A Framework for Climate Change Vulnerability Assessments

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A Framework for Climate Change Vulnerability Assessments

Based on the following documents:

Review of methodologies for assessing vulnerability – Report submitted to GIZ in the context of the project Climate Change Adaptation in Rural Areas of India composed by Jochen Hinkel, Global Climate Forum (GCF); Lisa Schipper, Stockholm Environment Institute (SEI); and Sarah Wolf, GCF.

Review of vulnerability assessments in India; Regional context for Vulnerability Assessment; Policy Framework in India to Address Climate Change and Development of Methodology for Climate Change Vulnerability Assessment by G.J. Lingaraj, Himani Upadhyay, Sambita Ghosh, Sneha Balakrishnan, Arabinda Mishra, Suruchi Bhadwal, and Sreeja Nair, all: The Energy and Resources Institute (TERI).

सत्यमेव जयते

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FOREWORD

It gives me immense pleasure to introduce the publication titled 'A Framework for Climate Change Vulnerability Assessments', one of the outcomes of the project titled 'Climate Change Adaptation in Rural Areas-India (CCA-RAI)' under the bilateral cooperation between the German development cooperation institution **Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH** and the Ministry of Environment, Forests and Climate Change (MoEF&CC), Government of India. Assessing vulnerability to climate change is critical for identifying the risks posed by climate change. At the same time, identifying measures to adapt to climate change impacts is also important.

India's Second National Communication to the United Nations Framework Convention on Climate Change, 2012, underlines that a majority of the rural population is vulnerable to climate change. The Government of India has taken several steps to address climate change and reduce the vulnerability of rural populations to the adverse impacts of climate change through the implementation of its eight National Missions under National Action Plan on Climate Change (NAPCC) and the preparation of State Action Plans on Climate Change (SAPCCs).

As a part of the national strategy, MoEF&CC and GIZ started the Indo-German bilateral cooperation project titled 'Climate Change Adaptation in Rural Areas of India – CCA RAI', funded by the German Federal Ministry of Economic Cooperation and Development with four states as project partners, namely Madhya Pradesh, Rajasthan, Tamil Nadu, and West Bengal in 2009. The project aims to enhance the resilience of rural communities and enable them to coexist with a changing climate. Most of the objectives of this project are in line with the objectives of the NAPCC.

This publication has been prepared with inputs from national and international experts in the field of climate change vulnerability assessment and adaptation. It introduces the readers to the concept of vulnerability to climate change, presents a general framework for assessing vulnerability and provides a rich selection of methods and tools to assess components of vulnerability at various levels.

I trust that the framework presented in this publication will prove to be a useful tool for decision makers at national and state level in carrying out vulnerability assessments. Further, this will enable them to make informed decisions to plan and implement measures for adaptation to the changing climate. Finally, I think that the publication is a good source book on the topic of assessing vulnerability.

(Dr V. Rajagopalan)

FOREWORD

The alarming impacts of climate change are highly visible and tangible – worldwide: Temperatures have increased, rainfall is more erratic, polar icecaps and glaciers are melting. The sea level is rising and extreme weather events are becoming more frequent and more intense. Droughts and floods occur more often and climatic zones are shifting. These facts severely impact multiple sectors and challenge the livelihood and food security of dependent communities and thereby sustainable development.

India is one of the most vulnerable countries of the world affected by climate related challenges. More than 70 per cent of India's population lives in rural areas and is heavily dependent on natural resources for survival. These people are particularly vulnerable to climate change: For making their living they depend directly on agriculture, forestry and fisheries, natural resources such as water, biodiversity, mangroves, coastal zones, and grasslands all being very climate sensitive. Based on these stifling facts – as reflected in India's Second National Communication (NATCOM II) to the United Nations Framework Convention on Climate Change (UNFCCC) – India and Germany are closely cooperating with the aim to adapt to the manifold impacts of global climate change.

It is against this backdrop that initiatives like this framework show how to pragmatically link approaches and techniques on the ground with the global good climate which is absolutely crucial. This innovative Framework for Climate Change Vulnerability Assessment was prepared under the Indo-German Development Cooperation project 'Climate Change Adaptation in Rural Areas of India – CCA-RAI'. It combines national and international expertise as well as short- and long-term experience to identify the most vulnerable people, areas and sectors.

Understanding regional climate change impacts and assessing vulnerabilities across different sectors are the first steps to prepare effectively for future risks imposed by climate change. This is why the Ministry of Environment, Forest and Climate Change (MoEF&CC), Government of India, and German

Development Cooperation GIZ on behalf of the German Federal Ministry for Economic Cooperation and Development, have developed this framework at hand. This very pragmatic framework describes different methods and approaches and showcases practical examples both for bottom-up community based assessments as well as top-down state level assessments. It certainly will assist decision makers and adaptation practitioners in carrying out vulnerability assessments for different sectors.

I would like to express my gratitude to MoEF&CC and GIZ for their excellent work. I am convinced that this cooperation will generate many more learnings of international relevance.

Heiko Warnken
Counsellor / Head of Department Economic Cooperation and Development
Embassy of the Federal Republic of Germany in India

ACKNOWLEDGEMENTS

The publication 'A Framework for Climate Change Vulnerability Assessments' was developed under the Indo-German development cooperation project 'Climate Change Adaptation in Rural Areas of India' (CCA RAI). This rich and comprehensive selection of methods and tools for assessing components of vulnerability will enable practitioners and policy decision makers to improve their work incorporating information on climate change. It comes just in time – as the newly established Indian Government puts more emphasis on climate change reflected also in the ministry's new title Ministry of Environment, Forests and Climate Change (MoEF&CC).

On behalf of GIZ India, I would like to express my gratitude to those who have provided their valuable contributions for completing this framework, in particular to Mr Susheel Kumar, Additional Secretary, MoEF&CC; Mr R.R. Rashmi, Additional Secretary, Ministry of Commerce, Government of India (former Joint Secretary, Climate Change, MoEF&CC); Mr Ravi S. Prasad, Joint Secretary, Climate Change, MoEF&CC; Dr S. Satapathy, Director, Climate Change, MoEF&CC; Dr D.N. Pandey, Member Secretary, State Pollution Control Board, Govt. of Rajasthan; Dr H. Malleshappa, Director, Department of Environment, Govt. Tamil Nadu; Mr Debal Ray, Chief Conservator Forests, Forest Department, Govt. of West Bengal (former Chief Environment Officer, Department of Environment and Forests, Govt. of West Bengal); Mr Lokendra Thakkar, Coordinator Climate Change Division, Environmental Planning and Coordination Organisation, Govt. of Madhya Pradesh.

Furthermore, I would like to acknowledge with due regard Dr Andrew Newsham, Institute of Development Studies, University of Sussex, Ms Catharien Terwisscha van Scheltinga, Wageningen University, and Dr Nana Künkel, GIZ, for providing valuable inputs and comments on the framework.

I would also like to express my deep appreciation to my colleagues from GIZ, Ms Ilona Porsché, Ms Anna Kalisch, Mr Dirk Rolker, Ms Somya Bhatt and Dr Sanjay Tomar, for their continued efforts of coordinating and editing the content of this publication.

Finally, I thank Dr Jochen Hinkel, Global Climate Forum, Dr Lisa Schipper, Stockholm Environment Institute, Dr Sarah Wolf, Global Climate Forum, and the team from the Earth Science and Climate Change Division of The Energy and Resources Institute for the excellent background documents that provided the basis for this framework.

Anticipating that you, dear esteemed readers and users of this framework, will appreciate this reference book as a user guide let me thank you in advance for your kind and constructive feedback.

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List of abbreviations and acronyms

BASIC	Building and Strengthening Institutional Capacities on Climate Change
CCA RAI	Climate Change Adaptation in Rural Areas of India
CMICP3	Coupled Model Intercomparison Project 3
EEA	European Environment Agency
FGD	Focus group discussion
GCM	Global Circulation Model
GHG	Greenhouse gases
GIZ	Deutsche Gesellschaft für Internationale Zusammenarbeit
GoMP	Government of Madhya Pradesh
IIMA	Indian Institute of Management in Ahmedabad
IISc	Indian Institute of Science
IIT	Indian Institute of Technology
IITM	Indian Institute of Tropical Meteorology
IMD	India Meteorological Department
JFM	Joint Forest Management
MoEF&CC	Ministry of Environment, Forests and Climate Change
NAPCC	National Action Plan on Climate Change
NCSP	National Communications Support Programme
NTFP	Non-timber forest products
PCMDI	Program for Climate Model Diagnosis and Intercomparison
PRA	Participatory Rural Appraisal
PRECIS	Providing Regional Climates for Impacts Studies
RCM	Regional Circulation Model
SAPCC	State Action Plan on Climate Change
SES	Socio-ecological system
UNDP	United Nations Development Programme
UNFCCC	United Nations Framework Convention on Climate Change

‘It used to rain continuously for about 15 days without stopping. This fantastic rain would leave all our lands, homesteads and crops completely saturated. But these continuous rains have stopped happening, which poses big challenges for our agricultural practices.’

Ramcharan Marco, 65 years
Pathadevgaon village, Madhya Pradesh

1 INTRODUCTION

The impacts of global climate change are increasingly being felt around the world. Rising temperatures, changing rainfall patterns, and the melting of glaciers and permafrost soils are affecting ecosystems and human societies in different ways. While climate change is expected to create new opportunities in some parts of the world, it is also expected to cause considerable distress. The extent of the impact depends on the magnitude of climatic changes affecting a particular system (exposure), the characteristics of the system (sensitivity), and the ability of people and ecosystems to deal with the resulting effects (adaptive capacities of the system). These three factors determine the vulnerability of the system.

Assessing vulnerability to climate change is important for defining the risks posed by climate change and provides information for identifying measures to adapt to climate change impacts. It enables practitioners and decision-makers to identify the most vulnerable areas, sectors and social groups. In turn, this means climate change adaptation options targeted at specified contexts can be developed and implemented.

Over the past decades, methods of vulnerability assessment have been developed in a wide range of development-related fields, ranging from natural hazards research, food security research and poverty analysis, to sustainable livelihoods research and related fields. All of these methods have been well documented and discussed. Several conceptual models have been developed to give environmental managers a framework for understanding vulnerability to natural disasters and how to reduce it (for example, Anderson & Woodrow, 1998; Blaikie, et al., 1994; Twigg, 2001). Experiences with these frameworks suggest that vulnerability is a complex subject that has many dimensions (economic, social, political and geographic), which may often have overlapping effects that make it difficult to tease out the precise cause-effect relationship. Consensus has been reached that vulnerability is bound to a specific location and context (Cutter, et al., 2003).

The impacts of and the vulnerabilities to climate change can vary across regions (e.g. global, national, subnational), economic sectors (e.g. agriculture, industry, shipping), social groups (e.g. urban populations, forest dwellers, coastal communities) or types of system considered (e.g. natural, social, economic, socio-ecological). Given these circumstances, the development of any one-size-fits-all solution for assessing vulnerability to climate change is problematic (Hinkel, 2011). This framework therefore provides a way of devising and applying case-specific vulnerability assessment methodologies.

Why this framework

This framework was prepared to provide decision-makers and adaptation implementers such as (local) government officials, development experts and civil society representatives with a structured approach and a sourcebook for assessing vulnerability to climate change. Furthermore, it provides a selection of methods and tools to assess the different components that contribute to a system's vulnerability to climate change. Key questions to be addressed are:

- How to plan for a vulnerability assessment?
- Which tools or methods to select to carry out a vulnerability assessment?
- How to carry out a vulnerability assessment?

The reader will first be acquainted with the theoretical background behind the concept of vulnerability. Next, two broad approaches for assessing vulnerability will be introduced: Vulnerability assessments can be carried out either at a local level using participatory methods and tools as well local climate data (bottom-up assessments) or at state, national or global level using large-scale simulation models and statistical methods (top-down assessments).

The introduction to the concept of vulnerability is followed by the main framework consisting of four different stages for assessing a system's vulnerability to climate change. Each stage in the vulnerability assessment consists of steps that specify which kinds of analyses should be carried out in that stage. Every step contains a set of guiding questions and a list of suggested methods and tools that can be used to answer these questions.

Each stage of the framework is followed by two practical examples of vulnerability assessments carried out in India: A bottom-up vulnerability assessment carried out at the outset of a GIZ supported climate change adaptation project and a top-down vulnerability assessment carried out for the Indian state of Madhya Pradesh as a whole.

Finally, the reader is presented with an extensive yet not exhaustive selection of methods and tools that can be used to assess the components of vulnerability to climate change at different levels.

How this framework was developed

This framework has been prepared as part of the Indo-German development cooperation project 'Climate Change Adaptation in Rurals Areas of India' (CCA RAI, www.ccarai.org). CCA RAI commissioned a number of background documents with the objective of preparing a practical approach to climate change vulnerability, risk and impacts assessment. A consortium consisting of the Global Climate Forum (GCF), Stockholm Environment Institute (SEI) and The Energy and Resources Institute (TERI) worked together to review existing outputs on vulnerability assessment, identify the gaps, and provide recommendations for the development of a framework.

The CCA RAI project team and its project partners used these background documents to develop this practical framework for vulnerability, risk and impact assessment.

'Around 20 years ago, you could find good, fertile soil here – up to one foot higher than the surface we are working on today. Now, our land is full of boulders and stones. We do have bulls, ploughs and the know-how to do efficient agriculture, but ongoing soil erosion keeps us from actually doing it.'

Lamua Osyam, 82 years
Payali Bahur, Niwas Block, Madhya Pradesh

2 UNDERSTANDING VULNERABILITY

2.1. Definitions

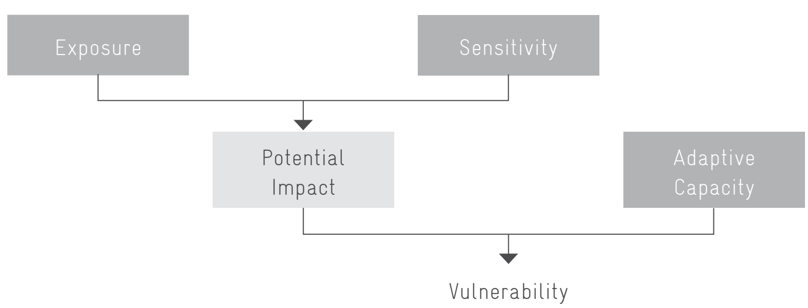
There is a multitude of definitions and interpretations of the term **vulnerability** (Hinkel, 2011). The only general consensus that seems to exist is that vulnerability is bound to a specific location and context (Cutter, et al., 2003). The Intergovernmental Panel on Climate Change (IPCC) identifies three components of climate change vulnerability: **exposure, sensitivity and adaptive capacity.**

This framework uses the above-mentioned terms in accordance with the definitions put forward by the IPCC and listed in the box on the following page. The interdependence between the three components and other key terms in the context of vulnerability assessments are shown in Figure 1.

Figure 1 describes vulnerability as a function of exposure to climate stimuli, sensitivity of the system to these stimuli, and the adaptive capacity of the system to adapt to climate change. Through the components of sensitivity and adaptive capacity, the diagram takes into account that socio-economic systems can reduce or intensify the impacts of climate change.

It is important to note that vulnerability is a theoretical concept. It cannot be directly measured or observed (Moss, et al., 2001; Hinkel, 2011; Patt, Schröter, et al., 2008). 'Measurement is the systematic process of assigning a number to a phenomenon'

Figure 1: Relationship between vulnerability and its defining concepts



(Source: adapted from Allen Consulting, 2005) that we can observe (Hinkel, 2011, p. 200). For example, we can measure the phenomenon 'heat' by assigning a number called 'temperature' to it. In this context, the term 'systematic' refers to the circumstance that the association needs to follow certain rules. For example, the warmer something is, the higher the associated number should be. A concept becomes observable when the members of a scientific discipline agree upon a simple way of measuring it (Hinkel, 2011). While there is general agreement on how to measure heat, there is no consensus yet on how to measure vulnerability (Moss, et al., 2001; Hinkel, 2011; Patt, et al., 2008; Hinkel, et al., 2010). Hence, it is more accurate to speak of 'making the concept of vulnerability operational' than of 'measuring vulnerability' (Hinkel, 2011). Making a theoretical concept operational consists of providing a method for mapping it to observable concepts. For example, developing a method to measure temperature is a way of operationalising the theoretical concept 'heat'. In the case of vulnerability, this method is called the **methodology of the vulnerability assessment** (Hinkel, 2011).

Vulnerability, exposure, sensitivity, adaptive capacity

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, the sensitivity and adaptive capacity of that system'.

Exposure refers to 'the nature and degree to which a system is exposed to significant climatic variations'.

Sensitivity refers 'to the degree to which a system is affected, either adversely or beneficially, by climate-related stimuli. 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 refers to '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'.

(McCarthy, et al., 2001)

Vulnerability to climate change

Sensitivity to climatic change is generally high when societies depend on natural resources or ecosystems, e.g. agriculture and coastal zones. While vulnerability must be defined on a case-by-case basis, it can generally be said that poor communities are especially vulnerable to climate change, variability and climate extremes. This is due to their limited access to: resources, secure housing, proper infrastructure, insurance, technology and information.

'Almost the whole of India has a high or extreme degree of sensitivity to climate change, due to acute population pressure and a consequential strain on natural resources. This is compounded by a high degree of poverty, poor general health and the agricultural dependency of much of the populace' (Maplecroft, 2010).

2.2. Common approaches to vulnerability assessment

Vulnerability assessments are commonly distinguished as either following **top-down** or **bottom-up** approaches (Dessai & Hulme, 2004). Top-down approaches start with an analysis of climate change and its impacts, while bottom-up approaches start with an analysis of the people affected by climate change (van Aalst, et al., 2008). This distinction reappears in the scientific literature and is also labelled 'end-point' versus 'starting-point' (Kelly & Adger, 2000), 'bio-physical' versus 'social' vulnerability (Brooks, 2003), or 'outcome' versus 'context' vulnerability (O'Brien, et al., 2007).

The choice of a certain approach has important implications for the resources needed for a vulnerability assessment. Top-down approaches are usually preferred at global, national and regional levels, while the bottom-up approaches start their analysis at the local level (e.g. households, villages, communities). There is no one-size-fits-all solution. Vulnerability cannot generally be assessed by taking a single, ready-made method 'off the shelf'. Rather, several methods, usually taken from different research fields, should be combined uniquely for a given case. Thus, these methods are not always systematically related (Hinkel, et al., 2010).

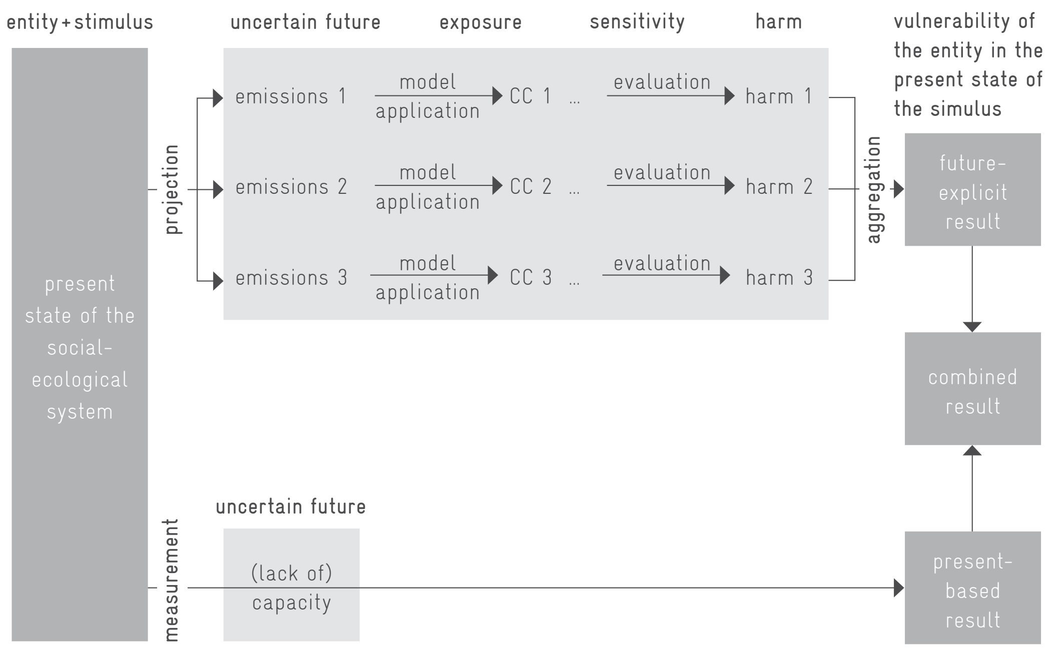
Top-down approaches

Most climate-impact and vulnerability assessment studies follow a top-down approach. These studies are future-explicit (Wolf, et al., 2013) in that they make use of simulation models to project future impacts. Generally speaking, top-down studies tend to **concentrate on biophysical effects of climate change that can be readily quantified.** Higher-order socio-economic impacts are only considered if quantitative models are available to link them to the biophysical effects. Therefore, the main output from such studies that can be used to inform policy is an assessment of physical vulnerability for a specified time period (Dessai & Hulme, 2004).

The quantity of greenhouse gases that will be emitted in the future depends on the size of the global human population and its consumption patterns. Top-down approaches use scenarios of the future socio-economic development of the world to feed Global or Regional Circulation Models (GCMs and RCMs). In turn, the GCMs and RCMs will project future climatic variables, e.g. mean annual precipitation, mean annual temperature, amount of monsoon precipitation, etc. Subsequently, the future state of the system of interest is evaluated according to previously defined criteria (Hinkel, et al., 2010; Mastrandrea, et al., 2010; Wolf, et al., 2013). A basic framework for top-down approaches to vulnerability assessments is shown in Figure 2.

Climate impact simulations form the starting point for top-down vulnerability assessments. These simulations generally assume a direct cause-effect relationship between climatic stresses and their impacts on biophysical systems, e.g. the effect of a decrease in total monsoon rainfall on crop growth. Climate impact simulations alone usually do not account for impacts of non-climatic variables. Vulnerability assessments, on the other hand, aim at overcoming such deficiencies. Unlike

Figure 2: Basic framework of top-down, future-explicit approaches combined with present-based capacity analysis



(Source: Wolf, et al., 2013)

pure climate impact assessments, which often consider adaptation measures only as a residual at the end of an analysis, top-down vulnerability assessments explicitly consider existing adaptive capacities and strategies that can reduce the negative impacts of climate change. The results of conducting simulation-based climate-impact assessment alone may, on the other hand, exaggerate the impacts of climate change (Füssel & Klein, 2006).

Strengths and weaknesses of top-down approaches

The main strength of top-down approaches lies in their ability to represent **direct cause-effect relationships** of climate stimuli and their biophysical impacts. Top-down approaches therefore provide a scientifically sound analysis that is based on a state-of-the-art understanding of the relationships between climate variables and biophysical processes, e.g. the relationship between rainfall and crop growth. Furthermore, top-down approaches are able to **project the state of a system far into the future.** Climate models can be coupled with sectorial models, e.g. agricultural or hydrological models, to assess how certain biophysical variables will develop in the future under different climate change scenarios. Top-down approaches are particularly suitable for **estimating large-scale climate change impacts** and informing national or international climate change adaptation policies.

Top-down approaches have two major weaknesses. The first and most obvious lies in the **uncertainties** that are inherent in every modelling exercise. Uncertainties about the future development of society and the economy are compounded by uncertainties about the climate system and the biophysical and socio-economic systems impacted. Moreover, most global simulation models are unable to effectively represent processes at the regional level, which thereby introduces another set of uncertainties should simulations be downscaled to assess vulnerability at finer spatial scales (Mastrandrea, et al, 2010).

Current versus future vulnerability

'Vulnerability is not static. The way in which people are vulnerable to existing climate patterns may not be the same way that they are vulnerable to future climate patterns. For example, if people are currently vulnerable to drought, but the climate shifts to become wetter, they may no longer be at risk. But if those people also change their crops to become more drought-tolerant in response to drought, and the climate still becomes wetter, they may be as vulnerable as before, or even more so. This means that understanding what is causing people to be vulnerable to existing climate variability is not always helpful in understanding what causes people to be vulnerable to future climate change, nor who is the most vulnerable.'

(Hinkel, et al., 2010, p. 44)

Secondly, top-down assessments generally **focus on the ecological component** of so-called socio-ecological systems (SES), 'since models are more readily available for the ecological than for the social component. If the social component is represented, then in a very stylised way' (Hinkel, at al., 2010, p. 42).
Hinkel, et al. (2010, p. 42) suggest that 'from an ideal perspective, assessing vulnerability would require [varying] climate and socio-economic scenarios as widely as plausible and [applying] several climate and impact models including with variations of their parameters. From a pragmatic perspective this is often difficult due to limited resources'.

Bottom-up approaches

Bottom-up approaches to vulnerability assessments provide an analysis of **what causes people to be vulnerable** to a given natural hazard such as climate change. Most bottom-up approaches have emanated from approaches in disaster risk reduction, humanitarian aid and community development (Hinkel, et al., 2010). Rather than putting the focus on the hazard itself, bottom-up approaches address the underlying development context of why people are sensitive and exposed in the first place. Moreover, bottom-up approaches explicitly take into account the fact that not all social groups are equally vulnerable to the negative impacts of climate change. Differences in vulnerability can stem from differences in class (including differences in wealth), occupation, caste, ethnicity, gender, disability and health status, age and immigration status (whether 'legal' or 'illegal'), and the nature and extent of social networks (Blaikie, et al., 1994).

Bottom-up approaches are participatory in nature and are conducted at local levels like households or rural communities. Unlike top-down approaches, most bottom-up approaches usually focus more on the assessment of current vulnerability rather than trying to estimate future vulnerability (Hinkel, et al., 2010). However, participatory tools for developing scenarios do exist and are frequently being used for planning adaptation programmes (Bizikova, et al., 2010; Chaudhury, et al., 2013).

The great majority of assessments that follow bottom-up approaches are found in developing countries, where vulnerability to present-day climatic variability is commonly perceived to be more of a threat than long-term climate change. In contrast, developed countries are often regarded as resilient to variability.

Bottom-up approaches generally do not rely on model-generated climate data, but involve collecting information from a specific location (Hinkel, et al., 2010; Wolf, et al., 2013). Most methods and tools used for bottom-up vulnerability assessment – like Participatory Rural Appraisal (PRA) tools – usually do not require extensive training. However, the outputs of bottom-up vulnerability assessments reflect many different voices, perceptions and experiences; as such, an ability to synthesise the results and identify priorities for action is required (Hinkel, et al., 2010). Apart from using the results from participatory exercises for analysis, bottom-up approaches can also accommodate quantifiable data like local weather data, downscaled climate simulations and data gathered through socio-economic household surveys.

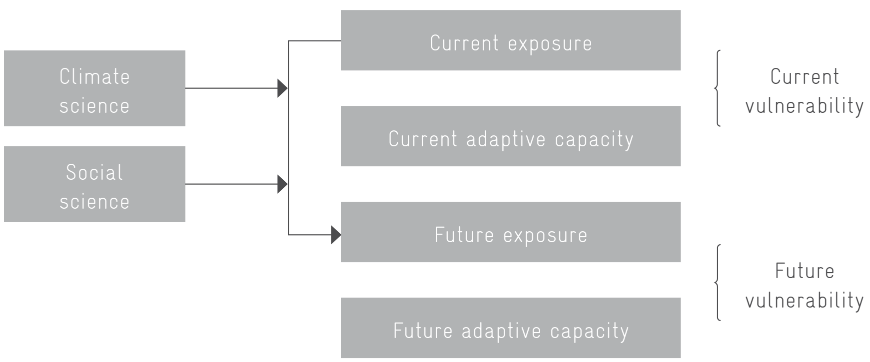
Bottom-up approaches are closely connected with other frameworks dealing with resource management, disaster management and sustainable development. This offers opportunities for integrating climate change considerations into existing decision-making and management contexts. A basic framework for bottom-up approaches to vulnerability assessments is shown in Figure 3.

Strengths and weaknesses of bottom-up approaches

The strength of bottom-up approaches lies in their ability to **point out which specific groups of people are vulnerable** to a natural hazard like climate change. Bottom-up approaches also allow the **differences in vulnerability** between different social groups to be brought out. The participatory nature of most bottom-up approaches to vulnerability assessment makes them highly suitable for including diverse groups of stakeholders and allowing them to voice their suggestions and comments on current vulnerabilities as well as planned or existing climate change adaptation measures and policies. Furthermore, bottom-up approaches allow **vulnerability to be assessed at small spatial scales**, i.e. at the local level, where large-scale simulation models cannot make reliable statements. The outputs of bottom-up vulnerability assessments can eventually be used to devise local climate change adaptation projects and measures.

