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# Facing the Facts: Ganga Basin's Vulnerability to Climate Change



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A summary version of this report – Vulnerability Assessment of People, Livelihoods and Ecosystem in the Ganga Basin) in English and Hindi is also available for download from WWF-India's website – [www.wwfindia.org](http://www.wwfindia.org)

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**FACING THE FACTS:  
GANGA BASIN'S  
VULNERABILITY TO  
CLIMATE CHANGE**



# FOREWORD

Addressing Climate Change poses formidable challenges for governments and communities worldwide. Responses to these challenges are, however, limited by lack of information and understanding of the impacts of climate change on people and ecosystems. Vulnerability assessments of communities which are being impacted or likely to be impacted most by climate change can help fill this gap and provide information for the design of appropriate strategies and policies.

WWF-India, as part of its Living Ganga Programme, studied the climate vulnerability of people living in the Ganga basin. Supported by HSBC, this study covered the states of Uttarakhand and Uttar Pradesh and identified the vulnerability of key sectors by assessing the exposure, sensitivity and adaptive capacity of an ecosystem to changing climate scenarios.

This report has helped us design adaptation strategies for most vulnerable communities and regions in the Central Ganges river basin. The adaptation pilots address issues related to water use management, irrigation efficiency, wetland management and biodiversity and sustainable agriculture. Even while adaptation pilots will take a while to show results, initial output from the field has been extremely encouraging, with communities sharing successes about productivity increase and soil health improvement.

We hope that these encouraging results serve as a precursor for main streaming climate change adaptation in policy initiatives of the government as they work to develop and implement state-level Climate Change Action Plans. A Vulnerability Assessment like the one conducted here is an important first step in identifying the areas and actions needed to tackle climate change impacts.

**Ravi Singh**  
WWF-India



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# ACRONYMS

<b>BPL</b>	: Below Poverty Line
<b>CGWB</b>	: Central Ground Water Board
<b>GHG</b>	: Greenhouse Gas
<b>HDI</b>	: Human Development Index
<b>IARI</b>	: Indian Agricultural Research Institute
<b>IMD</b>	: India Meteorological Department
<b>INCCA</b>	: Indian Network of Climate Change Assessment
<b>IPCC</b>	: Intergovernmental Panel on Climate Change
<b>LVI</b>	: Livelihoods Vulnerability Index
<b>MoEF</b>	: Ministry of Environment and Forests
<b>NATCOM</b>	: India's National Communication to the UNFCCC
<b>VCI</b>	: Vulnerability and Capacity Index
<b>PPM</b>	: Parts Per Million

## INTRODUCTION

India and its development challenges are significantly steep with a large fraction of population still tangled in the web of poverty. India's model of planned development with weak implementation of regulations over the last six decades has resulted in a high level of stress on natural resources, yet India faces problems of inequity and inequitable access to resources by the vast majority of its people. India's development problems get further accentuated with rapid environmental degradation and increasing evidence of human induced climate change impacts. As the science around climate change becomes clearer, it is evident that India is already experiencing its impacts. The climatic disruptions of the nature of uneven precipitation and higher concentration of precipitation in fewer days along with variability in temperature, especially with rise in winter temperatures, are already being felt in different parts of India. There is an urgent need for assessing vulnerability and developing adaptation strategies.

The scientific consensus, as represented by the fourth assessment report of the Intergovernmental Panel on Climate Change (IPCC), is unequivocal in pinpointing that the wide range of human activity is resulting in anthropogenic global warming (IPCC, 2007). Consequences of global climate disruptions on ecosystems, basic necessities and productive activities of humans are numerous and could be of varying degrees of severity. An average 4°-

5°C rise in global mean annual air temperature will severely stress human society and is highly likely to be beyond the reach of any societal adaptation. The scientific consensus is that the stabilization of Greenhouse Gas (GHG) concentrations at 450 ppm (parts per million) provides at least a 50% probability that the temperature rise could be limited to no more than a 2°C by end of this century. Most experts believe that this level of warming would put the effects of global warming within the reach of adaptation though still not without significant costs. Adaptation to at least a 2°C rise in global temperatures therefore seems to be inescapable in the years to come.

According to the observations by National Communications (NATCOM, 2004), a rise in temperature has already been observed in the Indian subcontinent. Projections show that the maximum temperatures are expected to rise by the 2050s by 2°C–4°C over South India. It is also projected that temperature is likely to increase by more than 4°C over Northern India (NATCOM, 2004). Recent report by Indian Network for Climate Change Assessment (INCCA) indicates accelerated warming trends for the period 1971–2007 mainly attributed to the increase in average air temperatures in winter and post-monsoon seasons. Mean temperature has increased by 0.2°C per decade for this period, with much steeper increase in minimum temperature than maximum temperature (GoI, 2010).

## 1.1 CLIMATE CHANGE IMPACTS: INDIA

Scientific assessments reveal that during the period 1901-2007, India has witnessed a warming trend of 0.51°C (Kothwale et. al, 2010). For a country which largely depends on monsoon patterns and winter months to boost its agricultural growth, any shift in the climatic conditions will have an adverse impact on not only India's economy but also its natural resources. An accelerated warming in the recent decade (1998-2007) has slowly but surely added to a perceptible shift in the growth patterns of crops and livelihoods (GoI, 2010).

Taking these factors into account, India's first NATCOM provides a broad overview of the past and the expected climate change impacts on the key sectors in India (Annexure I). Rapid development and urbanization have already posed major threats to the natural resources and the ecosystem in many parts of the country. Climate change impacts will further put stress on the resilience of ecosystems. Forests appear highly susceptible to the impacts of climate change. Different species may suffer varying degrees of stress, leading to changes in the composition of forests. Intrusion of species from other regions to changing climatic conditions may pose a further source of stress on forest ecosystems. Preliminary assessments based on model projections show shifts in forest boundary, changes in species-assemblage or forest types, changes in net primary productivity, possible forest die-back in the transient phase, and potential loss or change in biodiversity.

The agriculture sector which is vital for India's economy is projected to be significantly affected by climate change. The

impact of climate change on agriculture depends on a complex interplay between the effects of rising temperature, increased CO<sub>2</sub> concentrations and variations in rainfall. Considering the effect of rising temperature, it is known that for both rice and wheat a 2-3°C rise in temperature could lower yields by 15-17%. *Rabi* production would be more seriously affected than *kharif* production by increasing temperatures. A study by IARI on rice-wheat production systems in the Upper Ganga basin shows that in general under different scenarios irrigated rice is likely to lose yields (ranging from 2% to 23%) in some areas, whereas there will be much higher variability in wheat yields, ranging from the negative to the positive (WWF and IARI, 2010). The effect of projected variation in rainfall is unclear. However, since the majority of India's agriculture is rain-fed, the primary effect is likely to be increased vulnerability to lower yields due to increased variability in rainfall, especially for small and marginal land holding farmers. Similarly, yields from crops such as pulses that are primarily rain-fed, are likely to suffer due to rainfall uncertainties. Changes in rainfall could also affect the availability of irrigation water and soil erosion patterns, which are equally critical. Increased temperatures and changing rainfall patterns may also adversely affect the current pattern of pest-crop interactions leading to greater pressures on agricultural production. Considering that agriculture is the mainstay of Indian economy, the observed and projected impacts of Climate Change clearly indicate serious threats.

The INCCA report also indicates the vulnerability of the forest vegetation types of India in the four eco-sensitive regions (Himalayan Region, North-Eastern Region, Western Ghats and Coastal Region) to the

projected climate change in the short term (2030s). These model-based projections for key resources or parameters are summarised in Annexure I.

Water availability, which is crucial for sustaining the ecosystem and economy of the country, is likely to get affected. Although the projections give a mixed trend of water availability, still some regions might experience reduction in the water yield. Groundwater supplies are also likely to be affected by a number of factors such as higher runoff, increase in flooding and saline intrusion. These disturbances could lead to lower recharge of groundwater and impact the quality of alluvial and coastal aquifers. The frequency of extreme events such as floods and droughts could also be affected.

The cumulative effect of these above mentioned projected impacts could have repercussions on population and ecosystem across the country. This is further aggravated by large number of marginalised and poor people who are facing severe developmental challenges. Increasing resilience and coping capacity of the population will be an imperative measure to deal with the problems of climate change.

## 1.2 GANGA BASIN

The Ganga basin, which is one of the most densely populated regions of the world, has become an intricate mosaic of interactions between man and nature, poverty and prosperity and problems and possibilities in the last 50 years. The Ganga basin has the average population density of 550 individuals per km<sup>2</sup> and about 42% of India's population resides in this basin. (See Chapter 3 for more information).

The key to understanding the vulnerability of the Ganga Basin lies in its importance-

diversity of agro-climatic zones, socio-economic conditions, and position of holiness amongst million of Indians. The river remains principal driver for development in the basin and the management of its water present some formidable challenges in the context of both climatic and non-climatic stressors. Principal stressors which are exemplified in the light of climate change are increasing anthropogenic pressure, water withdrawals, and hydro-power development.

Rapid population increases in last couple of years have put tremendous pressure on the water availability. This increasing trend is worrying as more and more people migrate from cities to urban areas pushing the already-scarce resources to its limits.

A rapid expansion in water use in the Ganga basin to boost food security and access to water for irrigation has become pivotal for the livelihoods of the rural poor. Several factors such as intense exploitation of groundwater, declining water table due to lesser recharge, poor irrigation and pumping efficiency have resulted in exponential increase in water and energy demand even in the canal irrigated areas. Poverty in the rural areas of the region where agriculture is the main livelihood is substantially higher and high population growth rates in the basin remain a cause for concern in terms of water and food security, poverty alleviation and resource conservation. This becomes even more acute in the context of climate change.

The risks posed by the impacts of climate change on ecosystems are also not uniform. Certain ecosystems are at higher risk, whereas others have higher resilience to the phenomenon of climate change. The risks also vary throughout regions cutting across ecosystems, ecological zones and geographical boundaries. Populations which

have livelihoods largely dependent on natural resources are at high risk due to Climate Change impacts. Additionally, inhabitants of regions which are more sensitive to climate change will be even more prone to climate risks.

The Living Ganga Programme under the HSBC Climate Partnership of WWF – India is an initiative which aims to develop and implement strategies for sustainable energy and water resource management within the Ganga Basin, in the face of climate change. Climate adaptation is one of the key components under this programme. The objective of the component is to identify and demonstrate relevant adaptation strategies in the critical stretch of upper Ganga Basin based on vulnerability assessment of people, livelihoods and ecosystem. A 'top-down' approach has been adopted for achieving the objectives of the study. The strategic approach which has been devised to achieve the objectives of the component includes:

- Macro level vulnerability assessment based on secondary data for comparing and identifying the most vulnerable districts in the region.
- Detailed primary level assessment for the selected vulnerable areas to identify the most vulnerable communities and ecosystems.
- Develop adaptation pilots and identify development interventions with the aim to enhance the resilience of the vulnerable communities and ecosystems.

Understanding the linkages between people, ecosystems, livelihoods and assessing their vulnerability becomes critical to develop appropriate response strategies in the form of climate change adaptation. This report

analyses the current level of vulnerability of people, ecosystems and livelihoods in the Ganga basin at macro level. This study is based on secondary data. The objective for carrying out this study was assessing vulnerability to climate change. The focus of the analysis was on identification of vulnerable districts in the Ganga Basin. The study therefore makes recommendations for adaptation interventions and does not focus on policy recommendations. By assessing the past trends in climatic patterns and their impacts on ecosystem as well as capacity of people to adapt, it analyzes the changes in key variables—water (especially groundwater based irrigation), land-use change, agriculture productivity and changes in the forest cover—and the attempts to understand the causes for change.

The analysis takes into account how resilient the people, ecosystem and their livelihoods are to deal with shocks and their adaptive capacity to cope with current as well as potential future impacts. The output of the study helps in determining critical sectors which might be more vulnerable to climate change. It highlights the need for evolving special initiatives focusing on adaptation strategies and mainstreaming them in the development process. The adaptation interventions as identified involve efficient irrigation practices in the canal irrigated areas, soil and land management, managing groundwater usage and restoration of critical habitats for species conservation.

# VULNERABILITY ASSESSMENT METHODOLOGIES: A REVIEW

Adaptation is one of the most significant defence mechanisms which is required to combat the impacts of climate change. An assessment of the current level of vulnerability strengthens this process by providing a tool to identify the most vulnerable systems or groups in spatial and temporal extent. In this way it plays a key role for the selection and designing of appropriate adaptation strategies. Conceptually, vulnerability implies the susceptibility to damage or injury due to any negative impact. In the perspective of climate change, vulnerability simply refers to the probability of being negatively affected by the shifts in the climate, including extreme climate events. Due to the intricate interactions between diverse components of the natural system along with the human interventions, assessing vulnerability becomes a complicated piece of work. Nevertheless, vulnerability assessments are considered important tools required for adaptation of social and ecological systems.

The Intergovernmental Panel on Climate Change (IPCC) defines vulnerability to climate change as a function of three factors:

- a) The types and magnitude of exposure to climate change impacts
- b) The sensitivity of the target system to a given amount of exposure
- c) The adaptive capacity of the target system

**Exposure** reflects factors external to the system of interest, such as changes in climate variability including extreme weather events or the rate of shifts in mean climate conditions.

**Sensitivity** and **adaptive capacity** reflect internal qualities, resilience and coping characteristics of the system of interest. The adaptive capacity of a community depends on a combination of economic, social and technological factors such as extent of infrastructure development and distribution of resources. These three factors - **exposure, sensitivity** and **adaptive capacity** together govern the vulnerability of a system. Depending on the system and regional differentials, these factors are quite dynamic and vary considerably. In some cases, the high levels of exposure may be negated by a high adaptive capacity thus resulting in lower vulnerability values. Developing countries owing to their comparatively lower adaptive capacity are considered to be inherently more vulnerable to climate change.

## Definitions of some key terms

### **Vulnerability**

Vulnerability is the degree to which a system is susceptible to, and 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.

### **Sensitivity**

Sensitivity is the degree to which a system is affected, either adversely or beneficially, by climate variability or change. 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)

### **Adaptive capacity**

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.

(Source: IPCC, 2007)

An assessment of vulnerability to climate change mainly involves a research of the exposure, sensitivity and adaptive capacity levels of a system in the presence of a specific impact such as rising frequency of floods. The significance of vulnerability assessment lies in developing adaptation policies and response mechanisms for specific vulnerable groups and areas (Smit and Wandel., 2006). It thereby forms the basis for establishing response mechanisms towards climate change risk reduction. While performing a vulnerability assessment study it is important to include different dimensions which are crucial in influencing the vulnerability of a system. For example, while assessing the vulnerability of physical or natural systems, it is very important to include the social dimension as well (Adger, 2006; Bogardi, 2004). The social dimension includes a channel through which humans use resources and interact with the natural

system. Hence, it will be a key factor in the vulnerability of the natural system being taken into consideration. Also, in such assessments, one of the key steps is to determine the focus group to be studied and the most critical impact it will face in the scenario of changing climate.

Vulnerability is a dynamic concept, as exposures to climate variability and the capacity to cope with them changes on a temporal and spatial scale. The governing factors of vulnerability assessment studies mainly include scale of assessment; kind of impact or hazard being considered and the target group or system (O' Brien et al., 2004; Fussel, 2007). A change in any of these factors has the potential to change the entire picture of vulnerability. Vulnerability differs very much on the basis of scale of assessment. Studies at the macro level give a different picture of vulnerability as compared to the micro level analysis within

the region. Susceptibility of a specific location or group might not be reflected in the average assessment for the entire state or region. However, both levels of assessments hold significance in their own niche. Macro level assessments are required for a bird's eye view of vulnerability and as an initial step before narrowing down to local areas or specific locations. On the other hand, micro level assessment done at local level gives comprehensive and focused picture of vulnerability at the ground level and can capture a number of prevailing stressors in the region. Vulnerability also differs with respect to the time frame being considered for the assessment. Short term and long term hazards pose differential levels of vulnerabilities for a system. Adaptation practices in response to current climate variability can potentially decrease the vulnerability in the long term (Fussel., 2007).

Although vulnerability assessment is a very useful means for identifying the risks associated with climate change, there are still certain limitations. The current knowledge level might not be substantial enough to identify all the parameters that determine vulnerability. Also, many of these factors might not be quantifiable. These factors thus tend to get neglected as they cannot be incorporated in a composite vulnerability index (Kelly and Adger., 2000).

In light of the climate change, different organisms and systems are likely to respond differently based on their respective sensitivity and adaptive capacity levels. Vulnerability to multiple stressors and uncertainty regarding their interaction makes the assessment process even more challenging.

## 2.1 METHODOLOGIES

Assessing vulnerability to climate change has several approaches and various kinds of methodologies have been used for such studies. However, there is no standard methodology or set of indicators which can be used to measure vulnerability (Bogardi., 2004). Each and every system is unique in itself and thus any kind of approach for vulnerability assessment has to be selected only after careful scrutiny so that it is best suited for the region. A review of some methodologies used in several studies shows a wide spectrum of vulnerability assessments with different focal groups and areas (Table 2.1 and Annexure II).

