were taken by surprise and eventually arrested the problem but not before the disease had infected 614 people and killed 46. The plague also adversely affected tourism, business investments and created a poor public image for the city. Financially, economic studies estimated the toll at over US$1.5 billion.[xxvi]

A USAID study[xxvii] in 2004 reported that the average food consumption per woman per day goes down from 1,000 calories to 300 calories during disaster time. Inadequate food availability, increased vulnerability to disease, coupled with increased physical activity during post-disaster periods, leads to increasing severity in health problems.

Some of the adaptation options that alleviate the impact of climatic changes on human health include:

- Stock pile (food/water/medicine) for contingencies and epidemics;
- Strengthen and build preventive health care systems to control disease; and
- Strengthen social safety net mechanisms such as health insurance.

D4. Conclusion

Quantifying the monetary impact of climatic changes in India is limited by lack of resources and standardised metrics. Moreover, individual states show huge variations in climate, topography, infrastructure and economic development, all of which combine to make it necessary to customize the research and metrics at the local level. Therefore, the magnitude of the economic impact needs to be estimated and understood in the context of available qualitative and quantitative information.

India is frequently hit by natural disasters such as the drought, wind surge and floods, which serve as surrogates to assess the economic impact of climatic shifts. Overall the disaster impact on GDP for the country is estimated to be around 2%, its impact varies among states based on their economic development. The economic cost of disasters is estimated based on direct losses and the impact on human lives is difficult to assess. Climatic changes based on IPCC predictions for 2100, are anticipated to be around 9% of India's GDP.

Damage from floods is wide-ranging but shows a distinct upward trend. Frequency of droughts has risen in the past decades and droughts can lead to as much as a 3% drop in agriculture GDP due to declines in crop production and land often being left unsown.

Governments and private sector, along with international, national and regional institutions must work in harmony to build programs that focus on research needed to accurately assess the costs of natural disasters. There is a need for improved data collection and economic modelling at the local level (district and state levels) to identify the impact of climatic changes. Such a multi-sectoral, inter-institutional, and multi-disciplinary approach can effectively study and tackle the implications of climatic change in India.

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