There are several drawbacks with bottom-up approaches to vulnerability, which must be taken into account. First of all, bottom-up approaches are **place specific and difficult to generalise.** This means that some people may be more vulnerable to one type of hazard or change than other people. It is therefore difficult to make an assessment of the vulnerability of a village and then say something about the general level

Figure 3: Basic framework of bottom-up approaches



(Source: UNFCCC Compendium cited in Nair and Bharat, 2011) of vulnerability of a region or state, let alone a country. Secondly, it is very difficult to make statements or estimates about **future vulnerability** based on an assessment of existing vulnerability. Successful applications of bottom-up approaches should therefore take special care to identify the right triggers of vulnerability and relevant stakeholders (Hinkel, et al., 2010).

The use of indicators

The term 'indicator' is widely used in the context of vulnerability assessments. An indicator is 'a function from observable variables, called **indicating variables,** to a **theoretical variable**' (Hinkel, 2011, p. 200) – which is, in this case, vulnerability. For example, the presence of a certain species of lichen, an observable or indicating variable, is often used to indicate air quality, a theoretical variable (Hinkel, 2011).

'Vulnerability indicators are widely seen as the media of choice to build a bridge between the academic world and policy communities. Political organisations often recommend the development of indicators and hire teams of consultants and academics to carry out this task. By their very nature, indicators appear to be useful because they synthesise complex states of affairs – such as the vulnerability of regions, households or countries – into a single number that can then be easily used by policymakers' (Hinkel, 2011, p. 198). Many of the indicators developed have, however, failed to live up to this expectation and have been criticised as not being scientifically sound or policy relevant (Barnett, at al., 2008; Eriksen & Kelly, 2006; Hinkel, 2011; Klein, 2009). Developing indicators requires care and a clear definition of the purpose and context to which it will be applied (Hinkel, 2011).

Practically speaking, the development of indicators involves three basic steps (UNEP, 2001; OECD, 2008; Hinkel, 2011). 'The first step is the definition of what is to be indicated. In the case of climate change vulnerability indicators, this would be the vulnerability of an entity to climate change' (Hinkel, 2011, p. 201), e.g. the climate change vulnerability of the agricultural sector in a state. 'The second step is the selection of the indicating variables' (Hinkel, 2011, p. 201), e.g. the percentage of rain-fed agriculture as an indicating variable for the sensitivity of agricultural production to erratic rainfall. 'A possible, but not necessary, next step is the aggregation of the indicating variables' (Hinkel, 2011, p. 201). Generally, aggregated indices developed through bottom-up approaches will have little meaning, because the information gained from the bottom-up approaches will be diverse and detailed, and most of this will be lost in reducing it to a single number (Hinkel, et al., 2010). For a more detailed exploration on the methodological challenges of selecting and developing indicators of vulnerability, Hinkel (2011) can be helpful.

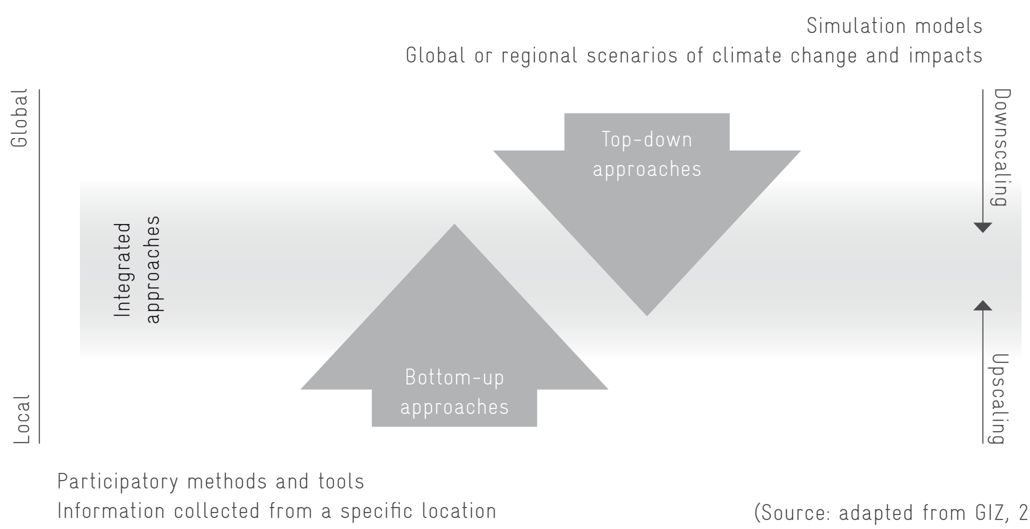
For bottom-up approaches, indicators can be as simple as variables that are useful proxies for vulnerability and its defining concepts. For example, the presence of certain village institutions that allow villagers to organise resource conservation activities can be regarded as an indicator for adaptive capacity. As this example shows, indicators for bottom-up approaches do not necessarily need to be quantitative but may also use qualitative scales. This could be done by identifying the factors that most people think drive vulnerability. This exercise can also be carried out separately for different sectors or actors (Hinkel, et al., 2010).

Integration of top-down and bottom-up approaches

Top-down and bottom-up approaches can provide complementary information. Top-down approaches focus mostly on the biophysical impacts of climate change but say less about why, which and how people are vulnerable. Bottom-up approaches, on the other hand, mainly provide information about the vulnerability of different social groups. The latter type of vulnerability is by nature also linked to many other stimuli, e.g. a generally low status of rural development, and is difficult to distinguish completely from the impacts of climate change (Hinkel, et al., 2010, p. 26). Consequently, bottom-up approaches are more suitable for assessing current vulnerabilities and adaptive capacities than for assessing the impacts of future climate change and vulnerabilities at larger scales. In contrast, top-down approaches are more appropriate for estimating large-scale climate change impacts and are less suitable on finer spatial scales and may fail to provide certain information, for example on extreme events (UNFCCC, 2011).

Comprehensively assessing vulnerability to rapid climate change requires an integration of both approaches (Mastrandrea, et al., 2010). This demand is rooted in the fact that climate change vulnerability is multifaceted, with interactions between socio-economic and biophysical aspects (Dessai & Hulme, 2004; Nair & Bharat, 2011). For both top-down and bottom-up assessments, a blend of scientific data and other types of knowledge is required.

Figure 4: Integration of top-down and bottom-up approaches



(Source: adapted from GIZ, 2013)

Figure 4 shows a schematic representation of how simultaneous upscaling and downscaling of the respective assessment types leads to the realm in which integrated approaches can be developed.

Even though the two approaches are not mutually exclusive, their integration requires careful observations and simultaneous upscaling and downscaling. Furthermore, successful integration demands close collaboration between stakeholders, social scientists and practitioners who carry out vulnerability and capacity assessments, as well as climate scientists who can clarify what is known and what is not known about the climate system's response to given scenarios of development (Mastrandrea, et al., 2010). Mastandrea et al. (2010, p. 90) point out that 'these partnerships can increase the understanding of a system's response to climatic stress and identify potential intervention points for managing vulnerabilities'.

Most assessments that have tried to integrate top-down and bottom-up methodologies in the past have started with a scenario-based approach in which, under a defined set of future conditions of climatic and non-climatic variables, vulnerability hotspots in the future were identified with top-down methods and tools. In a following step, community-based, i.e. bottom-up, assessments were carried out in these vulnerability hotspots to validate the results obtained through the top-down methods and tools.

Similarly, bottom-up vulnerability assessments at local scales have been used to determine thresholds of climate change vulnerability. This involves interviewing stakeholders at the local level to find out which conditions they would not be able to adapt to. These locally defined thresholds can then be mapped against the projections of top-down models and scenarios. This, in turn, means the likelihood that these thresholds will be passed in future can be estimated (Mastrandrea, et al., 2010).

2.3. Methods and tools

Prominent examples of toolboxes and collections of methods to evaluate impacts, vulnerability and adaptation to climate change include the following:

- The **United Nations Framework Convention on Climate Change (UNFCCC) Compendium** (UNFCCC, 2009) and ongoing follow-up work under the **Nairobi work programme** (UNFCCC, 2011) are offered in a web-based resource that provides key information on available frameworks, methods and tools to evaluate impacts of, and vulnerability and adaptation to, climate change.

- The **UNFCCC Resource Guide for Preparing the National Communications of Non-Annex I Parties – Module 2: Vulnerability and Adaptation to Climate Change** (UNFCCC, 2008b) is a resource guide that provides an overview of the main methods, tools and data used by Non-Annex I Parties to the UNFCCC to assess vulnerability and adaptation to climate change. It emphasises methods that are readily accessible and applicable.

- The **Toolkit for Vulnerability and Adaptation Training** by the Stockholm Environment Institute (Downing & Ziervogel, 2004) contains a selection of methods and tools for assessing vulnerability and the potential benefits of adaptation options. Most of the methods and tools can be classified as 'bottom-up'.

- **The National Communications and Support Programme (NCSP)** of the United Nations Development Programme (UNDP, 2012) maintains a collection of guidance documents and general methodologies.

- The **BASIC project (Building and Strengthening Institutional Capacities on Climate Change)** provides a set of methods that are specifically applicable to the Indian context (www.basic-project.net).

- **Participatory Scenario Development Approaches for Identifying Pro-Poor Adaptation Options** by the World Bank (Bizikova, et al., 2010) is a manual that presents readers with a generally applicable and detailed methodology for carrying out workshops to develop participatory scenarios.

- **Gender and Climate Change Research in Agriculture and Food Security for Rural Development** by the Food and Agriculture Organization (FAO, 2011) is a training guide that teaches the reader how to investigate the gender dimensions of vulnerability and adaptation to climate change in the fields of agriculture and food security.

These collections provide useful and extensive overviews of the existing approaches. However, they provide little practical help for choosing the right approach for assessing vulnerability in a given context (Hinkel & Bisaro, 2013).

Apart from these general collections of possible tools and methods, several guidebooks for climate change vulnerability assessments have been developed. These guidebooks advise their readers on how to combine a set of different methods and tools to carry out a vulnerability assessment. Most of these guidebooks and instructions can be identified as either applying mostly **bottom-up approaches** or predominantly **top-down approaches**.

Bottom-up

- **CRiSTAL – Community-based Risk Screening Tool – Adaptation and Livelihoods**
  CRiSTAL is a project-planning tool that helps project planners and managers to integrate risk reduction and climate change adaptation into livelihoods projects (www.iisd.org/cristaltool).

- **CARE Climate Vulnerability and Capacity Analysis Handbook** (CARE, 2009). This practical handbook presents a participatory methodology to assess climate change vulnerability at the community level. It emphasises that not all social groups are equally vulnerable.

- **Framework for Community-based Climate Vulnerability and Capacity Assessment in Mountain Areas** (ICIMOD, 2011). This publication presents an analytical framework and a participatory methodology for assessing climate change vulnerability in mountain communities.

- **Participatory Capacity and Vulnerability Analysis – Finding the Link Between Disasters and Development** (Oxfam, 2002). This handbook focuses on vulnerability to disasters rather than long-term climate change. However, it is a useful resource for carrying out participatory vulnerability assessments in rural and urban communities.

- **CEDRA – Climate change and Environmental Degradation Risk and adaptation Assessment** (Tearfund, 2012). This publication explicitly combines assessments of risks from both climate change and environmental degradation.

Top-down

- **Scanning the Conservation Horizon – A Guide to Climate Change Vulnerability Assessment** (Glick, et al., 2011). This guide focuses on assessing the ecological impacts of climate change.

- **Review of climate change adaptation methods and tools** (Schipper, et al., 2010). This review of adaptation methods and tools examines approaches that have been developed and applied around the world, with a particular emphasis on Asia.

- **Preparing for Climate Change – A Guidebook for Local, Regional, and State Governments** (Snover, et al., 2007). Chapter 8 of this guidebook presents a general framework for sectorial top-down vulnerability assessments. It includes examples of assessments in three sectors (hydrology and water resources, infrastructure, and transportation).

- **Impacts, Vulnerabilities and Adaptation in Developing Countries** (UNFCCC, 2007). This publication provides background information on the vulnerabilities and adaptation in developing countries, as well a general framework for carrying out vulnerability assessments at the national level. However, it provides little practical guidance on how to carry out these assessments.

- **Handbook on Vulnerability and Adaptation Assessment** (UNFCCC, 2008a). This handbook is intended to help Non-Annex I Parties to the UNFCCC (mostly developing countries) prepare the sections of their Second National Communications on Vulnerability and Adaptation. It gives detailed instructions on developing socio-economic and climate change scenarios, and on carrying out top-down vulnerability assessments in individual sectors (coastal resources, water resources, agriculture, and human health).

2.4. Main challenges for vulnerability assessments

Assessing climate change vulnerability can be challenging for a number of reasons:

The system under assessment is usually highly complex, which necessitates careful consideration of multiple risks, control variables and modulating influences.

Obtaining relevant data for different vulnerability drivers is usually difficult, thus complicating the task of establishing baselines and validating proposed integrated vulnerability assessment frameworks and models.

Future-explicit climate-change vulnerability assessments require projecting possible states of a complex system far into the future. This provides a serious methodological challenge but is necessary in order to be able to differentiate and accurately incorporate the effectiveness of competing present policy options and responses.

The specific purpose for conducting an assessment and the decision context expected to be derived from the assessment are often not clear when choosing relevant methodologies. In reality, vulnerability assessments use a wide range of methodologies. The preference of these methodologies often depends on a multitude of factors like purpose, resource availability, timescale, etc.

This framework is meant to help you overcome the above-mentioned challenges and choose suitable methods to carry out a climate change vulnerability assessment for a specifically defined purpose.

‘During my young days, rains were plenty and water flowed throughout the village, and the groundwater level was high. In order to irrigate our fields, we used to lift water from open wells by using the kamalai, the pot you can see behind me. Now, due to the changing patterns of the rains, water has become very scarce. I feel just like the pot behind me – we have both become irrelevant these days.’

Pappamal, 83 years
Chattrapati village, Tamil Nadu

3 FRAMEWORK FOR VULNERABILITY ASSESSMENTS

As presented in Chapter 2, there are two main approaches for assessing vulnerability: top-down and bottom-up. Each climate change vulnerability assessment has its unique set of challenges. The methodological framework presented in this chapter will guide you in designing a suitable combination of different methods and tools for your climate change vulnerability assessment and its specific purpose.

We have combined our proposed vulnerability assessment framework with results from two specific examples of vulnerability assessments carried out in India. This will give you an impression of how a climate change vulnerability assessment is actually carried out and how the results can be presented to the target audience, i.e. decision-makers and other stakeholders.

Stages and steps

Table 1 on the following page summarises the general framework for a vulnerability assessment. It is organised in four stages. Each stage consists of multiple steps. The first stage consists of defining the purpose of the vulnerability assessment. We emphasise this aspect in particular because the usefulness of vulnerability assessments has generally been limited due to a lack of clarity on the exact reason why they are being carried out (Hinkel, 2011). A framework devised to assist its user to successfully carry out a climate change vulnerability assessment must therefore provide guidance on answering the question: What do we want to know and why?

The second stage is equally important for the success of the assessment and consists of carefully planning the assessment with respect to the purpose identified at Stage 1. Stages 3 and 4 are then concerned with carrying out the assessment focusing on current and future vulnerability respectively.

Iterative process

The stages and steps depicted in Table 1 should not be seen as a purely linear sequence of activities. Rather, they should follow an iterative process in close cooperation with all relevant stakeholders. Over time, an adaptive planning and assessment process can allow the inclusion of improved scientific research and data, which can eliminate knowledge gaps and reduce the level of uncertainty.

Stakeholder involvement

Relevant stakeholders should be involved during all stages of the vulnerability assessment. During and at the end of all stages, findings and eventual results need to be verified and analysed with those stakeholders. Climate change impact and vulnerability assessments have strong policy implications. Therefore, a critical challenge is improving the linkage, particularly in the context of adaptation, between climate impacts and vulnerability research on the one hand,

and public and private planning and management decisions on the other (Mastrandrea, et al., 2010). Ideally, the findings of a vulnerability assessment are used to inform policymakers and decision-makers to devise strategies to adapt to climate change and to mitigate its adverse impacts. Broad sets of stakeholders should therefore be involved in this process, either directly or indirectly (BASIC, 2007).

Aside from helping to **achieve the overall objective of the vulnerability assessment**, an effective stakeholder involvement provides a multitude of benefits: it helps to **collect relevant data** and **refine the scope and focus** of the assessment; it facilitates the **sharing of ideas** and the **dissemination of findings**; and it **sensitises stakeholders** on possible climate change impacts, as well as on adaptation strategies.

Bottom-up vulnerability assessments are participatory by definition. These assessments focus on what causes people in a particular location to be vulnerable to a particular hazard such as climate change. Bottom-up vulnerability assessments rely on information collected in that particular location provided largely (though not exclusively) by the people concerned. Vulnerability assessments following

Table 1: Framework for climate change vulnerability assessments

	Stages	Steps	
Involvement of relevant stakeholders	1. Defining the purpose of the vulnerability assessment	Formulate **questions** to be answered by the assessment	Iterative Process
	2. Planning the vulnerability assessment	1. Set the **boundaries** of the vulnerability assessment 2. Define the **general approach** of the vulnerability assessment	
	3. Assessing current vulnerability	1. Assess the profile of the system of interest 2. Assess the observed climate **(exposure)** 3. Assess the impacts of climate stimuli on the system of interest **(sensitivity)** 4. Assess the responses to climate variability and extremes **(adaptive capacity)** 5. Assess overall **current vulnerability**	
	4. Assessing future vulnerability	1. Assess the future climate **(future exposure)** 2. Assess the future impacts on the system of interest **(sensitivity)** 3. Assess future socio-economic scenarios **(adaptive capacity)** 4. Assess the overall **future vulnerability**	

a bottom-up approach can allow for the voices of marginalised groups in a community to be heard.

Top-down vulnerability assessments focus on biophysical effects of climate change that can be readily quantified. These assessments involve the application of simulation models by qualified technical experts and scientists. Current top-down vulnerability assessments show varying degrees of stakeholder involvement. While some studies have involved stakeholders as reviewers of future scenarios of climate change and adaptation developed by experts, others have included them in the development and in the assessment of the feasibility of scenarios. Moreover, stakeholders can provide important 'reality checks' for model data generated by researchers (Schröter, et al., 2005).

A successful **integration of top-down and bottom-up approaches** requires direct partnerships between stakeholders and scientists (Mastrandrea, et al., 2010). Stakeholder engagement can also serve as a means to validate and enhance the technical quality of the climate change assessments through appropriate feedback mechanisms. The choice of engagement tool can be as important as the process itself. It can help demystify the science behind climate change and assist in customising information to suit the needs of different levels and layers of stakeholders.

Communicating vulnerability assessment results

Successfully communicating the results of a vulnerability assessment is equally important as involving relevant stakeholders during all stages of the assessment. This requires considering who the **key audiences** are and what kind of **key information** they need. Furthermore, one should ask what kind of strategy could be used to effectively present the results. One way of answering this question is by finding out which presentation strategies have worked well in the past (UNFCCC, 2011).

With assessments that follow a top-down approach, special care should be taken not to assume that policymakers and stakeholders have the technical or scientific knowledge necessary to carry out assessments and fully understand their results (UNFCCC, 2008b).

Understanding and addressing uncertainty

Top-down vulnerability assessments are usually future-explicit. Assessments of future vulnerability lead into unknown and uncertain territory. It is important to understand the degree to which such uncertainty exists and how it should be addressed. Uncertainty can result from a lack of information or from disagreements about what is known. There are many kinds of cause; running from quantifiable errors in data and ambiguously defined concepts or terminology, to uncertain projections of human behaviour (IPCC, 2007).

The guidance note to the IPCC synthesis report describes how uncertainty about future predictions can be communicated to the audience. The authors describe how both quantitative measures (e.g. a range of values calculated by various models) and qualitative statements (e.g. reflecting the judgement of a team of experts) can communicate the level of uncertainty in projections about the future. Regardless of the method used, it is essential to consistently communicate uncertainty in vulnerability assessments for the system of interest.

Several quantitative techniques are available to describe and communicate uncertainty. Wherever possible, experts should seek to describe results in terms of likelihood of occurrence and degree of confidence in being correct. The IPCC synthesis report (IPCC, 2007) provides a comprehensive discussion of language for describing uncertainty and levels of confidence in climate change assessments, including quantitative terminology. Depending on the audience addressed and the type of assessment, uncertainty of the results can either be communicated quantitatively (Table 2) or qualitatively (Figure 5). Qualitatively defined levels of confidence can be based on the available amount of evidence and level of agreement or consensus among the people involved in the assessment.

Table 2: Quantitatively calibrated levels of confidence

Terminology	Degree of confidence in being correct
Very high confidence (Almost certain)	At least a 9 out of 10 chance of being correct
High confidence (Likely)	About an 8 out of 10 chance
Medium confidence (Possible)	About a 5 out of 10 chance
Low confidence (Unlikely)	About a 2 out of 10 chance
Very low confidence (Rare)	Less than a 1 out of 10 chance

(Source: adapted from IPCC, 2007)

Figure 5: Qualitatively defined levels of confidence

Level of agreement or consensus			
	High agreement, limited evidence	High agreement, medium evidence	High agreement, much evidence
	Medium agreement, limited evidence	Medium agreement, medium evidence	Medium agreement, much evidence
	Low agreement, limited evidence	Low agreement, medium evidence	Low agreement, much evidence

Degree of evidence (literature, government reports etc.)

(Source: adapted from IPCC, 2007)

How to use this framework

Within most of the individual steps of our framework you will be posed a set of **possible questions** that the particular step is supposed to answer through the use of appropriate methods and tools. Please note that these lists are in no way exhaustive and should be seen as a starting point for developing your own set of questions to assess climate change vulnerability for the system that you are interested in.

The questions are followed by a list of **suggested methods and tools,** which can be applied individually or in combination, in order to answer the question. There are a variety of qualitative and quantitative methods available to conduct the different steps involved in a vulnerability assessment. Naturally, the selected method or tool has to be relevant for the objective for which it is going to be used. Depending on the availability of data and the context and limits of the assessment identified in the planning phase, you can choose the most applicable method. A combination of top-down and bottom-up methods and tools is advisable to add robustness to the methodology and the results.

Examples of climate change vulnerability assessments in India

After each stage, we present you the methodology and results from two practical examples of climate change vulnerability assessments. Example 1 is a state-level climate change vulnerability assessment of the Indian state Madhya Pradesh. This assessment is future-explicit and follows a top-down, indicator-based approach. Example 2 is a vulnerability assessment carried out at the beginning of a local climate change adaptation project in the districts of Malda and Murshidabad in West Bengal. This assessment is not future-explicit and largely follows a bottom-up approach.

You will find more information about these examples on the following pages.

Example 1: State-level climate change vulnerability assessment in Madhya Pradesh

After the release of its National Action Plan on Climate Change (NAPCC) in 2008, the Government of India directed the state governments to draft State Action Plans on Climate Change (SAPCCs). The SAPCCs are developed to capture regional climate change concerns and formulate appropriate strategies to address these concerns. GIZ supported 16 Indian states and two Union Territories in the development of their respective SAPCCs.

Any plan that proposes strategies to deal with the threats and opportunities of climate change should be based on a scientific analysis of observed and projected climatic trends (exposure), their impacts (sensitivity), as well as capacities to deal with these impacts (adaptive capacity). A properly conducted climate change vulnerability assessment can provide this basis and inform policymakers in the preparation of their respective SAPCC.

The first example presented here is a climate change vulnerability assessment for the Indian state of Madhya Pradesh. The vulnerability assessment was funded and commissioned by GIZ for the Government of Madhya Pradesh. The vulnerability assessment study was carried out by INRM Consultants Pvt Ltd from New Delhi, the Indian Institute of Management in Ahmedabad (IIMA) and the Indian Institute of Science in Bangalore (IISc).

Madhya Pradesh has a predominantly agrarian economy, undulating terrain, and vast forest cover in many places.

Example 2: Vulnerability of agriculture-based livelihoods in flood-prone areas of West Bengal

So far, there is very little detailed empirical knowledge about how to deal with the risks of climate change or exploit the opportunities it may bring. The Indian Ministry of Environment and Forests (MoEF&CC) and GIZ are working together to identify adaptation priorities and strategies in four Indian states. The Indo-German project Climate Change Adaptation in Rural Areas of India (CCA RAI) supports local communities and NGOs in developing and carrying out adaptation measures in rural areas. Once tested, these adaptation measures can be fine-tuned and implemented in other regions with similar agricultural and climatic conditions.

The second example is a vulnerability assessment carried out at the outset of a local climate change adaptation project in three selected villages in the districts of Malda and Murshidabad in West Bengal. The demonstration project and the vulnerability assessment were implemented by the NGO Development Research Communication & Services Centre (DRCSC). A large part of the joint delta of the Ganges and Brahmaputra rivers is located in West Bengal. Strong and erratic rainfall frequently causes flooding and waterlogging in the Bengali lowlands, leading to the destruction of agricultural crops, the displacement of rural communities and – in the worst cases – the loss of human life. At present 42.3 % of the total area of West Bengal, spanning over 110 blocks* in 18 districts, is susceptible to flooding.

* ‘Blocks’ are urban or rural district sub-divisions in India.

Agriculture in Malda District is heavily affected by waterlogging.

3.1. Stage 1: Defining the purpose of the vulnerability assessment

Stage	Steps
1. Defining the purpose of the vulnerability assessment	Formulate **questions** to be answered by the assessment

A clear definition of the purpose of the vulnerability assessment is a prerequisite to its planning. The purpose should clearly identify which questions the assessment will answer. A climate change vulnerability assessment is always directed towards a particular user or audience who will be using the results of the assessment, e.g. a state or national government. Ultimately, the purpose of the assessment, its level of complexity and the approach to communicate the results will depend on the specific audience of the assessment (NWF, 2011).

Vulnerability assessments may be carried out for various purposes. Generally speaking, the purpose of a vulnerability assessment is to inform decision-making (Schröter, et al., 2004). More specifically, Hinkel (2011) identified six broad categories of purposes under which vulnerability assessments can be classified:

- Identify mitigation targets
- Identify particularly vulnerable people, regions or sectors
- Raise awareness of climate change
- Allocate adaptation funds to particular vulnerable regions, sectors or groups of people
- Monitor the performance of adaptation policy and interventions
- Conduct scientific research

The list of vulnerability assessment purposes is not meant to be comprehensive but rather serves to inspire the reader to define the specific purpose of his or her own vulnerability assessment. In identifying the purpose of the assessment, one has to be explicit and specific about the problems that the vulnerability assessment will address. The identification of the specific purpose of the vulnerability assessment has to be done in close collaboration with all partners, clients and stakeholders that are relevant within the scope of the assessment.

Purpose of the state-level climate change vulnerability assessment in Madhya Pradesh

The specified purpose of the vulnerability assessment is to assess the vulnerability of Madhya Pradesh to climate change in order to mainstream climate change adaptation into the development process. The vulnerability assessment is supposed to identify areas that are particularly vulnerable to climate change and need special attention in terms of adaptation. This will help the government to take an informed policy decision when channelling funds for state development activities.

Purpose of the vulnerability assessment of agriculture-based livelihoods in flood-prone areas of West Bengal

The specific purpose of the assessment was to assess the vulnerability of agriculture-based livelihoods to shifting rainfall patterns, erratic rainfall and micro-level waterlogging conditions. The key functions of the vulnerability assessment were to: prioritise and adapt climate change adaptation options in the three selected project villages in the districts of Malda and Murshidabad; identify criteria for the selection of beneficiaries; and, subsequently, select the project beneficiaries.

3.2 Stage 2: Planning the vulnerability assessment

Stage	Steps
2. Planning the vulnerability assessment	1. Set the **boundaries** of the vulnerability assessment 2. Define the **general approach** of the vulnerability assessment

The planning stage can be one of the most research-intensive stages of a vulnerability assessment study. The scope and the scale of the vulnerability assessment have to aim for a level of detail that meets the purpose as identified in the previous stage.

Step 1: Set the boundaries of the vulnerability assessment

Depending on the outcomes of this step, adjustments to the identified purpose may be required as the study proceeds. The following points should be considered in this step:

- **Define the resources available for the assessment**
  - The availability of **financial resources** can expand or limit the level of detail to which the assessment can be performed.
  - The availability of **human resources** (including skilled personnel) is also critical to deliver the

level and type of skills required at the different stages of the assessment (e.g. the application of new methods requires appropriate technical skill-sets that may only be available at specialised institutions). Often the necessary personnel are not available within the organisation requesting the assessment. In these cases, parts of the vulnerability assessment, or the whole assessment, should be outsourced to specialised experts, institutes or consultancies.
> Available time is one of the deciding factors for the kind of assessment to be carried out (e.g. rapid assessment versus detailed assessments).