Though the basic framework of vulnerability is found to be similar in many studies still each assessment is unique in itself with the approach custom-made to suit the study area and focal group. There are many studies carried out for a larger area to get an overview of vulnerability scenario for the entire region. Assessment of climate change vulnerability for seven countries of South-East Asia (Yusuf and Francisco., 2009), vulnerability of agriculture sector across provinces of South Africa (Gbetibouo and Ringler., 2009) and vulnerability of agriculture to multiple stressors (such as climate change and globalization) across the districts of India (O'Brien et al., 2004) can be cited as few examples done at the macro level. All of these studies have a common approach where vulnerability has been considered as a function of three factors-exposure, sensitivity and adaptive capacity. The assessment was done using secondary data for the indicators normalized using the Human Development Index (HDI) formula and the overall vulnerability has been obtained by combining all of this analysis. In some cases, equal

**Table 2.1 Review of some Vulnerability Assessment Methodologies**

<b>Study</b>	<b>Focus Area</b>	<b>Study Area</b>	<b>Data Collection Method</b>
Climate Change vulnerability mapping for South-East Asia	Vulnerability of regions to climate change	South-East Asia	Secondary
Livelihoods Vulnerability Index (LVI – IPCC)	Livelihood	Moma and Mabote Districts of Mozambique	District level study using Household Survey
Vulnerability Assessment of Freshwater resources	Freshwater resources	Ganges-Brahmaputra - Meghna River Basin, Helmand River Basin and Indus River Basin	Basin level study using secondary data
Vulnerability and Capacities Index (VCI)	Vulnerability of communities towards risks and hazards.	Eastern Uttar Pradesh, Gujarat and Rawalpindi (Pakistan)	Household and Community level study using Primary data collection based on Household Survey or focus group discussions.
Mapping vulnerability to multiple stressors	Agricultural vulnerability to two stressors: climate change and economic globalization	All the districts of India	District level study using secondary data

weightage is assigned to the indicators while in others differential weights have been used based on either stakeholder consultations or statistical techniques such as Principal Component Analysis (PCA). The LVI approach applied in Moma and Mabote districts of Mozambique is also a similar one using indicators and components under the three broad themes. However, this study was done at a micro level and the data was collected using household surveys (Hahn et al., 2009).

Besides this, there have been studies which cover a broad range of environmental stressors while assessing vulnerability. For instance, a basin level study was undertaken by United Nations Environment Programme to assess the vulnerability of freshwater resources to environmental change (Babel and Wahid., 2008). The assessment was done using a composite vulnerability index based on four components -

- i) resource stresses
- ii) development pressures
- iii) ecological insecurity
- iv) management challenges with indicators under each of them.

To avoid bias equal weightage was given to each of them. Similarly, a bushfire vulnerability assessment was done for Sydney, Australia using a GIS approach for spatial data analysis (Preston et al., 2009). Scores (Qualitative ranking) were given on the basis of frequency distribution of data however in this case also equal weights were given to the indicators.

As a contrast to the above mentioned macro level assessments there have been a number of studies at very micro level to get perception

of vulnerability of local level. For instance, the Vulnerability and Capacity Index (VCI) study was done at village and community level in Eastern Uttar Pradesh and Gujarat to understand the vulnerability in disaster and extreme climate risk regions (Mustafa et al., 2008). The VCI comprises of three dimensions of vulnerability-material, institutional and attitudinal. Indicators were chosen under each of them and different weightage was assigned based on literature review and stakeholder consultation. Other village level studies included the one done for Kothar & Srirangapur villages in Andhra Pradesh and Rajasthan for assessing vulnerability for the agriculture, water, rural energy and livestock sector.

In this case also the primary data was gathered at village level (Ramkumar et al., 2008). Kelkar et al., 2009 conducted a study to assess vulnerability and adaptive capacity in particular to climate variability and water stress for a particular watershed in Uttarakhand. A mix of modelling and community level surveys was used to carry out this study.

Based on the above review, it can be said that the scale of assessment is an important determinant of the kind of data collection required. Usually, for micro level studies primary data is collected. For macro level studies, an analysis of broader scale indicators is done using secondary data. Besides the data collection method, the selection of methodology is also crucial for the study. As comprehended, there are different types of analytical tools applied for assessing vulnerability. Among the commonly used analytical tools for such assessments is the use of indicators. In this approach a combination of indicators suitable to the study area or group are chosen. These indicators act as a proxy medium to reflect the state of exposure, sensitivity and adaptive capacity of the area.

Vulnerability is measured by aggregating these indicators through appropriate statistical methods. As evident, this method has been applied in different case studies. However, one of the limitations of this approach is that there are several complex interactions within the system which are too complicated to be captured in the form of indicators. The linkages between nature and

society are not easily defined. Data availability and assigning proper weightage also poses a serious challenge for such assessments. Nevertheless, the indicator approach is widely used for undertaking vulnerability assessments. The approach gives the flexibility to take a wide range of dimensions. For practical purposes of decision making the approach gives a view of susceptible groups.



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Participatory Rural Appraisal methodology used for gathering community perspective in Ganga Basin

## GANGA BASIN: VULNERABILITY ASSESSMENT

The Ganga river is the most important and sacred river of India overspreading nearly one-third of its geographical area. The Ganga and its tributaries have formed a large flat and fertile plain in North India extending over an area of 1,086,000 km<sup>2</sup> (Jain et al., 2007). The vast fertile region of the Ganga Basin sustains more than 500 million people and several ecosystems. The basin covers the states of Uttarakhand, Uttar Pradesh, Madhya Pradesh, Bihar, Rajasthan, West Bengal, Haryana, Himachal Pradesh and the Union Territory of Delhi.

The Ganga basin is a large repository of natural resources. It is the home for wide variety of species such as the highly endangered Ganga River dolphin (*Platanista gangetica*), freshwater turtles amongst others. The Ganga River which has been declared the National river of India is one of the most important sources of water for the people in the basin. Snow and glacier melt during the summer provide large flows to Ganga and its tributaries which is a crucial source of water supply for the people inhabiting this basin. The availability of abundant water resource, fertile soil and suitable climate has led to the development of a highly agriculture based civilization in this area. The agricultural outputs from the region are a vital source for the food supply of the country as well as for the raw material inputs to the industries. Thus, the Ganga basin forms a critical component of the economy of India.

The significance of the agricultural sector in the Ganga basin makes it even more

sensitive to climate change and its subsequent impacts on water availability. A large part of the agricultural land in this basin is irrigated from the surface as well as groundwater. This is apparent from the fact that approximately 47% of the total irrigated area in India is located in the Ganga basin. In case of any changes in the monsoon pattern in the form of shifts in the time period, frequency or magnitude, there can be substantial impacts on crop outputs.

The Ganga Basin faces a number of climatic and non-climatic stressors. Due to several reasons including the rising food demand, there has been substantial deforestation and conversion to agricultural land in the basin in the last century. The ever-increasing population in this region has contributed to water scarcity and water quality degradation throughout much of the river system. Nearly all of the sewage from these populations including human waste as well as industrial waste, primarily from agricultural fertilizers and pesticides enters the basin waterways untreated. In addition to these domestic and industrial pollutants, hundreds of human corpses and thousands of animal carcasses are released into the river everyday for a perceived 'spiritual rebirth.'

The excess withdrawals of water for agriculture in the Ganga basin has caused reductions in the surface water resources and increasing dependence on groundwater. In addition to these, there are water

diversions through barrages. At least 95 % of the river's water is diverted before it reaches the Sunderbans. Excessive water diversions threaten to eliminate natural water flows and severely damage people's livelihoods in the basin. In addition, there is an expected growth in domestic water demand in the basin, not only because of the provision of water services to the currently unserved communities, but also due to expected increases in standards of living owing to the rise in economy. The agricultural sector is the biggest user of water in the basin and considerable opportunities for water conservation and water use efficiency exist in this sector.

There is an extensive spectrum of climatological and geographical features existing in this region which makes it distinctive. This directly implies that any changes in the natural resources of this region can give rise to a chain of impacts on communities and ecosystems. Climate change accompanied by other non-climatic stressors pose a crucial threat to this basin. Climate change projection scenarios suggest the possibility of short term increases in river flow as glacier melt increases, followed by substantial drops in river flow once these have largely melted. Climate change is exacerbating the problems caused by water extraction as the Himalayan glaciers supply substantial amount of water in the Ganges, which is particularly critical in the dry season prior to the monsoon rains. The impacts will be particularly severe in the dry season.

### 3.1 STUDY AREA

Since the states of Uttarakhand and Uttar Pradesh cover 34% of the drainage area of the Ganga basin, they were selected for a macro level assessment. Uttar Pradesh (UP)

is the most populous state of India with a population of more than 166 million (Census of India, 2001). With a strong agricultural base and diverse industries, the economy of UP has a fundamental role in the overall development of the country. Its neighbouring state of Uttarakhand was carved out of it as a separate state in 2000. Uttarakhand has a total geographic area of 53,483 km<sup>2</sup>, of which 93% is mountainous and 64% is covered by forest (Government of Uttarakhand, 2010). Most of the northern parts of the state are a part of the Himalayan range, covered by the high Himalayan peaks and glaciers. The unique Himalayan ecosystem plays host to a large number of animals (including *Bharal*, Snow Leopards, Leopards and Tigers), plants and rare herbs. Two of India's chief rivers, the Ganga and the Yamuna originate in the glaciers of Uttarakhand and are supplied by myriad lakes, glacial melts and streams in the region.

### 3.2 METHODOLOGY

The basic approach for the macro level vulnerability assessment has been in the form of comparative analysis of vulnerability index values for all the districts of Uttar Pradesh and Uttarakhand to identify the most vulnerable areas (*Fig. 3.1*). The results of this study have been used as inputs for a detailed community level vulnerability assessment study and implement adaptation pilots. As the study is secondary data based so it does not give any policy recommendations. However, the detailed community level assessment done using primary data can be useful in generating recommendations for policy advocacy.

The methodology for assessing the vulnerability has been broadly based on its definition which takes it as being a function of

three broad factors of exposure, sensitivity and adaptive capacity. The multi-disciplinary indicators covering diverse dimensions of climate, population, ecosystem and socio-economic conditions have been used to analyze vulnerability in this region.

The method for assessing the vulnerability of the two states has been selected after reviewing varied methodologies. The method which was found to be most appropriate and replicable in our study is the LVI-IPCC (Livelihoods Vulnerability Index) methodology. This methodology which was used for calculating the vulnerability index was applied in the case of **'The Livelihood Vulnerability Index: A pragmatic approach to assessing risks from climate variability and change—A case study in Mozambique'**. This study assesses the vulnerability of the livelihoods of the households in two districts of Mozambique.

The basic approach of this LVI –IPCC study has been adopted in our research for the Ganga Basin after making necessary modifications. However, except for the main structure, all indicators have been chosen to suit our study area on the basis of existing literature and consultation. The methodology has been modified to the extent possible so that it is relevant to the study for the Ganga Basin. The approach places multiple indicators under the broad umbrella of three factors which define vulnerability—exposure, sensitivity and adaptive capacity. *Figure. 3.2* explains the broad structure of this assessment framework.

The assessment of vulnerability involves four steps moving from indicators to profiles and eventually to the final vulnerability index (*See Box 1*). The initial step involved the selection of indicators which was done based on literature and discussion within the

**Fig. 3.1 Ganga River Basin highlighting the state of Uttar Pradesh and Uttarakhand\***

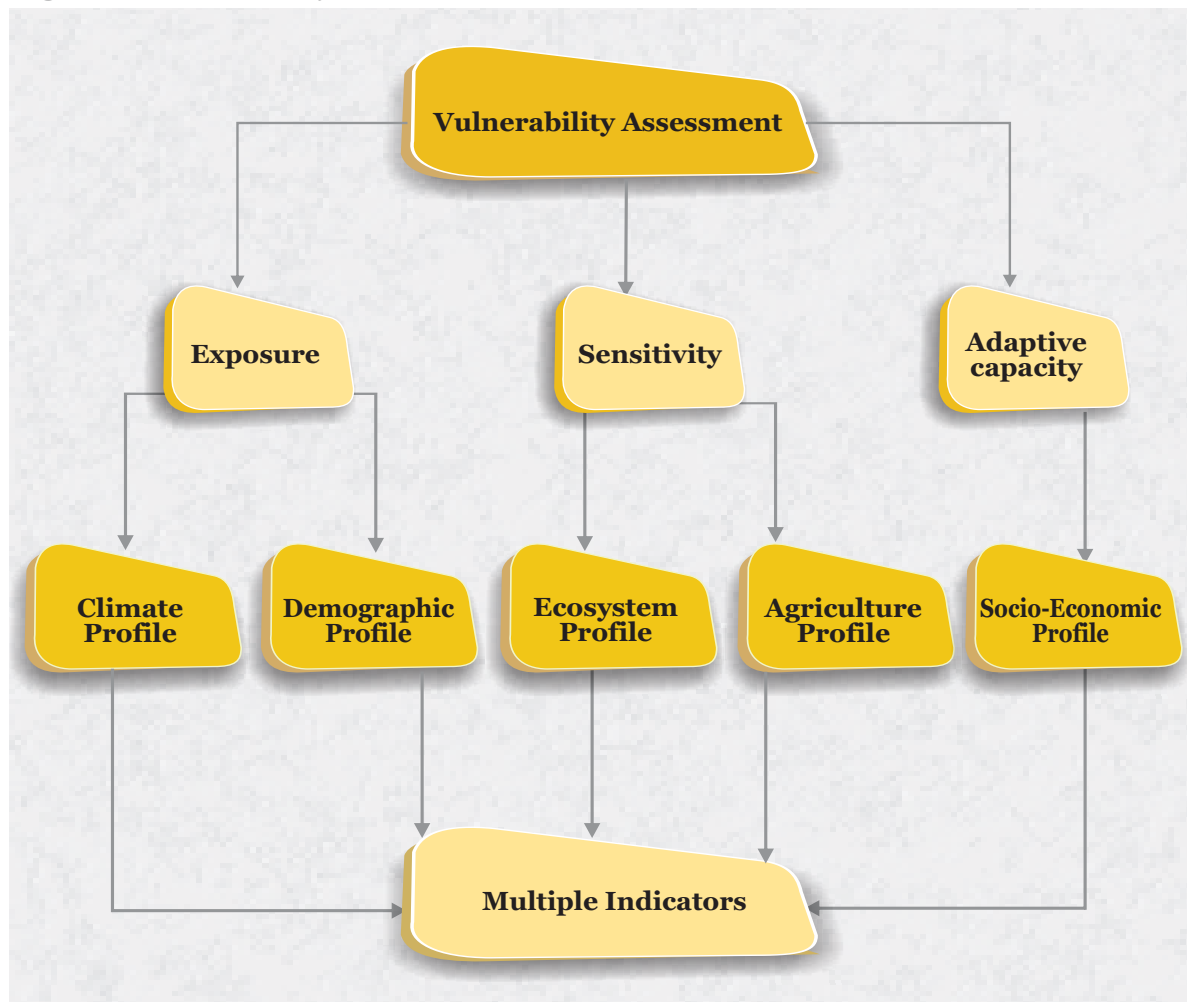


\* The box highlighted in the map shows the critical stretch of 800 km expanded from Gangotri in Uttarakhand to Kanpur in Uttar Pradesh and includes the key sites of Living Ganga Programme

project team. Secondary data was collected for the selected indicators from reliable and authentic sources. The data for the indicators was then normalized using the UNDP Human Development Index (HDI) formula to bring consistency. Thus, after normalisation the values for all the indicators were brought in the range of 0 to 1. Higher values (near 1) for an indicator reflected higher exposure, sensitivity or adaptive capacity depending on the component in which it was placed. In some cases the values for the indicators had to be reversed after normalisation to maintain this consistency. For instance, in case of sex-ratio, higher values reflected lower exposure values. Hence, the values were reversed so that higher values reflected higher exposure

values. The next step involved the calculation of each profile value by combining the data for the indicators under it. Thus, based on the combination of the normalized values for each indicator the 5 outputs (*Climate, Demographic, Agriculture, Ecosystem and Socio-economic Profiles*) were obtained. The profile values in turn were the inputs for calculating the values for the three components: **Exposure, Sensitivity and Adaptive Capacity**. The **Vulnerability index** for the region was derived by combining the values of these components. GIS techniques were used for the generation of thematic maps as well as graphically presenting data.

**Fig. 3.2 Vulnerability Assessment Framework**



## Box 1 : Steps to calculate the vulnerability index

The steps can be broadly summarized as:

### Step 1: Indicators

- Values for all the indicators are to be standardized for all the districts.

- Indicator Index (**I<sub>x</sub>**) = 
$$\frac{I_d - I(\text{min})}{I(\text{max}) - I(\text{min})}$$

Where, **I<sub>x</sub>** = Standardized value for the indicator

**I<sub>d</sub>** = Value for the Indicator I for a particular district, d.

**I (min)** = Minimum Value for the indicator across all the districts

**I (max)** = Maximum Value for the indicator across all the districts

### Step 2: Profiles

- Indicator Index Values are combined to get the values for the profiles

- Profile (**P**) = 
$$\frac{\sum_{i=1}^n \text{Indicator Index } i}{n}$$

where, **n** – number of indicators in the profile

Indicator Index **i** – Index of the *i* th indicator.

### Step 3: Components

- Values of the profiles under a component are to be combined to get the value for that component.