- **Define the system of interest**
  The system of interest depends on the purpose of the vulnerability assessment. Vulnerability assessments may be carried out at different scales, i.e. at the national, subnational or local level. The system of interest can be delimited by either socio-economic boundaries (e.g. country, state, district, community, groups within a community) or natural/ecological boundaries (e.g. river basin, sub-basin, watershed, agro-climatic zone, ecosystem). Assessments of the latter types of systems can, however, pose some serious challenges when collaboration between different political administrations becomes necessary.

- **Define the unit of measurement**
  The unit of measurement for collecting information/data is selected according to the purpose of the vulnerability assessment and the system of interest involved. It may include either administrative or socio-economic units (e.g. district, block, village, household, gender group) or natural/ecological units (e.g. river sub-basins, watersheds, agro-climatic zones).

- **Data availability**
  Data availability is the most important deciding factor when selecting methods, tools and levels of detail for the assessment. Limitations in available data can significantly reduce the range of potential methods and tools to be used in the assessment.

Step 2: Define the general approach of the vulnerability assessment

The decision for a certain climate change vulnerability assessment approach depends on: the specific **purpose** of the assessment, its **focus**, the **system of interest**, its **unit of measurement**, and the available **resources**. The approach (top-down, bottom-up or a blend of both approaches) will subsequently determine which specific combination of methods and tools will be used during the assessment.

The purpose and focus of a vulnerability assessment strongly determine its approach. Bottom-up approaches are more suitable for assessing current vulnerabilities and adaptive capacities than for assessing the impacts of future climate change and vulnerabilities at larger scales. In contrast, top-down approaches are more appropriate for estimating large-scale climate change impacts and are less suitable for finer spatial scales.

Available resources are another very important determining factor for deciding on the vulnerability assessment approach. Most top-down approaches require skilled personnel, access to data, specialised computer software, and knowledge of methodologies that require prior training. However, the outputs of top-down approaches are more likely to be understood by policymakers and decision-makers. Bottom-up approaches, on the other hand, are mostly based on Participatory Rural Appraisal (PRA) tools, do not require extensive training, and can incorporate a wide variety of stakeholders and their perceptions. The challenge of bottom-up approaches is to synthesise the findings of the vulnerability assessment and identify priorities for action (Hinkel, et al., 2010).

The different approaches also require the involvement of different groups of **stakeholders.** A top-down vulnerability assessment must involve governmental agencies to ensure that the results are relevant to political decision-making processes. Moreover, data availability for top-down approaches is facilitated by ensuring cooperation with the government agencies that collect sector-specific data. Research institutions and consultancies are crucial partners when following a top-down approach. They have the necessary specialist knowledge and are able to work with the necessary simulation models.

At least in their initial stage, bottom-up approaches have to make sure to involve all local stakeholders. Special care should be taken to guarantee that marginalised groups (e.g. women, ethnic minorities, landless labourers) are not left out of a bottom-up vulnerability assessment. NGOs often have an intimate knowledge of local environments and social dynamics and can provide guidance on carrying out a vulnerability assessment or can be recruited to deliver it themselves.

During each stage and step in the vulnerability assessment, specific methods and tools must be selected. Since this framework suggests treating the vulnerability assessment as an iterative process, the selection of tools and methods should follow a flexible approach.

Stage 2:
Planning the state-level climate change vulnerability assessment in Madhya Pradesh

The statewide climate change vulnerability assessment for Madhya Pradesh followed a classic **top-down indicator-based approach.** The entire state of Madhya Pradesh was considered as the system of interest for which climate change vulnerability was assessed. The individual districts of the state were selected as the assessment's unit of measurement. Apart from assessing current vulnerability, the assessment also includes a future-explicit climate change vulnerability assessment. For this, climate simulation models and sectorial impact models were used. Vulnerability per district was assessed by compiling sectorial vulnerability indices (social, economic, agriculture, water resource, forest, climate and health) into a so-called composite vulnerability index (CVI).

Vulnerability is a theoretical concept and cannot be measured directly, so indicators are widely used as a tool to make the theoretical concept operational. Making a theoretical concept operational consists of providing a method for mapping it to observable concepts. The simplest kind of indicator is a scalar indicator that maps one observable variable to one theoretical variable (Hinkel, 2011). Often, several indicating variables are needed to make a concept operational. 'A composite indicator or an index is an indicator that maps (or aggregates) a vector of observable variables to one scalar theoretical variable' (Hinkel, 2011, p. 201).

The sectorial indices were developed by multivariate analyses of a wide range of variables from different sectors. Each variable contributes to one of the three components of climate change vulnerability (exposure, sensitivity and adaptive capacity). While all climate variables were grouped under exposure, indicating variables for the different sectors were classified under either sensitivity or adaptive capacity. The relative contribution of the individual variables to the vulnerability components, i.e. factor loadings and weights of the variables, was determined through Principal Component Analysis (PCA).

In total, 61 indicating variables were identified for analysis. The identification of the variables was based on a review of the existing literature on climate change vulnerability and discussions with subject experts. The initial selection of indicating variables was mostly based on deductive arguments. Deductive arguments are based on the use of available scientific knowledge in the form of frameworks, theories or models about the vulnerable system of interest (Hinkel, et al., 2010). For example, agriculture in districts where a high percentage of cropland that is irrigated by surface water is more sensitive to changes in rainfall patterns. Hence the variable became part of the indicator for climate change sensitivity in the agricultural sector.

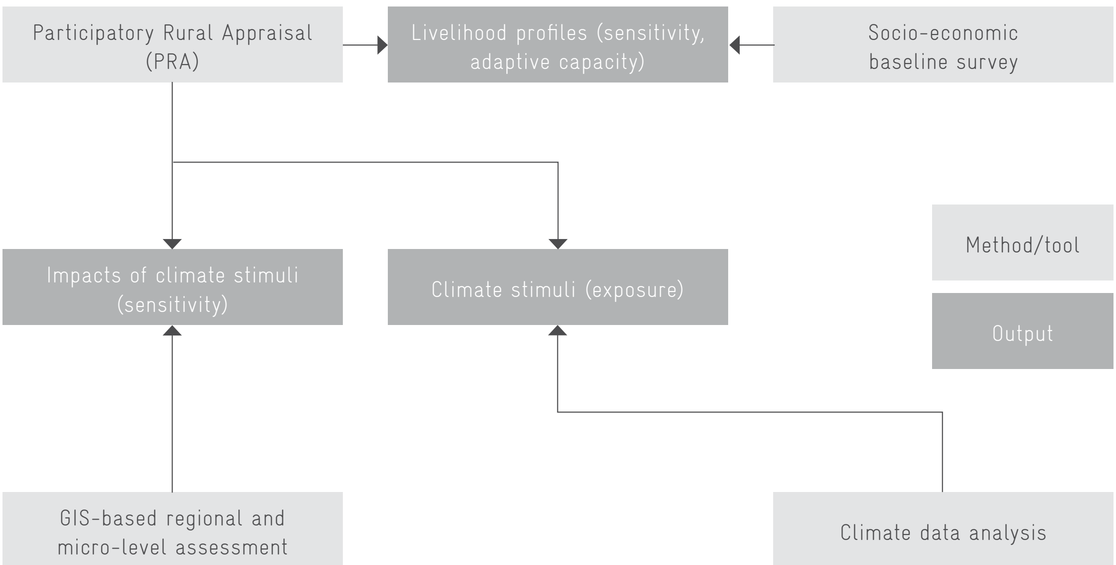
Checklist for the planning of the state-wide climate change vulnerability assessment in Madhya Pradesh

Purpose of assessment:	Identify policy recommendations to mainstream climate change adaptation into the development process in order to reduce the climate change vulnerability of districts in Madhya Pradesh
Financial resources:	Adequate
Human resources:	Available through cooperation with specialist consultancies
Time available:	9 months
System of interest:	The state of Madhya Pradesh
Sectors to be covered:	Water, agriculture, forestry, health
Unit of measurement:	District
Data availability:	Adequate for water and forestry, average for health and agriculture
Assessment type (rapid or detailed):	Rapid vulnerability assessment for current and future (2021–2050 and 2071–2100) conditions
Assessment approach:	Top-down, indicator-based
Capacity development needs:	Consultants, in collaboration with the nodal department

Stage 2:
Planning the vulnerability assessment of agriculture-based livelihoods in flood-prone areas of West Bengal

The assessment in West Bengal combined bottom-up with top-down methods and tools from different theoretical backgrounds to form a coherent methodology described in the following figure. The methodology is divided into four major activities that apply both qualitative and quantitative methods. Qualitative information was gathered through participatory exercises (>> see Practical methods and tools II) involving mainly focus group discussions and the participatory generation of resource maps and crop calendars. These qualitative methods were complemented by quantitative data gathered through literature reviews, socio-economic baseline surveys and a GIS-based regional and micro-level assessment.

Methodology applied in a local-level vulnerability assessment in three villages in West Bengal



Participatory Rural Appraisal (PRA) tools are used at a local level to identify the key vulnerabilities of local communities, to understand how community members perceive risks and threats to their lives and livelihoods, and to analyse resources and strategies to address or reduce risks. The outputs produced using PRA tools cut across the different components of vulnerability. The information gathered using the individual PRA tools usually informs different aspects of the assessment. A **household survey** was carried out to gather basic information on household assets, food security, loans and remittances, and levels of education and training. Based on long-term climate data, **climate trend analyses** were performed for the districts in which the project villages are located. Finally, **GIS-based regional and micro-level assessments** were carried out to identify areas that are particularly prone to flooding and waterlogging.

Though a limited number of appropriate tools exist, most vulnerability assessments that follow a bottom-up approach are not future-explicit. This means that they focus more on current vulnerabilities rather than making predictions about future exposure, sensitivity and adaptive capacity. The vulnerability assessment presented here has a very strong focus on bottom-up approaches. Therefore, it does not include Stage 4 (Assessing future vulnerability) as suggested in our general framework.

Purpose of assessment:	Identify the vulnerability of local farming systems to shifting rainfall patterns, erratic rainfall, flooding and waterlogging
Financial resources:	Moderate
Human resources:	Qualified personnel available at project sites
Time available:	4-5 months; PRA per project site: 3 days
System of interest:	Manikchak Block in Malda District and Bhagabangola I Block in Murshidabad District
Sectors to be covered:	Crop production, fisheries, livestock keeping
Unit of measurement:	Local communities/villages
Data availability:	Climate data available at the district level, other data to be collected through the household survey and PRA tools
Assessment type (rapid or detailed):	Rapid assessment of current vulnerabilities
Assessment approach:	Mostly bottom-up, with input from climate data analysis and GIS data analysis
Capacity development needs:	People with expertise in GIS application, climate data analysis, PRA tools, socio-economics

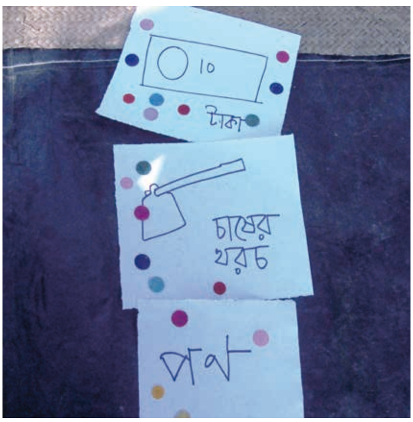
Participatory Rural Appraisal (PRA) tools

Participatory Rural Appraisal (PRA) describes a range of methods and tools to enable local people to share, enhance and analyse their knowledge of life and rural living conditions. PRA also enables people to plan and act on that knowledge. PRA is rooted in activist participatory research, agro-ecosystems analysis, applied anthropology, field research on farming systems, and rapid rural appraisal (RRA). With PRA, information is shared and owned by local people. Participatory methods include mapping and modelling, transect walks, matrix scoring, seasonal calendars, trend and change analysis, wellbeing and wealth ranking and grouping, and analytical diagramming.

Focus group discussions (>> see Practical methods and tools II)

Focus group discussions (FGDs) with villagers were carried out for a variety of purposes. One of them was to identify and rank perceived problems. During an initial brainstorming session, problems and risks were identified and written down on cards and collected. Subsequently, villagers were given the chance to vote for the three problems they consider to be most pressing. The output of this exercise was a location-specific ranking of problems as perceived by the stakeholders themselves.

FGDs were also used to discuss major sources of income and livelihood options and how these changed over time. Villagers were asked to estimate the number of members of their community who were engaged in different activities in both 2000 and 2011. Conclusions could then be drawn on how the relative importance of different livelihood options had changed over time. During the accompanying discussions, the FGD participants were able to point out the reasons they believe lie behind these changes.



Ranking of livelihood problems and risks in Murshidabad District

Community mapping (>> see Practical methods and tools II)

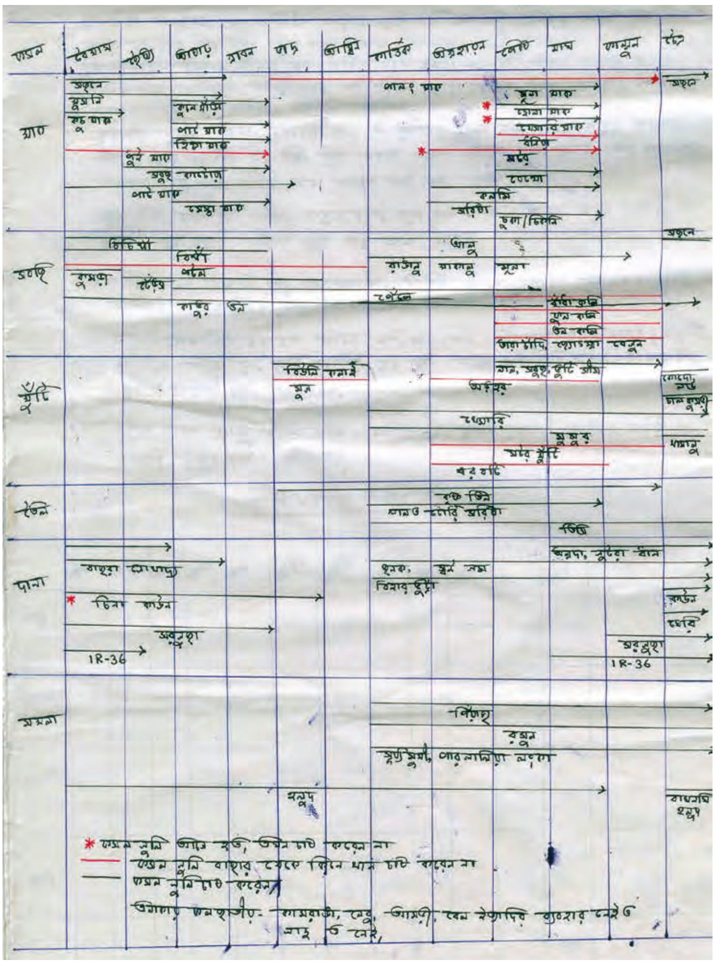
Resource maps are types of **community maps**. They depict the location of spatial features and the availability of resources in a given locality. Together with a facilitator, villagers developed resource maps for all three villages during a community mapping exercise. The villagers were first asked to quickly sketch the east-west and north-south axes, village boundaries, and major roads and railways. Subsequently, a discussion ensued about the location of certain other village features, e.g. markets and ponds. Finally, the villagers also indicated water bodies, irrigation water sources, areas that are particularly prone to flooding and waterlogging, and cropping patterns.

Participatory development of a resource map in Murshidabad District

Seasonal calendars (>> see Practical methods and tools II)

Crop calendars were drawn up during focus group discussions with villagers. In addition to specifying which crops are cultivated in which period of the year, the crop calendars identify crop consumption patterns. Based on crop production and consumption patterns, periods of food shortage and livelihood patterns can then be characterised. The crop calendar exercise also helped to identify major sources of income, threats to local livelihoods, and seasonal migration patterns of agricultural labourers.

Crop calendar from Malda District



Seasonal climate calendars draw out rainfall and temperature patterns and their extremes throughout the year. By constructing these calendars for the perceived current and past climate, changes in local climatic conditions became apparent. Moreover, this exercise formed the basis of discussions about the influence of weather conditions on agricultural production.

GIS-based regional and micro-level assessment

Researchers from the School of Oceanographic Studies at Jadavpur University, West Bengal, carried out the GIS-based regional and micro-level assessment. The researchers assessed topography and land use in the villages and surrounding areas using GIS and Remote Sensing tools. The GIS-based assessment was complemented by field trips, ground surveys and discussions with villagers in the concerned areas. The aim of this part of the vulnerability assessment was to assess the regional ground condition of surface runoff and identify areas that are heavily affected by waterlogging. The assessment followed a four step process:

1. Assessment of topography and land use through GIS and Remote Sensing
2. Field trip/ground survey
3. Discussion with villagers
4. Synthesis of findings and recommendations

3.3. Stage 3: Assessing current vulnerability

Stage	Steps
3. Assessing current vulnerability	1. Assess the profile of the system of interest 2. Assess the observed climate **(exposure)** 3. Assess the impacts of climate stimuli on the system of interest **(sensitivity)** 4. Assess the responses to climate variability and extremes **(adaptive capacity)** 5. Assess overall **current vulnerability**

The objective of a current vulnerability assessment is to identify current vulnerability conditions based on past and current exposure, and the sensitivities and adaptive capacities of the system of interest. The current vulnerability assessment first **establishes a profile of the system of interest** based on available information about: natural resources, the state of development, and socio-economic and environmental issues. Secondly, the current vulnerability assessment provides insights on past-observed climatic trends and factors (**exposure**) that have contributed to the vulnerability of the system of interest (**sensitivity**). Current vulnerability assessments also provide an opportunity to learn from adaptive responses in the past (**adaptive capacity**) – both failures and successes – and thus enable the design of future adaptation responses or adjustments in ongoing climate change adaptation programmes.

Assessments of current vulnerability are based on observed changes and trends in climatic variables over time. Hence, it is essential to set the baseline year from which vulnerability is to be assessed. This is important because vulnerability is dynamic and, as such, the baseline may vary over time, changing not only the current vulnerability profile but also its manifestation in the future.

Choosing baselines

For socio-economic information and biophysical parameters, we suggest collecting information for the past 10 years. For hydro-meteorological information, we recommend collecting information for at least the past 30 years.

Step 1: Assess the profile of the system of interest

The first step in assessing current variability is to assess the profile of the system of interest. The profile gives the general status quo of the system of interest. Vulnerability to climate change is not only dependent on climate-related stresses and stimuli but, to a large extent, is also dependent on socio-economic factors. Climate change can, for example, exacerbate socio-economic problems that already exist in the system of interest. There is no pre-defined set of questions or topics available for studying the profile of the system of interest. However, the following list provides recommendations on formulating key questions to understand the profile of the system of interest.

Questions

- **What is the state of natural resources in the system of interest?**
  - > Identification of natural resources (e.g. forests, agriculture, water)
  - > Spatial distribution of natural resources (e.g. area under a certain forest type, soils suitable for crop production, location of rivers)
  - > Quantification of natural resources (e.g. available volume of timber and water)
  - > Access to these resources (e.g. acces to potable water or water for irrigation, access to agricultural land)
  - > Temporal trends of natural resources (e.g. change in forest cover and type, change in groundwater availability for irrigation)
  - > Quality of natural resources (e.g. biodiversity, water quality, soil nutrient status)

- **What kind of socio-economic dynamics exist in the system of interest?**
  - > Demographic profile (e.g. number and density of the population, population below poverty line, literacy rate)
  - > Livelihood profiles (e.g. main sources of livelihood, diversity of livelihood strategies, gender-specific livelihood strategies)
  - > Intra-household dynamics (e.g. due to gender, age, occupation)
  - > Inter-household dynamics (e.g. due to caste, class, ethnicity)
  - > Human health status (e.g. incidences of vector-borne diseases)

- **What are the environmental issues in the system of interest?**
  - > Identification of key environmental issues (e.g. overgrazing, deforestation, water pollution)
  - > Sectorial implications due to identified environmental issues (e.g. impacts on forest-dependent or agriculture-dependent livelihoods)
  - > Temporal trends (e.g. percentage decline in forest cover, decline in water quality or groundwater table)

- **What are the developmental issues in the system of interest?**
  - > Governance and institutional context (e.g. existing governance structure, rules, regulations, village institutions)
  - > Key developmental issues (e.g. migration from rural areas)
  - > Regions, sectors and groups that should be the focus for development activities (e.g. regions with low access to basic infrastructure, women, children, landless agricultural labourers)

The questions to be considered when studying the profile of the system of interest depend on the purpose of the vulnerability assessment. During the study of the profile of the system of interest, new questions that were not considered at the outset are likely to arise. At the end of this analysis, you should have gained the basic information about the biophysical and socio-economic status of the system of interest.

Suggested methods and tools

The following top-down and bottom-up methods and tools can be used to collect information on the state of the environment and natural resources, as well as on socio-economic parameters and development in the region.

1) **Top-down**

- **Driving forces-Pressures-State-Impacts-Responses (DPSIR) framework:** This framework can encourage and support decision-making by pointing to clear steps in the causal chain where the chain can be broken by policy action (EEA, 2007).

- **Indicator-based methods**
  (>> see Practical methods and tools III)

- **Literature review:** A literature review of government and published sources (including censuses, statistical abstracts, sectorial reports, planning documents) can provide the required secondary information pertaining to the above-mentioned areas of information.
  (>> see Practical methods and tools IV for useful data sources)

- **Statistical analyses:** Different statistical analyses may be used for capturing average and extreme values and changes in variables related to the above-mentioned areas of information.
  (>> see Practical methods and tools IV for useful data sources)

2) **Bottom-up**
(>> see Practical methods and tools II)

- **Brainstorming**
- **Community mapping**
- **Focus group discussions**
- **Household surveys**
- **Institutional analyses**
- **Oral histories**
- **Seasonal calendars**
- **Stakeholder consultations**
- **Timelines**
- **Transect walks**

Step 2: Assess the observed climate (exposure)

Exposure

Exposure refers to 'the nature and degree to which a system is exposed to significant climatic variations'.

(McCarthy, et al., 2001)

Past observed climatic trends, variability and extremes in the system of interest provide information on the current exposure of the region in question. We recommended collecting information on observed climate exposure for the past 30 years. Specific questions can define how information should be collected in order to assess the observed climate in relation to exposure.

Questions

- **How high is the inter-annual variability of climate variables?**
- **What are the frequency, intensity, timing and duration of extreme events?**
- **What are the observed key climatic hazards in the system of interest?**
- **Where are the hotspots, i.e. where have the largest changes occurred in climate variables from past to present conditions?**
- **How trustworthy is the information available for answering these questions?**

Apart from these main questions, there are a number of key variables that should be considered in the assessment of the current exposure of the system of interest. These variables are all climate or weather related and are part of the current exposure.

- Maximum, minimum and average monthly temperature
- Maximum, minimum and average monthly precipitation
- Standard deviation of average summer monsoon precipitation
- Severity of extreme events (droughts, floods, cyclones, etc.)
- Return period of extreme events

Suggested methods and tools

At present, most approaches to assess current exposure apply basic statistical methods; the most commonly used being the calculation of mean, median and standard deviation, and also trend analysis. In order to determine climate extremes, it is necessary to calculate the recurring interval or the return period of certain events (droughts, floods, cyclones, etc.). These methods provide information on the likelihood of the future occurrence of these events with respect to past and present trends. It should be kept in mind that this does not yet include the effect that future climate change will have on the occurrence of extreme events and the degree of inter-annual or spatial climate variability. Generally, climate data should be collected from as many weather stations as possible to reduce uncertainty at the temporal and spatial scales.

1) **Top-down**

- **Climate data analysis using Global and Regional Climate Models (GCMs and RCMs):**
  Future-explicit top-down vulnerability assessments compare current climate conditions to conditions under climate change scenarios. To facilitate this comparison, it can be useful to validate GCM and/or RCM simulations for current conditions with the help of observed climate data. If a model performs well, its simulations of the past and present climate can be more easily compared to simulations of a future climate. Eventually, this can allow a more meaningful comparison between past, present and future climates.
  (>> see Practical methods and tools Ib for tools and methods and Practical methods and tools IV for useful data sources)

- **Statistical analysis of climate data time series:**
  Climate data are available from various public sources. Basic statistical methods can be used to analyse these data and identify climatic trends.
  (>> see Practical methods and tools IV for useful data sources)

2) **Bottom-up**
(>> see Practical methods and tools II)

- **Hazard trend analyses**
- **Oral histories**
- **Seasonal calendars**
- **Statistical analysis of climate data time series:** Collecting weather data and climate predictions for local conditions is often very difficult. In cases where data from local weather stations are not available, data for higher spatial aggregations (e.g. district level) or from nearby stations can be used (>> see Practical methods and tools IV for useful data sources). Basic statistical methods can be used to analyse these data and identify climatic trends.
- **Timelines**

For each climate variable, trends can be classified into the following categories:

- **No trend:** No clear trend can be identified.
- **Trend:** The direction of change (positive or negative) can be identified.
- **Order of magnitude trend:** An order of magnitude change can be identified, that is, the values of the respective climate variable have changed significantly over time.

Step 3: Assess the effects of climate stimuli on the system of interest (sensitivity)

Sensitivity

Sensitivity refers to the degree to which a system is affected, either adversely or beneficially, by climate-related stimuli. 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).

(McCarthy, et al., 2001)

The system of interest can be exposed to the various climatic stimuli; however, the effect of these stimuli on the system may be influenced by other socio-economic and biophysical variables. The sensitivity of a system basically describes the dose-effect relationship between its exposure to climatic stimuli and the resulting impacts (Füssel & Klein, 2006). Sensitivity is analysed by determining whether the system of interest is significantly affected by climate-related stimuli or not. If the system is affected by climate-related stimuli, particularly current climate variability and extreme events, it should be considered sensitive.

In this step, information on the impact of climate stimuli on the identified sectors of the system of interest is collected at the level of the unit of measurement.

Questions

- **How do observed climate conditions** listed in Step 2 of Stage 3 (assess the observed climate/ exposure) **affect the system of interest** as identified in Step 1 of Stage 3 (assess the profile of the system of interest)?
  (E.g. direct/indirect, long term/short term)
- **How do current climatic variability and extremes impact on the system of interest?**
- **Which climate variables impact on non-climatic stresses?**
  (E.g. natural forest exposed to the non-climatic stress of deforestation would be impacted by climate stimuli like changes in precipitation and temperature)

Suggested methods and tools

The following top-down and bottom-up methods and tools can be used to collect and analyse information about the effect of climatic stimuli on the environment, natural resources and region's development.

1) **Top-down**

- **Driving forces-Pressures-State-Impacts-Responses (DPSIR) framework:** This framework has been widely used for the assessment and management of environmental issues (EEA, 2007).
- **Indicator-based methods**
  (>> see Practical methods and tools III)
- **Sector-specific simulation models**
  (>> see Practical methods and tools Ia)
  > **agriculture**
  > **water**
  > **coastal areas**
  > **human health**
  > **terrestrial ecosystems**
- **Statistical analysis:** This may be used for capturing average and extreme values and changes in variables related to the environment, natural resources, socio-economic factors, and development. For example, statistical relationships between climatic variables and non-climatic variables can be established through a regression analysis.
  (>> see Practical methods and tools IV for useful data sources)

2) **Bottom-up**
(>> see Practical methods and tools II)

- **Climate hazard trend analyses**
- **Community mapping**
- **Household surveys**
- **Participatory scenario analysis: 'What if?' tool**
- **Stakeholder consultations**
- **Timelines**
- **Transect walks**

Step 4: Assess the responses to climate variability and extremes (adaptive capacity)

Adaptation to climate change refers to adjustments in human and natural systems in response to actual or expected climate stimuli or their impacts that moderate harm or exploit beneficial opportunities.

(IPCC, 2007)

Adaptive capacity refers to 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.

(McCarthy, et al., 2001)

In practice, adaptation to climate change means doing things differently because of climate change (UNDP, 2004). Most often, it does not mean doing completely new things, but rather purposefully modifying development interventions. Adaptation itself is not a development objective, but is necessary for safeguarding beneficial outcomes. Adaptation measures may be compared with a baseline of 'doing nothing', which would incur losses and fail to make use of opportunities arising. Losses are particularly incurred when those affected have no capacity to respond in any other way (for example, in extremely poor communities) or where the costs of adaptation measures are considered to be high relative to the risk of expected damage.

The term 'adaptive capacity' basically describes the system's ability to modify its characteristics or behaviour so as to better cope with changes in external conditions (Füssel & Klein, 2006). This stage assesses the capacity of the system of interest to respond and adapt to climate change. This is achieved through assessing how the system has adapted – or is adapting – to current climate variability and extremes and assessing underlying capacities that may allow further adaptation in the future.

Adaptive capacity exists at different scales (family, community, region and nation) and is fundamentally dependent on access to resources (Easterling, et al., 2004; Adger, et al., 2004; Wall & Marzall, 2006). Sufficient resource availability is a prerequisite of adaptive capacity. However, the system requiring the resources for adaptation must also be able to mobilise them effectively (Wall & Marzall, 2006). As shown in Table 3, Wall & Marzall (2006) distinguish five types of resources relevant for the assessment of adaptive capacity to climate change.

Table 3: Framework for adaptive capacity

Resource	Definition	Variables	Possible indicators
Social	People's relationships with each other through networks and the associational life of their community	• Community attachment • Social cohesion	• Number of community events
Human	Skills, education, experiences and general abilities of individuals combined with the availability of 'productive' individuals	• Productive population • Education infrastructure • Education levels	• Trends in dependency ratios • School/institutional availability
Institutional	Government-related infrastructure (fixed assets): utilities like electricity; transportation; water; institutional buildings and services related to health; social support; and communications	• Political action • Utilities infrastructure • Emergency preparedness • Health services • Communications services	• Elected representation • Age and condition of utilities infrastructure • Number of health services available
Natural	Endowments and resources of a region belonging to the biophysical realm, including forests, air, water, arable land, soil, genetic resources, and environmental services	• Potable water quality • Potable water quantity • Surface water • Soil conditions • Forest reserves • Fish reserves	• Frequency of potable water contamination • Frequency of potable water shortage • Quality and quantity of fish reserves
Economic	Financial assets, including built infrastructure and a number of features enabling economic development	• Employment levels and opportunities • Economic assets	• Trends in job diversity • Trends in income levels • Local business ownership rates

(Source: adapted from Wall & Marzall, 2006)

Step 4 helps in understanding the existing capacities to respond to climatic stimuli and in identifying factors that have enabled effective responses to climatic hazards in the past. A range of questions can be considered in this step. A lot of these questions relate to the availability of resources that are indicative of adaptive capacity in the system of interest.

Questions

- **How have the key environmental, socio-economic and developmental issues been addressed by various measures?**
  (E.g. policies, programmes, local adaptation measures)
- **What response measures exist to deal with climate variability and hazards?**
- **Have the response measures specifically addressed the identified hotspots?**
  (E.g. regions, sectors, groups)
- **How effective have the response measures been?**
- **What factors have determined the effectiveness of identified response measures?**
  - > What social networks exist within the system of interest?
  - > What knowledge networks exist within the system of interest?
  - > What institutional arrangements have helped with adaptation to climate variability and extremes?
  - > What natural resources have been conducive for adapting to climate variability and extremes?
  - > What economic resources have been conducive for adapting to climate variability and extremes?

Suggested methods and tools

1) **Top-down**
- **Indicator-based methods**
  (>> see Practical methods and tools III)
- **Multi-criteria analysis**
  (>> see Practical methods and tools Ib)
- **Policy review and gap analysis**

2) **Bottom-up**
   (>> see Practical methods and tools II)
- **Cognitive mapping**
- **Community mapping**
- **The Delphi technique**
- **Focus group discussions**
- **Household surveys**
- **Participatory scenario analysis: 'What if?' tool**
- **Timelines**
- **Wealth ranking**

Step 5: Assess the overall current vulnerability

The overall current vulnerability of the system of interest is prepared by combining the outputs from Steps 1 to 4 of Stage 3, namely: 1. Assess the profile of the system of interest; 2. Assess the observed climate (exposure); 3. Assess the effects of climate stimuli on the system of interest (sensitivity); 4. Assess the responses to climate variability (adaptive capacity). The following key questions should be asked to develop links between the previous steps of the assessment.

Questions

- What have been the impacts of climate variability and hazards on key environment, natural resource and development issues?
- Which regions, sectors and groups have been most impacted?
- What non-climatic factors determine the severity of climate impacts?
- Which resources have resulted in successful adaptation to climatic variability and extremes?
- What levels of adaptive capacity already exist?
- How is existing adaptive capacity distributed across geographical regions, and across gender, age, and ethnic groups?

Suggested methods and tools

1) Top-down

- Indicator-based methods
  (>> see Practical methods and tools III)
- Sector-specific simulation models
  (>> see Practical methods and tools Ia)
  > agriculture
  > water
  > coastal areas
  > human health
  > terrestrial ecosystems

2) Bottom-up
   (>> see Practical methods and tools II)

- Brainstorming
- Climate hazard trend analyses
- Cognitive mapping
- Community mapping
- Focus group discussions
- Hazard mapping
- Impact matrices
- Participatory scenario analysis: 'What if?' tool
- Seasonal calendars
- Transect walks
- Vulnerability matrices

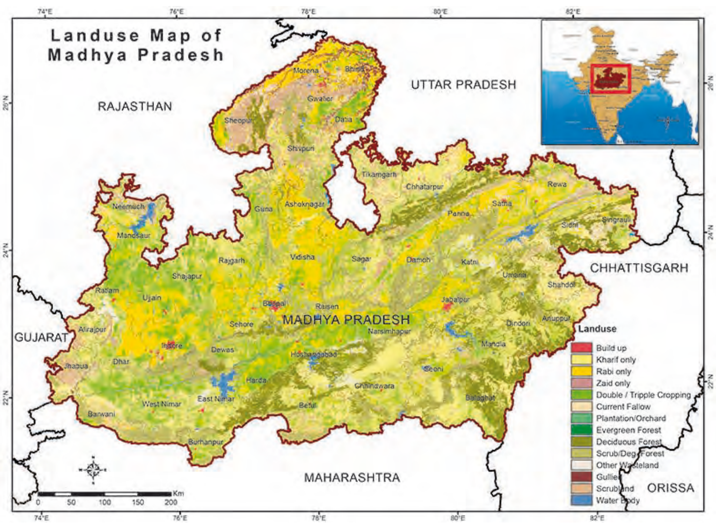
Stage 3:
Assessing the current state-level climate change vulnerability assessment in Madhya Pradesh

Step 1: Assess the profile of the system of interest

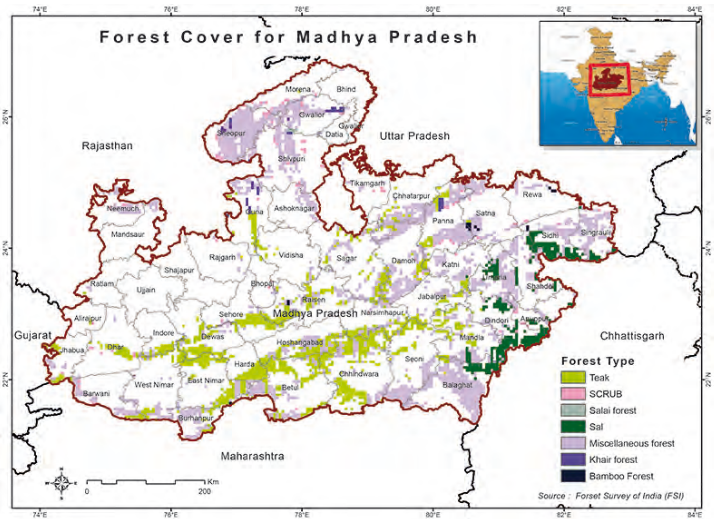
For the state vulnerability assessment of Madhya Pradesh, a literature review was carried out. Information was collected on natural resources (i.e. physiography, climate, water resources, status of forests, biodiversity, and land use), socio-economic variables (i.e. demography, economy, and agriculture), physical infrastructure (i.e. transport, irrigation, power supply, telecommunications, urban infrastructure, water supply, and industrial infrastructure) and social infrastructure (i.e. education sector and health infrastructure).

The results of this initial analysis were presented in the form of running text, tables, diagrams and maps depicting the spatial distribution of resources and socio-economic features. Two of these maps can be seen below.

Land use map of Madhya Pradesh



Spatial distribution of forest types in Madhya Pradesh



Step 2: Assess the observed climate (exposure)

Long-term trends in observed seasonal precipitation and temperature over Madhya Pradesh were analysed using data from the India Meteorological Department (IMD) for the years from 1969 to 2005. IMD precipitation and temperature data are available in the form of gridded maps with a spatial resolution of 0.5×0.5 degrees (about 50×50 km).

To simplify further analysis and to allow more meaningful comparisons between current and future climates, the output from a regional circulation model (RCM, >> see Practical methods and tools Ib) called PRECIS (Providing Regional Climates for Impacts Studies, >> see Practical methods and tools IV) was used. Like all RCMs, PRECIS uses the input of a global circulation model (GCM, >> see Practical methods and tools Ib). The GCM that provides the input to PRECIS, the Hadley Centre Coupled Model version 3 (HadCM3), has a spatial resolution of 2.5×3.75 degrees (about 417×278 km). With PRECIS, HadCM3 simulations can be downscaled to a spatial resolution of 0.44×0.44 degree (about 50×50 km).

A comparison between observed climate data supplied by IMD and PRECIS simulations showed that PRECIS is able to adequately simulate current climate conditions. In order to allow more meaningful comparisons between past and current conditions, PRECIS simulations were used in all further analyses.

The Expert Team on Climate Change Detection and Indices (ETCCDI [1]) has developed a suite of climate change indicators, which are based on values for daily temperatures and precipitation amounts. While some of the indicators are based on fixed thresholds, others are location-specific. For the state vulnerability assessment of Madhya Pradesh, indicators were calculated using the software RClimDex. The set of indicators of current and future (mid-century: 2021–2050; and end-century: 2071–2100) climate exposure in Madhya Pradesh are summarised in the following table.

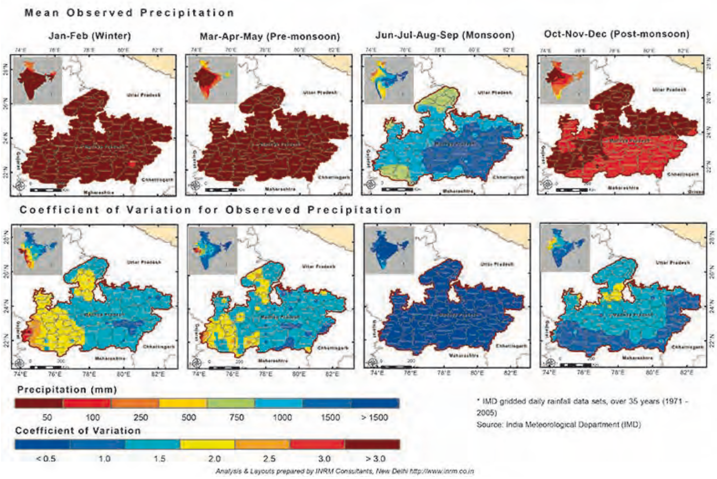
Variables of climate exposure in Madhya Pradesh

Variable	Unit	Source	Baseline years
Cool nights: days when minimum temperature < 10th percentile	%	PRECIS climate data (IITM, Pune)	1961–1990
Warm nights: days when minimum temperature > 90th percentile	%	PRECIS climate data (IITM, Pune)	1961–1990
Cool days: cool nights – days when maximum temperature < 10th percentile	%	PRECIS climate data (IITM, Pune)	1961–1990
Warm days: cool nights – days when maximum temperature > 90th percentile	%	PRECIS climate data (IITM, Pune)	1961–1990
Frost days: annual count when daily minimum < 0° Celsius	No. of days	PRECIS climate data (IITM, Pune)	1961–1990
Warm spell duration: annual count of days with at least 6 consecutive days when maximum temperature > 90th percentile	No. of days	PRECIS climate data (IITM, Pune)	1961–1990
Average annual rainfall	mm	PRECIS climate data (IITM, Pune)	1961–1990
Number of rainy days	No. of days	PRECIS climate data (IITM, Pune)	1961–1990
Extremely wet days – days where rainfall > 99th percentile of annual total rainfall	mm	PRECIS climate data (IITM, Pune)	1961–1990
Consecutive dry days – maximum number of consecutive days with rainfall less than 1 mm	No. of days	PRECIS climate data (IITM, Pune)	1961–1990
Frequency of drought	No. of weeks	IIT Delhi, MoEF&CC (NATCOM)	1961–1990
Flood discharge	m^3 per second	IIT Delhi, MoEF&CC (NATCOM)	1961–1990

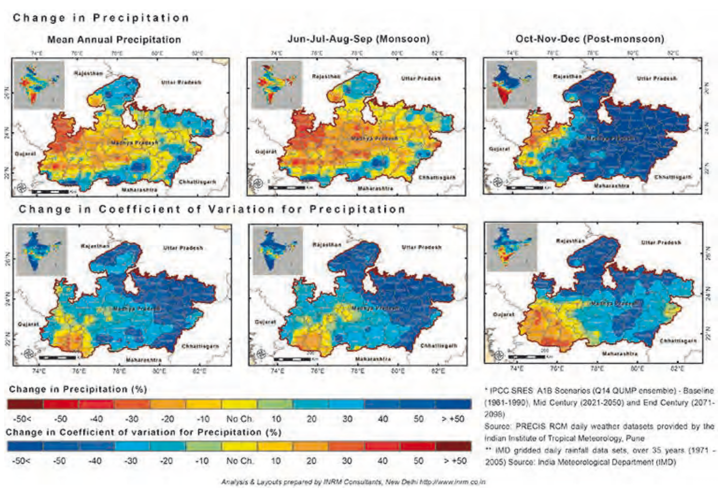
[1] http://www.clivar.org/organization/etccdi/etccdi.php

The results of the analysis of the observed and simulated current climate exposure were presented in the form of running text, tables, diagrams and maps depicting the spatial distribution of average precipitation and temperatures. Some of these are presented below.

Observed seasonal precipitation statistics for Madhya Pradesh (1971–2005)



Differences between observed precipitation and simulated precipitation for Madhya Pradesh



Step 3: Assessment of the effect of climate stimuli on the system of interest (sensitivity)

The effect of climate stimuli on the system of interest was assessed with the help of variables indicating sector-specific sensitivity. The selection of indicating variables was based on a literature review and subject to data limitations. Most of the data needed for the assessment of current sensitivity was taken from official publications of the Government of India and the Government of Madhya Pradesh.

Climate impact models are often only available for biophysical systems. Simulations of socio-economic systems, on the other hand, are much less readily available. For one of the sectors (water), the SWAT (Soil and Water Assessment Tool) simulation model (>> see Practical methods and tools Ia) was used. This made it possible to compare current sensitivity to that under a changed future climate. The SWAT modelling exercise was carried out by the Department of Civil Engineering at the Indian Institute of Technology (IIT) in New Delhi. The study was part of India's Second National Communication (NatCom II) to the UNFCCC (>> see Practical methods and tools IV).

Variables of climate change sensitivity for Madhya Pradesh

Variable	Unit	Source	Baseline years
Socio-economics			
Density of population	People per km^2	Census of India	2011
Sex ratio	No. of females/ 1000 males	Census of India	2011
Proportion of child population in the age group 0–6	%	Census of India	2011
Proportion of elderly population aged 65 and above	%	Census of India	2001
Percentage of people below the poverty line	%	State Planning Commission, Madhya Pradesh	2005
Number of slum dwellers per slum	No. of people	Madhya Pradesh HDR, 2007	2004
Percentage share of marginal workers	%	Census of India	2001
Percentage of scheduled tribes population	%	Planning Atlas, State Planning Board, GoMP	2001
Percentage of scheduled caste population	%	Planning Atlas, State Planning Board, GoMP	2001

>

Variable	Unit	Source	Baseline years
Agriculture			
Percentage of net irrigated area to geographical area by groundwater	%	Commissioner of Land Records, Madhya Pradesh	2006–2007
Percentage of land holdings below 1 hectare	%	Commissioner of Land Records, Madhya Pradesh	2001
Percentage share of agricultural and cultivator main workers	%	Census of India	2001
Forest			
Percentage of wasteland to geographical area	%	Commissioner Land records, Madhya Pradesh	2004–2007
Water			
Crop water stress (evapotranspiration/ potential evapotranspiration)	mm	IIT Delhi, MoEF&CC (NATCOM)	1961–1990
Health			
Percentage of people having diarrhoea	%	Department of Health & Family Welfare, Government of Madhya Pradesh	2006
Index of malaria	No. of reported cases/ population	Department of Health & Family Welfare, Government of Madhya Pradesh	2010

Water resources

The catchments of some of India's major rivers lie in Madhya Pradesh. Most of the smaller rivers in the state eventually drain into the Ganges in the north of Madhya Pradesh. About a third of the total geographical area of the state drains into the Narmada river in the south of Madhya Pradesh.

The SWAT model was used to determine the impact of current and future climate stimuli on the water resources in the state. The model requires information on the area's climate, terrain, soil profiles and land use as an input. These data were acquired from various sources:

- Climate data: PRECIS simulations for India (>> see Step 2: Assess the observed climate)
- Digital elevation model: Shuttle Radar Topography Mission (SRTM) at 90 m resolution [2]
- Drainage network: HydroSHEDS [3]
- Soil maps and associated soil characteristics: FAO Global soil [4]
- Land use: Global Land Cover Facility [5]

2 http://srtm.csi.cgiar.org
3 http://hydrosheds.cr.usgs.gov/
4 http://www.fao.org/geonetwork/srv/en/metadata.show?id=14116
5 http://glcfapp.glcf.umd.edu:8080/esdi/index.jsp

Step 4: Assess the responses to climate variability and extremes (adaptive capacity)

For the Madhya Pradesh state climate change vulnerability assessment, variables of adaptive capacity were identified based on existing vulnerability assessment literature. The identified variables were divided into four different sectors (i.e. socio-economics, agriculture, forests and water resources).

Variables of adaptive capacity to climate change for Madhya Pradesh

Variable	Unit	Source	Baseline years
Socio-economics			
Literacy rate	%	Census of India	2011
Percentage of households with access to safe drinking water	%	Census of India	2001
Percentage of households with access to sanitation facilities	%	Census of India	2001
Percentage of households with access to electricity	%	Planning Atlas, State Planning Board, Government of Madhya Pradesh	2007
Percentage of households owning radio, transistor, television and telephones	%	Madhya Pradesh HDR, 2007	2001
Road density	km of road per 100 km^2 of land area	Madhya Pradesh HDR, 2007	2003
Population served per health centre (community, primary and sub health centres)	No. of people	Madhya Pradesh HDR, 2007	2006
Number of primary, middle, high and higher secondary educational institutions per 100,000 population	No./100,000 people	Madhya Pradesh HDR, 2007	2006
Level of urbanisation	%	Planning Atlas, State Planning Board, GoMP	2001
Per capita income at current prices	INR	Economic Survey of MP, 2010–11	2001–2009
Net district domestic product at current prices	In 100,000 INR	Economic Survey of MP, 2010–11	2001–2009

>

Variable	Unit	Source	Baseline years
Scheduled commercial banks per 100,000 population	No.	Planning Atlas, State Planning Board, GoMP	2005–06
Agricultural credit societies per 100,000 population	No.	Planning Atlas, State Planning Board, GoMP	2005–06
Loan disbursed by agricultural credit societies per cultivator	INR	Planning Atlas, State Planning Board, GoMP	2005–06
Agriculture			
Percentage of net irrigated area to geographical area by surface water	%	Commissioner of Land Records, Madhya Pradesh	2006–2007
Fertiliser consumption	kg/ha	Directorate of Farmer Welfare and Agriculture Development	2006–2007
Yield of all crops	kg/ha	Department of Agriculture, GoMP	2005–2008
Percentage of bio-farming villages out of total villages	%	Department of Agriculture, GoMP	2004
Electrified pump sets per thousand hectares of gross cropped area	No.	Planning Atlas, State Planning Board, GoMP	2005–2006
Crop diversity (number of crops grown)	No.	Department of Agriculture, GoMP	2006
Cropping intensity	No. of croppings per year	Planning Atlas, State Planning Board, GoMP	2005–2006
Livestock population	No. per household	Administrative Reports of the Department of Animal Husbandry, GoMP	18th census, 2007
Poultry population	No. per 1,000 households	Administrative Reports of the Department of Animal Husbandry, GoMP	18th census, 2007
Milk production per capita	gm/day	Administrative Reports of the Department of Animal Husbandry, GoMP	2006–2009
Egg production per capita	eggs/year	Administrative Reports of the Department of Animal Husbandry, GoMP	2006–2009

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Variable	Unit	Source	Baseline years
Forests			
Percentage of high-density forest area to geographical area	%	Forest Survey of India	2004
Percentage of medium-density forest area to geographical area	%	Forest Survey of India	2004
Percentage of low-density forest area to geographical area	%	Forest Survey of India	2004
Sites developed as ecotourism sites	No.	MP Ecotourism Development Board	2011
Number of JFM communities	No.	Forest Department, GoMP	2010
NTFP diversity (no of varieties)	No.	Forest Department, GoMP	2010
Water resources			
Surface water availability	mm	IIT Delhi, MoEF&CC (NATCOM)	1961–1990
Groundwater availability	mm	IIT Delhi, MoEF&CC (NATCOM)	1961–1990

Step 5: Assessment of overall current vulnerability

The argument of co-variation or multi-variation is frequently used to reduce the number of indicating variables. Principle Component Analysis (PCA) and similar methods for multivariate data analysis are applied to reduce the number of dimensions (here, the number of indicating variables) needed to describe the state of the system whose vulnerability is to be indicated (Hinkel, 2011). To assess the vulnerability of the districts in Madhya Pradesh, a Composite Vulnerability Index (CVI) was developed. Principal Component Analysis (PCA) was used to reduce the number of indicating variables and to calculate the relative weights of the variables that determine the values for climate exposure, sensitivity and adaptive capacity. Based on these three values, climate change vulnerability was calculated as follows:

Vulnerability = sensitivity + exposure – adaptive capacity

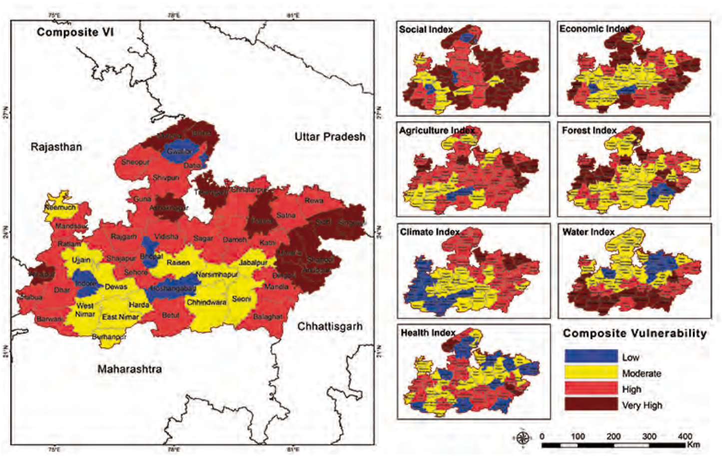
This can, in turn, be written as:

$$V = (wS_1 + wS_2 + \ldots + wS_n + wE_1 + wE_2 + \ldots + wE_n) - (wA_1 + wA_2 + \ldots + wA_n)$$

Where V is the vulnerability index, w is the weight obtained from the PCA scores, A_1 to A_n are the indicators for adaptive capacity, S_1 to S_n are the indicators for climate change sensitivity, and E_1 to E_n are the indicators for the climate exposure of the system of interest. A higher net value for V indicates lesser vulnerability while low values indicate a higher vulnerability to climate change. For the final analysis, a cluster analysis was performed to group the districts of Madhya Pradesh into different vulnerability categories. Cluster analysis is a class of statistical techniques that can be applied to data that exhibit 'natural' groupings. A cluster is a group of cases or observations that exhibit similar characteristics.

Results of the overall current vulnerability assessment of Madhya Pradesh show that socio-economic and environmental variables vary widely between districts. The following figure depicts the spatial distribution of clusters for the composite vulnerability index, and for sectorial vulnerability indices under current conditions.

Spatial distribution of the composite vulnerability index in Madhya Pradesh



Under current conditions, the districts with the highest vulnerability are located in the north and northeast of Madhya Pradesh. The districts within the second highest variability cluster are found throughout the state. The remaining districts – those that exhibit either moderate or low vulnerabilities – are mostly located in the south of the state. Interestingly, these districts are characterised by low incidences of extreme events and favourable socio-economic conditions (i.e. high literacy rate, high per capita income and better access to infrastructure).

Stage 3:
Assessing the current vulnerability of agriculture-based livelihoods in flood-prone areas of West Bengal

Step 1: Assess the profile of the system of interest

Information on the profile of the system of interest was collected through a review of academic literature, governmental and local data sources, household surveys, focus group discussions and other PRA tools, i.e. community mapping, seasonal calendars and transect walks. The assessment of the system of interest in this example begins with an assessment of the wider regional context in which the project sites are located. This initial analysis was largely done through a review of existing literature on the regional context in which the villages are located.

The results of the assessment of the profile of the system of interest were presented in the form of running text, tables, GIS maps, maps and tables derived from PRA exercises, and photographs taken in the respective villages.

Results

At the state, district and block level

At present more than 40 % of the total area of West Bengal is frequently hit by floods. Both of the project sites lie in regions with the highest incidents of flooding and waterlogging in West Bengal.

The Ganges River receives water from 11 states before it passes through Malda District in West Bengal. Before entering the neighbouring country, Bangladesh, parts of the Ganges river flow are diverted southwards at the Farakka Barrage. Apart from the Gangetic waters, Malda District also receives floodwater from the Mahananda River originating in Nepal. The Mahananda River passes through parts of Bihar and through Malda District before it joins the Ganges delta system in Bangladesh.

Murshidabad District lies to the south of Malda District. Located in the north of Murshidabad is the source of the (Bhairab-Jalangi-Sealmari) river system that flows through Murshidabad and its southern neighbour, Nadia district, before joining the Hooghly River in the central-western part of Nadia District.

Government statistics show that the economy of Manikchak Block of Malda District is based on agricultural production. Rice and jute are the main crops and account for more than 90 % of the total amount of crops produced in the district. Rice is cultivated in three seasons. Jute, wheat, potatoes and lentils are only grown in the winter (*rabi*[6]) season. Oilseeds, such as mustard, are also grown in parts of Manikchak Block. Soils in the Manikchak area are predominantly of the clayey loamy type. Of the total cultivated area of about 25,000 hectares in Manikchak Block, close to 30 % is irrigated.

As in Manikchak, the economy of Bhagabangola I Block in Murshidabad District is dominated by agricultural production. Rice is cultivated in three seasons throughout the year. It accounts for more than 90 % of cereal production in the block. Other crops (jute, wheat and potatoes) are cultivated in the winter, or *rabi*, season. Apart from these four major crops, various types of lentils and oilseeds are also produced in some parts of the block.

At the village level

The resource maps show the spatial distribution of farmland and houses in and around the villages. The maps also show the location of rivers and streams as well as other sources of irrigation water in the villages. Moreover, they identify on which agricultural fields double or even triple cropping frequently takes place.

Apart from identifying and quantifying the existing resources within the system of interest, the resource maps were also used to identify some of the key threats to local livelihoods. Agriculture in all three villages suffers severely from waterlogging. The resource maps point out the location, extent and severity of waterlogging on agricultural land in the villages.

Crop calendars show that villagers suffer from **food shortages** in the months from August to November and that most of the consumed vegetables are purchased from the market rather than produced by the villagers themselves. Moreover, crop cultivation in the villages depends to a **high degree on external inputs**, i.e. mineral fertilisers, chemical pesticides and hybrid seeds. In Gesarotola village in Malda District, farmers pointed out the very high importance of jute cultivation and how it suffers particularly heavily from **erratic rainfall** and **waterlogging.**

The problem identification and ranking methods that were used in focus group discussions (FDGs) produced different results for the two project sites. In Malda, community members listed **waterlogging** and **floods**, **demographic changes** and **health concerns** as their main problems. In Murshidabad, villagers prioritised the generally high degree of **poverty**, **concerns about raising sufficient funds for dowries**, and **the increasing costs of agricultural production** due to frequent crop failures and the high costs of external inputs.