- Component (**C**) = 
$$\frac{\sum_{i=1}^n W_{pi} P_i}{\sum_{i=1}^n W_{pi}}$$

where, **W<sub>pi</sub>** is the weightage of the Profile **i**

- Weightage of the profile will depend on the number of indicators under it such that ***within a profile each indicator has equal weightage***

### Step 4: Vulnerability Index

- The combination of the values of the three components will give the vulnerability Index.
- Vulnerability Index = (Exposure – Adaptive Capacity) x Sensitivity
- Scaling is done from -1 to +1 indicating low to high vulnerability.

### 3.3 INDICATORS

The indicators chosen for this study were chosen to incorporate the climate, biophysical as well as social dimensions

(Table 3.1). Thus, the temperature and precipitation parameters were taken under climate whereas variables such as decadal population growth and population below poverty line were taken under the demographics profile.

**Table 3.1 Indicators for Vulnerability Assessment**

<b>Component</b>	<b>Input Profile</b>	<b>Indicators</b>	<b>Output</b>
Exposure	Climate	Average Temperature Rainfall	1. Climate Profile
	Demographics	Sex Ratio (Reversed) Population in the age group 0-6 Decadal Population Growth Below Poverty Line (BPL) Population	2. Demographic profile
Sensitivity	Ecosystem	Change in forest cover (Reversed) Land use pattern ( <i>Kharif &amp; Rabi</i> ) Groundwater extraction	3. Ecosystem Profile
	Agriculture	Crop Production (Reversed) Land Capability Irrigation pattern Ratio of agricultural workers	4. Agriculture profile
Adaptive Capacity	Socio-Economic structure	Livestock population density Literacy rate Access to basic amenities (Drinking water, electricity, cemented or <i>pucca</i> houses) Biomass Dependency (Reversed) Infrastructure (Educational, Health, Banking and Communication facilities)	5. Socio-Economic Profile

While choosing indicators for the ecosystem profile, all three key resources of the forest, land use and water were incorporated. The dependency of the working population on agriculture and irrigation pattern was considered an indicator of the sensitivity of the region under the agricultural profile. The socio-economic profile largely encompassed infrastructure status and access to basic amenities. Thus, an attempt has been made to capture the vulnerability scenario of the region by having this wide range of indicators.

Detailed explanation of the selected indicators is given in the following section and the data sources are listed in Annexure III.

### **3.3.1 EXPOSURE**

#### **3.3.1.1 Climate Sensitivity Profile**

##### ***Temperature Variability***

Temperature is a critical parameter of climate which strongly influences people, biodiversity and ecosystems. It is an important driver of both natural and managed systems such as agriculture. It governs the distribution and abundance patterns of both plant and animal species. Temperature and related parameters affect the snow and glacier patterns in the cryosphere. Rising levels of GHG emissions have resulted in an increase in global as well as regional temperatures. This is likely to cause impacts at local, regional and global level. Several climate models are being used to understand and project the extent of changes likely in future under different scenarios of development. In the last few decades, the average temperatures have been found to vary beyond the normal ranges. Year to year variations in average temperature are indicative of the trend. Variability, leading to higher temperatures shows higher exposure level of the district.

##### ***Rainfall***

Precipitation is an important component of the water cycle as well as natural ecosystem. Usually, rainfall patterns are dependent on a range of factors such as topography, local climate and wind patterns. Consequently, precipitation exhibits an extensive variation on temporal and spatial scale. Climate change has impacted the rainfall pattern differently in diverse regions. Analysis of the long term rainfall data shows that over the past century, some areas have experienced an increase in average rainfall, while the others witnessed a reduction. Changes have been observed in the intensity and frequency of rainfall event also.

Reduced rainfall and/or higher temperatures can lead to persistent and severe decline in water balance (as the water demand will go up and supply will come down) and also increase the aridity. A change in the timing of the run-off will impact the water availability. Water scarcity can hinder progress in developing areas and will threaten food security. It will impact crops, agriculture and eventually the economy. Average variability of rainfall derived from year to year variations reflect the overall changes in pattern. Reduced precipitation in a region shows higher level of exposure to climate change.

#### **3.3.1.2 Demographic Profile**

##### ***Sex Ratio***

Vulnerability to climate change can be differentially defined on the basis of gender. Climate variability is likely to have disproportionate impacts on females as compared to males. Differences in the role of men and women in the society, work and domestic life have variable implications on their vulnerability and coping capacity. Greater reliance of women on natural resource dependent activities such as

agriculture is a common feature in India. Changes in these natural resources due to changes in the climate are more likely to affect women through various direct and indirect means such as water and fuel wood availability. Limited access and rights over property and also wealth, act as a major barrier for women to adapt to the changing climate. Nutritional deficiencies in women and children make them even more susceptible to the impacts of climate change. Despite the vulnerability to climate change women play a key role in being effective agents of bringing in adaptation and mitigation related changes.

Sex-ratio is an indicator of the gender distribution in a society. It shows the number of females per thousand males and indicates the health and survival status of women. Ideally the sex ratio should be 1, however, an assessment of many areas in India indicate that the number of females is much lower than the number of males. A low sex ratio in general represents a lesser social status of women, which creates conditions for discrimination at various levels. Lower sex-ratio in any district increases the possibility of vulnerability as well as lowers the coping capacity and resilience of the society. Thus a lower sex ratio in any district would reflect its higher exposure to climate change.

### ***Population (0-6 years)***

Children are likely to be more vulnerable to natural disasters and extreme Climate Change events. The chain of impacts such as reduction in food and water availability projected due to the changes in climate patterns could have implications for children. The health impacts in the form of increased cases of diseases such as malaria, due to changing weather patterns can also severely impact children. In case of weather related disasters children can be more sensitive, due to malnutrition, injuries or

diseases which could result in large number of deaths. With higher frequency of extreme events projected due to climate change these impacts are likely to get augmented further. These might also have an effect on their well being such as their ability to go to school. If a district has a high population density of children below 6 years of age (population under 6 per geographical area) then the district is more likely to be exposed to the impacts of climate change. Also, if these factors combine with a low adaptive capacity, then the vulnerability towards climate change will become very high.

### ***Decadal Population Growth (1991-2001)***

Population growth is a significant indicator of development. However, it also indicates a stress on the resources. A rapid expansion in population indicates the rising pressure on natural resources as the resource base of the area does not increase in proportion to the population. The additional climatic and non-climatic stressors due to the changing climate will further amplify the burden on resources. The demand for climate related key resources such as water and food is likely to increase rapidly in future due to the combination of climate change and rising population.

Equity issues related to access and rights over resources is another major challenge especially in developing countries. There are several communities and sections of society which have limited access to the resources due to various reasons. Also, population growth is an inevitable fact happening in these areas as a result of development. Hence, in future there is a likelihood of a large population having restricted income opportunities and limited access to natural resources as well as infrastructure. This section of population will consequently have less adaptive

capacity to cope up with the harsh impacts of climate change. Thus, a district having very high population growth is likely to be more exposed and vulnerable to the effects of the climate change especially since they will compete for scarce resources.

### ***Below Poverty Line (BPL)***

The categorization of households living below poverty line is based on the criterion of income of the family. These households have limited access to basic necessities of life i.e., food, water and shelter. Households below poverty line are deprived of a good quality life and access to basic requirements such as education. Being the vulnerable section of the society, their adaptive capacity to cope with any natural disasters is minimal. Climate change is likely to worsen the condition of such households as the additional stress on resources will further increase their vulnerability. If the frequency of extreme events increases then their ability to withstand such events will be further decreased. A district with a high BPL population is likely to be more exposed and vulnerable to climate change.

## **3.3.2 SENSITIVITY**

### **3.3.2.1 Ecosystem Profile**

#### ***Change in Forest Cover***

Forests are one of the most important ecosystems in the world. They are not only important ecologically for conserving water, soil and other natural resources but also for sustaining the biodiversity of the area. They also provide major inputs to the economy through their natural resource base and NTFPs. In context of climate change, forests act as major carbon sinks absorbing much of the CO<sub>2</sub> being emitted by anthropogenic activities.

Reduction in the forest cover due to several factors such as deforestation and conversion to agricultural land can have economic as well as ecological repercussions. *A district in which there has been reduction of forest cover* is likely to have imbalances in ecology as well as economy. From a climate perspective it implies that the capacity to absorb GHG will be decreased in the area apart from releasing more GHGs due to deforestation. There will be effects on the natural resources and the biodiversity of the region in the form of decline in wildlife habitat, biodiversity loss and increased soil erosion. It will also cause changes in albedo, lower evapotranspiration and can alter water and heat balances (IPCC, 2007). The changes in temperature, precipitation and CO<sub>2</sub> concentration will further affect the existing forest cover. *The district would thus be more sensitive and vulnerable to climate change if there has been a reduction in forest cover.*

#### ***Land Use Change: Change in area sown under Kharif and Rabi crops***

Land use changes significantly influence the local climate and the landscape. Deforestation, habitat fragmentation, urban sprawl, conversion of land to agriculture and other modifications have significantly changed the land use pattern. These land use changes also have a direct linkage with climate change. In the last three decades, direct GHG emissions from the land use changes have seen a growth of 40 % (IPCC, 2007).

Extensive land use changes have an impact on people, livelihoods and ecosystems. Unsustainable and ill-managed changes in land use can increase the vulnerability of the ecosystem. Clearing of vegetation leading to land degradation and filling of wetlands that can provide flood protection will increase

the sensitivity towards climate variability. Consequently, there will be likely impacts on biodiversity leading to species extinction, range shifts and changes in the abundance (population) of species. In fact, the endemic species might be severely affected.

Conversion to agricultural land and an increase in the gross sown area has repercussions for the land as well as climate. An increase in the area used for cultivating *Rabi* (winter crops) can have a direct impact on water extracted for irrigation. The stress on surface and groundwater might rise significantly. Similarly, an increase in *Kharif* (monsoon dependent) crops indicates higher dependence on monsoons. Any change in monsoon patterns will directly affect the *Kharif* crops and indirectly impact the *Rabi* crops due to reduction in surface and groundwater recharge. Thus, an increase in gross sown area will raise the sensitivity levels of the district towards climate change.

### **Groundwater extraction**

Groundwater is an indicator of natural water resource of an area. It is imperative to have a balance between groundwater recharge and its extraction. Growing demand for water and the limited availability of surface water in some areas has led to over extraction of groundwater and consequently its balance has been disturbed. A large amount of groundwater is being extracted which may have adverse implications for the water scenario in future. Due to the changing climate, the total water availability is likely to be reduced which will also impact the groundwater recharge. A deviation from the recharge - extraction balance will ultimately result in falling water tables. This will also have an impact on the extraction costs of water. The reserve water resources of the area will get

depleted leading to high vulnerability. *More the extraction of groundwater in a district, greater will be its sensitivity towards climate change.*

Criteria for categorization of assessment units based on groundwater level decline as defined by Central Ground Water Board (CGWB) is given below. According to the definition, this percentage is the stage of groundwater development which refers to the annual groundwater extraction from all existing groundwater structures during monsoon as well as non-monsoon period out of the total groundwater available. Based on the percentage of stage of groundwater development there are four categories: -

- i)** Safe—which refers to the areas which have groundwater potential for development
- ii)** Semi-critical—which refers to areas where cautious groundwater development is recommended,
- iii)** Critical and **iv)** Over-exploited—refers to areas where there should be intensive monitoring and evaluation and future groundwater development be linked with water conservation measures

<= 70% Safe
> 70% and <=90% Semi-Critical
>90% and <=100% Critical
> 100% Over exploited

(All values in %)

*Source: Central Ground Water Board, Ministry of Water Resources, Government of India.*

### 3.3.2.2 Agriculture Profile

#### ***Change in Crop Production***

Agriculture is one of the most sensitive sectors to climate. In India, a large portion of crop production is mainly dependent on the monsoons. Variation in precipitation has a direct impact on the crop production. As India is mainly an agricultural country, crop production is crucial for its economic growth as well as food security. In states like Uttar Pradesh, agriculture is one of the most important sectors contributing to its economic growth. A large section of the population is dependent on agriculture for its livelihoods. Also, being the major producer of some key crops of India, this sector is crucial for the food supply of the entire country. If there are any negative changes in the crop yield then it is going to impact the livelihoods of thousands of people in the state and will raise food security issues for the country. Changes in the rainfall trends affecting water availability will impact the irrigation of the region. These changes will be more crucial if there are water intensive crops such as sugarcane, rice and wheat being grown in the region. In this case, the sensitivity of the region towards climate change would be more.

For the purpose of analysis in this study, we are taking changes in crop production as an indicator of food supply and the district with maximum reduction in production as more sensitive. However, while analyzing we are aware that the system will be sensitive even if there is an increase in production of these crops (rice, wheat and sugarcane) as all these are water intensive crops and will raise the water demand of the agriculture system.

#### ***Irrigation***

Percentage of irrigated area out of the net

sown area gives an indication of the dependence on rainfall as well as utilization of surface and groundwater. Irrigation water withdrawals account for almost 70 % of global water withdrawals. Of all the sectoral water demands, the irrigation sector will be affected most strongly by climate change (IPCC, 2007). Higher temperatures and an increased variability of precipitation would in general, lead to an increased irrigation water demand, even if the total precipitation during the growing season remains the same.

If the area irrigated is high in a district then it can have implications both for short term as well as long term. In the short term rainfall dependence will be less but there will be more stress on surface and ground waters. As the flow in the rivers might increase due to glacial melt in the short term so this might appear to be feasible but in the long term the flow in the rivers is likely to decline due to receding glaciers which are the freshwater reserves or due to new water infrastructure coming into place such as hydropower reservoirs. This will make such irrigation dependent agriculture more sensitive to climate change. *Higher reliance on irrigation can be greater vulnerability.*

According to our analysis the district which is more dependent on irrigation will be more sensitive. But this does not mean that rain fed districts will be any less sensitive. For our analysis, we have chosen this as an indicator for assessing long term sensitivity of the agricultural system towards climate change.

#### ***Land Capability***

Land capability takes into account the number of times an area is cropped in a year (Total cropped area divided by net sown area). Higher the land capability, greater will be the crop productivity from the land.

However, it also implies that there is greater pressure on resources such as water (and would also imply more use of fertilizers). *In districts where the land capability is high it mainly implies a greater stress on resources and thus higher sensitivity.*

### ***Ratio of Agricultural workers to other workers***

The indicator takes the ratio of agricultural workers (cultivators and labourers) to the other workers. Effectively, it gives a picture of how much of the working population is dependent on agriculture. A large number of workers being dependent on agriculture would mean that the changes in climate patterns would have an impact on the livelihoods of a large population. If this population has limited means of alternative livelihoods then they will have very less options for coping with the impacts of climate change and switching to some other means of income. *Districts with higher ratio of agricultural workers to other workers would be more sensitive to climate change.*

## **3.3.3 ADAPTIVE CAPACITY**

### **3.3.3.1 Socio-Economic Profile**

#### ***Livestock Density***

Livestock is an important component of the agriculture system. It is an asset for a family as it provides inputs in various forms. It provides the significant energy input to the croplands required for ploughing, threshing and other farm operations. Animal dung provides essential nutrients required for soil fertility and crop yields in the form of organic manure. In some cases, livestock also provides a means of additional / alternative livelihoods.

**Livestock density is evaluated as follows:**

$$\text{Livestock density} = \frac{\text{Livestock population}}{\text{Area of the region}}$$

The livestock density holds significance in context of climate change. In case of disasters or any impact on agriculture, livestock can serve as means of coping mechanism. It can be a source of alternative or additional income for the farmers. Thus, higher livestock density would indicate higher adaptive capacity.

In this study, livestock has been taken as indicator of adaptive capacity but it is also true that the livestock are likely to suffer more in case of extreme events. However, their importance in serving as an alternative source of income is crucial in determining vulnerability of the people.

#### ***Female work Participation Rate***

The variable gives the percentage of females out of the total female population who have a paid employment. This number indicates the adaptive capacity and independence of females in a society. *The higher the percentage of women the greater will be their capacity to be resilient to climate change.* They will be self-sufficient to a certain extent to deal with the impacts of climate change, irrespective of the nature of the economic activity. However, it must be noted that if their occupation is mainly dependent on agriculture, then the same population would be more sensitive towards climate variability.

## **Literacy**

The literacy rate of an area is a clear indicator of the adaptive capacity of the people and how equipped they are in terms of knowledge and education. It shows the degree to which the community can have access to the right kind of knowledge in understanding changes in the environment and the management practices required to deal with them. This variable shows the percentage of the total population which is literate.

**The formula for literacy rate is:**

$$\text{Literacy Rate} = \frac{\text{No. of literates}}{\text{Population above 7 years}} \times 100$$

According to the Census of India, a literate person is the one who is aged 7 years and above and can both read and write, with an understanding in any language. For this analysis, it has been assumed that a district having a higher literacy rate will probably have a better knowledge base to deal with and adapt to climate change.

## **Access to basic amenities**

- *Access to safe drinking water*

This variable gives the total number of households having access to safe drinking water which in this case is considered to be tap water or hand pump. The access is considered for the households who have these sources either within premises or near their households which is less than 100m of range in case of urban areas and within 500m in case of rural areas. The households having the source of drinking water away from their premises (>100m for urban areas and >500m) in

case of rural areas are not considered in this number as it can not be categorized as access to safe drinking water.