FGDs about livelihood options and their changes over time drew out different socio-economic dynamics in the two project sites. In Malda, the number of families increased from about 400 in the year 2000 to about 485 in the year 2011. While the total number of families in the area has remained unchanged, the **relative importance**

6 There are two major crop growing seasons in the Indian Ganges basin. Summer, or kharif, crops are sown at the onset of the southwest monsoon and harvested from October up to February. The winter, or *rabi*, crop-growing season starts just after the southwest monsoon and extends well into the summer

of farming activities has decreased and the number of people employed as day labourers has increased. Villagers attribute this to a **lack of arable land** and a **low interest in agriculture due to the high costs of production**. In 2000, only one third of all families were involved in making *beedi*[7] cigarettes. By 2011, all families had taken up *beedi* production to improve their financial resource base. Similarly, in Murshidabad the number of community members migrating to avoid seasonal unemployment has increased in recent years.

Step 2: Assess the observed climate (exposure)

Due to limited data availability, actual climate data could not be analysed at the level of the selected villages. Instead, data was analysed for the whole districts of Malda and Murshidabad based on long-term climate data provided by the India Meteorological Department (IMD). Climate trends at the level of the individual villages were assessed through the participatory development of seasonal calendars that focus on weather behaviour for the past ten years.

Results

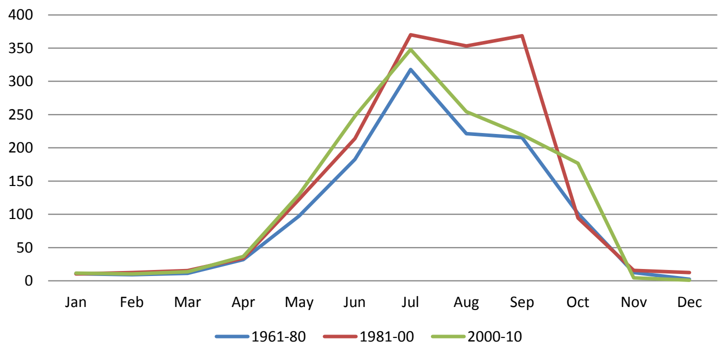
At the district level

Malda District receives an average of 1,593 mm of rain per year. The average temperature is about 9°C in winter and 41°C in summer. The rainy season in Malda District generally lasts from June to September with limited amounts of rainfall in May and October. The months from January to April are characterised by low and infrequent precipitation. Additional rainfall in December has become a rare phenomenon since 1998.

In the years from 1981 to 2000, the rainfall **peak of the monsoon season has shifted** from July to September. In the period from 2000 to 2010, monsoon rainfall has seen a slight shift back to a rainfall peak in July, as shown in the following figure.

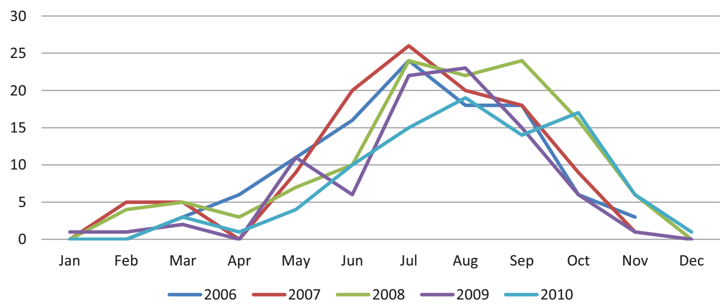
[7] Small Indian cigarettes made of a rolled Coromandel ebony leaf filled with tobacco. A pack of about 25 to 30 *beedis* sells for around INR 10.

Average rainfall pattern in Malda District



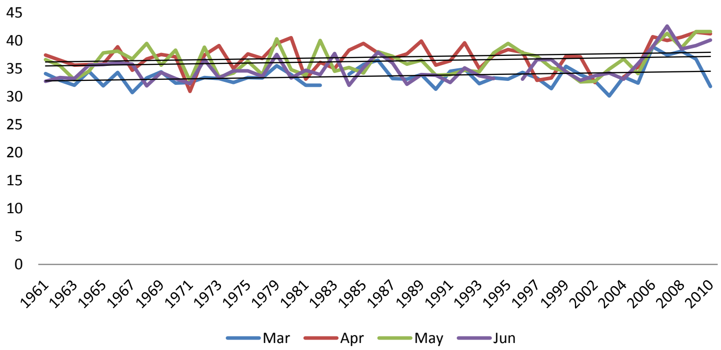
The long-term trend analysis for the past 50 years (1961 to 2010) shows a considerable **increase in total rainfall** in Malda District. Since 1990, **rainfall has become increasingly more erratic**. The number of rainy days and the amount rain per month vary considerably from year to year. Rice harvesting activities in October and November are frequently interrupted by unexpected sudden downpours. The following figure shows the number of rainy days per month for 2006 to 2010.

Number of rainy days in a month in Malda District



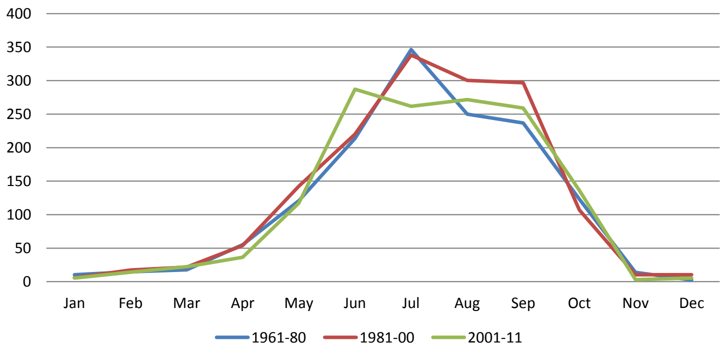
Temperature data analysis from 1961 to 2009 shows that **temperatures in Malda become gradually warmer**. As can be seen in the next figure, maximum temperatures in summer are becoming hotter while minimum winter temperatures are increasing. Moreover, the differences between minimum and maximum winter and summer temperatures are increasing.

Maximum summer temperature in Malda District



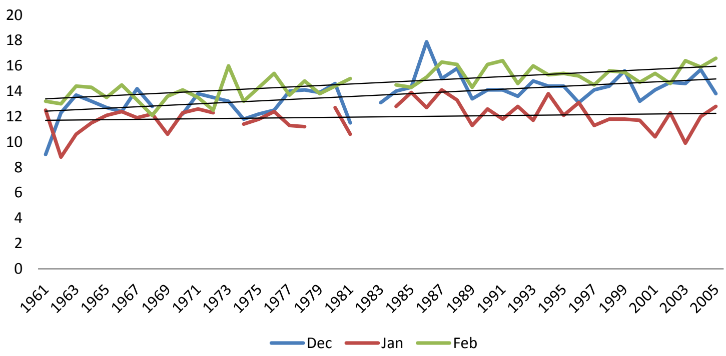
Murshidabad District receives an average of about 1,500 mm of rain per year. The rainy season in Murshidabad generally lasts from June to September with small amounts of rainfall in May and October. The period from January to April exhibits infrequent and low precipitation. Rainfalls in December and November have become rare since 1992. Since 1995, **rainfall intensity has decreased and become more erratic in nature**.

Average rainfall pattern in Murshidabad District



Temperature trend analyses for Murshidabad District show that **minimum winter temperatures are steadily increasing** (except in January). Likewise, the differences between minimum and maximum temperatures are steadily increasing as shown in the following figure. Unlike winter temperatures, summer temperatures show no discernible trend in the years from 1961 to 2010.

Minimum winter temperature in Murshidabad District



At the village level

Focus group discussions and seasonal climate calendars show results that are not always in accordance with statistical analysis at the district level. Nevertheless, villagers identified similar trends to those observed through climate data analysis. In both project sites, farmers identified periods of the year in which **strong and erratic rainfalls cause severe waterlogging** (July to October). Community members also pointed out **increasing temperatures**, especially in the summer months.

Step 3: Assess the impacts of climate stimuli on the system of interest (sensitivity)

Information on the sensitivity of the system of interest was collected through a literature review, a GIS-based regional and micro-level assessment, the participatory mapping exercise as described in Step 1, as well as through focus group discussions and the participatory construction of crop and climate calendars.

Results

At the state and district levels

Large parts of West Bengal are susceptible to **flooding, riverbank erosion and waterlogging.** The districts of Malda and Murshidabad in central West Bengal belong to the districts in West Bengal that are most frequently hit by devastating floods.

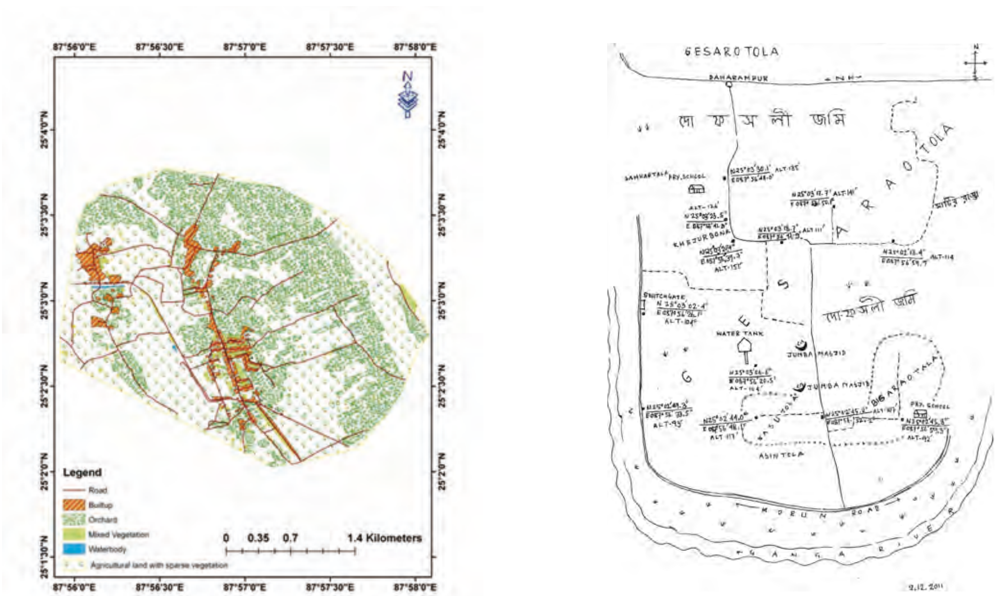
Apart from floods, the **erosion of riverbanks** is also a particular cause for concern. Hot spots for this erosion are found on the left bank of the Ganges upstream from the Farakka Barrage and in other parts of the Ganges-Padma and Bhagirathi-Hooghly river systems. In future, several towns on the banks are threatened with destruction if bank erosion continues unchecked.

At the village level

Government statistics, the socio-economic baseline survey and focus group discussions showed that rain-fed **agriculture remains the primary occupation** in the project areas. The main crops for small farmers are paddy rice, wheat, potato and jute. Apart from flooding, waterlogging over a long period puts additional stress on agriculture in both districts.

The GIS-based regional and micro-level assessment produced various maps of the project villages. First, land use maps were generated by processing high-resolution satellite images. Second, a ground survey was conducted to verify land use characteristics and identify micro-level waterlogging conditions. During the ground survey, areas that were particularly heavily affected by flooding and waterlogging were geo-referenced with handheld GPS devices. The ground survey was conducted in close collaboration with local inhabitants.

Land use map of Gesarotola village in Malda District



This map was prepared using remote sensing data (left), and also using GPS devices and stakeholder interaction (right).

Focus group discussions and seasonal calendars show that, among farmers, **the months from September to November are known as the waterlogging – and thus unproductive – period of the year**. Due to changes in precipitation patterns, incidences of waterlogging are increasing and agricultural yields are going down. Paddy and jute grown during the summer monsoon have always been sensitive to long periods of waterlogging lasting up to 6 or 7 months in a year. With shifting rainfall patterns, the impact on rice production is expected to worsen.

Added to this, because of the earlier onset of the summer monsoon, the jute harvest has suffered heavily in recent years. This is because heavy rains causing waterlogging have recently been starting in July instead of August, which is the month of the jute harvest. The growth of jute plants is hampered by the stagnant water in July. On the other hand, delaying monsoon can also harm the retting of Jute.

Climate data analysis shows that the duration of high temperatures during summer is extending. This circumstance leads to reduced production of late-sown paddy. Wheat and potato, which are the major winter crops (*rabi* season), mainly suffer from increasing winter temperatures and decreasing rainfall. In this way, erratic rainfall severely affects the livelihoods of villagers. To ensure the family's income, at least one male family member works as a labourer in one of the bigger cities.

Step 4: Assess the responses to climate variability and extremes (adaptive capacity)

Various PRA tools were used to assess the responses of local communities to observed climate variability, trends and extremes in the project areas. Farming households perceive themselves to be highly vulnerable to extreme events, especially flooding, and have developed various strategies to cope with these extreme situations.

These strategies include the protection of property in times of extreme events. During floods, for example, people in the project areas prepare temporary shelters from bamboo. These shelters are being built to protect valuables and important documents (IDs or passports and other legal documents). In very extreme flooding situations, villagers also take shelter in these temporary structures. Another coping strategy involves villagers replacing their mud-made ovens with aluminium ones.

Villagers perceive that the local government for the project sites is unable to provide much support at all in times of flood. It is only in extreme flood events that local government institutions provide boats for transport, packaged food and tarpaulins.

Local farming communities do not just have to deal with extreme events like floods; they must also respond to low crop production or total crop failure due to waterlogging, high temperatures or insufficient rainfall.

The two most common strategies for members of these communities are: 1) to migrate from the areas in which they feel vulnerable due to climate extremes and vulnerability, and 2) to find work as day labourers instead of working in agriculture.

In order to ensure sufficient financial household resources, farmers also often borrow money at a high interest rate from local moneylenders. Another common way to deal with a lack of financial resources in times of crisis is to sell livestock, thereby diminishing the household's resource base.

Step 5: Assess the overall current vulnerability

In order to assess the vulnerabilities of people living in three villages in the districts of Malda and Murshidabad in West Bengal, a variety of methods were combined: participatory exercises, household surveys, literature reviews, and climate data analyses. Climate data analyses were performed to understand which kinds of climatic variability and extremes the villagers are exposed to. Focus group discussions were used to determine people's risk perceptions and to assess the basis of their livelihoods. Seasonal calendars were developed with the participation of local communities to understand how livelihood patterns change throughout the year and what kinds of risks the people and agricultural systems are facing. Household surveys were carried out in the villages to quantify the state of household resources in the project villages. Moreover, the surveys could be used to quantify the importance of different livelihood options in the villages.

The overall current vulnerability assessment for the selected project villages showed that local livelihoods are heavily dependent on rain-fed agricultural production. Shifting rainfall patterns and increasing temperatures lead to decreasing crop yields. Longer periods of waterlogging put an additional stress on crops and further reduce yields. The jute harvest, for example, often suffers greatly from an early onset of the summer monsoon, with heavy rains causing waterlogging as early as in July, as opposed to August in the past. As a result, the growth of jute plants is stunted by the stagnant water. Wheat and potatoes, the main winter crops, mainly suffer from higher winter temperatures and decreasing amounts of rainfall in November and December. As a response to decreasing agricultural production due to shifting rainfall patterns and increasing temperatures, most villagers tend to shift to non-farming activities.

The project sites suffer from additional stresses through flooding and riverbank erosion. Rising temperatures due to global climate change are likely to lead to glacier melt in the Himalayas. In that case, both Malda and Murshidabad Districts could receive higher amounts of floodwater, which would lead to an even higher number of floods in these regions.

3.4. Stage 4: Assessing future vulnerability

Stage	Steps
3. Assessing future vulnerability	1. Assess the future climate **(future exposure)** 2. Assess the future impacts on the system of interest **(sensitivity)** 3. Assess future socio-economic scenarios **(adaptive capacity)** 4. Assess the overall **future vulnerability**

This stage comprises four steps for assessing the future vulnerability of the system of interest. It builds on earlier stages during which current climate conditions were analysed and current climate vulnerability was assessed. It combines the results of those analyses to develop scenarios. Bottom-up approaches do not usually assess future vulnerability. Instead, bottom-up approaches assess vulnerability to current conditions. This is done under the assumption that adapting to current climate variability and extremes will reduce vulnerability to climate change in the future.

Future vulnerability assessments link projections of the future climate and projections of socio-economic development (non-climatic factors) to possible future scenarios. The projections vary both spatially and temporally and show long-term changes in climatic and socio-economic variables.

Scenario

A scenario is a plausible description of how the future may develop based on current recognisable signals and trends, and on assumptions about how these will progress in the future. Scenarios allow the user to analyse the future in the context of climate change. The development of most scenarios follows top-down approaches in which small teams, consisting of experts from different sectors, work on generalised and often global models. This provides the user with scenarios developed within a consistent framework.

Bottom-up scenarios are developed using participatory methods and tend to be oriented toward local levels. They are more likely to capture local vulnerabilities and dynamics but perform increasingly poorly at increasing spatial aggregations.

(Downing & Ziervogel, 2004)

Step 1: Assess the future climate (future exposure)

This step attempts to determine how climatic variables will change in the future.

Top-down vulnerability assessments use climate models to project the effect of higher levels of greenhouse gases (GHG) on the earth's climate. Globally, temperatures are rising due to increasing concentrations of GHG in the atmosphere. Elevated levels of GHG lead to more solar radiation being trapped in the atmosphere, which causes the earth to heat up like a greenhouse. It is expected that GHG emissions will increase in the future, leading to a further rise in temperatures.

Climate models require a certain level of technical capacity and highly skilled technical experts. Most organisations that carry out future vulnerability assessments use the outputs from specialised research institutes engaged in climate modelling.

Global and Regional Circulation Models (GCMs and RCMs) simulate the effects of higher GHG concentrations on the different components of the earth's climate, i.e. temperature, precipitation, wind, humidity, etc. Each climate model is unique and based on different assumptions. Consequently, different models produce somewhat different projections of the future climate when provided with the same data. The 25 climate projections prepared for the IPCC were collected under the Program for Climate Model Diagnosis and Intercomparison (PCMDI) and are available under the name Coupled Model Intercomparison Project 3 (CMIP3). An update of the CMIP3 database, called CMIP5, is scheduled for release in September 2013 (PCMDI, 2012).

In India, the Indian Institute of Tropical Meteorology (IITM) specialises in developing climate scenarios for the Indian subcontinent. The institute uses ensembles of 10 GCMs and an RCM called Providing Regional Climates for Impacts Studies (PRECIS) to downscale global climate change projections to regional levels.

In bottom-up approaches, scenarios can be developed by the stakeholders involved in a participatory process. This is done by evaluating past-observed trends of climatic changes and the inputs of top-down models and projections. This information can be integrated to come up with likely changes in key climate variables at the local level (Bizikova, et al., 2010).

The outputs of both top-down and bottom-up scenarios should help in answering the following questions. Most bottom-up assessments are not future-explicit. Top-down assessments, on the other hand, almost always involve future scenarios of some kind. Given these facts, most of the questions are only relevant for top-down scenarios.

Questions

- **What is the projected change in key climatic variables?**
  (E.g. change in inter-annual or inter-seasonal variability of climatic variable, change in average value of climatic variable, change in maximum or minimum value of climatic variable)
- **What is the projected change in extreme events?**
  (E.g. occurrence and timing of floods, dry spells and heat waves)
- **What are the uncertainties in the selected climate projections?**
- **What top-down climate projections are available for use in participatory scenario development?**

Apart from these main questions, the same key variables as those in the assessment of current exposure should be considered. An assessment of future exposure seeks to determine how these key variables will develop in specified time frames in the future:

- Maximum, minimum and average monthly temperature
- Maximum, minimum and average monthly precipitation
- Standard deviation of average summer monsoon precipitation
- Severity of extreme events (meteorological droughts, floods, cyclones, etc.)
- Return period of extreme events

Suggested methods and tools

1) **Top-down**
   (>> see Practical methods and tools Ib)
- **Global Climate Modelling (GCM) projections**
- **Regional Climate Modelling (RCM) projections**

2) **Bottom-up**
   (>> see Practical methods and tools II)
- **Participatory scenario analysis: 'What if?' tool**

Step 2: Assess the future impacts on the system of interest (sensitivity)

Step 2 of the assessment of future vulnerability will assess how the current vulnerabilities are likely to be affected by the projected changes in climate variables and which new vulnerabilities might emerge as a consequence.

For top-down approaches, this step involves the use of specific biophysical models to come up with scenarios of sensitivity to future exposure for individual sectors (e.g. agriculture, forests, water and coastal areas). Such sector models attempt to describe future scenarios by integrating the outputs of climate projections and socio-economic scenarios. Top-down assessments of future sensitivity using simulation models are a data-intensive exercise that requires skilled personnel.

Due to data limitations and technical complexity, most assessments have so far focused on single sectors. However, impacts of climate change on one sector can have direct and indirect implications for other sectors (some adverse and some beneficial). To be more policy relevant, future analyses need to account for the interactions between different sectors, particularly at the national level but also in terms of global trade and financial flows.

Bottom-up assessments of the future effects of climate stimuli on the system of interest rely mostly on participative scenario development. Within the scenario development process, stakeholders get a chance to identify climate change impact chains and evaluate which social groups may become most vulnerable and where the highest concentrations of vulnerable groups will be located (Bizikova, et al., 2010).

Bottom-up approaches that assess current vulnerability to climatic variability and extremes can contribute to determining thresholds of exposure for the system of interest. This can indicate the conditions that are likely to be hardest to deal with. Moreover, these thresholds can eventually be compared with downscaled climate projections to gauge the impacts of future climate change at a more localised level.

In the following you will find key questions to be considered when determining the future impacts of climate change on the system of interest.

Questions

- **What likely changes in biophysical parameters are expected as a result of climate change?** (E.g. change in land use, land cover, water availability and quality, crop yields and production)
- **Will climate change cause the demand for a resource to exceed its supply?**
- **Does the system have limiting factors that may be affected by climate change?**

Suggested methods and tools

1) **Top-down**
   (>> see Practical methods and tools Ia)

- **Indicator-based methods**
  (>> see Practical methods and tools III)
- **Sector-specific simulation models**
  (>> see Practical methods and tools Ia)
  - > **agriculture**
  - > **water**
  - > **coastal areas**
  - > **human health**
  - > **terrestrial ecosystems**

2) **Bottom-up**
   (>> see Practical methods and tools II)

- **Participatory scenario analysis: 'What if?' tool**

Step 3: Assess future socio-economic scenarios (adaptive capacity)

Step 3 of the assessment of future vulnerabilities involves the development of socio-economic scenarios that are indicative of the changes most likely to emerge in the system of interest in the future. Assessments may consider human population growth patterns in the system of interest, economic shifts or land use changes. The description of indicators of projected non-climatic variables and stresses may be either qualitative or quantitative.

In future-explicit top-down assessments, socio-economic scenarios are key drivers of projected changes in future GHG emissions and climate variables. They are also key determinants of most climate change impacts, potential adaptations and vulnerability (Malone & La Rovere, 2005). Furthermore, the scenarios influence the policy options available for responding to climate change. Climate change impact, vulnerability and adaptation assessments increasingly include scenarios of changing socio-economic conditions, which can substantially alter assessments of the effects of future climate change (Alcamo, et al., 2006; Parry, et al., 2004; Goklany, 2005; Hamilton, et al., 2005; Schröter, et al., 2005). Many scenarios are developed at a broader scale, requiring downscaling of aggregated socio-economic scenario information.

For bottom-up assessments, participatory scenario development is a powerful tool for creating scenarios of possible future adaptive responses and capacities. Using previously identified scenarios of future climate change and climate change impact chains, participating stakeholders can identify existing adaptation options and come up with improvements to the same. Furthermore, the stakeholders can be given a chance to rank adaptation measures according to their urgency and identify barriers and trade-offs associated with their implementation (Bizikova, et al., 2010; Chaudhury, et al., 2013).

Questions

- **What are the socio-economic scenarios that can emerge?** (Regions, groups, time frame)
- **What possible measures exist for adapting to climate change in the future?**
- **How will existing capacities for adapting to climate change develop in the future?**

Suggested methods and tools

1) **Top-down**

- **Statistical techniques**
  (>> see Practical methods and tools IV for useful data sources)
  > **Ratio method for population growth**
  > **Trend analysis** (e.g. polynomial trend analysis)
- **Modelling techniques**
  > **Agent-based modelling**
  (>> see Practical methods and tools Ib)
  > **Dynamic Interactive Vulnerability Assessment (DIVA)**
  (>> see Practical methods and tools Ia)
  > **Integrated Model to Assess the Greenhouse Effect (IMAGE)**
  (>> see Practical methods and tools Ia)
  > **RamCo and ISLAND MODEL**
  (>> see Practical methods and tools Ia)

> The South Pacific Island Methodology (SPIM)
(>> see Practical methods and tools Ia)

2) **Bottom-up**
(>> see Practical methods and tools II)
- **Participatory scenario analysis: 'What if?' tool**
- **Role-play**

Step 4: Assess the overall future vulnerability

The assessment of the overall future vulnerability basically follows the same approach as the assessment of overall current variability. It is prepared by combining the outputs from Steps 1 to 3 of Stage 4: 1. Assess the future climate (exposure); 2. Assess future the impacts on the system of interest (sensitivity); and 3. Assess future socio-economic scenarios (adaptive capacity). The following key questions should be asked to develop links between the previous steps of the assessment.

Questions
- **What will be the impacts of selected climate scenarios on likely socio-economic and biophysical scenarios?**
- **Which regions, sectors and groups are likely to be most impacted?**
- **What non-climatic factors may determine the severity of climatic impacts?**

Suggested methods and tools
1) **Top-down**
- **Indicator-based methods**
(>> see Practical methods and tools III)
- **Sector-specific simulation models**
(>> see Practical methods and tools Ia)
  > agriculture
  > water
  > coastal areas
  > human health
  > terrestrial ecosystems

2) **Bottom-up**
(>> see Practical methods and tools II)
- **Brainstorming**
- **Cognitive mapping**
- **Community mapping**
- **Climate hazard trend analyses**
- **Focus group discussions**
- **Hazard mapping**
- **Impact matrices**
- **Participatory scenario analysis: 'What if?' tool**
- **Vulnerability matrices**

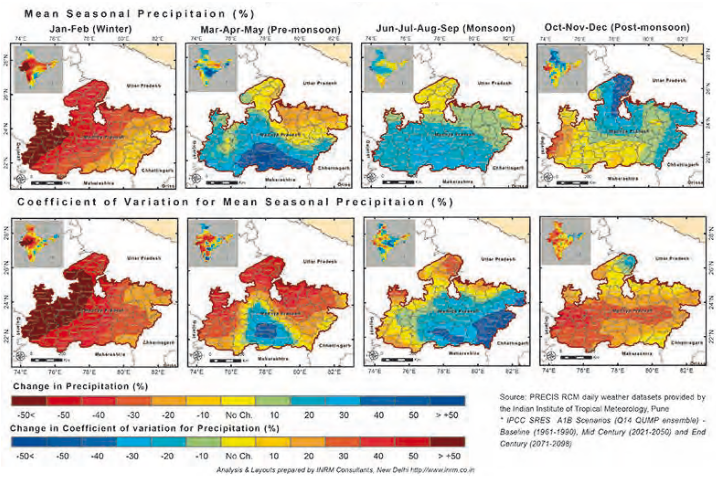
Stage 4:
Assessing the future state-level climate change vulnerability in Madhya Pradesh

Step 1: Assess the future climate (future exposure)

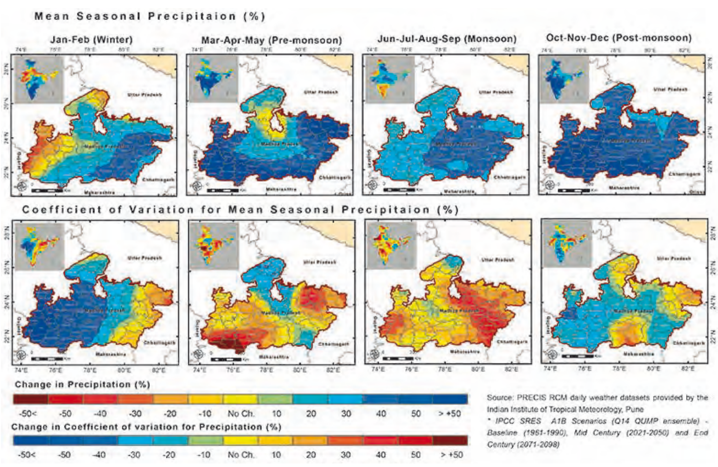
To assess the future climate of Madhya Pradesh, the output of the PRECIS simulations (>> see Step 2: Assess the observed climate) was analysed. Future climate exposure was considered for two time frames in the future: mid-century (2021–2050) and end-century (2071–2100).

The authors of the state climate change vulnerability assessment conclude that PRECIS simulations indicate an all-round warming over Madhya Pradesh. In the mid-century scenario (2021–2050), the minimum and maximum air temperatures are expected to rise by 2.3°C and 1.9°C respectively. By the end of the century (2071–2100) minimum and maximum air temperatures are expected to rise by around 4.8°C and 3.9°C respectively above current conditions. Mean annual precipitation is simulated to increase by about 11 % in the mid-century scenario and about 30 % towards the end of the century. PRECIS simulations further indicate that the frequency of certain climatic extremes will significantly increase. Warm days and nights and consecutive dry days are expected to increase while the number of cold days and nights is expected to decrease.

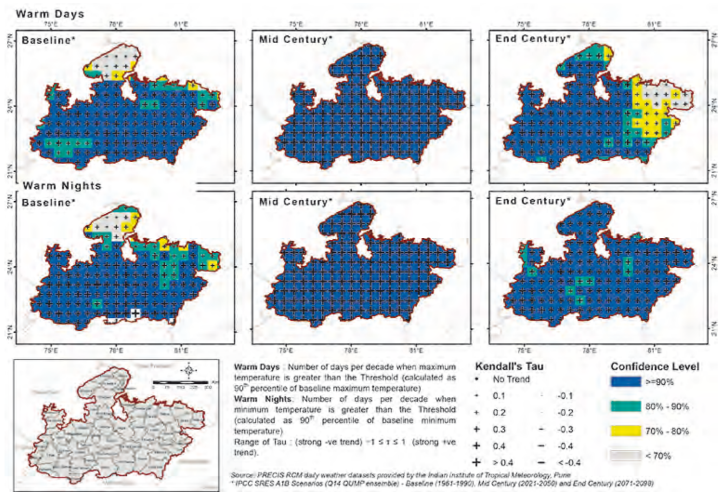
Projected future changes in seasonal precipitation statistics in the mid-century period (2021–2050) with respect to the baseline (1961–1990) for Madhya Pradesh



Projected future changes in seasonal precipitation statistics in the end-century period (2071–2100) with respect to the baseline (1961–1990)



Spatial pattern of trends of indices for hot extremes in Madhya Pradesh in the mid-century (2021–2050) and end-century (2071–2100) scenarios with respect to the baseline (1961–1990)



The size of the '+' sign indicates the magnitude of the projected trend.

Step 2: Assess the future impacts of climate stimuli on the system of interest (sensitivity)

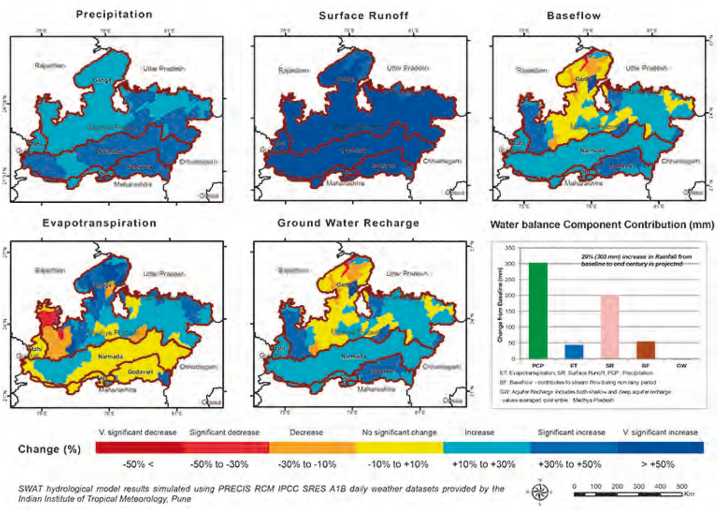
Future-explicit climate change sensitivity analyses were carried out for two sectors, i.e. water resources and forestry. The impact of climate change on water resources was assessed using the SWAT model (Soil and Water Assessment Tool, >> see Practical methods and tools Ia). The impact on forest resources was assessed by applying the IBIS model (Integrated Biosphere Simulator, >> see Practical methods and tools Ia).

Water resources

The impacts of climate change on water resources in the state were determined by applying the SWAT model. The SWAT model analysis of climate change impacts on water resources was part of a study conducted for India's Second National Communication to the UNFCCC. The SWAT study was conducted by the Department of Civil Engineering at the Indian Institute of Technology (IIT) in Delhi.

Six major river basins fall within the territory of Madhya Pradesh: Ganges, Narmada, Godavari, Tapi, and Mahi. For the end-century scenario, an increase in precipitation of 29 % is projected. During the monsoon months, surface runoff and evapotranspiration are projected to increase considerably offering opportunities for increased water harvesting and groundwater recharge. Due to substantially higher evapotranspiration rates during the *rabi* season, groundwater recharge is projected to decrease despite projected higher precipitation. The following figure depicts the end-century simulations of climate change impacts on groundwater resources in Madhya Pradesh.

Distribution of changes in water balance components in the end-century scenario (2071–2100) with respect to the baseline (1961–1990)

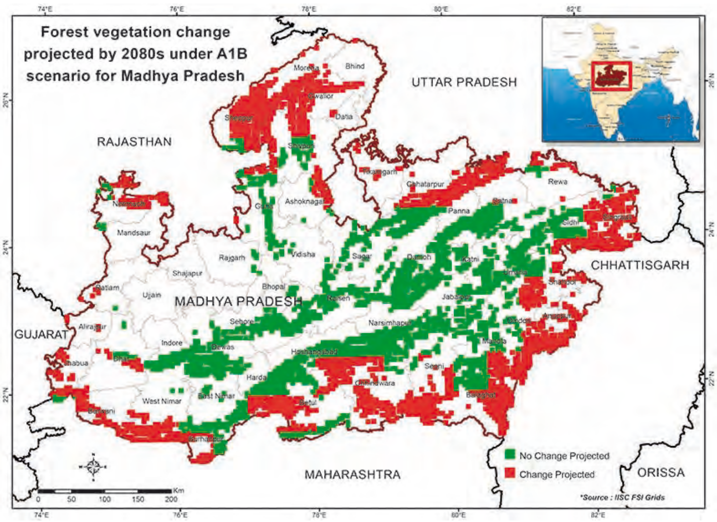


Forests

The impact of climate change on forest resources in Madhya Pradesh was assessed using a dynamic vegetation model called IBIS (Integrated Biosphere Simulator, >> see Practical methods and tools Ia). IBIS needs climatic data (taken from PRECIS simulations), soil parameters and topographic data as inputs.

IBIS simulations indicate that, in the near future (2021–2050), 23 % of the state's forested area is going to be negatively affected by climate change. At the end of the century (2071–2100), 48 % of the total forested areas are expected to suffer from the impacts of climate change.

Forest vegetation change projected by the 2080s under the A1B scenario for Madhya Pradesh



Step 3: Assessment of future socio-economic scenarios (adaptive capacity)

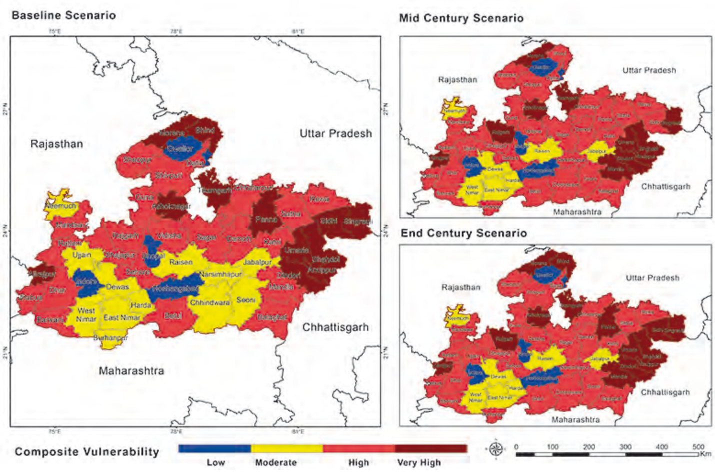
An assessment of future socio-economic scenarios requires projections about various socio-economic variables. Appropriate models for projecting the variables in the future are often not readily available. Due to data and model limitations, the state vulnerability assessment of Madhya Pradesh does not contain simulations for most of the variables identified in Step 3 of Stage 3 (variables of adaptive capacity to climate change). Instead values for the baseline conditions were assumed to remain unchanged in the future.

For the state-level vulnerability assessment of Madhya Pradesh, only the following key variables were projected into a mid-century and end-century scenario: the **population per district** of Madhya Pradesh was projected using the ratio method; **district-wise income per capita** and **net domestic product** were projected using polynomial trends based on data from the years 2000 to 2010.

Step 4: Assess overall future vulnerability

The assessment of overall future vulnerability was performed by applying the same methodology used in Step 4 of Stage 3: assessment of overall current vulnerability. The results of the mid- and end-century scenarios are shown below.

Spatial distribution of clusters of the Composite Vulnerability Index (CVI) in Madhya Pradesh for current (left), mid-century (top right) and end-century (bottom right) conditions



In the **mid-century scenario,** a number of districts move to higher CVI categories when compared to current vulnerability conditions. In total, six districts move to higher vulnerability categories while two districts move to a lower vulnerability class. In the **end-century scenario**, the vulnerability of three further districts increases, moving them from the 'high vulnerability' category to the 'very high vulnerability' category.

Lessons learnt from the state-level vulnerability assessment in Madhya Pradesh

The results of the state-level vulnerability assessment in Madhya Pradesh became part of the State Action Plan on Climate Change in Madhya Pradesh. Despite its apparent advantage of representing climate change vulnerability in the form of simple indicators, there are certain limitations to this approach that need to be pointed out.

First of all, there is a big risk that results are created but are not then communicated to relevant stakeholders, policymakers, decision-makers and implementers. The scientific methods and tools applied in the assessment need to be put into a comprehensive narrative to make the end-users of the assessment understand how data were analysed and results generated. For example, the development of vulnerability indicators is based on the aggregation of a number of indicating variables. The process of aggregating these variables is, in turn, based on mathematical procedures such as Principal Components Analysis (PCA). While it is not necessary for readers of the vulnerability assessment to understand the specifics of PCA, it is imperative that they understand enough about the procedure to accept the validity of its outcome. However, this requires presenting the methodology and the results in a form that is understandable to the end-user.

Secondly, the development of indicators is constrained by the availability of data on indicating variables. Time series of socio-economic data are often especially difficult to obtain, making it very challenging to determine past trends and project future scenarios. Very often these data are not available in the format in which they are needed. In Madhya Pradesh, for example, crop production statistics for the district level are available online for the year 1999 onwards. Crop production statistics prior to 1999 have not been digitised and are only available in paper format in various offices across the state.

Thirdly, though the greatest possible care was taken in the selection of indicating variables, the presented approach remains subjective. Given sufficient data availability, any number of variables could theoretically be included in the assessment.

Lastly, vulnerability to climate change is not only determined by quantifiable variables but also by more qualitative variables. Accommodating these variables in an indicator-based approach, such as the one presented here, is extremely difficult.

Lessons learnt from the vulnerability assessment of agriculture-based livelihoods in flood-prone areas of West Bengal

PRA exercises were used to **identify the characteristics** of farm households that are suitable to be included in the demonstration project's first phase. Based on these characteristics, **beneficiaries were selected** and a socio-economic baseline survey was carried out among the beneficiaries. Moreover, existing women's self-help groups were identified as potential partners for the implementation of some of the proposed interventions, e.g. nutrition gardens in homestead areas.

The integrated results of the vulnerability assessment were used to **identify and adapt the most suitable adaptation options** from a wide selection of options proposed by the Development Research & Communication Services Centre (DRCSC). For example, jute is o ne of the main high-value crops in Malda District. Jute production suffers heavily from waterlogging and erratic rainfall; hence intercropping of jute and plants resistant to waterlogging was identified as a suitable adaptation option.

PRA exercises lie at the heart of the vulnerability assessment. PRA tools can provide essential information on all aspects of a community's vulnerability to climate change: 1) the degree to which the community is exposed to climate stimuli; 2) how sensitive the community's livelihoods are due to climatic and non-climatic stimuli; and 3) the capacity of a community to adapt to these impacts. PRA exercises can be carried out by skilled personnel who are often available in NGOs that focus on rural development and natural resource management.

Climate data analysis requires at least a basic knowledge of climatic variables and how they impact on the system being assessed for climate change vulnerability. Since climate data are often not available at the local level, data from a higher spatial aggregation must be used. In the case of India, some district-level climate data are publicly available, while other data can be obtained at a relatively low cost.

GIS-based assessments, like the one presented in this study, require relatively high data and financial inputs. The required expertise cannot be expected to be present in organisations that implement climate change adaptation projects. Hence, these assessments incur additional costs for bringing in external consultants. Moreover, certain necessary data, e.g. high-resolution digital elevation models, are often not available.

‘I stopped cultivating vegetables ten years ago because water-logging caused by rainwater used to destroy my vegetables. Thanks to the new techniques I learned, I can now grow vegetables again. Some of it I use at home to prepare food, some of it I sell at market to earn money. I take care of my garden like I take of my child.’

Sayera Bibi, 36 years
Balarampur village, Murshidabad District, West Bengal

4 PRACTICAL METHODS AND TOOLS

Practical methods and tools Ia: Sector specific top-down tools for vulnerability assessment

Top-down or scenario-driven studies to assess impacts of climate change predominantly use impact models. These include crop models, hydrological models, simulation models for coastal areas, human health assessment methods and terrestrial ecosystem models. Sectorial methods and tools can provide a quantitative estimate of the possible harm to certain sectors and/or systems due to future climate change. However, they are limited by the uncertainty inherent in every simulation model, as well as by their input parameters. Moreover, most of these models are not good for representing conditions at finer spatial scales. Following are some of the most widely used tools and methods for sector-specific climate impact assessments.

AGRICULTURE

Method/tool	Description
Agricultural Catchments Research Unit (ACRU)	ACRU is a multipurpose model that integrates water budgeting and runoff components of the terrestrial hydrological system with risk analysis. ACRU can be used at the catchment or sub-catchment level to study the impact of climate change and enhanced CO_2 conditions on crop yields and water balances. **Resources** General information and background to the ACRU model: http://dbnweb2.ukzn.ac.za/unp/beeh/acru/information/infoFrame.htm Compendium on methods and tools to evaluate impacts of, and vulnerability and adaptation to, climate change (UNFCCC, 2009): http://unfccc.int/adaptation/nairobi_work_programme/knowledge_resources_and_publications/items/5299.php
Agricultural Production Systems Simulator (APSIM)	APSIM is a modular modelling framework developed to simulate biophysical processes in farming systems. It relates particularly to the economic and ecological outcomes of management practices in the face of climate risk. APSIM is a powerful tool for exploring agronomic adaptations such as changes in planting dates, cultivar types, fertiliser/irrigation management, etc. It can also be used to study changes in crop yields and shifts in agro-ecological zones relative to different climate change scenarios. **Resources** The Agricultural Production Systems Simulator (APSIM): http://www.apsim.info Compendium on methods and tools to evaluate impacts of, and vulnerability and adaptation to, climate change (UNFCCC, 2009): http://unfccc.int/adaptation/nairobi_work_programme/knowledge_resources_and_publications/items/2674.php

Data requirements and output
Inputs required for the application of ACRU include: • Weather data › maximum and minimum temperatures › rainfall • Catchment › location › area › configuration › altitude • Land cover • Soil properties (texture, depth) ACRU's main **outputs** consist of estimates for the following variables under different climate change scenarios: • Crop yields • Water balances (including irrigation needs, runoff, etc.)
APSIM is data-intensive and requires, among others, **input** data on: • Soil properties • Daily climate data • Cultivar characteristics • Agronomic management Main **outputs** of the APSIM model consists of estimates of the following variables under climate change scenarios: • Changes in crop and pasture yields • Yield components • Soil erosion losses

>

AGRICULTURE

Method/tool	Description
CENTURY	CENTURY is a general model of plant-soil nutrient cycling that has been used to simulate carbon and nutrient dynamics for different types of ecosystems, including grasslands, agricultural lands, forests and savannahs. CENTURY is composed of a soil organic matter/decomposition sub-model, a water budget model, a grassland/crop sub-model, a forest production sub-model, and management and events scheduling functions. The scope of CENTURY is site-specific, but the model has been used at watershed, drainage basin, and regional scales using GIS. **Resources** CENTURY Soil Organic Matter Model Version 5: http://www.nrel.colostate.edu/projects/century5/ Compendium on methods and tools to evaluate impacts of, and vulnerability and adaptation to, climate change (UNFCCC, 2009): http://unfccc.int/files/methods_and_science/impacts_vulnerability_and_adaptation/methods_and_tools_for_assessment/application/pdf/century.pdf
CROPWAT	CROPWAT is a decision support system. It was designed as a tool to help agro-meteorologists, agronomists, and irrigation engineers carry out standard calculations for evapotranspiration and crop water-use studies, particularly in the design and management of irrigation schemes. CROPWAT can be used for testing the efficiency of different irrigation strategies (e.g. irrigation scheduling, improved irrigation efficiency) under climate change. However, it does not have the capacity to simulate the direct effects of rising atmospheric carbon dioxide concentrations on crop water-use. **Resources** CROPWAT: http://www.fao.org/nr/water/infores_databases_cropwat.html Compendium on methods and tools to evaluate impacts of, and vulnerability and adaptation to, climate change (UNFCCC, 2009): http://unfccc.int/adaptation/nairobi_work_programme/knowledge_resources_and_publications/items/5404.php

Data requirements and output

CENTURY requires a range of **input** data:
• Weather data
  › monthly average maximum and minimum air temperature
  › monthly precipitation
• Soil texture
• Plant data
  › nitrogen content
  › phosphorus content
  › sulphur content
  › lignin content
• Atmospheric and soil nitrogen inputs
• Initial soil carbon and nitrogen (phosphorus and sulphur optional)
 	
CENTURY provides **outputs** according to different climate change scenarios:
• Changes in soil carbon and nutrient balances
• Changes in crop, pasture and forest production

CROPWAT needs **input** data on climatic and crop variables. These data can be taken from the CLIMWAT database, which is included in the distribution package of CROPWAT. Main **outputs** of the CROPWAT model include: • Reference evapotranspiration • Crop water requirements • Crop irrigation requirements

>

AGRICULTURE

Method/tool	Description
Decision support systems linking agro-climatic indices with GCM-originated climate change scenarios	Decision support systems linking agro-climatic indices with GCM-originated climate change scenarios can be used to study expected shifts in the agro-climatic zones for different crop types under possible climate change scenarios, as well as to explore the adaptive ability of crop types and management options (e.g. planting date, cultivar types). **Resources** Compendium on methods and tools to evaluate impacts of, and vulnerability and adaptation to, climate change (UNFCCC, 2009): http://unfccc.int/adaptation/nairobi_work_programme/knowledge_resources_and_publications/items/5354.php
Information and Decision Support System for Climate Change Studies in South East South America (IDSS-SESA Climate Change)	IDSS-SESA can be used to study the impacts of possible climate change scenarios on different agricultural production systems (livestock, crops, mixed) and on the natural resource base. It helps to explore adaptive technological options (crop/pasture management, input use, mixes of crop and pasture types). **Resources** Assessment of Impacts and Adaptations to Climate Change in Multiple Regions and Sectors: http://sedac.ciesin.columbia.edu/aiacc/methods.html Compendium on methods and tools to evaluate impacts of, and vulnerability and adaptation to, climate change (UNFCCC, 2009): http://unfccc.int/adaptation/nairobi_work_programme/knowledge_resources_and_publications/items/5398.php
ORYZA2000	ORYZA2000 is the successor to a series of rice growth models. It can be used to study the impact of climate change on rice yields and to explore adaptive management options (fertiliser, cultivar type, irrigation strategy, sowing date, etc.). ORYZA2000 has been used to simulate the growth, development and water balance of rice under conditions of potential production, water limitations and nitrogen limitations. **Resources** Oryza2000 Growth Model: http://www.knowledgebank.irri.org/oryza2000/ Compendium on methods and tools to evaluate impacts of, and vulnerability and adaptation to, climate change (UNFCCC, 2009): http://unfccc.int/files/adaptation/methodologies_for/vulnerability_and_adaptation/application/pdf/oryza_2000.pdf

	Data requirements and output
	Input data used for these decision support systems include: • Gridded observed climate data • Agro-climatic indices for different crop species and cultivars These systems provide **output** information on: • Changes in crop yields • Shifts in agro-ecological zones
	The **input** data required for IDSS-SESA include: • Soil • Weather • Land use data • National and regional statistics of crop/livestock production • Prices of inputs and products **Outputs** of the model are in formats (e.g. maps, tables) that can be easily understood by laypeople. The model's main outputs include: • Changes in agricultural productivity and economic results • Variation in agricultural and environmental risk

	Input data for the ORYZA2000 model include:
	• Daily climate data
	  › sunshine hours
	  › minimum and maximum temperature
	  › early morning vapour pressure
	  › mean wind speed
	  › precipitation
	• Soil properties
	• Crop management
	
	The main **output** of ORYZA2000 are:
	• Rice yields under different climate change scenarios

AGRICULTURE

Method/tool	Description
RICEMOD	RICEMOD is an eco-physiological model for irrigated rice production. It includes a number of physical parameters, including accommodation of subroutines dealing with soil and plant chemistry, as well as the physical processes of the atmospheric environment. RICEMOD can be used to study the relative constraining effects of rice plant growth. The model is particularly useful for predicting production scenarios under climate change. **Resources** Compendium on methods and tools to evaluate impacts of, and vulnerability and adaptation to, climate change (UNFCCC, 2009): http://unfccc.int/adaptation/nairobi_work_programme/knowledge_resources_and_publications/items/5463.php
WOFOST (World Food Studies)	WOFOST is a simulation model for the quantitative analysis of the growth and production of annual field crops. It is a mechanistic model that explains crop growth on the basis of the underlying processes, such as photosynthesis and respiration, and how these processes are influenced by environmental conditions. WOFOST considers only ecological factors under the assumption that optimum management practices are applied. Its application to regions relies on the selection of representative points, followed by spatial aggregation or interpolation (e.g. linked to a GIS). **Resources** WOFOST/WOrld FOod STudies: http://www.wofost.wur.nl/UK/ Compendium on methods and tools to evaluate impacts of, and vulnerability and adaptation to, climate change (UNFCCC, 2009): http://unfccc.int/adaptation/nairobi_work_programme/knowledge_resources_and_publications/items/5511.php

	Data requirements and output
	RICEMOD is a very data-intensive model requiring the following **input** data: • Soil data • Plant data • Atmospheric data Main **outputs** of RICEMOD are related to characteristics of rice plant growth: • Total area index (LA1, leaves and stem) • Growth rates • Dry weights • Dry matter partitioning • Grain yield • Number of grains • CO_2 assimilation • Amount of radiation absorbed by the canopy
	WOFOST requires a range of **input** data on climate and crop characteristics: • Weather data › rainfall › temperature › wind speed › global radiation › air humidity • Soil moisture content at various suction levels • Data on saturated and unsaturated water flow • Site-specific soil and crop management WOFOST's main **output** consists of: • Crop yield and variability for different climate change scenarios

WATER

Method/tool	Description
Aquarius	Aquarius is a computer model depicting the temporal and spatial allocation of water flows among competing traditional and non-traditional water uses in a river basin. The model can be used for determining economically efficient water allocation strategies. It supports the following types of water uses (system components): • Storage reservoir • Hydropower plants • Agricultural water use • Municipal and industrial water use • In-stream recreation water use • Reservoir recreation use • Stream flow protection **Resources** Aquarius: A Modeling System for River Basin Water Allocation: http://www.fs.fed.us/rm/value/aquarius Compendium on methods and tools to evaluate impacts of, and vulnerability and adaptation to, climate change (UNFCCC, 2009): http://unfccc.int/files/methods_and_science/impacts_vulnerability_and_adaptation/methods_and_tools_for_assessment/application/pdf/aquarius.pdf
Interactive River and Aquifer Simulation (IRAS)	IRAS is a surface water resource simulation tool, based on water balance accounting principles that can test alternative sets of conditions of both supply and demand. The tool is used in long-range planning to evaluate the performance or impacts of alternative designs and operating policies of regional water resource systems, ranging from simple to complex systems. IRAS has more significant water quality modelling ability than WEAP (see p. 118), but it does not include a detailed demand-modelling environment. Strengths include its modelling capability for groundwater, natural aquatic systems and water quality. The tool includes wetland analysis and helps in understanding system performance in meeting demand requirements. **Resources** Compendium on methods and tools to evaluate impacts of, and vulnerability and adaptation to, climate change (UNFCCC, 2009): http://unfccc.int/adaptation/nairobi_work_programme/knowledge_resources_and_publications/items/5399.php

Data requirements and output
The **input** data for Aquarius has been divided into physical and economic data: • Physical data › information associated with the dimensions and operational characteristics of the system components, such as maximum reservoir capacity or power plant efficiency • Economic data › demand functions of the various water uses competing for water The main **output** from the application of the model consists of: • Economically efficient allocations that meet prescribed demands
IRAS needs a range of **input** data on the configuration of the considered system, its components, capacities, and operating policies: • Water demand › demand requirements at various nodes • Water supply › historical inflows at various time-steps › evaporation and seepage losses from the system › aquifer recharge rates › wetland characteristics • Water quality › waste loads • Scenarios: › reservoir operating rule modifications › pollution changes and reduction goals The main **outputs** of the model relate to the system's performance in meeting demand requirements: • Flows • Storage volumes • Energy • Water quality

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WATER

Method/tool	Description
Joint UK Land Environment Simulator (JULES)	JULES is a process-based model that simulates the fluxes of carbon, water, energy and momentum between the land surface and the atmosphere. Different versions of JULES have been employed to quantify the effects on the land carbon sink of separately changing atmospheric aerosols and tropospheric ozone, as well as the response of methane emissions from wetlands to climate change. JULES represents the carbon allocation, growth and population dynamics of five plant functional types. The process-based descriptions of key ecological processes and trace gas fluxes in JULES mean that this community model is well suited for use in carbon cycle, climate change and impacts studies, either in standalone mode or as the land component of a coupled Earth system model. **Resources** Joint UK Land Environment Simulator: https://jules.jchmr.org/ The Joint UK Land Environment Simulator (JULES), Model description – Part 2: Carbon fluxes and vegetation (Clark, et al., 2011): http://www.geosci-model-dev-discuss.net/4/641/2011/gmdd-4-641-2011-print.pdf
MIKE BASIN	For addressing water allocation, conjunctive use, reservoir operation, or water quality issues, MIKE BASIN couples the power of ArcView GIS with comprehensive hydrologic modelling to provide basin-scale solutions. The MIKE BASIN philosophy is to keep modelling simple and intuitive, yet provide in-depth insight for planning and management. **Resources** MIKE BASIN 3000 – A Versatile Decision Support Tool For Integrated Water Resources Management Planning (DHI, 2006): http://www.iemss.org/iemss2006/papers/w5/MB-manual.pdf Compendium on methods and tools to evaluate impacts of, and vulnerability and adaptation to, climate change (UNFCCC, 2009): http://unfccc.int/adaptation/nairobi_work_programme/knowledge_resources_and_publications/items/5436.php

Data requirements and output
Inputs required for JULES are: • Weather data › precipitation › air temperature, pressure and humidity › wind speed › radiation **Outputs** of the JULES model include: • Soil temperature, moisture and respiration • Surface runoff • Drainage • Plant growth and transpiration • Surface fluxes of heat and carbon
MIKE BASIN is highly data-intensive and requires significant **input** data for detailed analysis: • A digitised river system layout • Withdrawal and reservoir locations • Water demand (time series of water demand, percentage of ground abstraction, etc.) The tool can be used to generate the following **outputs**: • Mass balances • Detailed flow descriptions throughout the water system • Water diversions • Hydropower generation • Hydropower trade-offs to other operating objectives • Water quality descriptions

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WATER

Method/tool	Description	
River Basin Simulation Model (RIBASIM)	RIBASIM is a generic model package for simulating the behaviour of river basins under various hydrological conditions. The model package is a comprehensive and flexible tool that links the hydrological water inputs at various locations with the specific water users in the basin. RIBASIM enables the user to evaluate a variety of measures related to infrastructure and operational and demand management, and to see the results in terms of water quantity and flow composition. **Resources** RIBASIM – River Basin Planning and Management: http://www.deltares.nl/en/software/101928/ribasim Compendium on methods and tools to evaluate impacts of, and vulnerability and adaptation to, climate change (UNFCCC, 2009): http://unfccc.int/files/methods_and_science/impacts_vulnerability_and_adaptation/methods_and_tools_for_assessment/application/pdf/ribasim.pdf	
Soil and Water Assessment Tool (SWAT)	SWAT addresses simple management issues, with a strong focus on modelling water supply. The model lightly touches on the demand-side of water management modelling. It can be used to predict the effects of management decisions on water, sediment, nutrient and pesticide yields on un-gauged river basins. It also considers complex water quality constituents. SWAT is used to predict the impact of land management practices on water, sediment and agricultural chemical yields in large complex watersheds with varying soils and land use and management conditions over long periods of time. **Resources** Soil and Water Assessment Tool: http://swatmodel.tamu.edu/documentation/	