Source of drinking water is required as an indicator to assess the vulnerability to climate change in the case of changing water scenario. In a scenario where there is a lack of alternative safe water resources, people will be more exposed to water stress. Reduction in the availability of drinking water can also lead to water conflicts. Also, if the source of drinking water is very far from the house, then it involves a higher opportunity cost in the form of time spent to acquire the resource. In the case of a disaster, the accessibility to the source might be lost. The source of drinking water gives a picture of (insufficient) investment in rural development. *Better the access, higher will be the adaptive capacity.*

- *Source of lighting*

The source of lighting is an indicator of well being of a society. It gives the benefits of better energy services. Percentage of households getting light through electricity has been considered as an indicator of adaptive capacity. *Thus, better lighting facilities in a district would mean higher adaptive capacity and lesser vulnerability.*

- *Biomass dependency*

Biomass dependency is an indicator of the reliance on natural resources for cooking. In light of climate change, there might be an impact on these natural resources as well. If there is very high dependence on biomass, it would also mean a higher exploitation of natural resources. In terms of emissions,

excessive biomass burning would mean high amounts of GHG emissions. It would also increase the levels of indoor pollution and subsequent health issues. The variable shows the percentage of households still dependent on biomass for cooking fuel. The biomass here includes firewood, crop residue and cow dung cake. *Higher dependence would mean low adaptive capacity.* Reverse normalized values have been used for this variable so that *low values indicate low adaptive capacity.*

- *Type of houses*

The indicator takes into account the percentage of households having a permanent housing structure. Those houses whose walls and roof are made of permanent materials are considered permanent houses. Permanent houses provide resilience to absorb climate change impacts. In case of disasters, such houses are most likely to withstand the shocks. *Higher percentage of permanent houses would indicate better coping capacity.*

### **Infrastructure**

- *Educational Facilities*

Educational facilities indicate the infrastructure available to adapt to climate change in terms of knowledge. The number of schools will show the extent to which a district is developed in terms of education. The indicator chosen is the number of junior, senior and senior secondary schools per geographic area of the district. It gives the number of options in a region for access to education. *Districts with a low density of schools would have lesser options left for education.* Lack of sufficient number of

schools in the area would leave many students deprived of education.

In the case of climate related extreme events such as floods, these institutional set ups also become centers of relief where people can take shelter. Overall, the educational facilities provide preparedness to climate change impacts.

- *Health Facilities*

Health facilities are an important indication of health adaptive capacity in case of disasters and other related health impacts. Sufficient number of hospitals and health centers are a pre-requisite for providing proper medical services in a region. *The number of beds in allopathic and ayurvedic hospitals per geographic area denotes the level of preparedness available to deal with health related impacts.*

The projected changes in the climate might lead to an increase in the spread of some diseases. In such cases, better medical facilities would be required as a response measure to cope up with the health impacts.

- *Transport Facilities*

$$\text{Road Density} = \frac{\text{Length of metalled roads}}{1000 \text{ km}^2 \text{ of area}}$$

Road networks are a crucial indicator of development and connectivity across regions. A well structured road network acts as a means of providing access to facilities. It also signifies an improved access to the markets for a better income generation. Especially in case of rural

areas, developed road infrastructure would mean better accessibility of rural communities to the economic centers for trade and business. In the case of extreme events, metalled roads act as means of providing relief.

- *Communication Facilities*

Communication facilities are an indicator of extent of development. With all the modern means of communication, connectivity among people has improved significantly. The number of telephone connections per lakh (0.1 million) of population has been chosen as an indicator of communication facilities. These facilities are required for information flow

and creating awareness about climate related events especially in case of disasters. They act as means of adaptive capacity.

- *Banking Facilities*

Banking Facilities are an important indicator of wealth and provide information related to the adaptive capacity of the region in context of extreme events or climate related shocks. This variable includes the number of banks (public, private and foreign banks), rural banks and non-commercial nationalized banks Cooperative Bank Branches and Cooperative agriculture and village development branches.

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Some of the indicators (livestock, population under the age of 6 years, access to drinking water and type of housing structures) used in vulnerability assessment study

## Assumptions and Caveats:

The methodology for this vulnerability assessment has been chosen on the basis of suitability to the region and data availability. However, like any other study this research also has some assumptions and caveats which are mentioned below:

- This analysis has been done at a district level due to constraints in data availability at block and village level. However, we are aware that there might be regional variations within a district boundary as well. The reason for selection of district as a unit was that the data for the kind of broad indicators chosen for this study was available only at the district level. The data availability was limited at lower administrative levels for some of the indicators chosen for this study.
- The macro level analysis is based on secondary data and obtained from published reports of the Central and State government departments. Thus, it has been used only to get an understanding of the vulnerability scenario.
- The methodology gives equal weightage to all the indicators. However, some variables might have more effect in determining vulnerability. But on the other hand assigning weightage to variables also brings in subjectivity. Thus, this method of giving equal weightage was found to be appropriate for application at the district level.
- The data used for climate analysis has been interpolated for the districts using the  $1^{\circ}\times 1^{\circ}$  grid-wise data from India Meteorological Department (IMD) for the year 1995 to 2005 due to unavailability of district level data for the climate parameters. This gridded data in turn has been interpolated based on the available station data. For some of the regions observed data sets are limited and thus this data might not give the actual on-ground reality.
- As the data for Ganga Basin is classified due to trans-boundary water sharing issues thus limited data was available for surface water flows. Even the information available would pertain to the water flowing in rivers and canals. For this reason groundwater extraction was used as an indicator for water resource in the districts. Percentage of agricultural area irrigated has also been analyzed to get more insights on surface and groundwater usage.
- The data used for demographic variables has been obtained from Census of India, dated back to 2001 as it was the latest data available.

## ANALYSIS AND RESULTS

The assessment for this study was carried out for a total of 83 districts which fall under the administrative boundary of Uttar Pradesh and Uttarakhand. The analysis of the large data set for the indicators for all these district units reveals interesting trends. The descriptive analysis of each of the components, profiles and indicators is presented below:

### 4.1 EXPOSURE

The exposure component encompasses two broad elements – the aspects of the system of interest which are likely to be affected

from climate change and the changes in the climate itself. This statement forms the rationale for having two profiles under this component – **Climate** and **Demographic**. The Demographic-profile includes the trends of population growth, gender inequality, population below the age of six and the Below Poverty Line (BPL) population. This profile inherently indicates what is at risk in the view of exposure to climate change. The Climate profile takes into account the change in the climate parameters. For the purpose of analysis, the values were divided into three categories – low, medium and high (Fig. 4.1).

**Fig.4.1 Exposure Levels of the districts of Uttar Pradesh and Uttarakhand**



The final values for the exposure levels of the districts show that almost half of the total districts lie in the medium exposure category. In Uttarakhand's case, these are the hilly districts of Tehri Garhwal and Pithoragarh; whereas in Uttar Pradesh, this category of districts covers almost the entire state except the eastern region. A combination of moderate variation in climate and medium values of demographic profile are the probable causes for these districts being moderately exposed. Approximately, 20% of the districts in the study area are found to be highly exposed to the changes in the climate. Remarkably, many of these districts such as Dehradun, Haridwar, Ghaziabad, Lucknow and Kanpur Nagar are the predominant urban districts of these states. Elevated values of demographic profile due to rapid population growth, lower sex ratio and high density of population below the age of six are the prime reasons of these districts being highly exposed. The other districts under this category namely Uttarkashi, Bijnor, Bareilly, Faizabad and Jyotiba Phule Nagar are the ones which have experienced higher levels of change in temperature and precipitation.

The districts which are found to be lesser exposed to climate change are primarily found to be located in the eastern parts of UP as well as Uttarakhand. Higher sex ratio along with relatively lower level of urbanization and population growth are the pushing factors for the districts such as Rudraprayag, Garhwal, Bageshwar, Almora, along with Azamgarh, Mau, Deoria and Gorakhpur in Eastern UP being classified under this category. However, being placed in this category does not imply that these districts are not vulnerable to climate change. It just

indicates their relative vulnerability when compared with other districts.

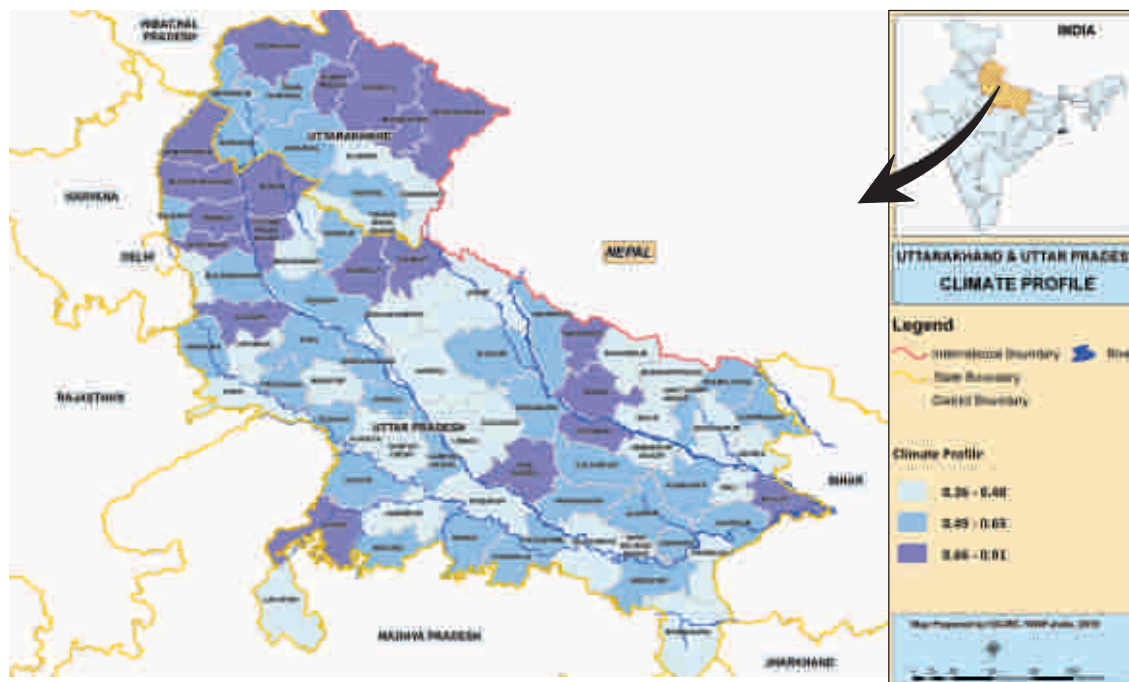
#### 4.1.1 Climate Profile

The climate profile analyzes the changes in two important indicators of climate-temperature and rainfall. The yearly average calculated for the districts using daily gridded ( $1^{\circ}\times 1^{\circ}$ ) temperature and rainfall data obtained from the India Meteorological Department (IMD) has been used for this analysis. The moving average method has been used to capture the year-to-year changes from 1995 to 2005 in the two parameters.

A t-test was done out to identify the significance of the change in the temperature and amount of rainfall over the period of 1995-2005. The results obtained through the t-test were found to be statistically significant at 95% confidence level for the majority of the districts. It can be concluded that for UP and Uttarakhand, the average rainfall and temperature over our analysis period correspond with the overall trend. For the deviations, it can be said that those districts are influenced by local changes. However, the changes that occur in respect of shifts in time for the rainfall across the districts are statistically valid.

According to the combined values of the climate profile it is apparent that the districts with comparatively higher values mainly lie on the western side of Uttar Pradesh and higher altitudes of Uttarakhand (*Fig. 4.2*). An analysis of the individual indicators was carried out to understand the trends in temperature and rainfall. The **temperature** data for the districts of Uttar Pradesh shows that almost

**Fig. 4.2 Climate Profile Value Distribution for the districts of Uttar Pradesh and Uttarakhand**



all the districts have their normalized values between 0.40 and 0.65. This implies that in majority of the districts an increase of 0.3-0.4°C has been observed on the basis of average yearly temperature data. A minor increase of 0.2°C was seen in the Eastern region while moving towards the western region of UP the increase is towards a slightly higher side (0.35– 0.5 °C). For the state of Uttarakhand, all the districts except Champawat have positive values showing increasing trend mostly in the range of 0.5 to 1°C over the last 10 years. The average temperature increase was found to be more in Gharwal region as compared to the Kumaon region. The trend based on the analysis of decadal average temperature change shows that there has been higher temperature increase in upper altitudes.

#### **Average Temperature Comparison**

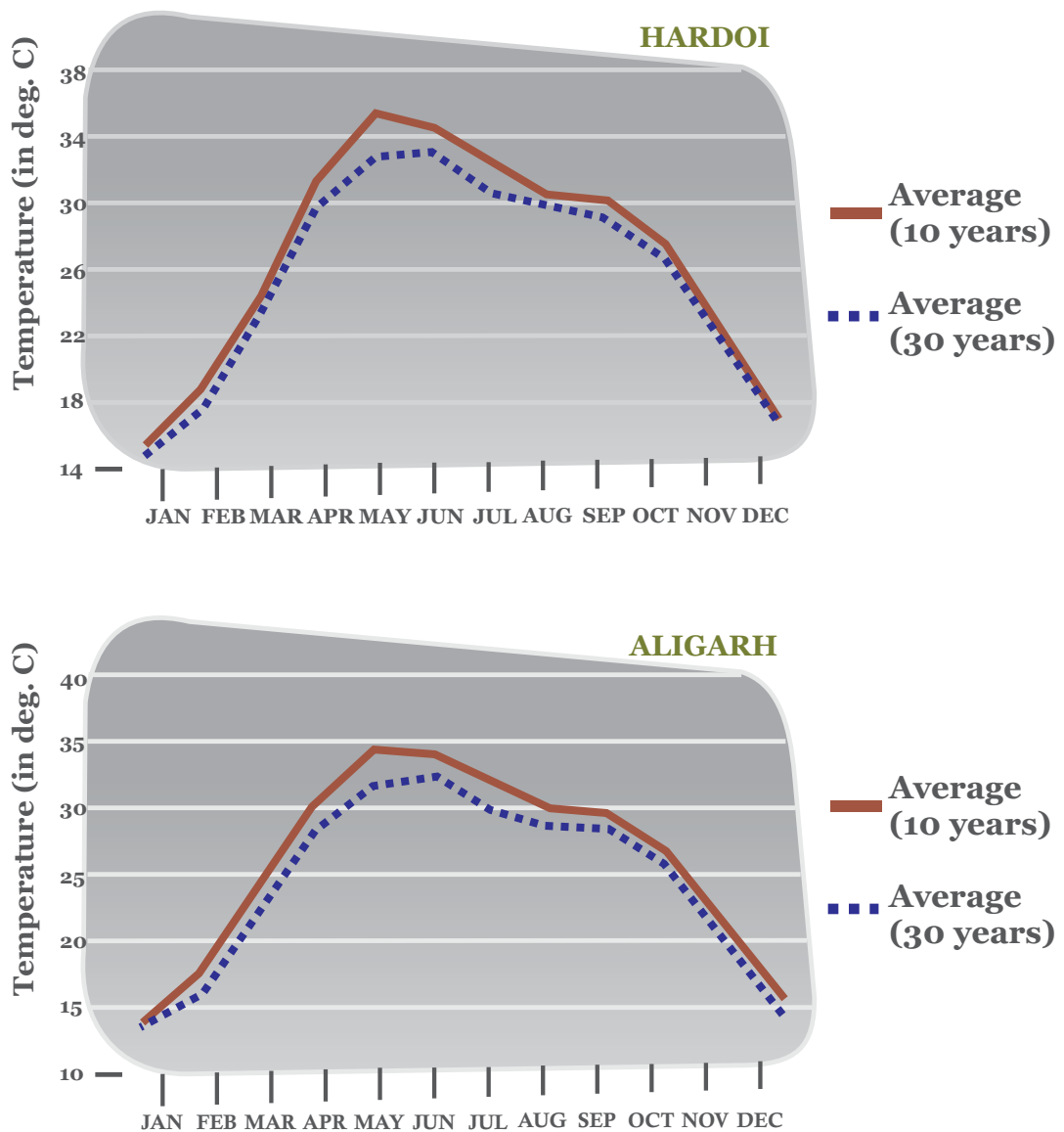
The data for a 10 years' period gave some trends of temperature increase more towards

Western UP. To substantiate this analysis and to have some analysis on seasonal aspects a comparison was done between the averages of 10 years' data (1995 -2005) with the long term normals data (1995 -2005) with the long term normals data (1995 -2005) with the long term normals data (1995 -2005) from India Meteorological Department (IMD) for a few randomly selected districts. In the case of temperature, the normals have been prepared using 30 years' of data (1971- 2000). The comparison in almost all cases shows a similar pattern of temperature round the year. However, what differs is the temperature figures. A small upward shift is observed in the 10 years' average from the 30 years' average. It is evident in the graphs given below for Aligarh and Hardoi. In both cases, the rise in temperature is seen more in the summer months of April and May. The data for **rainfall** does not highlight any significant changes. However, there are some trends of minor, non-statistically significant declines. In the case of Uttarakhand, the rainfall showed a declining trend over the last 10 years' (1995-2005), with a greater decline observed in the Gharwal region as compared to

the Kumaon region. An altitudinal trend is also evident through a reduction of more than 100mm of rainfall seen in the higher altitude districts of Pithoragarh, Uttarkashi and

Rudraprayag, as compared to negligible changes in the lower elevation districts of Udham Singh Nagar and Dehradun. However, in the case of UP, a mixed trend has been

**Fig. 4.3 Comparison of 10 years' average temperature with 30 years' average temperature for Hardoi and Aligarh**



observed and no clear conclusions could be deduced.

### Average Rainfall Comparison

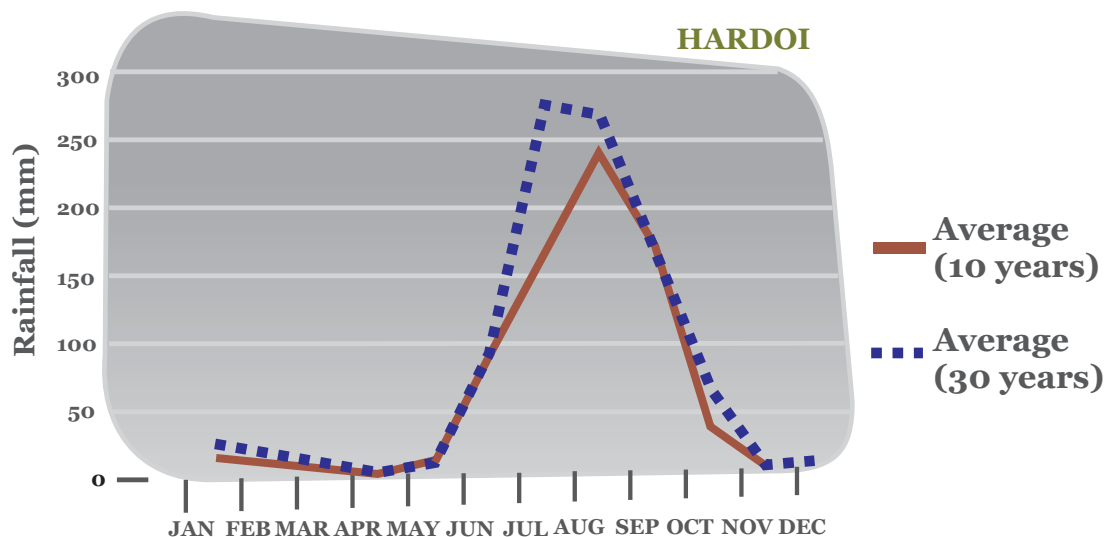
The rainfall data for 10 years time period (1995-2005) was compared with normals prepared using 50 years of data (1941-1990) for randomly selected districts. The analysis shows that there has not been much change in winter rainfall. However, a shift has been observed in monsoon rainfall. In some cases like Hardoi and Aligarh, the 30 years' average rainfall is well distributed in the months of July and August. However, it is evident from the 10 years' average that there has been a reduction in rainfall in the month of July and the rainfall is mainly seen only in the month of August.

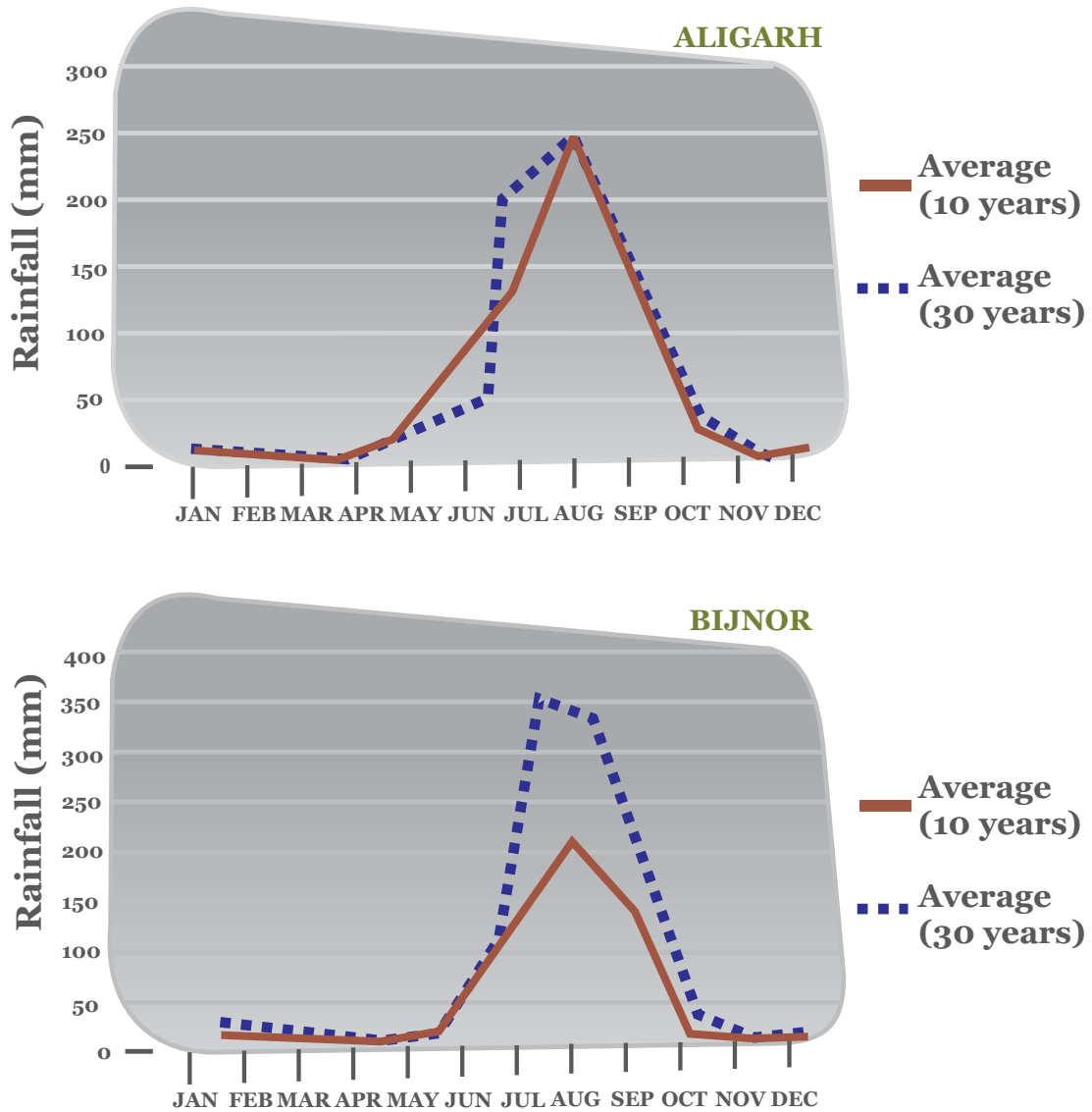
The data for Bijnor shows a total reduction in rainfall during the complete monsoon

period. As seen in *Fig. 4.4* the 10 years' average monsoon rainfall is considerably lesser than the 30 years' average.

These figures indicate changes in the climate parameters including seasonal shifts. Though this comparative analysis was done only for few districts, it does point towards changes which are taking place. Reduction in rainfall during the monsoon period can have serious implications for this region which is largely agriculture based. In spite of the fact that much of the agricultural land in this region is irrigated still lesser rainfall is bound to affect the surface and groundwater resources of the area with cascading effects on agricultural productivity. These likely impacts on water and agriculture can increase the vulnerability of people as well as the ecosystem.

**Fig. 4.4 Comparison of 10 years' average rainfall with 30 years' average rainfall for Hardoi, Aligarh and Bijnor**





#### 4.1.2 Demographic Profile

The combined demographic profile values as evident from (Fig. 4.5) *Demographic profile map*, are skewed and except for a few, most districts of UP and Uttarakhand have low to medium values. The higher values are clustered around the central region of Uttar Pradesh. Further analysis reveals a consistent trend of lower **sex-ratio**, and greater **population growth** in western parts of UP. In case of

the sex-ratio, reversed normalized values have been used so that low sex-ratio implies high exposure levels. Almost half of the total districts have high (>0.80) reverse normalized values for this variable. This innately means that the gender distribution is not good in these districts and they have low sex ratio values. This trend is particularly seen in the districts of Eastern UP including Ambedkar Nagar, Azamgarh, and Deoria, as well as the hilly districts of Uttarakhand such as Almora and Tehri.

Population growth has been the highest in the urban districts over the last ten years. In other places, there is a mixed trend with not much growth in the Bundelkhand region. The data for below poverty line (**BPL**) **households** significantly ranges from 8.6 to 74 % in the case of UP. Bahraich, Hardoi and Kaushambhi are among the districts having maximum values as more than 70% of the population is BPL. Many districts of Eastern and Central UP excluding the urban ones have high levels of poverty as 40-70 % of the households are BPL. In Uttarakhand's case although there is not much variation in data, the comparative analysis shows that the highest value for demographic profile is for Dehradun followed by Almora and Chamoli.

biophysical effects of climate change are broadly grouped under the sensitivity component. These include the changes in the natural ecosystems as well as managed systems such as agriculture. Changes in forest cover, land use pattern and groundwater extraction (in this case, only for UP) have been chosen as indicators of the **Ecosystem Profile**. As the agricultural sector forms a crucial and integral component of people and livelihoods in the Ganga Basin, a separate **agricultural profile** was incorporated in the Index. This profile includes the variables of changes in crop production, percentage of irrigated area, land utilization and percentage of agricultural workers out of the total workforce. Variations in the ecosystem and agriculture profile together govern the sensitivity levels of the districts.

## 4.2 SENSITIVITY

Sensitivity reflects the degree of response to a given shift in climate. As a result, the

As apparent from the sensitivity level distribution, almost the entire state of UP is in the medium to high division (*Fig. 4.6*). The area of western UP in particular has

**Fig. 4.5 Demographic Profile Value Distribution for the districts of Uttar Pradesh and Uttarakhand**



maximum number of districts in the highly sensitive category. Higher groundwater extraction and excessive dependence on irrigation are the governing factors for the elevated sensitivity values in these districts. Hence, the rising pressure on surface and groundwater resources as indicated through the data, the ecosystem and the agriculture system in this basin are likely to be more sensitive to the shifts in temperature and precipitation pattern. For the state of Uttarakhand, the division is mainly into low and medium category primarily because the highly influential variable of groundwater was not taken for this state. The only district which is an outlier is Udham Singh Nagar mainly due to a combination of maximum reduction in forest cover and larger area being dependent on irrigation.

#### 4.2.1 Ecosystem Profile

Although a majority of the districts in UP lie in medium or high category, a comparison

of the ecosystem profile values shows that Sonbhadra, Mirzapur, Chandauli on the Eastern border of UP and Balrampur in Western UP have the lowest values mainly because of lesser values of forest cover as well as groundwater extraction. The highest values for the ecosystem profile thus indicating greater sensitivity is for the districts of western UP mainly including - Shahjahanpur, Mainpuri, Hathras and Budaun which lie in the critical area (Fig. 4.7). In the case of Uttarakhand, most districts have low values with only two exceptions – Rudraprayag and Udham Singh Nagar.

Further analysis of the **forest cover** data shows that there has been a change in the range of -1 to +2 % in the districts of UP and Uttarakhand. Udham Singh Nagar, Ghazipur and Mau have the maximum values as there has been a decrease of more than 0.5 % of forest cover in these districts. Also, in most districts there has been a decrease in **area of land under Rabi**

**Fig. 4.6 Sensitivity Levels of the districts of Uttar Pradesh and Uttarakhand**



**crops**, the maximum being for Jhansi. On the other hand, an increase of land area under *Rabi* crops has been seen for Mainpuri, Lalitpur and Shahjahanpur. Likewise, in Uttarakhand there has been a decrease in land area under *rabi* crops in all the districts except Pithoragarh, Rudraprayag and Udham Singh Nagar. The land area under *Kharif* crops has mostly decreased in the districts of Eastern UP and Bundelkhand region whereas there has been minor increase in the Western side. In Uttarakhand, marginal decrease of **land area under Kharif crops** is seen in almost all districts except Rudraprayag, Udham Singh Nagar and Uttarkashi where there has been a substantial increase.

**Groundwater extraction** has been taken as the indicator for water resources due to data availability constraints. The stage of groundwater extraction is basically computed for irrigation, domestic and industrial uses including groundwater extraction from all structures during both

monsoon and non-monsoon seasons. When the stage of groundwater development is more than 100 %, it implies that the average annual groundwater consumption is more than average annual groundwater recharge (CGWB, 2006). There is large variation in the data for stage of groundwater development for the state of UP. The lowest values are for the Bundelkhand region primarily because the groundwater extraction level is low there but that does not make it less sensitive. This region faces sensitivity in terms of water scarcity. On the contrary, when moving towards the other side, most districts of Western UP lie in the semi-critical category, where the extraction lies between 70% to 90%. Budaun is the most over-exploited area with more than 100% stage of groundwater development followed by Hathras, Moradabad and Saharanpur in Western UP which lie in the critical category (>90 % extraction). An assessment of the extraction levels at block unit shows that most of the over-exploited blocks are located in Agra, Budaun,

**Fig. 4.7 Ecosystem Profile Value Distribution for the districts of Uttar Pradesh and Uttarakhand**



Baghpat, Hathras, J.P. Nagar, Moradabad and Saharanpur of Western UP. As Uttarakhand is a largely hilly state and has a mixed hydrological set up consisting of Gangetic alluvial plain and Himalayan mountain belt, so the ground-water data is available only for four districts and thus this variable was not taken for this state. The limited data available shows that Haridwar is most over-exploited district for groundwater extraction.

#### 4.2.2 Agriculture Profile

The aggregate of all the variables for the agricultural profile places most of the districts of UP predominantly in the high category. On the contrary, almost all the districts of Uttarakhand lie in the low to medium category (*Fig. 4.8*). The outcomes obtained for UP are primarily because of greater reliance of the agriculture system on irrigation and engagement of a large fraction of the working force in agriculture in this region.

A very high percentage (>90%) of agricultural land is irrigated in almost the entire state of UP. With the current trends, the water demand in this region is likely to only rise in the near future placing more pressures on the limited water resources. The only exception in this case is the Bundelkhand region where low percentages are seen. However, the area is quite sensitive even if the percentage of area irrigated is low as this particular area usually receives less rainfall along with lesser groundwater availability and if there is any reduction in rainfall the area and its rainfall dependent activities will be affected. On the other hand, in the case of Uttarakhand very less percentage of area is irrigated out of the net sown area mainly because of the hilly terrain. Udham Singh Nagar, Dehradun, Haridwar and Nainital are the only districts having high (50 to 90% area irrigated). Yet, these areas can also be considered sensitive as any changes in rainfall will have a direct impact on cropping pattern.

**Fig. 4.8 Agriculture Profile Value Distribution for the districts of Uttar Pradesh and Uttarakhand**



The other indicator which has been found to be predominant in this profile is the ratio of agricultural workers to the rest of the working population. A large number of districts have fairly large population (approximately three times than the other workers) dependent on agriculture for their livelihoods. In districts such as Shrawasti, Balrampur, and Siddharth Nagar the ratio is very high with the agricultural workers almost 6-8 times higher in proportion to the other workers. This shows that there is a significantly large population which has high dependence on agriculture, which is a climate sensitive sector.

health and educational facilities, road density can be the indicators of infrastructure development. Similarly, access to safe drinking water, lighting and *pucca* (permanent) houses indicate the extent of access to basic resources available to the population. Literacy rates and female work participation also determine the level of development of people. Together, these indicators are determinant of the socio-economic profile and consequently, of the adaptive capacity of the districts.

From the snapshot of the final component values, it is evident that most districts have very low adaptive capacity as the level of infrastructure development and access to basic amenities is substantially low (Fig. 4.9). Higher adaptive capacity values are seen only in the foremost urban districts such as Dehradun, Meerut, Gautam Budh Nagar, Ghaziabad and Lucknow. A majority of the districts are very low in provision of basic necessities of living especially in Eastern UP and Bundelkhand region as well

### 4.3 ADAPTIVE CAPACITY

Adaptive capacity denotes the capacity to cope with changes and adapt to the changing conditions. It is dependent on several socio-economic factors such as infrastructure development, access to key resources and literacy levels. For instance,

**Fig.4.9 Adaptive Capacity Levels of the districts of Uttar Pradesh and Uttarakhand**



as hilly districts of Uttarakhand. Even in terms of infrastructure development such as education and health facilities, these districts rank very low as compared to the few urban districts of the state showing discrepancy in development levels. These districts are also highly dependent on biomass (firewood, crop residue and cowdung cake) as a large proportion of the households (60-90%) use it as fuel for cooking purposes. The figure reflects the high dependence on natural resources for energy requirements.

The literacy rate values have been found to be low for some districts of Eastern UP and fairly high for the urban districts, but besides this the trend is not very clear for either of the states. For the variable of female work participation, clear distribution of values have been obtained with only few districts having larger numbers, essentially concentrated on the eastern side of UP. Some are also clustered in and around Bundelkhand region. On the other hand, districts having lowest values are mainly located in the Western region of Uttar Pradesh.

#### 4.4 VULNERABILITY INDEX

These variables on infrastructure and access to basic amenities show a general trend that the urban districts have better services and resources. The Bundelkhand region scores among the lowest values for these indicators. Other regions of eastern and central UP also have lesser values. This mainly implies that this area lacks in terms of infrastructure development and in case of any changes in the climate, these areas might not be able to cope with the severity. They need more attention for the general upliftment of these lesser developed areas of UP along with making them better adapted to climate change.