Data requirements and output

RIBASIM needs data on the configuration of the system, component capacities, and operating policies as **inputs**:
• Water demand
  › spatially explicit demographic, economic, crop water requirements
  › current and future demands and pollution generation
• Economic data
  › water use rates
  › capital costs
  › discount rate estimates
• Water supply
  › historical inflows at a monthly time-step
  › groundwater sources
• Scenarios
  › reservoir operating rule modifications
  › pollution changes and reduction goals, socio-economic projections
  › water supply projections
 	
The **output** of the RIBASIM model consists of basic information on the water balance:
• Quantity of water
• Composition of flow at every location and any time in the river basin

SWAT requires **inputs** of specific information about certain features of the watershed under consideration: • Weather • Soil properties • Topography • Vegetation • Land management practices SWAT generates a number of **output** data for different spatial scales: • Surface runoff • Return flow • Percolation • Evapotranspiration • Transmission losses • Reservoir storage • Crop growth and irrigation • Groundwater flow • Nutrient and pesticide loading

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WATER

Method/tool	Description
Water Evaluation and Planning System (WEAP)	WEAP is a user-friendly software tool that takes an integrated approach to water resources planning. It is a surface water and groundwater resource simulation tool, based on water balance accounting principles, which can test alternative sets of conditions of both supply and demand. The user can project changes in water demand, supply and pollution over a long-term planning horizon to develop adaptive management strategies. **Resources** WEAP – Water Evaluation And Planning: http://www.weap21.org Compendium on methods and tools to evaluate impacts of, and vulnerability and adaptation to, climate change (UNFCCC, 2009): http://unfccc.int/adaptation/nairobi_work_programme/knowledge_resources_and_publications/items/5508.php

Data requirements and output
WEAP needs a range of **input** data on the configuration of the considered system and its components, capacities, and operating policies: • Water demand › spatially explicit demographic, economic, crop water requirements › current and future demands and pollution generation • Economic data › water use rates › capital costs › discount rate estimates • Water supply › historical inflows at a monthly time-step › groundwater sources • Scenarios › reservoir operating rule modifications › pollution changes and reduction goals, socio-economic projections › water supply projections WEAP's key **outputs** are: • Mass balances • Water diversions • Sectorial water use • Cost/benefit scenario comparisons • Pollution generation and pollution loads

COASTAL AREAS

Method/tool	Description	
Coastal Zone Simulation Model (COSMO)	COSMO is a decision-support model that allows coastal zone managers to evaluate potential management strategies under different scenarios, including long-term climate change. COSMO demonstrates the main steps in the preparation, analysis and evaluation of Coastal Zone Management (CZM) plans. COSMO helps to determine the advantages and disadvantages of adaptation alternatives, either as an educational or decision-support tool, in conjunction with other, more quantitative analyses. **Resources** Compendium on methods and tools to evaluate impacts of, and vulnerability and adaptation to, climate change (UNFCCC, 2009): http://unfccc.int/adaptation/nairobi_work_programme/knowledge_resources_and_publications/items/5353.php	
Dynamic and Interactive Vulnerability Assessment (DIVA)	The DIVA model is an integrated, global model of coastal systems that assesses the biophysical and socio-economic consequences of sea-level rise and socio-economic development taking into account coastal erosion (both direct and indirect), coastal flooding (including rivers), wetland change and salinity intrusion into deltas and estuaries, as well as adaptation in terms of raising dykes and nourishing beaches. **Resources** Dynamic and Interactive Vulnerability Assessment (DIVA): www.diva-model.net Compendium on methods and tools to evaluate impacts of, and vulnerability and adaptation to, climate change (UNFCCC, 2009): http://unfccc.int/files/national_reports/non-annex_i_natcom/cge/application/pdf/diva_print_me_first.pdf	

Data requirements and output
The key **input** for COSMO is: • The user's chosen management strategy The main **output** of the model is: • A range of different management options
The main **inputs** for DIVA are: • Coastal elevation data • Population data • Coastal geomorphology • Sea-level rise • Socio-economic scenarios The main **outputs** of the model are: • Impacts of sea-level rise under a range of different scenarios, including some adaptation options

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COASTAL AREAS

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Method/tool	Description
RamCo and ISLAND MODEL	RamCo and ISLAND MODEL are cell-based decision support tools designed as a means of asking structured questions about how external and internal components of coastal zone management problems interact. The socio-economic system is explicitly defined and can interact with the physical effects of climate change as well as with regional and global changes to boundary conditions, such as global trade patterns. **Resources** Compendium on methods and tools to evaluate impacts of, and vulnerability and adaptation to, climate change (UNFCCC, 2009): http://unfccc.int/files/adaptation/methodologies_for/vulnerability_and_adaptation/application/pdf/ramco_and_island_model.pdf
Shoreline Management Planning (SMP)	SMP is a generic approach for the strategic management of the combined hazards of erosion and flooding hazards in coastal areas, which are key concerns under climate change and sea-level rise. **Resources** Shoreline Management Plans (SMPs): http://www.environment-agency.gov.uk/research/planning/104939.aspx Compendium on methods and tools to evaluate impacts of, and vulnerability and adaptation to, climate change (UNFCCC, 2009): http://unfccc.int/adaptation/nairobi_work_programme/knowledge_resources_and_publications/items/5481.php
South Pacific Island Methodology (SPIM)	SPIM is an index-based approach that uses relative scores to evaluate different adaptation options in a variety of scenarios. The coastal zone is viewed as six interacting systems. There are three 'hard' systems (natural environment, people, infrastructure) and three 'soft' systems that encompass the less tangible elements of the coastal system (institutions, socio-cultural factors, economic system). SPIM is particularly useful in coastal settings with limited quantitative data but considerable experience and qualitative knowledge. **Resources** Compendium on methods and tools to evaluate impacts of, and vulnerability and adaptation to, climate change (UNFCCC, 2009): http://unfccc.int/adaptation/nairobi_work_programme/knowledge_resources_and_publications/items/5494.php

Data requirements and output
Key **inputs** for RamCo and the ISLAND MODEL are: • Scenarios and management strategies chosen by the user **Output** of RamCO and the ISLAND MODEL: • A wide range of outcomes for different scenarios and strategies
SMP requires a range of i**nput** data, including: • Historical shoreline change • Contemporary coastal processes • Coastal land use and values • Appropriate scenarios of change SMP's **outputs** are: • Strategic approaches for flood and erosion management for the next 50 to 100 years
SPIM requires the following **inputs:** • Expert judgment and qualitative information on the relative performance of various adaptation options SPIM's **output** consists of: • A sustainable capacity index for the subsystems defined

HUMAN HEALTH

Method/tool	Description	
CIMSiM and DENSiM Dengue Simulation Model (DENSiM)	CIMSiM is a dynamic life-table simulation entomological model that produces mean-value estimates of various parameters for all cohorts of a single species of Aedes mosquito within a representative one-hectare area. DENSiM is the corresponding account of the dynamics of a human population driven by country- and age-specific birth and death rates. An accounting of individual serologies is maintained, reflecting infection and birth to seropositive mothers. The entomological factors passed from CIMSiM are used to create the biting mosquito population. The models can be used to: optimise dengue control strategies using multiple control measures, develop transmission thresholds in terms of Aedes mosquito per person as a function of temperature and herd immunity, and to evaluate the impact of climate change. **Resources** A Simulation Model of the Epidemiology of Urban Dengue Fever: Literature Analysis, Model Development, Preliminary Validation, and Samples of Simulation Results (Focks, et al., 1995): https://www.nescent.org/wg/selfishdna/images/e/e5/Focks_et_al._1995_DENSIM_a_detailed_model_of_dengue_epidemiology.pdf Compendium on methods and tools to evaluate impacts of, and vulnerability and adaptation to, climate change (UNFCCC, 2009): http://unfccc.int/files/adaptation/methodologies_for/vulnerability_and_adaptation/application/pdf/cimsim_and_densim__dengue_simulation_model_.pdf	

	Data requirements and output

	CIMSiM and DENSiM need the following data as **input**:
	• A pupal/demographic survey is required to estimate the productivities of the various local water-holding containers
	• Daily weather data
	  › maximum and minimum temperature
	  › rainfall
	  › saturation deficit
	
	The models' **outputs** consist of estimates on the following parameters:
	• Demographic
	• Entomologic
	• Serologic
	• Infection information on a human age-class and/or time basis

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HUMAN HEALTH

Method/tool	Description
Environmental Burden of Disease Assessment (EBD)	EBD tools include guidelines on how to estimate the approximate magnitude of the health impacts of various environmental factors, including climate change, at the national or regional level. EBD tools help to determine priorities for action and are usually applied on a national or regional scale. An EBD assessment for climate change indicates which impacts could be greatest and in which regions, and how much of the climate-attributable disease burden could be avoided by emissions reduction. It also guides health-protection strategies. **Resources** WHO Environmental burden of disease series: http://www.who.int/quantifying_ehimpacts/publications/en/ Compendium on methods and tools to evaluate impacts of, and vulnerability and adaptation to, climate change (UNFCCC, 2009): http://unfccc.int/adaptation/nairobi_work_programme/knowledge_resources_and_publications/items/5364.php
Lyme simulation model (LymSIM)	LymSIM shows seasonal and geographical distributions of the Lyme disease agent and its vectors as a function of climate. The model simulates the effects on tick populations of ambient temperature, saturation deficit, precipitation, habitat type, host type and density. The model accounts for epidemiological parameters, including host and tick infectivity, transovarial and transstadial transmission. This way, the model realistically simulates the transmission of the Lyme disease spirochete between vector ticks and vertebrate hosts. **Resources** Compendium on methods and tools to evaluate impacts of, and vulnerability and adaptation to, climate change (UNFCCC, 2009): http://unfccc.int/adaptation/nairobi_work_programme/knowledge_resources_and_publications/items/5429.php Handbook of Current and Next Generation Vulnerability and Adaptation Assessment Tools (BASIC, 2007): http://www.basic-project.net/data/final/Paper08India%20Vulnerability%20and%20Adaptation%20Assessment%20Tools%85.pdf

Data requirements and output
EBD assessments require the following **input** data: • Baseline burden of climate-sensitive diseases • Estimated increase in the risk of disease/disability per unit increase in exposure to climate change • Current or estimated future population distribution of exposure The main **output** of an EBD assessment comprises: • DALYs (disability adjusted life years) or avoided deaths
Required **inputs** for LymSIM are: • Proportions of forested, meadow and ecotone territory • Density of the four to six types of hosts • Weekly weather data › average temperature › rainfall total › relative humidity › saturation deficit **Outputs** of the model consist of: • Seasonal and geographical distributions of the Lyme disease agent and its vectors

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HUMAN HEALTH

Method/tool	Description
Modelling Framework for the Health Impact Assessment of Man-Induced Atmospheric Changes (MiASMA)	MiASMA is a computer model that simulates several health impacts of global atmospheric change and includes simulations for three modules: 1) vector-borne diseases, including malaria, dengue fever, and schistosomiasis; 2) thermal heat mortality; 3) UV-related skin cancer due to stratospheric ozone depletion. MiASMA can be used to link GCM (›› see Practical methods and Tools Ib, p. 138) outputs on climate change or scenarios of stratospheric ozone depletion to any of the human health outcomes mentioned previously. The applicability of this model is limited only by the scope of available data. **Resources** Compendium on methods and tools to evaluate impacts of, and vulnerability and adaptation to, climate change (UNFCCC, 2009): http://unfccc.int/adaptation/nairobi_work_programme/knowledge_resources_and_publications/items/5435.php
WHO Guidelines: Methods of Assessing Human Health Vulnerability and Public Health Adaptation to Climate Change	These WHO guidelines provide qualitative and quantitative methods for assessing human health vulnerability and public health adaptation to climate change. The WHO guidelines make it possible to assess the current and future human health vulnerability of specific populations to climate change and can help with the development of appropriate responses. **Resources** Methods of assessing human health vulnerability and public health adaptation to climate change: http://www.euro.who.int/__data/assets/pdf_file/0009/91098/E81923.pdf Compendium on methods and tools to evaluate impacts of, and vulnerability and adaptation to, climate change (UNFCCC, 2009): http://unfccc.int/adaptation/nairobi_work_programme/knowledge_resources_and_publications/items/5504.php

Data requirements and output
The **input** for MiASMA is module- or disease-specific, e.g. for thermal stress: • Maximum and minimum temperatures The **output** of MiASMA is equally module- or disease-specific, e.g. for thermal stress: • Cardiovascular disease, respiratory disease and total mortality
Inputs for the WHO guidelines depend on the type of assessment: • A basic assessment can be conducted using readily available information and data such as previous assessments, literature reviews by the IPCC and others, or available region-specific data • A more comprehensive assessment could include a literature search focused on the goals of the assessment, some quantitative assessment using available data, some quantification of effects, and a formal peer review of results **Outputs** of this method consist of: • Descriptions of the current distribution and burden of climate-sensitive diseases • Descriptions of the adaptation baseline; evaluation of the health implications of the potential impact of climate change on other sectors • Estimates of the future potential health impact of climate change using scenarios of future climate change, population growth, and other factors • Identification of additional adaptation measures to reduce current and future vulnerability

TERRESTRIAL ECOSYSTEMS

Method/tool	Description
Agro-Ecological Zones (AEZ) methodology	The AEZ methodology enables rational land-use planning on the basis of an inventory of land resources and evaluation of biophysical limitations and potentials. The methodology can be applied at global, regional, national and sub-national levels. The methodology also provides a means of identifying how natural resources and agricultural production is likely to be perturbed under future climate scenarios and what crops and locations are suitable under future climate scenarios. **Resources** Global Agro-Ecological Zones (GAEZ): http://webarchive.iiasa.ac.at/Research/LUC/GAEZ/ Compendium on methods and tools to evaluate impacts of, and vulnerability and adaptation to, climate change (UNFCCC, 2009): http://unfccc.int/adaptation/nairobi_work_programme/programme_activities_and_work_areas/items/5305.php
Carnegie-Ames-Stanford Approach (CASA)	CASA is used for climate change analysis of ecosystem productivity. CASA calculates monthly terrestrial Net Primary Production (NPP) based on the concept of light-use efficiency, modified by temperature and moisture stress scalars. Soil carbon cycling and Rh flux components of the model are based on a compartmental pool structure, with first-order equations to simulate loss of CO_2 from decomposing plant residue and surface soil organic matter (SOM) pools. **Resources** NASA-CASA Project: http://geo.arc.nasa.gov/sge/casa/projects.html Compendium on methods and tools to evaluate impacts of, and vulnerability and adaptation to, climate change (UNFCCC, 2009): http://unfccc.int/adaptation/nairobi_work_programme/knowledge_resources_and_publications/items/5323.php

	Data requirements and output
	Required **inputs** for the AEZ methodology include: • Climate, topography and soil characteristics • Demographic, socio-economic, cultural and political factors, for example: › population density › land tenure › markets › institutions › agricultural policies The main **output** of the methodology comprises: • Maximum potential and agronomically attainable crop yields for basic land resource units
	CASA requires the following **inputs**: • Air surface temperature • Precipitation • Long-term (30-year) mean values • Surface solar irradiance measurements The main **outputs** of CASA are: • Global gridded estimates of primary production • Above and below ground biomass • Leaf area index (LAI) • Trace gas fluxes

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TERRESTRIAL ECOSYSTEMS

Method/tool	Description
Integrated Biosphere Simulator (IBIS)	IBIS represents a wide range of ecosystem and land surface processes in a single, physically consistent framework. IBIS performs integrated assessments of water balance, carbon balance and vegetation structure on both global and regional scales based on an integrated modelling approach that explicitly represents competition between plant functional types (competition for light and water) and characterises their responses to global change drivers (land use changes, climate variability and change, atmospheric CO_2). **Resources** IBIS (Integrated Biosphere Simulator): http://www.sage.wisc.edu/download/IBIS/ibis.html Integrated Biosphere Simulator Model (IBIS), Version 2.5: http://daac.ornl.gov/cgi-bin/dsviewer.pl?ds_id=808 Compendium on methods and tools to evaluate impacts of, and vulnerability and adaptation to, climate change (UNFCCC, 2009): http://unfccc.int/adaptation/nairobi_work_programme/knowledge_resources_and_publications/items/5392.php
Integrated Model to Assess the Greenhouse Effect (IMAGE)	IMAGE is used to find out how land use and climate change affect land productivity. IMAGE takes a global approach with the entire earth system as the subject of investigation. It is integrated because it is designed to simulate the dynamics and interconnections between three major sub-systems of the globe: climate, biosphere and society. Resources IMAGE model site: http://themasites.pbl.nl/tridion/en/themasites/image/ Compendium on methods and tools to evaluate impacts of, and vulnerability and adaptation to, climate change (UNFCCC, 2009): http://unfccc.int/adaptation/nairobi_work_programme/knowledge_resources_and_publications/items/5396.php

	Data requirements and output
	Inputs for IBIS include data on: • Climate • Site • Vegetation • Soils **Outputs** of the model consist of: • Gross Primary Production (GPP) • Above and below ground Net Primary Production (NPP) • Data on carbon sinks and sources
	Key **input** data for IMAGE include: • Climate • Soil • Land use cover • Regional demands for cropland and rangeland • Fuel wood demand **Outputs** of the model include: • Cumulative GHG emissions • Resulting atmospheric concentrations • Global warming • Sea-level rise • Changing patterns of land use and cover • Agricultural impacts • Ecosystem risks • Costs of policies for emissions reduction or control

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TERRESTRIAL ECOSYSTEMS

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Method/tool	Description	
Lund-Potsdam-Jena Model (LPJ)	The LPJ model combines process-based, large-scale representations of terrestrial vegetation dynamics and land-atmosphere carbon and water exchanges in a modular framework. **Resources** LPJ & LPJmL Web Distribution Portal: http://www.pik-potsdam.de/research/projects/lpjweb Compendium on methods and tools to evaluate impacts of, and vulnerability and adaptation to, climate change (UNFCCC, 2009): http://unfccc.int/adaptation/nairobi_work_programme/knowledge_resources_and_publications/items/5427.php	
MC1	MC1 consists of three linked modules simulating biogeography, biogeochemistry, and fire disturbance. MC1 is a new dynamic vegetation model created to assess the impacts of global climate change on ecosystem structure and function at a wide range of spatial scales from landscape to global. **Resources** MC1: A Dynamic Vegetation Model for Estimating the Distribution of Vegetation and Associated Ecosystem Fluxes of Carbon, Nutrients, and Water (Bachelet, et al., 2001): http://www.fsl.orst.edu/dgvm/mcgtr508.pdf Compendium on methods and tools to evaluate impacts of, and vulnerability and adaptation to, climate change (UNFCCC, 2009): http://unfccc.int/adaptation/nairobi_work_programme/knowledge_resources_and_publications/items/5432.php	

	Data requirements and output
	The main **inputs** for LPJ are: • Climate data • Soil texture data • Data on CO_2 concentrations Main **outputs** of the model are: • Vegetation structure • Biomass carbon
	MC1 requires the following main **inputs**: • Monthly precipitation • Mean monthly average minimum and maximum temperatures • Vapour pressure • Wind speed • Solar radiation MC1 delivers **outputs** on: • Vegetation structure • Fire events • Plant productivity • Vegetation carbon • Soil carbon and nitrogen • Evapotranspiration under changing climatic conditions

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TERRESTRIAL ECOSYSTEMS

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Method/tool	Description
MEDRUSH vegetation model	MEDRUSH simulates the effects of recent historical changes in climate and CO_2 in evergreen sclerophyllous shrub land. MEDRUSH is a landscape-scale model of vegetation structure and productivity, hydrology and soil erosion. It simulates the structure, productivity, and water relations of Mediterranean vegetation using a mechanistic, i.e. process-based, approach. **Resources** MEDRUSH – spatial and temporal modelling at scales commensurate with global environmental change: http://wgbis.ces.iisc.ernet.in/energy/HC270799/austria.html Compendium on methods and tools to evaluate impacts of, and vulnerability and adaptation to, climate change (UNFCCC, 2009): http://unfccc.int/adaptation/nairobi_work_programme/knowledge_resources_and_publications/items/5433.php
Terrestrial Ecosystem Model (TEM)	TEM is a process-based ecosystem model that describes carbon and nitrogen dynamics of plants and soils for terrestrial ecosystems. It is used to study regional to global climate effects on ecosystem dynamics by assessing spatially referenced information on climate, elevation, soils, vegetation, and water availability, as well as soil- and vegetation-specific parameters, in order to make monthly estimates of important carbon and nitrogen fluxes and pool sizes of terrestrial ecosystems. **Resources** TEM – The Terrestrial Ecosystem Model: http://ecosystems.mbl.edu/TEM/ Compendium on methods and tools to evaluate impacts of, and vulnerability and adaptation to, climate change (UNFCCC, 2009): http://unfccc.int/files/adaptation/methodologies_for/vulnerability_and_adaptation/application/pdf/tem__terrestrial_ecosystem_model_.pdf

Data requirements and output
MEDRUSH requires the following **inputs**: • Climate data • Concentration of atmospheric CO_2 • Soil texture data MEDRUSH delivers **outputs** on: • Vegetation productivity • Vegetation composition • Soil erosion • Hydrology
TEM requires the following **inputs**: • Vegetation • Soil texture • Elevation • Solar radiation • Precipitation • Air temperature TEM delivers **outputs** on: • Gross Primary Production (GPP) • Net Primary Production (NPP) • Evapotranspiration • Soil carbon and nitrogen • Vegetation carbon and nitrogen

Practical methods and tools Ib: Climate data analysis and other top-down methods and tools

Top-down impact and vulnerability assessments use scenarios of the future socio-economic development of the world to feed Global or Regional Circulation Models (GCMs and RCMs). In turn, the GCMs and RCMs will project future climatic variables, e.g. mean annual precipitation, mean annual temperature, amount of monsoon precipitation, etc. (Hinkel, et al., 2010; Mastrandrea, et al., 2010; Wolf, et al., 2013).

Climate data analysis

Method/tool	Description
Climate Data Operators (CDO)	CDO is a collection of command line operators for manipulating and analysing climate and numerical weather prediction (NWP) model data. **Resources** Climate Data Operators: https://code.zmaw.de/projects/cdo
Ferret	Ferret is an interactive computer visualisation and analysis environment designed to meet the needs of oceanographers and meteorologists analysing large and complex gridded data sets. It runs on most Unix systems, and on Windows XP/NT/9x using X Windows for display. It can transparently access extensive remote internet data sources. **Resources** An Analysis Tool for Gridded and Non-Gridded Data: http://ferret.pmel.noaa.gov/

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Method/tool	Description
Global Circulation Models (GCM)	GCM are numerical models that represent physical processes in the atmosphere, ocean, cryosphere and land surface. GCM are the most advanced tools currently available for simulating the response of the global climate system to increasing greenhouse gas concentrations. While simpler models have also been used to provide globally or regionally averaged estimates of the climate response, only GCMs (possibly in conjunction with nested regional models) have the potential to provide the geographically and physically consistent estimates of regional climate change that are required for impact analysis. GCM provide climate simulations for grid cells with a resolution of about 300×300 km. **Resources** IPCC Data Distribution Centre – What is a GCM?: http://www.ipcc-data.org/guidelines/pages/gcm_guide.html
Grid Analysis and Display System (GrADS)	GrADS is an interactive desktop tool that is used for easy access, manipulation, and visualisation of earth science data. **Resources** Overview of GrADS: http://www.iges.org/grads/
Regional Circulation Models (RCM)	RCM provide finer spatial and temporal detail than GCM. Like a GCM, it is a comprehensive physical model representing the important components of the climate system. It has a higher resolution than a GCM and covers a limited area of the globe. The RCM is 'nested' within a GCM. This means that the RCM takes inputs from a GCM, which, in turn, influences the behaviour of the regional climate. As opposed to GCM, RCM have a resolution of about 50×50 km. **Resources** IPCC Working Group I: The Scientific Basis – Regional Climate Models (RCMs): http://www.ipcc.ch/ipccreports/tar/wg1/380.htm Regional Climate Model Simulations of Present-Day and Future Climates of Southern Africa (Hudson & Jones, 2002): http://precis.metoffice.com/docs/HCTN_39.pdf

Other top-down methods and tools

Method/tool	Description
Multicriteria analysis (MCA)	MCA describes any structured approach used to determine overall preferences among alternative options, where the options accomplish several objectives. The actual measurement of indicators does not have to be in monetary terms; often it is based on the quantitative analysis (through scoring, ranking and weighting) of a wide range of qualitative impact categories and criteria. Different environmental and social indicators may be developed side by side with economic costs and benefits. **Resources** Handbook of Current and Next Generation Vulnerability and Adaptation Assessment Tools (BASIC, 2007): http://www.basic-project.net/data/final/Paper08India%20Vulnerability%20and%20Adaptation%20Assessment%20Tools%85.pdf Compendium on methods and tools to evaluate impacts of, and vulnerability and adaptation to, climate change (UNFCCC, 2009): http://unfccc.int/files/adaptation/methodologies_for/vulnerability_and_adaptation/application/pdf/multicriteria_analysis__mca_pdf.pdf
Agent-Based Models (ABM)	ABM is a computer-assisted technique for knowledge elicitation. It assists in building rules of how people respond to a variety of stimuli and scenarios of environmental and social conditions. It is applicable to various stages of the design of a strategy to respond to climate change and its subsequent implementation in specific measures. **Resources** Compendium on methods and tools to evaluate impacts of, and vulnerability and adaptation to, climate change (UNFCCC, 2009): http://unfccc.int/files/adaptation/methodologies_for/vulnerability_and_adaptation/application/pdf/consolidated_version_updated_021204.pdf

Practical methods and tools II: Bottom-up methods and tools for vulnerability assessment

There are many bottom-up methods and tools that can be used for discussing similar issues and situations. Not all of these will work in all contexts. This is because socio-cultural and political circumstances, among other things, dictate what sorts of interactions are appropriate. There are at least four criteria that should be considered when selecting the approach to take (Hinkel, et al., 2010):

1. Objective of the study
2. Scale of the study
3. Familiarity with the study site
4. Qualitative versus quantitative requirements.

'It is important to recognize that quantitative approaches are not more accurate or valuable than qualitative approaches. Rather, qualitative approaches are more descriptive and hence more detailed and nuanced, but less useful for comparative purposes, e.g. when there are limited funds to be spent only on the most urgent and vulnerable people. A combination of the two is likely to be the optimal solution, however identifying which variables should be quantified and which qualified can be tricky' (Hinkel, et al., 2010, p. 37).

In some cases, the tools described here may not be able to draw out the nuances in a given location. Hence, it is important to understand the tools well: what they can – and cannot – do and to which context they are best suited. This will help to ensure that the overall combination of tools is sufficient to cover all of the relevant factors. For example, if all of the tools are centred on exploring one or two key questions identified through a rapid rural appraisal, they might fail to touch on some important unrelated issues. Therefore, it is important that at least one of the tools offers an opportunity to brainstorm all possible factors determining vulnerability. A similar exercise may also be needed to identify all possible groups who are vulnerable. In other words, the combination of tools should provide as broad an overview as possible (Hinkel, et al., 2010).