The final vulnerability index for the districts has been calculated by combining all the three

components of exposure, sensitivity and adaptive capacity. The cumulative values for the index lie between -1 and +1 with lesser value symbolizing lower vulnerability of the district (*Fig. 4.10 and Table 4.1 and 4.2*). The final values have been divided into four classes for the purpose of analysis. The districts with negative values (below 0) form one class of districts with are least vulnerable (represented in white) while the districts having high positive values ( $>0.13$ ) are the most vulnerable in comparison to others (represented in dark shade). Many districts which fall under least vulnerable category are the key urbanized districts of these two states such as Lucknow, Meerut, Ghaziabad and Dehradun. This is essentially because of better infrastructure development and improved access to basic amenities resulting in higher adaptive capacity of these districts. These values not only reduce the vulnerability levels of these districts but also offset the high exposure and sensitivity values. These numbers imply that better resilience of people can help in reducing their vulnerability. However, it may be noted that in many cases the district level value might be influenced by the values of a couple of developed cities and towns within that district while the rest of the region might still be backward.

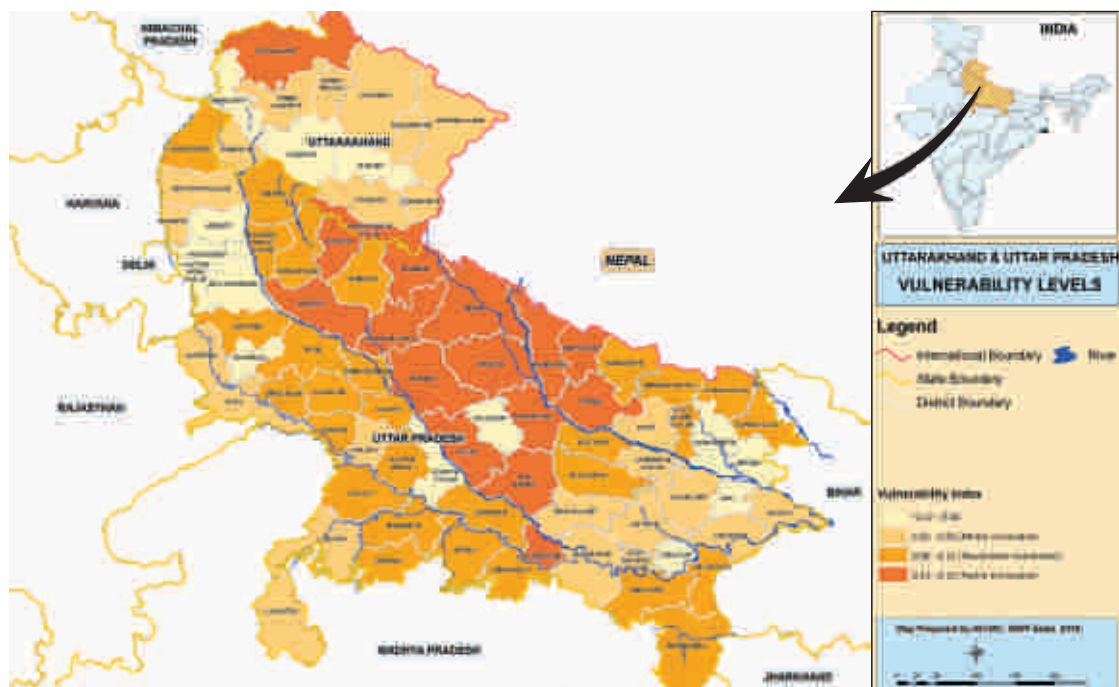
The least vulnerable category also includes some of the less developed districts of UP such as Hathras, Mau, Deoria and Gorakhpur. The adaptive capacity of these districts is quiet low. Still, they are coming out to be less vulnerable primarily because of low exposure values. Both the climatic and demographic profile values are low for these districts. A couple of districts such as Almora and Garhwal of Uttarakhand also fall in least vulnerable category because of low demographic values. The reasons for the low exposure values of these districts of both the states have been discussed in the earlier section (refer Section 4.1). In the case of

Uttar Pradesh, except Hathras, these districts lie in the Eastern region. Further, the neighbouring districts such as Azamgarh, Basti, Ballia and Ghazipur also fall in the less vulnerable category. On a regional scale and on the basis of the indicators of this study, it can be said that Eastern Uttar Pradesh is less vulnerable than the rest of the state.

The region between the Ganga and Yamuna River, mainly the Kanpur Circle of Central region covering the districts of Auraiya, Etawah, Kannauj and Kanpur as well as the Bundelkhand region are moderately vulnerable. While the Central UP region has high sensitivity levels, the Bundelkhand region scores dismally low in adaptive capacity levels. This also highlights the point that overall development of people is the key to reduce their vulnerability. In the case of Uttarakhand, the moderate vulnerable category includes districts such

as Rudraprayag, Champawat and Haridwar. Most districts along the river Ganga or in its flood plain are highly or moderately vulnerable. This mainly includes the districts such as Hardoi, Kheri, Unnao, Budaun and Pilbhit in UP and Uttarkashi and Udham Singh Nagar in Uttarakhand. This is because their exposure and sensitivity levels are very high whereas their adaptive capacity levels are very low. There has been comparatively more climatic variability in these regions due to uncertain precipitation pattern and increasing temperature over the last decade. The sex ratio is low and a large population is below poverty line. A combination of these factors has resulted in high exposure values. The pressure on the ecosystem is more in these districts with more land utilization, higher groundwater extraction and larger area under irrigation, which has made them more sensitive to any form of impacts in context of climate variability. Lower levels

**Fig.4.10 Vulnerability Levels of the districts of Uttar Pradesh and Uttarakhand**



of development in the form of infrastructure and low levels of access to resources as well as assets have resulted in lower coping capacity of the people in these districts which makes them more vulnerable to any form of impacts occurring due to climate change.

Overall, it can be said that a large part of the state is very vulnerable to changes in the climate as it is already stressed with

inequitable distribution and the allocation of natural resources such as water and low level of development. Being extremely important for the food security of the nation, some steps must be taken to reduce the vulnerability of this region. These include better natural resource management and measures for adaptation to climate change besides the better development of people.

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Critical sensitive sectors such as agriculture and water highlighted through the Vulnerability Assessment study

**Table 4.1 Vulnerability Index and component wise values for Uttar Pradesh**

District	Exposure			Sensitivity			Adaptive Capacity		Vulnerability Assessment Values
	Climate Profile	Demographic Profile	Total Exposure Values	Ecosystem Profile	Agriculture Profile	Total Sensitivity Values	Socio - Economic Profile	Total Adaptive Capacity	
Lucknow	0.48	0.61	0.57	0.66	0.50	0.52	0.77	0.77	-0.103
Gautam Buddha Nagar	0.46	0.58	0.54	0.54	0.41	0.42	0.64	0.64	-0.047
Meerut	0.69	0.41	0.50	0.58	0.55	0.50	0.59	0.59	-0.045
Kanpur Nagar	0.53	0.61	0.58	0.65	0.39	0.49	0.67	0.67	-0.044
Varanasi	0.63	0.59	0.60	0.63	0.48	0.49	0.68	0.68	-0.040
Gorakhpur	0.40	0.41	0.40	0.61	0.55	0.51	0.46	0.46	-0.031
Bulandshahar	0.57	0.35	0.42	0.61	0.54	0.51	0.46	0.46	-0.020
Hathras	0.34	0.38	0.36	0.73	0.60	0.59	0.39	0.39	-0.018
Deoria	0.39	0.33	0.35	0.66	0.64	0.57	0.38	0.38	-0.017
Mau	0.47	0.42	0.44	0.72	0.60	0.58	0.45	0.45	-0.006
Ghaziabad	0.71	0.61	0.64	0.52	0.54	0.46	0.65	0.65	-0.005
Basti	0.28	0.44	0.39	0.65	0.54	0.53	0.38	0.38	0.005
Mathura	0.65	0.43	0.51	0.63	0.59	0.54	0.50	0.50	0.005
Sant Ravidas Nagar Bhadohi	0.41	0.47	0.45	0.64	0.59	0.54	0.43	0.43	0.011
Baghpat	0.64	0.33	0.43	0.70	0.60	0.58	0.41	0.41	0.012
Agra	0.44	0.52	0.49	0.68	0.58	0.63	0.47	0.47	0.013
Allahabad	0.41	0.47	0.45	0.57	0.51	0.48	0.41	0.41	0.019
Jhansi	0.66	0.38	0.47	0.44	0.35	0.35	0.39	0.39	0.028
Azamgarh	0.54	0.32	0.39	0.67	0.65	0.58	0.34	0.34	0.029
Lalitpur	0.36	0.32	0.33	0.54	0.67	0.52	0.26	0.26	0.036
Auraiya	0.26	0.45	0.39	0.59	0.61	0.52	0.32	0.32	0.036
Ballia	0.68	0.40	0.50	0.61	0.60	0.53	0.36	0.36	0.037
Jaunpur	0.52	0.32	0.39	0.69	0.61	0.57	0.32	0.32	0.040
Pratapgarh	0.53	0.33	0.39	0.53	0.62	0.50	0.30	0.30	0.045
Muzaffarnagar	0.68	0.41	0.50	0.65	0.57	0.54	0.40	0.40	0.049
Ghazipur	0.54	0.42	0.46	0.65	0.61	0.56	0.37	0.37	0.050

## Uttar Pradesh

District	Exposure			Sensitivity			Adaptive Capacity		Vulnerability Assessment Values
	Climate Profile	Demographic Profile	Total Exposure Values	Ecosystem Profile	Agriculture Profile	Total Sensitivity Values	Socio - Economic Profile	Total Adaptive Capacity	
Ambedkar Nagar	0.36	0.45	0.42	0.62	0.67	0.56	0.33	0.33	0.051
Aligarh	0.68	0.39	0.49	0.67	0.57	0.62	0.40	0.40	0.056
Mahrajganj	0.51	0.43	0.46	0.54	0.74	0.55	0.33	0.33	0.061
Sonbhadra	0.47	0.56	0.53	0.17	0.32	0.21	0.22	0.22	0.064
Jalaun	0.59	0.45	0.50	0.45	0.44	0.39	0.33	0.33	0.066
Siddharth Nagar	0.43	0.42	0.43	0.65	0.64	0.56	0.31	0.31	0.068
Etawah	0.60	0.47	0.51	0.52	0.59	0.48	0.37	0.37	0.068
Fatehpur	0.40	0.40	0.40	0.62	0.50	0.50	0.25	0.25	0.070
Saharanpur	0.76	0.45	0.55	0.63	0.53	0.51	0.41	0.41	0.072
Firozabad	0.54	0.50	0.51	0.66	0.60	0.55	0.37	0.37	0.072
Bijnor	0.85	0.42	0.56	0.60	0.48	0.48	0.40	0.40	0.077
Sant Kabir Nagar	0.58	0.40	0.46	0.63	0.65	0.56	0.32	0.32	0.078
Sultanpur	0.52	0.39	0.44	0.62	0.56	0.52	0.29	0.29	0.078
Balrampur	0.46	0.42	0.43	0.42	0.34	0.34	0.27	0.27	0.078
Farrukhabad	0.59	0.50	0.53	0.63	0.52	0.51	0.37	0.37	0.082
Chandauli	0.40	0.49	0.46	0.39	0.68	0.45	0.27	0.27	0.085
Mirzapur	0.53	0.55	0.54	0.29	0.46	0.32	0.28	0.28	0.085
Chitrakoot	0.54	0.51	0.52	0.46	0.27	0.33	0.24	0.24	0.090
Moradabad	0.48	0.48	0.48	0.69	0.58	0.56	0.32	0.32	0.090
Hamirpur	0.45	0.50	0.48	0.51	0.38	0.40	0.24	0.24	0.095
Banda	0.62	0.44	0.50	0.47	0.33	0.36	0.23	0.23	0.097

## Uttar Pradesh

District	Exposure			Sensitivity			Adaptive Capacity		Vulnerability Assessment Values
	Climate Profile	Demographic Profile	Total Exposure Values	Ecosystem Profile	Agriculture Profile	Total Sensitivity Values	Socio - Economic Profile	Total Adaptive Capacity	
Faizabad	0.72	0.48	0.56	0.64	0.59	0.54	0.37	0.37	0.097
Mahoba	0.60	0.36	0.44	0.51	0.38	0.40	0.21	0.21	0.099
Kanpur Dehat	0.37	0.53	0.48	0.55	0.51	0.48	0.26	0.26	0.107
Kannauj	0.62	0.44	0.50	0.60	0.64	0.54	0.30	0.30	0.108
Bareilly	0.76	0.49	0.58	0.64	0.59	0.54	0.38	0.38	0.109
Kushinagar	0.60	0.47	0.51	0.52	0.59	0.48	0.29	0.29	0.111
Jyotiba Phule Nagar	0.81	0.45	0.57	0.68	0.41	0.49	0.33	0.33	0.118
Etah	0.59	0.45	0.50	0.68	0.62	0.57	0.29	0.29	0.121
Mainpuri	0.45	0.50	0.48	0.87	0.65	0.68	0.30	0.30	0.122
Barabanki	0.52	0.49	0.50	0.61	0.64	0.55	0.27	0.27	0.131
Gonda	0.68	0.43	0.51	0.60	0.60	0.53	0.26	0.26	0.132
Rampur	0.65	0.50	0.55	0.63	0.71	0.58	0.32	0.32	0.134
Unnao	0.44	0.50	0.48	0.60	0.62	0.53	0.22	0.22	0.138
Rae Bareli	0.67	0.44	0.52	0.62	0.63	0.54	0.26	0.26	0.141
Pilibhit	0.68	0.48	0.54	0.62	0.62	0.55	0.28	0.28	0.142
Kaushambi	0.58	0.58	0.58	0.59	0.47	0.47	0.27	0.27	0.152
Kheri	0.48	0.56	0.53	0.55	0.54	0.48	0.20	0.20	0.157
Shahjahanpur	0.42	0.55	0.51	0.74	0.65	0.61	0.23	0.23	0.166
Shrawasti	0.68	0.65	0.66	0.60	0.59	0.52	0.29	0.29	0.193
Sitapur	0.60	0.58	0.58	0.60	0.58	0.52	0.20	0.20	0.196
Budaun	0.64	0.48	0.53	0.72	0.68	0.61	0.20	0.20	0.203
Bahraich	0.59	0.61	0.60	0.63	0.46	0.49	0.18	0.18	0.206
Hardoi	0.39	0.63	0.55	0.71	0.58	0.57	0.17	0.17	0.216

**Table 4.2 Vulnerability Index and component wise values for Uttarakhand.**

District	Exposure			Sensitivity			Adaptive Capacity		Vulnerability Assessment Values
	Climate Profile	Demographic Profile	Total Exposure Values	Ecosystem Profile	Agriculture Profile	Total Sensitivity Values	Socio - Economic Profile	Total Adaptive Capacity	
Almora	0.45	0.24	0.31	0.30	0.47	0.40	0.60	0.60	-0.117
Garhwal	0.52	0.11	0.25	0.34	0.22	0.27	0.57	0.57	-0.087
Dehradun	0.60	0.78	0.72	0.36	0.36	0.36	0.78	0.78	-0.024
Rudra Prayag	0.69	0.28	0.42	0.73	0.38	0.53	0.42	0.42	-0.001
Champawat	0.34	0.35	0.35	0.24	0.58	0.44	0.35	0.35	0.001
Haridwar	0.52	0.71	0.65	0.40	0.47	0.44	0.64	0.64	0.005
Tehri Garhwal	0.63	0.39	0.47	0.24	0.39	0.32	0.45	0.45	0.005
Pithoragarh	0.82	0.28	0.46	0.31	0.56	0.45	0.40	0.40	0.026
Bageshwar	0.72	0.26	0.41	0.29	0.73	0.54	0.36	0.36	0.028
Nainital	0.62	0.65	0.64	0.38	0.56	0.48	0.55	0.55	0.046
Chamoli	0.77	0.36	0.50	0.37	0.32	0.34	0.34	0.34	0.053
Udham Singh Nagar	0.29	0.80	0.63	0.92	0.65	0.76	0.44	0.44	0.148
Uttarkashi	0.91	0.45	0.60	0.45	0.47	0.46	0.25	0.25	0.163

## CONCLUSION AND NEXT STEPS

Paying a closer attention to the nexus between development and the consequence of climate change impacts is essentially critical in the context of planning adaptation measures to reduce current and future vulnerabilities. In regions or ecosystems where there are significant resource depletion and development deficits, it is important to bear in mind that the scales at which climate change will impact is expected to have significant bearing on developing adaptive solutions. The need for appropriate response to adaptation would be irrelevant if climate had no discernible influence on development. However, this is not true for a number of reasons. As presented in the previous chapter, there is a growing body of evidence that climate change is already a serious factor affecting livelihoods and ecosystems across the Ganga Basin. The vulnerability of geographical regions, districts in this case, which have extensive and direct dependence on ecosystem resources show a much direct impact on livelihoods. Observed changes in the biophysical environment (shifts in temperature and rainfall patterns) together with degradation in quality and quantity of ecosystem resources (change in land use and forest cover, shifts in irrigation pattern including over dependency on groundwater) and limited adaptive capacity of the communities are difficult to ignore. In order to deal with the changes and vulnerabilities caused by climate change, a two fold action can be taken. Firstly, adaptation strategies must be developed based on the known impacts of

climate change and the current situation. Thereafter, a long-term response strategy should be evolved based on long-term models and their subsequent results. It is also evident that the impact on ecosystems and livelihoods of people may also set back moderate gains made from development efforts through existing development programmes, unless these programmes are not made climate proof. In the absence of such attention, it is likely that adaptation strategies to climate impacts will have much higher costs in the future to tackle climate change.

### 5.1 KEY LESSONS

This study puts forward a methodology and a set of broad indicators to identify areas of high vulnerability in the two states of the Ganga Basin. As the assessment is entirely based on secondary data, the lessons learnt have been mainly used for identifying intervention areas and not for making policy recommendations. It provides a gateway for conducting more detailed community level assessments the results of which can be further used for policy advocacy. As discussed in previous chapter, the districts in the state of Uttarakhand and Uttar Pradesh in the Ganga Basin were classified into four classes from being least vulnerable to being most vulnerable. As observed in the concluding section of the last chapter, the districts with stronger adaptive capacity emerged as least vulnerable and most of these were urban districts. However, it does

not imply that these urban districts are less vulnerable. They are still vulnerable not only from the context of high exposure to climate variables but also from direct impact on people, infrastructure and the ecosystem resources. For example, even though Kanpur Nagar gets classified as least vulnerable, from the assessment of other studies undertaken under the Living Ganga Programme (Sinha, 2010), it is evident that there are high levels of stress on water resources including inefficiency in their distribution along with utilization and increasing pressure on freshwater resources due to the high level of water pollution and poor measures of pollution abatement.

Despite high ecosystem vulnerability and low adaptive capacity, districts of Eastern UP were found to be less vulnerable due to low values of demographic profile. While this result is somewhat surprising, especially as these districts have high levels of poverty (and were expected to be more vulnerable), their vulnerability to climate variability is high along with the vulnerability to ecosystems variables.

It has also emerged that the southern districts of central Uttar Pradesh are moderately vulnerable owing to the high sensitivity of the ecosystem variables. These districts are vulnerable from water and forest resources and increasing pressure on land due to changing land-use pattern. However, the northern districts of Central Uttar Pradesh are highly vulnerable due to high exposure and sensitivity and low adaptive capacity. The Bundelkhand region of Uttar Pradesh is vulnerable mainly due to low adaptive capacity of the districts. These districts which are semiarid and drought prone, are witnessing climate variability of extreme nature. However, the productivity of the land remains low and alternative livelihoods for the communities here remain

limited. These factors combined with a series of development programmes aimed at enhancing the adaptive capacity resulting in maladaptation, have further magnified the Bundelkhand region's high vulnerability to current as well as future impacts of climate change. However, the recent policy measures in the form of Bundelkhand package for the region is expected to motivate development programmes which are sound as well as sensitive to climate impacts.

Unlike the previous analysis, a much more complex scenario emerges from the districts of western Uttar Pradesh, with these districts falling in all four classes of vulnerability assessment. It has districts lying in all four categories of vulnerability with the more developed ones being the least vulnerable. The districts along the river Ganga and those in its flood plains are either highly or moderately vulnerable. This is owing to three factors-high exposure, sensitivity levels and low adaptive capacity. While being a major contributor to the food basket of India, these districts are also witnessing a climate variability and increasing pressure on the ecosystem.

The districts of Almora and Garhwal in the state of Uttarakhand, appear as the least vulnerable despite their high exposure to climate variability and vulnerability. These districts hold some of the most diverse ecosystems of the Indian Himalayas, which are quite sensitive to climate variability. The districts of Rudraprayag and Champawat emerge as moderately vulnerable due to their high sensitivity and their low adaptive capacity. The Uttarkashi district and the Udham Singh Nagar district have very high vulnerability index. This is primarily due to high exposure index. In the case of the Udham Singh Nagar district, the dependence on irrigation (surface and

groundwater) is very high and this has resulted in high sensitivity values. On the other hand along with high exposure, lack of infrastructure development and high biomass dependency have resulted in low adaptive capacity values for the Uttarkashi district, making it highly vulnerable.

livelihoods. Diversification of livelihood opportunities and better management of ecosystem resources needs to be a part of the development thrust.

Climate change adaptation requirements are likely to restrict the range of development pathway choices that would otherwise be available or development efforts that may have intended or unintended environmental co-benefits. Adaptation would require the evaluation of different technical options to factor in future climate change effects. The identification of specific requirements which are dictated by climate change considerations appears to be mired with uncertainties. In this context, it is important to design and implement various adaptation measures against the short and medium-term impacts that they can have on the lives of the vulnerable sections of the population, by intervening at the variables which are sensitive to climate change impacts.

## 5.2 WAY FORWARD

The issue of climate change adaptation is not restricted to addressing challenges posed by vulnerability alone. On the contrary, it is linked to good development practice of which human development and livelihood security is clearly a significant component. As seen from the vulnerability analysis, higher levels of exposure to the negative impacts of climate change is also correlated to direct dependence on natural resources and excessive utilisation. Reducing such exposure would involve the reduction from the current levels of direct dependence on the ecosystem resources for

**Fig. 5.1 Highly vulnerable and sensitive districts for identifying adaptation intervention areas**



Ecosystem services such as water and land-use, which have a direct impact on livelihood and human development as a part of the ecosystem, need to be designed and implemented.

Ecosystem based adaptation interventions can help in building resilience to climate impacts and uncertainty regarding the natural resource management of a region. Integrating the principles of biodiversity and ecosystem services into the overall adaptation strategy forms the basic premise of ecosystem based adaptation. Such interventions are not only cost-effective but also provide social and economic benefits. This can subsequently help in enhancing the resilience of communities dependent upon these natural resources for securing their livelihood options. With this rationale the results of the vulnerability assessment were used to identify highly sensitive and vulnerable districts in the critical stretch of the Ganga basin for ecosystem based adaptation interventions. In order to identify the vulnerable districts which are also highly sensitive, the sensitivity map was overlaid on the overall vulnerability index map (*Fig.5.1*). The resultant map highlighted districts along the river such as Budaun, Mainpuri, Etah, Hardoi and Unnao which have high sensitivity as well as vulnerability levels. Over-extraction of groundwater as well as surface water for irrigation are main causes of high sensitivity level and highlight the inefficient irrigation practices and indicated a nexus between water and energy in these districts. Variability in rainfall patterns further negatively impacts the water availability scenario in these areas. Growing agricultural practices involving use of chemical fertilizers and pesticides, and irrigation practices with improper drainage channels have affected the soil quality in this region. These changes have in

turn impacted the natural wetlands of this region which are critical for the health of the ecosystem and are key habitats for many species.

In the backdrop of climate change, efficient and an effective management of natural resources assumes vital significance. As noted previously in the vulnerability analysis, the growing stress on land and water is projected to be one of the most significant impacts of climate change for people and their livelihood in the Ganga basin. Thus to counter these inevitable changes, special initiatives need to be devised and implemented and lessons from these initiatives then should be used to design effective policies. This consequently shows the need to base our adaptation initiatives centered on the management of key natural resources in response to the likely changes in the climate. It also shows the requirement of mainstreaming adaptation in the development process.

The Living Ganga Programme of WWF-India has initiated ecosystem based adaptation interventions in the Ganga Basin. The overall goal of this adaptation programme has been to reduce the vulnerability of the communities by enhancing their resilience and adaptive capacity with respect to water resources. Inputs from the macro level vulnerability assessment conducted for this basin along with stakeholder consultation have been instrumental in designing the adaptation interventions. Broadly these interventions are centered around water conservation through water storage and irrigation efficiency; sustainable agriculture and wetland restoration. Based on these broad themes, there are four adaptation pilots which are being implemented in the Ganga Basin. Each of these pilots have a combination of techniques and measures to achieve the objectives of the broader

adaptation goals. The four adaptation interventions are as follows:

- **Efficient irrigation practices in districts with canal irrigated areas:**

A recent study on problems and prospects of saving water and energy in agriculture in Upper Ganga River Basin, highlights that the overall efficiency of the Kanpur Branch Canal is only approximately 30% and for other irrigation systems in Uttar Pradesh including canals the efficiency lies between 30%-40% (Sinha, 2010). According to 'The National Commission on Integrated Water Resources Development and Plan' (NCIWRDP), approximately 20% increase in irrigation efficiencies is easily achievable in these systems and this alone can result in substantial savings. Thus, strategies involving efficient irrigation practices and better water management can be potentially beneficial adaptive measures.

- **Soil and land management to enhance productivity and reduce environmental degradation of land:**

Accumulation of toxic salts and poor irrigation management over the years has deteriorated the soil quality of large parts of Uttar Pradesh and consequently they have been facing the problems of sodification and declining crop productivity. Environment friendly measures of soil and land management through organic methods can be helpful in improving the soil quality of the region.

- **Managing groundwater and energy nexus in agriculture and addressing options of cropping pattern change and economic policies for water and energy in irrigated agriculture:**

Canals are not the only source of irrigation in these fields. Approximately one-third of

water requirement is met by tubewells during the water shortage periods of canal. However, the figures of total water depth provided by both sources as compared to the total requirement reveals that much more water is being pumped than required. Lack of awareness among farmers along with poor irrigation and water management result in substantial amount of water and energy being wasted. Even a small measure of improvement (for instance 10% improvement) in distribution and application efficiencies can save 1.82 BCM of water in case of canals. In the case of shallow tube wells, 63 million kWh of electricity can easily be saved. Such solutions can be incorporated in the overall ecosystem based adaptation plans.

- **Management of soil and water for restoration of critical habitats for species conservation:**

Wetlands in this region suffer from various problems like shallow water and high water turbidity. Completely or partially dried lakes are used for cultivation of crops leaving remnants of modern agriculture and degrading the natural reservoirs of water. Restoration of these lakes and water bodies is essential for recharging the water level of aquifers and the survival of flora and fauna of the area.

It is necessary to bring the climate risk information to the mainstream to build the capacities of communities to deal with change. Access to information is critical and this requires diffusion of agrometeorological system with advanced scientific capabilities that can deliver information targeted to appropriate recipient populations. There is also a need for sophisticated and detailed information that is presented in an accessible form for the people.

Equity considerations suggest that the best strategy would be a greater regulation of resources by community participation with the state providing enabling policy frameworks. Instituting governance mechanisms that have a tendency to treat unequal stakeholders as equals in the governance process is also critical for adaptation strategies.

Considering the inherent limitations in these adaptation strategies, the economic growth of the country becomes a key factor in accelerating changes. This is consistent with India's National Action Plan on

Climate Change (NAPCC) which focuses on two points. Firstly, protecting the poor and the vulnerable through inclusive, sustainable development that is sensitive to climate change issues. The second point in NAPCC highlights the need to achieve growth objectives through a qualitative change in ecological sustainability and mitigating greenhouse gas emissions. In order to achieve these imperatives, there is a need for integrating development strategies with adaptation and appropriate response strategies.

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## KEY OBSERVATIONS AND PROJECTIONS FROM NATIONAL COMMUNICATION AND INCCA

Parameter / Resource	National Communication <sup>1</sup>	INCCA <sup>2</sup>
Temperature	An increase of 0.4°C in annual average surface air temperature observed over the last 100 years.	A significant warming trend of 0.51°C per 100 years, observed in annual mean temperature during the period 1901–2007 (Kothawale et al., 2010). Accelerated warming observed between 1971 and 2007 by about 0.2°C per decade, mainly due to intense warming in the recent decade 1998–2007 contributed by increasing temperatures in the winter and post-monsoon seasons. Much steeper increase in minimum temperature than maximum temperature.
	Maximum temperatures expected to rise by the 2050s by 2°C – 4°C over South India (i.e south of latitude 25° N) and by more than 4°C over Northern India (north of latitude 25°N). Minimum temperatures expected to rise by more than 4°C over entire India in the same period.	All-round warming indicated by PRECIS simulations for the 2030s over the Indian subcontinent. The likely rise in annual mean surface air temperature by the 2030s ranges from 1.7°C to 2.0°C. The variability of seasonal mean temperature may be more in winter months
Rainfall	No significant change observed in the total rainfall delivered by the monsoon. However, regional variations are observed, ranging	No significant trend. However, the average figure shows a slight negative trend i. e. -0.4mm/year. Regions with increasing/decreasing trends over

<sup>1</sup> The projections made in the NATCOM report are not time –bound

<sup>2</sup> The INCCA report gives projections for 2030s.

	<p>from increases of 10-12% over some regions and decreases of 6-8% in the others.</p>	<p>India seen. Trend analysis of 1-day extreme rainfall series based on the period 1951-2007, indicate that the extreme rainfall amounts are increasing at many places in India</p>
	<p>The total rainfall from the monsoon is expected to be relatively unchanged through to the 2050s. However the spatial variability of the rainfall is likely to be extended. A decrease in the number of rainy days is expected with a corresponding increase in rainfall intensity in terms of rainfall per day ranging from 1-4mm/day.</p>	<p>A small increase likely in annual precipitation in the 2030s with respect to the baseline in many regions. However on a seasonal scale, except for the Himalayan region, all other regions are likely to have lower rainfalls in the winter period as well as pre-summer period. Spatial patterns of monsoon rainfall indicate a significant decrease in the monsoon rainfall in future except in some parts of the southern peninsula. The frequency of the rainy days is also likely to decrease in most parts of the country.</p>
<p>Cyclonic storm</p>	<p>While the average frequency of cyclonic storms over the period 1887-1987 appears to be unchanging, there appears to be a slight increase in the frequency of severe cyclonic storms in recent decades.</p>	<p>Observations since 1986 indicate a decreasing frequency in cyclones along the eastern coast surrounded by the Bay of Bengal and the Northern Indian ocean. No trend is seen in the western coast – along the Arabian sea – for the same period.</p> <p>The projected number of cyclonic disturbances along both the coasts in the 2030s is likely to decrease with respect to the 1970s.</p>
<p>Extreme events</p>	<p>The severity of droughts and intensity of floods is likely to increase. Preliminary results suggest that peak discharge</p>	<p>An increase in the drought development is projected in those areas that have either a projected decrease in precipitation or an enhanced level of</p>

	<p>under climate change could be as high as twice the current peak discharge in some basins.</p>	<p>evapotranspiration in the 2030s. Moderate to extreme drought severity is pronounced for the Himalayan region where the increase is more than 20% for many areas despite the overall increase in precipitation.</p> <p>Change in peak discharge indicates that flooding in the 2030s varies between 10% and over 30% of the magnitudes in the 1970s in most of the regions.</p>
Water	<p>Surface run off patterns are likely to change, with reduction of the runoff in many river basins. Varying levels of water shortage are likely to appear across different basins ranging from severe to little variation. Perennial water shortages are expected in the Mahi, Pennar, Sabarmati and Tapi basins. Seasonal water shortages and regular water-stressed conditions are expected in the Ganga, Cauvery, Narmada and Krishna river basins. The Godavari, Mahanadi and Brahmani basins are likely to experience only moderate water-shortage at a few locations.</p>	<p>Water resources have been assessed in terms of water yield in the various river basins which is the total surface runoff, and is usually a function of the precipitation, its distribution, evapotranspiration (ET) and soil characteristics. Water yield shows a mixed trend with increase in some regions while decrease in other.</p>
Water Glaciers and snowfields	<p>The Himalayan glaciers and snowfields are generally on the decline though there is need for substantial further scientific work to establish more accurately the changes taking place.</p>	<p>Fluctuation in retreat rates observed in the glaciers during the last century with most of the glaciers in Western Himalayas receding. Long term monitoring and database required for climate change assessment regarding impacts of rising temperature and reducing snowfall on glacier mass balance.</p>

Sea – level rise	<p>Sea-level rise along India's coastlines currently ranges between 0.4-2 mm per year with the highest increases along the coast in the Gulf of Kutch and coastal West Bengal.</p>	<p>The mean sea-level rise along the Indian coasts is estimated to be about 1.3 mm/year on an average. A large trend of 5.74 mm/year of sea level rise has been recorded at Diamond Harbour (Kolkata), which is attributed partly to the subsidence of the Ganges-Brahmaputra delta.</p>
	<p>Though considerable uncertainties are involved in estimating the sea-level rise in the future along specific sections of the coastline, it is estimated that a general sea-level rise of up to 1 m may be expected by the end of the century.</p>	<p>Model-based projections of global average sea level rise at the end of the 21st century (2090–2099) made for a number of climate scenarios indicate that the sea level may rise from a minimum of 0.18 m to a maximum of 0.59 m.</p>
Agriculture	<p>Irrigated rice yields might have a small gain, irrespective of the scenario throughout India. Negative effect on productivity likely due to reduced crop durations as a result of higher temperature increase.</p>	<p>Decrease in rice production likely in South India in the range of 4 – 20 % with regional variation whereas the production for North Eastern region could vary between -10% and 5% (for irrigated) and -35% to 5% (for rain-fed) depending upon the region. Crops like maize and sorghum are also expected to decrease across many regions. Production of cash crops such as coconut might increase by 10 to 40% due to CO<sub>2</sub> fertilization.</p>
Natural Ecosystems and Biodiversity	<p>Net primary productivity (NPP) of forest ecosystems projected to increase due to enhanced levels of CO<sub>2</sub>. Rising salinity would favour mangrove plants that tolerate higher salinity. An increase in sea-surface temperature would lead to the bleaching of corals. Coral reefs could also be potentially impacted by sea-level rise.</p>	<p>Decrease in net primary productivity is projected in forest vegetation. Increase in temperature will lead to coral bleaching. Increasing salinity in coastal areas due to sea level rise might favour higher salt tolerant varieties of mangroves.</p>

Source: NATCOM, MoEF, 2004; INCCA, MoEF, 2010

# REVIEW OF VULNERABILITY ASSESSMENT METHODOLOGIES

## Methodology

### Vulnerability Mapping for South East Asia

The aim of this exercise was to identify the most vulnerable regions in the light of climate change. A quick assessment was done to assess the current vulnerability in the study area using available past and present data. Following the standard IPCC definition indicators were chosen under exposure, sensitivity and adaptive capacity. Climate related hazards were used to determine the exposure levels. Sensitivity of the region was assessed on the basis of human sensitivity (population densities) and ecological sensitivity (% of protected areas). However, while calculating final sensitivity values higher weightage was given to human sensitivity. Socio economic factors, technology and infrastructure together comprised the adaptive capacity index. The overall vulnerability index was calculated by combining the above three factors. The values in case of data were standardized using UNDP Human Development Index formula.