Method/tool	Description	Process	Limitations
Brain-storming	Brainstorming is a semi-structured process for capturing free-flowing ideas and options within a group of stakeholders.	Brainstorming can be used to gather ideas on many themes. For example, it might be used to establish what risks a certain livelihood group is exposed to. The brainstorm can be taken further by examining the characteristics of certain risks. For example, natural hazards, and in particular heavy rainfall and frost, might be specified as a risk.	• It is difficult to ensure the accuracy of the answers. • The facilitator may unconsciously introduce bias. • The sample size is usually small and may not be representative.
	Resources Capacity strengthening in climate change vulnerability and adaptation strategy assessments (Downing & Ziervogel, 2004)		
Checklist	Checklists are a logical format that can be used by an expert or group of stakeholders to evaluate a range of options in a cursory manner.	Checklists can be prepared to examine a range of possible options available for an intervention or examine the range of factors affecting an intervention.	• It is important that the use of the checklist is clearly established. For example, is the purpose of the checklist to evaluate a range of methods for undertaking a task or a range of strategies for achieving a goal?
	Resources Community-Based Climate Vulnerability Assessment and Adaptation Planning (ADB, 2011): http://www.tribesandclimatechange.org/docs/tribes_470.pdf		
Climate hazard trend analysis	Climate hazard trend analysis is a participatory tool that helps in capturing the impact of climatic hazards but also the changes in impact over time. It also captures the reactions to the hazards and coping/adaptation strategies for climatic hazards in the past.	The process starts with the earliest hazard event anyone can remember. A timeline lasting 50 years is developed to show large climatic hazard events. Participants can stand on the line at the appropriate place and describe the event.	• The availability of knowledgeable persons who can provide historical insights can be a challenge.
	Resources Participatory Tools and Techniques for Assessing Climate Change Impacts and Exploring Adaptation Options (LFP, 2010): http://eldis.org/go/home&id=61611&type=Document#.U-w1X-OSwZ7		

	Data requirements and output	Duration of assessment	Time frame of assessment	Applicability
	Qualitative/quantitative	Rapid/1 year	Current decision/ short-term planning/ long-term planning	Current vulnerability
	Qualitative/quantitative	Rapid/1 year/ several years	Current decision/ short-term planning/ long-term planning	Current vulnerability
	Capacity strengthening in climate change vulnerability and adaptation strategy assessments (Downing & Ziervogel, 2004)			
	Qualitative/quantitative	Rapid/1 year	Current decision/ short-term planning/ long-term planning	Sensitivity & adaptive capacity
	Framework for Community-based Climate Vulnerability and Capacity Assessment in Mountain Areas (ICIMOD, 2011): http://lib.icimod.org/record/8096			

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Method/tool	Description	Process	Limitations	
Cognitive mapping	The term cognitive map refers to a group of methods rather than a single tool or method. Cognitive mapping uses interactive methods to illustrate different perceptions. It helps identify how different stakeholders perceive their reality, and draw out what they prioritise.	This method can usefully summarise and communicate information on the interrelations between connected concepts and ideas. Cognitive mapping is a useful tool to use: a) when different stakeholders have different perceptions of the problem; b) when the options for addressing the problem are unclear; or c) when a common framework is desired.	• All cognitive mapping techniques reveal concepts that people hold to be important but they vary in terms of the nature of the relationships among the concepts that they identify. • Some maps only look at simple categories while others aim to reveal deeper underlying arguments.	
	Resources Cognitive mapping techniques: http://omni.bus.ed.ac.uk/opsman/oakland/inst18.htm			
Community mapping	Community mapping involves facilitating community members in developing spatial representations of their areas by creating maps on the ground or on a large piece of paper.	You work with groups of key informants (women, men, livestock herders, etc.). A facilitator helps the group to draw a map with the boundaries of the area of interest. Participants are then asked to indicate the spatial location of resources, sources of livelihoods, settlements of different social groups within the community, land use, and other features. Participants can decide how they want to represent these features – either on paper with writing or by using local materials such as sticks, stones or seeds.		
	Resources Participatory Rural Appraisal For Community Forest Management: Tools and Techniques (Asia Forest Network, 2002): http://www.communityforestryinternational.org/publications/field_methods_manual/pra_manual_tools_and_techniques.pdf			

	Data requirements and output	Duration of assessment	Time frame of assessment	Applicability
	Qualitative	Rapid/1 year/ several years	Short-term planning/ long-term planning	Current vulnerability & adaptive capacity
	Capacity strengthening in climate change vulnerability and adaptation strategy assessments (Downing & Ziervogel, 2004)			
	Qualitative/quantitative	Rapid/1 year	Current decision/ short-term planning/ long-term planning	Sensitivity & adaptive capacity

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Method/tool	Description	Process	Limitations
Decision/ probability tree	Decision trees help to visualise and evaluate what the implications of different courses of action from one decision might be. It is a useful process for deciding what action to take when choices will lead to uncertain outcomes.	Decision trees start by articulating the decision. Four steps are involved in developing a decision tree: 1) structuring the problem as a tree with end nodes as payoffs under a given scenario; 2) assigning probabilities to events in the tree; 3) assigning payoffs with particular paths; 4) deciding what action is to be taken.	• If the decision tree is carried out as a participatory process it has to be well facilitated to ensure the opinions of all stakeholders are kept at the forefront.
	Resources Capacity strengthening in climate change vulnerability and adaptation strategy assessments (Downing & Ziervogel, 2004)		
The Delphi technique	The Delphi technique aims to elicit judgment and information from a range of experienced participants without bringing them together. The range of views of these participants is generated through iterative written correspondence.	First, the key issues are identified. A coordinator is required to establish and coordinate communication between participants. The issue or question is sent via email, fax or letter to the participants. The information provided by experts is used to help develop planning suggestions and aid decision-making. The objectives might include identifying trends and the future implications of decisions, dealing with priorities or obtaining expert views about issues affecting the community.	• The process takes quite a long time, from a few days up to a few weeks. • It is important to have a neutral coordinator who does not bias the process.
	Resources Capacity strengthening in climate change vulnerability and adaptation strategy assessments (Downing & Ziervogel, 2004)		

Data requirements and output	Duration of assessment	Time frame of assessment	Applicability
Qualitative/quantitative	Rapid/1 year	Short-term planning/ long-term planning	Adaptive capacity
Qualitative/quantitative	Rapid/1 year/ several years	Current decision/ short-term planning/ long-term planning	Current vulnerability & adaptive capacity

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Method/tool	Description	Process	Limitations
Expert judgement	Expert judgements are expert evaluations of specific propositions.	Expert judgement can be used in many instances for both vulnerability assessments and adaptation assessments and planning. For example, if there was a decision to undertake adaptation in the water sector, a team of experts might be assembled to help decide on possible strategies. This team could include hydrologists, engineers, water resource managers, etc.	• The facilitator/coordinator needs to be trained in assembling an expert panel, formulating questionnaires, and interpreting and aggregating the experts' opinions.
	Resources Capacity strengthening in climate change vulnerability and adaptation strategy assessments (Downing & Ziervogel, 2004)		
Focus group discussion	Focus groups provide a forum for stakeholders to discuss their opinions on certain topics and help elicit dominant perspectives from people at the local level.	A focus group discussion might involve sitting down with 6-10 women to ask them about the role of agriculture in their village. The discussion might focus on what activities women undertake, what decisions they can take, and the constraints they face.	• There may be reluctance on the part of focus group members when dealing with sensitive topics. • Selected groups may or may not be representative of the majority view.
	Resources Capacity strengthening in climate change vulnerability and adaptation strategy assessments (Downing & Ziervogel, 2004)		
Impact matrix	An impact matrix is used to identify and discuss the impact of climatic hazards on the community, including the changes in impact over time, and also to assess the effectiveness of coping strategies in the past.	Together with community members, a matrix is developed setting out the climatic hazards for the community, and past and current coping/ adaptation strategies and their effectiveness.	• This method needs scientific validation and is dependent on the experience and knowledge of the participating members.
	Resources Framework for Community-based Climate Vulnerability and Capacity Assessment in Mountain Areas (ICIMOD, 2011): http://lib.icimod.org/record/8096		

Data requirements and output	Duration of assessment	Time frame of assessment	Applicability
Qualitative/quantitative	Rapid/1 year/ several years	Current decision/ short-term planning	Current vulnerability & future vulnerability
Qualitative	Rapid/1 year/ several years	Current decision/ short-term planning/ long-term planning	Adaptive capacity
Framework for Community-based Climate Vulnerability and Capacity Assessment in Mountain Areas (ICIMOD, 2011): http://lib.icimod.org/record/8096			
Qualitative/quantitative	Rapid/1 year	Current decision/ short-term planning	Adaptive capacity & current vulnerability

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Method/tool	Description	Process	Limitations
Institutional analysis	Institutional analyses include the mapping of key actors and their interactions and the evaluation of formal and informal rules, norms and organisations that govern behaviour. It is important to note that decisions are rarely made in relation to climate risk alone. Institutional change (through change of social, cultural and other norms) can play a much larger role than the signal of climatic variability and change. Institutional change can be highly variable and unpredictable and it can limit and/or facilitate adaptation, today and in the future.	An institutional analysis of a farming group might be achieved by using a number of tools to gather information about the institutions that govern farmers' behaviour. For example, community timelines would illustrate important events and key changes in livelihoods. Surveys might provide perceptions about the tendencies of socio-economic change (points of vulnerability/ opportunity) and of the impact of non-climatic versus climatic factors that influence decisions.	
	Resources Institutional Analysis in Natural Resources Research (Matsaert, 2002)		
Livelihood indicator approach	The livelihood indicator approach builds on the livelihood framework in order to assess the vulnerability of livelihood typologies to different stresses. The method takes advantage of expert knowledge in a structured way. It builds on bottom-up local observations and can readily lead to formal indicators.	The approach requires an initial analysis of the dominant livelihood typologies in the case study region. The threats to these livelihood typologies are then identified. A matrix is developed that assesses how sensitive each typology is to each risk identified. This serves to reveal who is vulnerable to different threats and stresses. The outputs can be ranked according to different variables.	• This approach is not directly linked to actual adaptation policy responses and decision-making. • More often than not, it identifies the obvious. It could be more effective if it also estimated the level and the extent of the problem – for example, by linking the approach with independent surveys.
	Resources Capacity strengthening in climate change vulnerability and adaptation strategy assessments (Downing & Ziervogel, 2004)		

	Data requirements and output	Duration of assessment	Time frame of assessment	Applicability
	Quantitative	Rapid/1 year/ several years	Current decision/ short-term planning/ long-term planning	Adaptive capacity
	Capacity strengthening in climate change vulnerability and adaptation strategy assessments (Downing & Ziervogel, 2004)			
	Quantitative	Rapid/1 year/ several years	Short-term planning/ long-term planning	Current vulnerability & future vulnerability
	Developing a livelihood-sensitivity matrix (weADAPT, 2011): http://weadapt.org/knowledge-base/vulnerability/appendix-a-developing-a-livelihood-sensitivity-matrix			

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Method/tool	Description	Process	Limitations	
Oral history+	Oral histories are qualitative narratives sourced through individuals' telling their histories and strategies. They are particularly effective for gathering information on local vulnerabilities over past decades, where there is often limited data.	The information is usually acquired through semi-structured interviews and participatory tools. Interviewees should be told what the purpose of the exercise is. They are then asked to talk about how things were in the past. Certain questions can lead the interviewee to focus on aspects of interest to the interviewer, such as past climate, farming practices or water management strategies, for example.	• The information given by the individuals is an account of their experience and has to be verified with scientific facts.	
	Resources Capacity strengthening in climate change vulnerability and adaptation strategy assessments (Downing & Ziervogel, 2004)			
Participatory scenario analysis: 'What if?' tool	The development and analysis of participatory scenarios is a powerful tool for creating and assessing possible future developments. Scenarios are possible futures. The future is unknown and so it is necessary to consider many alternatives of what the future might be, taking account of the full range of imaginable futures.	Bottom-up scenarios tend to be oriented more towards local levels with a base in participatory and stakeholder methods. Bottom-up scenarios are more likely to capture local vulnerabilities and dynamics. It is considerably more difficult to construct a participatory, representative process for global scenarios.	• This method demands sufficient diversity in the group in terms of knowledge, age, etc. • In reality, the future is likely to be a mix of various elements. Some elements might not be considered at all.	
	Resources Capacity strengthening in climate change vulnerability and adaptation strategy assessments (Downing & Ziervogel, 2004)			

Data requirements and output	Duration of assessment	Time frame of assessment	Applicability
Qualitative	Rapid/1 year	Current decision/ short-term planning/ long-term planning	Adaptive capacity & current vulnerability
Qualitative	Rapid/1 year	Current decision/ short-term planning/ long-term planning	Sensitivity, current vulnerability & future vulnerability
Participatory Scenario Development (PSD) Approaches for Identifying Pro-Poor Adaptation Options (World Bank, 2010): http://climatechange.worldbank.org/sites/default/files/documents/PSD-Pro-Poor-Adaptation_EACC-Social%20.pdf			

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Method/tool	Description	Process	Limitations
Role-play	Role-playing activities prompt discussion, pave the way for improved communication, and thus stimulate collaboration. Applicable at both community and agency levels, these activities involve participants as a group in analytic thinking and assessment.	An open-ended story is told to the participants or a written case description is used to describe the setting for the action. The participants are then asked to act out potential scenarios to uncover what might happen under different circumstances.	• There are chances that the group might deviate from the focus, so it is important to have a good facilitator who can maintain the focus on the issues at hand and guide the whole process.
	Resources Capacity strengthening in climate change vulnerability and adaptation strategy assessments (Downing & Ziervogel, 2004)		
Seasonal calendar	A seasonal calendar is a participatory tool for documenting regular cyclical periods and significant events that occur during a year and influence the life of a community. Major climatic and environmental periods and hazards should be marked in the calendar.	This exercise can provide insight into the community's perceptions of change. It is recommended to conduct this exercise in gender-differentiated groups with a mix of older and younger participants to reveal the gender- and age-related differences in the perception of change.	• This tool provides only general insights, which will need further validation as the tool very much depends on the experience and knowledge of the participating members.
	Resources Framework for Community-based Climate Vulnerability and Capacity Assessment in Mountain Areas (ICIMOD, 2011): http://lib.icimod.org/record/8096		

	Data requirements and output	Duration of assessment	Time frame of assessment	Applicability
	Qualitative	Rapid/1 year	Current decision/ short-term planning/ long-term planning	Current vulnerability & future vulnerability
	Qualitative/quantitative	Rapid/1 year	Current decision/ short-term planning	Exposure
	Climate Vulnerability and Capacity Analysis – Handbook (Dazé, et al., 2009): http://www.careclimatechange.org/cvca/CARE_CVCAHandbook.pdf			

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Method/tool	Description	Process	Limitations	
Stakeholder consultation	Stakeholder consultations are discussions with individuals and/or groups affected by future processes. There are many ways of engaging stakeholders. At the local level, meetings may be held, interviews undertaken, and key informants approached. The broad focus of the consultation will be to identify key problems in the region (vulnerabilities) and to undertake to transform problems into solutions (adaptation options). This can be done either from the stakeholders' perspective, by using their unique skills and knowledge, or from a more scientific perspective, where state-of-the-art knowledge can be translated into applicable solutions that users can then provide feedback on.	If a project is designed to help people in a rural village to plant trees, it is important to consult various stakeholders before the project goes ahead. A meeting could be planned inviting local chiefs, agricultural extension officers and community members.	• Selected groups may or may not be representative of the opinion of the majority.	
	Resources Capacity strengthening in climate change vulnerability and adaptation strategy assessments (Downing & Ziervogel, 2004)			

	Data requirements and output	Duration of assessment	Time frame of assessment	Applicability
	Qualitative	Rapid/1 year	Short-term planning/ long-term planning	Exposure, sensitivity, adaptive capacity & current vulnerability

Stakeholder Engagement: A Good Practice Handbook for Companies Doing Business in Emerging Markets (IFC, 2007): http://www1.ifc.org/wps/wcm/connect/topics_ext_content/ifc_external_corporate_site/ifc+sustainability/publications/publications_handbook_stakeholderengagement__wci__1319577185063

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Method/tool	Description	Process	Limitations
Timeline	Timelines are used to identify and discuss climate change induced hazards that have had a certain impact on the community over previous decades. They are used to gain understanding and make participants aware of trends and/or changes in the frequency of climatic hazards over time.	This method displays changes over time and, therefore, provides a good mean to track longer-term changes. It can stimulate a valuable discussion about the speed and extent of positive and negative changes, why a situation is as it is, and why different groups or individuals hold the views they do. This method provides a human dimension to data.	• Timelines provide only general insights, which will need further validation and are dependent on the experience and knowledge of the participating members.
	Resources Framework for Community-based Climate Vulnerability and Capacity Assessment in Mountain Areas (ICIMOD, 2011): http://lib.icimod.org/record/8096		
Transect walk	A transect walk is a structured walk through an area to get a qualitative map of that area. The walk includes assessing the availability and quality of resources, land use and infrastructure, including problems and risks encountered.	Transect walks are structured walks along an area of interest. One of the outcomes of a transect walk is a cross-sectional drawing of the path taken. Below the cross sectional drawing a table should list the findings at the respective part of the route taken (e.g. presence of settlements, forests, etc.). However, if this is too abstract, then it might be more useful simply to draw the walk as a bird's eye view line on a map, with the related information written alongside.	• This method only gives a snapshot of a situation in a specific geographic location, which changes over the course of the seasons and years.
	Resources Participatory Tools and Techniques for Assessing Climate Change Impacts and Exploring Adaptation Options (LFP, 2010): http://community.eldis.org/.59c484e1/Participatory%20CC%20impact%20tool.pdf		

	Data requirements and output	Duration of assessment	Time frame of assessment	Applicability
	Qualitative/quantitative	Rapid/1 year	Current decision/ short-term planning	Exposure
	Qualitative	Rapid/1 year	Short-term planning/ long-term planning	Sensitivity & adaptive capacity
	Framework for Community-based Climate Vulnerability and Capacity Assessment in Mountain Areas (ICIMOD, 2011): http://lib.icimod.org/record/8096			

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Method/tool	Description	Process	Limitations
Vulnerability matrix	The aim of a vulnerability matrix is to link up with the outputs of the 'Climate hazard trend analysis' (›› see p. 142). It is used to differentiate vulnerability to climatic hazards across different sectors and social groups and to identify the most vulnerable groups within the district and the most vulnerable sectors.	Hazards identified through the 'Climate hazard trend analysis' are listed along the vertical axis of a grid. Different social groups (age, gender, ethnic, caste groups) or different sectors (agriculture, water, tourism, etc.) are listed on the horizontal axis. Participants discuss the vulnerability of each sector and social group to each climatic hazard to determine if they are: not affected, moderately affected, or heavily affected.	• It is difficult to include the most marginalised if they are unable to attend. • It depends on the participants' knowledge and understanding about climate change issues.
	Resources Participatory Tools and Techniques for Assessing Climate Change Impacts and Exploring Adaptation Options (LFP, 2010): http://community.eldis.org/.59c484e1/Participatory%20CC%20impact%20tool.pdf		
Wealth ranking	Wealth ranking helps to understand different stratifications of groups within a community as understood by community members.	The community unit analysed by this method varies depending on the situation and environment of the participants. The relevant boundaries for a wealth ranking exercise might be a village, a farming group or an extended family. The categories for the wealth ranking can be either decided by the group or in a pilot wealth-ranking exercise that is completed in different communities. The researcher then compiles a list of categories.	• If there are only a few participants they should have a good knowledge of the people in their community and should be representative of the cross-section of groups.
	Resources Framework for Community-based Climate Vulnerability and Capacity Assessment in Mountain Areas (ICIMOD, 2011): http://lib.icimod.org/record/8096		

Data requirements and output	Duration of assessment	Time frame of assessment	Applicability
Qualitative/quantitative	Rapid/1 year	Current decision/ short-term planning/ long-term planning	Current vulnerability
Framework for Community-based Climate Vulnerability and Capacity Assessment in Mountain Areas (ICIMOD, 2011): http://lib.icimod.org/record/8096			
Qualitative/quantitative	Rapid/1 year	Current decision/ short-term planning	Adaptive capacity

Practical methods and tools III: Indicator-based methods for vulnerability assessment

Method/tool	Description	Process	Limitations
Vulnerability indicators or vulnerability mapping	Mapping the different indicators of vulnerability is an index-based method to assess vulnerability. It is the most widely used method to assess vulnerability. Indicators and indexes are one way of quantifying the level of vulnerability. An indicator is a single measure of a characteristic and an index is a composite measure of several indicators or indices. Indicators can be a useful policy tool because they enable clear visual mapping of priority areas.	The first step in an indicator-based vulnerability assessment is to select indicators. The next, most common step is to transform the indicators into some sort of standard scores. Often these scores are mapped to identify geographic 'hot spots'. Standard scores are the relative location between the low and high value in the data set, generally in the range of 0 to 1 or 0 to 100. The use of regional climate projections and impact assessment modelling could also be complemented by stakeholder-driven bottom-up methods for the validation of data.	• Comparing indicators and indexes that assess different temporal and spatial scales is challenging because the units of measurement are often inconsistent. This can result in inappropriate comparisons. It is therefore critical that the methods for collecting and combining individual indicators are understood.
	Resources Capacity strengthening in climate change vulnerability and adaptation strategy assessments – Toolkit for Vulnerability & Adaptation Assessments (Downing & Ziervogel, 2004)		

Data requirements and output	Duration of assessment	Time frame of assessment	Applicability
Quantitative	Rapid/1 year/ several years	Short-term planning/ long-term planning	Exposure, sensitivity, adaptive capacity, current vulnerability & future vulnerability

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Method/tool	Description	Process	Limitations	
Vulnerability profile	When indicators are aggregated into indices one speaks about vulnerability profiles. Vulnerability profiles enable factors and trends to be compared between households or groups. The profiles enable many of the livelihoods indicators to be included and can illustrate the impact of environmental variability and change. Selected indicators can be integrated with the spatial database on a GIS platform to carry out vulnerability assessments.	Profiles can be compiled using standard indicators of poverty and vulnerability, such as people below the poverty line, illiteracy, health, etc. A matrix should be compiled that draws together the different groups and their scores for the chosen indicators.		
	Resources Capacity strengthening in climate change vulnerability and adaptation strategy assessments – Toolkit for Vulnerability & Adaptation Assessments (Downing & Ziervogel, 2004)			

Data requirements and output	Duration of assessment	Time frame of assessment	Applicability
Quantitative	Rapid/1 year/ several years	Short-term planning/ long-term planning	Exposure, sensitivity, adaptive capacity, current vulnerability & future vulnerability

Methods for assessing coastal vulnerability to climate change (Ramieri, et al., 2011):
http://cca.eionet.europa.eu/docs/TP_1-2011

Practical methods and tools IV: Data sources

Data sources

This section provides a collection of data resources relevant for both top-down and bottom-up vulnerability assessments. This includes historical and projected climate data at different spatial aggregation levels, GIS and Remote Sensing, as well as socio-economic data specific to the Indian context.

Climate data

Name/institution	Data	Data source
APHRODITE's Water Resources (Asian Precipitation – Highly-Resolved Observational Data Integration Towards Evaluation of Water Resources), Ministry of the Environment, Japan	• Historical precipitation data	http://www.chikyu.ac.jp/precip/
British Atmospheric Data Centre (BADC), Natural Environment Research Council (NERC), UK	• Climate data: › historical climate data › GCM and RCM data • Atmospheric data	http://badc.nerc.ac.uk
Climate Change Knowledge Portal, World Bank	• Climate data: › historical climate data › GCM and RCM data • Climate change impacts: › agriculture › natural hazards › water resources • Vulnerability indicators: › population › health › agriculture	http://sdwebx.worldbank.org/climateportal/index.cfm
Climate Data Archives, University of Delaware, USA	• Historical climate data	http://climate.geog.udel.edu/~climate/html_pages/archive.html

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Name/institution	Data	Data source
Climate Impacts: Global and Regional Adaptation Support Platform (ci:grasp), Potsdam Institute for Climate Impact Research (PIK), Germany	• Climate data: › GCM data • Climate change impacts • GHG emission data	http://cigrasp.pik-potsdam.de/
Climate Research Unit, University of East Anglia, England	• Climate data: › historical climate data › GCM and RCM data	http://www.cru.uea.ac.uk/data
India Meteorological Department, Ministry of Earth Sciences, India	• Historical climate data	http://www.imd.gov.in/
Indian Institute of Tropical Meteorology	• Historical climate data	http://www.tropmet.res.in/Data%20Archival-51-Page
KNMI Climate Explorer, Royal Meteorological Institute, Netherlands	• Climate data: › historical climate data › GCM and RCM data	http://climexp.knmi.nl/start.cgi?id=someone@somewhere
National Climatic Data Center, National Oceanic and Atmospheric Administration, USA	• Historical climate data • Drought indices	http://www.ncdc.noaa.gov/temp-and-precip/
National Data Center, India Meteorological Department, Pune, India	• Historical climate data	http://www.imdpune.gov.in/research/ndc/ndc_index.html
The NCEP/NCAR Reanalysis Project, National Oceanic and Atmospheric Administration, USA	• Historical climate data	http://www.esrl.noaa.gov/psd/data/reanalysis/reanalysis.shtml
The PRECIS Regional Climate Modelling System, Met Office, UK	• PRECIS climate change scenarios, spatial resolution of 0.44×0.44 degree (about 50×50 km)	http://www.metoffice.gov.uk/precis/

GIS and Remote Sensing data

Name/institution	Data	Data source
General Bathymetric Chart of the Oceans, GEBCO	• Global bathymetric data	http://www.gebco.net
Global Digital Elevation Model (GDEM), The CGIAR Consortium for Spatial Information (CGIAR-CSI)	• SRTM 90m Digital Elevation Data	http://srtm.csi.cgiar.org/
Global Land Use Data, University of Wisconsin-Madison, USA	• Global database of land use and land cover by combining satellite data and census data	http://www.sage.wisc.edu/iamdata
Global Maps of Urban Extent from Satellite Data, University of Wisconsin-Madison, USA	• Global database of urban extent from satellite data	http://sage.wisc.edu/people/schneider/research/data.html
LUGE (Land Use and the Global Environment) Lab, McGill University, USA	• Global cropland and pasture data from 1700–2007	http://www.geog.mcgill.ca/-nramankutty/Datasets/Datasets.html
MIRCA2000, University of Frankfurt, Germany	• Global data set of monthly irrigated and rain-fed crop areas around the year 2000 (MIRCA2000)	http://www2.uni-frankfurt.de/45218023/MIRCA?legacy_request=1

Data specific to the Indian context

Name/institution	Data	Data source
Census of India, Indian Ministry of Home Affairs	• Demographic data	http://censusindia.gov.in/
Crop Production Statistics Information System, Agriculture Informatics Division, Indian Ministry of Communication & IT	• Crop production information at the district level	http://apy.dacnet.nic.in/
District Planning Map Series, National Atlas and Thematic Mapping Organisation (NATMO), Indian Department of Science and Technology	• Crop production information at the district level • District level maps of India	http://natmo.gov.in/dp_mapseries.htm
Farm Harvest Prices, Department of Agriculture and Cooperation, Indian Ministry of Agriculture	• Farm harvest price information at the district level	http://eands.dacnet.nic.in/FHP(District).htm

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Name/institution	Data	Data source
Hydrological Information System (NATCOM), Department of Civil Engineering, IIT Delhi	• SWAT model outputs	http://gisserver.civil.iitd.ac.in/natcom/
Indian Institute of Remote Sensing, Indian Department of Space	• GIS data • Remote sensing data	http://www.iirs.gov.in/
Indian Network for Climate Change Assessment, Indian Ministry of Environment and Forests of India	• Climate Change and India: A 4X4 Assessment – A sectorial and regional analysis for the 2030s	http://envfor.nic.in/division/indi-an-network-climate-change-as-sessment-2
NRHM Health Management Information System (HMIS) Portal, Indian Ministry of Health and Family Welfare	• National family health survey (NFHS) • District-level household and facility survey	http://nrhm-mis.nic.in/Publications.aspx
Retail Price Information System, Directorate of Economics and Statis-tics, Indian Ministry of Agriculture	• Retail price information (food and non-food) at the state level	http://rpms.dacnet.nic.in/
Rural Development Statistics, National Institute of Rural Development, India	• Rural development statistics	http://www.nird.org.in/publications.aspx
State of Environment Atlas of India, Development Alternatives with support from the Indian Ministry of Environment and Forests	• State- and district-level maps: › environmental data › socio-economic data	http://www.soeatlas.org/
Web-Based Land Use Statistics Information System, Agriculture Informatics Division, Indian Ministry of Communication & IT	• Land use information at the district level	http://lus.dacnet.nic.in/

Other

Name/institution	Data	Data source
EM-DAT – The International Disas-ter Database, Université catholique de Louvain, Belgium	• Global database on natural disasters	http://www.emdat.be
United Nations International Strategy for Disaster Reduction (UNISDR), United Nations Office for Disaster Risk Reduction	• Disaster trends and disaster risk reduction	http://www.unisdr.org/

'I remember my parents cultivating the millet crops kodo and kutki on large scale when I was a child. But this tradition was lost when everyone moved over to paddy. Now that one of our biggest challenges is erratic rainfall, I have brought back the cultivation of kodo and kutki and have also introduced ragi on my fields. These millets produce good yields and nutritious foods, even with erratic rainfall conditions.'

Dasrath Osyam, 32 years
Payali Bahur, Niwas Block, Madhya Pradesh

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