### Farming Sector Vulnerability to Climate Change and Variability

This study was carried out to compare the vulnerability of the agriculture sector across the provinces of South Africa. A set of 19 indicators of the agriculture system were chosen under the three components of IPCC – Exposure, Sensitivity and Adaptive Capacity. The data for the indicators was standardized using the Human Development Index Formula. Weights were assigned to the indicators using Principal Component Analysis (PCA). Data Analysis and statistical software was used to run the PCA with the indicators. The final vulnerability index

## Application

### Case Study:

Climate Change Vulnerability Mapping for Southeast Asia

### Focus Area:

Vulnerability of regions to climate change

### Study Area:

Sub-national areas/ units of Southeast Asian countries (Thailand, Vietnam, Laos, Cambodia, Indonesia, Malaysia, and Philippines)

### Reference:

Yusuf A. A. and Francisco H., 2009. Climate Change Vulnerability Mapping for Southeast Asia. Economy and Environment Program for Southeast Asia (EEPSEA).

### Case Study:

Mapping South African Farming Sector Vulnerability to Climate Change and Variability

### Focus Area:

Agriculture Sector

### Study Area:

South Africa

was calculated by using the formula:

$$V_j = \sum_{i=1}^k [b_i (a_{ji} - x_i)] / S_i$$

where, v was the vulnerability index, b was the weight from PCA, a was the indicator value, x was the mean indicator value, and S was the standard deviation of the indicators. Using this methodology the most vulnerable region of the study area was determined.

### **Livelihoods Vulnerability Index (LVI – IPCC) Approach:**

The LVI consists of seven major components under the three IPCC defined broad categories of **Exposure, Sensitivity** and **Adaptive Capacity**. Each of these components has several indicators under them chosen on the basis of literature review and the practicality of collecting the needed data through household survey.

The LVI uses a balanced weighted average approach where each indicator contributes equally to the overall index even though each major component is comprised of a different number of indicators. The value for each indicator is first standardized as an index using the Human Development index formula.

The standardized values for the indicators were combined then to get the value of each major component.

Subsequently, values of the components under an IPCC defined category were combined to get the value for that category.

Once the values of the 3 categories were calculated, they were combined to get the vulnerability index using the formula:

**Livelihood Vulnerability Index = (Exposure – Adaptive Capacity) x Sensitivity**  
The Scaling of the LVI was done from -1 to +1 indicating low to high vulnerability.

### **Data Collection Method:**

Analysis for provinces of South Africa using secondary data

### **Reference:**

Gbetibou G. A. and Ringler C., 2009. Mapping South African Farming Sector Vulnerability to Climate Change and Variability - A Subnational Assessment. IFPRI Discussion Paper 00885

### **Case Study:**

The Livelihood Vulnerability Index: A pragmatic approach to assessing risks from climate variability and change—A case study in Mozambique

### **Focus Area:** Livelihood

### **Study Area:**

Moma and Mabote Districts of Mozambique

### **Data Collection Method:**

District level study using Household Survey

### **Reference:**

Hahn, M.B., et al., The Livelihood Vulnerability Index: A pragmatic approach to assessing risks from climate variability and change—A case study in Mozambique. Global Environ. Change (2009), doi:10.1016/j.gloenvcha.2008.11.002

## Mapping Vulnerability to Multiple Stressors

Unlike the conventional studies which assess vulnerability to climate change in isolation from other stressors this study maps the vulnerability to two stressors at the district level for the country of India. The approach basically is to develop a national vulnerability profile for climate change and a separate national vulnerability profile for an additional stressor followed by superimposing the two profiles to identify the districts in India that are 'double exposed'. Case studies were conducted in selected districts.

For assessing the vulnerability to climate change the three major components of exposure, sensitivity and adaptive capacity were considered with few crucial indicators under each of them. For the exposure and sensitivity components a climate sensitivity index was constructed based on past 30 years data followed by the incorporation of projection results from HadRM2 model, a regionally downscaled GCM. For measuring the adaptive capacity, significant biophysical, socio-economic, and technological factors that influence agricultural production were taken.

To get the final climate change vulnerability map these three indices were combined. The map represents current vulnerability to future climate change across districts.

The vulnerability to globalization considered the structural changes due to trade liberalization. In this case also indicators were taken under the same three components.

Finally, The climate and globalization vulnerability maps were combined to identify areas that are vulnerable to both stressors.

### **Case Study:**

Mapping vulnerability to multiple stressors: climate change and globalization (TERI).

### **Focus Area:**

Agricultural vulnerability to two stressors: climate change and economic globalization

### **Study Area:**

All the districts of India

### **Data Collection Method:**

District level study using secondary data

### **Reference:**

O'Brien et al., 2004. Mapping vulnerability to multiple stressors: climate change and globalization in India. *Global Environmental Change* 14, 303-313.

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## Vulnerability Assessment of Freshwater Resources

The analysis in this study is based on the premise that the vulnerability assessment of a river basin must have a precise understanding of the four major components of the water resource system which are

### **Case Study:**

Vulnerability Assessment of Freshwater Resources to Environmental Change

**i)** total water resources **ii)** water resources development and use **iii)** Ecological Health; and, **iv)** management. Each of these components had indicators under them. A composite vulnerability index was calculated based on these four components.

In order to quantify the vulnerability index, the indicators for each component were determined and quantified. The value of vulnerability ranges from 0 to 1.0, with 1.0 indicating the most vulnerable situation.

To give the final **VI** value in a range from 0 to 1.0, the following rules were applied in assigning the weights: **(a)** the total of weights given to each indicator should equal 1.0; and **(b)** the total of weights given to all components should equal 1.0. To avoid bias equal weights were assigned among indicator in the same component, as well as among different components.

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### **Bushfire Vulnerability Assessment**

As an initial step of vulnerability assessment a conceptual model was developed to highlight key drivers of vulnerability. Indicators for different drivers of vulnerability were identified under the three broad categories of Exposure, Sensitivity and Adaptive Capacity. The indicators were chosen from data that were readily available to the public. As the data for the variables was at different scales, firstly, the data was processed using Arc GIS to bring to a homogenous scale. Once this was done, the data was then assigned a qualitative ranking from 1 to 5. In case of exposure and sensitivity 1 represents low exposure or sensitivity while for the indicators of the third category it meant high adaptive capacity. Scoring was done by dividing the frequency distribution for data into quintiles of roughly equivalent size using Arc GIS.

The data for the indicators was integrated for each component using the Spatial Analyst extension of Arc GIS to prevent any one component from biasing the results. Individual indicators for a component were weighted equally due to lack of knowledge about their relative importance or the quantitative relationships among variables. However, the 3

**Focus Area:**  
Freshwater resources

**Study Area:**  
Ganges-Brahmaputra - Meghna River Basin, Helmand River Basin and Indus River Basin

**Data Collection Method:**  
Basin level study using secondary data.

**Reference:**  
Babel. M.S. and Wahid. S. M. (2008) Freshwater under threat—South Asia. Vulnerability Assessment of Freshwater Resources to Environmental Change. UNEP, South Asia. 29 pp.

**Case Study:**  
Igniting change in local government: lessons learned from a bushfire vulnerability assessment

**Focus Area:** Bushfire

**Study Area:** Sydney, Australia

**Data Collection Method:**  
Secondary data collection

components were given different weights due to expert judgment regarding their relative importance. The sum for a particular component were then rescored to a scale from 1 to 9 based on quantiles where 1 represented low exposure or sensitivity and conversely high adaptive capacity. Final vulnerability was arrived at by integrating the scores of the three components and again scoring it to a scale of 1 to 9 showing low to high vulnerability.

### **Vulnerability and Capacities Index (VCI)**

This methodology is to assess the vulnerability in disaster and extreme climate risk regions. The VCI comprises of three dimensions of vulnerability – material (income, education), institutional (infrastructure, social capital) and attitudinal (sense of empowerment) with eleven critical drivers of vulnerability under them; and is applicable for measuring differential vulnerability at the household and community level in both rural and urban areas.

The VCI covers the differential dimensions of vulnerability among different social groups and also the households within such groups. The overall weightage distribution for the three categories is 35, 50 and 15% which has been assigned by literature review and expert consultation. The internal weights for the indicators within the dimensions are assigned differently for the household and community level assessments as well as for the rural and urban areas.

The values of material, institutional and attitudinal vulnerabilities were combined to get the overall vulnerability of the target group and to make the comparisons with the other target groups for assessing who is more vulnerable.

### **Reference:**

Preston, B. L. et al., 2008. Igniting change in local government: lessons learned from a bushfire vulnerability assessment. *Mitigation and Adaptation Strategies for Global Change* doi:10.1007/s11027-008-9163-4

### **Case Study:**

Pinning Down vulnerability—from narratives to numbers.

### **Focus Area:**

Vulnerability of communities towards risks and hazards.

### **Study Area:**

Households in Aalamchak village and Sonatikar village in Eastern Uttar Pradesh; and in coastal villages in Gujrat. Community VCI –Villages in Gujrat (India) and Rawalpindi (Pakistan)

### **Data Collection Method:**

Household and Community level study using Primary data collection based on Household Survey or focus group discussions. Can also be replicated using secondary data from existing surveys.

### **Reference:**

Mustafa D., Ahmed, S., E. Saroch and The Risk to Resilience Study Team, (2008): *Pinning down Vulnerability: From Narratives to Numbers, From Risk to Resilience Working Paper No. 2*, eds. Moench, M., Caspari, E. & A. Pokheral, ISET, ISET– Nepal and Provention, Kathmandu, Nepal, 28 pp.

### **Vulnerability Assessment to Climate Change:**

The methodology assesses the vulnerability of a sector towards climate change. Based on the discussions with experts, 15 climate sensitive indicators were chosen. These indicators were classified into three Groups - severe, moderate and less important.

Each indicator was assigned an optimum value based on the performance of that particular indicator at the National/State, mostly reflecting the average value of the indicator. The value below or above the chosen optimum mark signifies the level of sensitivity expressed in terms of severe vulnerability, moderate vulnerability and light vulnerability scales. Different scores were assigned to the indicators depending on the category in which the value of the indicator lies, with the maximum points being assigned for the severe category & the least for the lesser.

The scores for these categories were defined heterogeneously for the 3 broad groups of severe, moderate and less important. Based on the aggregate points arrived as a result of the combination of scores for all the indicators for an area the vulnerability scale for that area was classified ranging from severe to low vulnerability.

### **Case Study:**

Vulnerability assessment and Enhancing the Adaptive Capacity to Climate Change in Semi -Arid Regions of India.

### **Focus Areas:**

Agriculture, Water, Rural energy and Livestock

### **Study Area:**

a) Kothar & Srirangapur villages in Mehabubnagar district of Andhra Pradesh.

b) Kundai & Amda villages in Udaipur district of Rajasthan.

### **Data Collection Method:**

Village level study using primary data

### **Reference:**

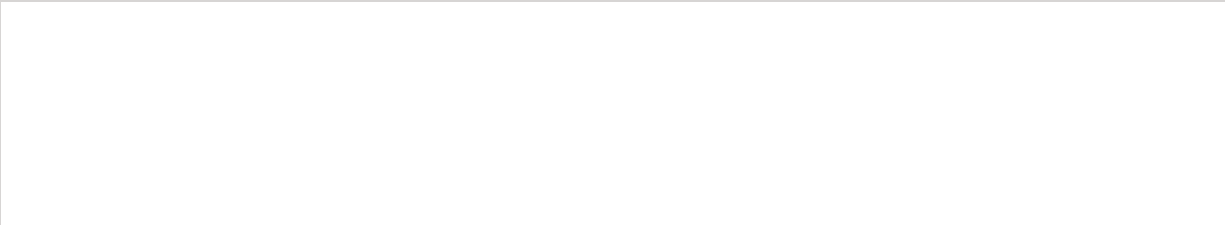
<http://www.climateadapt.net/index.php>. Last Accessed on February 16, 2009.

## INDICATORS AND DATA SOURCES

Theme	Indicator	Data Source
<b><u>Climate</u></b>		
Temperature	Average change in mean temperature (1995 – 2005)	High Resolution (1°X1°) Daily Gridded Temperature Data for the Indian Region 1969 – 2005, India Meteorological Department
Precipitation	Average change in total annual rainfall (1995 -2005)	High Resolution (1°X1°) Daily Gridded Rainfall Data for the Indian Region 1951 -2007. India Meteorological Department
<b><u>Demographic</u></b>		
	Sex Ratio	Census of India, 2001
	Population Density (Population in the age group 0-6 / Geographic area)	Census of India, 2001; Forest Survey of India, 2005
	Decadal Population Growth: from 1991 to 2001	Census of India, 1991 & 2001 (Statistical Abstract India 2007, CSO, Ministry of Statistics and Programme implementation)
	Percentage of Below Poverty Line (BPL) rural households to total households	BPL Census, 2002 & Directorate of Economics & Statistics, Uttarakhand 2002

<b><u>Ecosystem</u></b>		
Forest	Change of percentage of forest cover to total geographic area from 2005 to 2009	State of Forest Report, 2005 & 2009; Forest Survey of India (FSI)
Land use	Average change in land under Kharif and Rabi crops	Directorate of Economics and statistics, Government of UP & Uttarakhand
Water	Stage of groundwater development	Central Ground Water Board, 2004
<b><u>Agriculture</u></b>		
Crop production	Change in the production of crops	Ministry of Agriculture; Directorate of Economics and Statistics, GoUT
Land Capability	Ratio of total cropped area to net sown area	Ministry of Agriculture
Irrigation pattern	Percentage of area irrigated out of the net sown area	Directorate of Economics and Statistics, UP
Agriculture dependence	Ratio of Agricultural workers to other workers	Census of India, 2001
<b><u>Socio – economic</u></b>		
Livestock	Livestock density	Livestock Census 2003, Dept. of Animal Husbandry; FSI, 2005
Female employment	Female work Participation Rate	Census of India, 2001
Literacy	Literacy Rate	Census of India, 2001

Access to basic amenities	Percentage of households with access to safe drinking water (tap& hand pump)	Census of India, 2001
	Percentage of households with access to electricity	
	Percentage of households still dependent on biomass as fuel for cooking	
	Percentage of households having permanent houses	
Educational Facilities	Density of No. of schools	Directorate of Economics & Statistics, Government of UP; Directorate of Economics & Statistics, Government of Uttarkhand; FSI, 2005
Health Facilities	Density of no. of beds in allopathic and ayurvedic hospitals	
Accessibility	Ratio of Length of pukka roads (metalled) to total geographic area	
Communication Facilities	No. of telephones per lakh of population	
Banking Facilities	No. of Banks per lakh* of population	





## LIVING GANGA PROGRAMME

The HSBC Bank (under the HSBC Climate Partnership) has partnered with WWF, The Climate Group, Earthwatch Institute and Smithsonian Tropical Research Institute. This is a five years partnership (2007 - 2011) with key objectives to help in the protection of four of the world's major rivers - the Amazon, Ganga, Thames and Yangtze - from the impacts of climate change, benefiting 450 million people who rely on them. In India, this partnership intends to support WWF - India's work on climate change across the upper Ganga basin, focusing on river restoration, community education and engagement, business and governance involvement and biodiversity conservation. This initiative is called "The Living Ganga Programme".

The Living Ganga Programme aims to bring together knowledge and experience in Environmental Flows, climate adaptation and water allocation coupled with waste-water management and wise energy management in the water sector in Ganga Basin. For the purpose of this programme, the critical stretch of upper Ganga, from Gangotri to Kanpur was identified; this stretch is about 800 kilometers long. The scope and scale of interventions is crosscutting at various levels of pilots, case studies, institutional mechanisms and state as well as central level policy machinery.

Major areas being addressed under this programme are water allocation, Environmental Flows and efficiency in irrigation, industrial effluents and energy efficiency, municipal water supply and waste-water treatment, water and energy efficiency in the upcoming infrastructure sector. This programme has seven work components as follows:

- **Sustainable Water Management**
- **Climate Adaptation**
- **Pollution Abatement**
- **Water and Energy Co-management**
- **Sustainable Hydropower**
- **Biodiversity Conservation**
- **Communication and Business Engagement**

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The HSBC Climate Partnership was launched in India in January 2008 and supports Earthwatch, WWF, The Climate Group and Smithsonian Tropical Research Institute to combat the impact of climate change on forests, freshwater, cities and people.  
For more information, please visit: [www.hsbc.co.in](http://www.hsbc.co.in)



**Why we are here**

To stop the degradation of the planet's natural environment and to build a future in which humans live in harmony with nature.

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