B A S I C

Paper 8

Handbook of Current and Next Generation Vulnerability and Adaptation Assessment Tools

September 2007

Amit Garg, Ashish Rana and P.R. Shukla, Energy Environment Analytics Limited India, Manmohan Kapshe, Maulana Azad National Institute of Technology, India, with contributions from, K. Narayanan, D. Parthasarathy, and Unmesh Patnaik, Indian Institute of Technology, Bombay, India

The BASIC Project is a capacity strengthening project – funded by the European Commission – that supports the institutional capacity of Brazil, India, China and South Africa to undertake analytical work to determine what kind of climate change actions best fit within their current and future national circumstances, interests and priorities. Additional funding for BASIC has also been kindly provided by the UK, Department for Environment, Food and Rural Affairs and Australian Greenhouse Office. For further information about BASIC go to *http://www.basic-project.net/*

About BASIC

The BASIC Project supports the institutional capacity of Brazil, India, China and South Africa to undertake analytical work to determine what kind of national and international climate change actions best fit within their current and future circumstances, interests and priorities. BASIC has created a multi-national project team linking over 40 individuals from 25 research and policy institutions, the majority based in BASIC countries. Project activities comprise a mix of policy analysis, briefings, workshops, conferences, mentoring and training clustered around five tasks lead by teams as follows:

- Task 1 – Mitigation and sustainable development (China Team);
- Task 2 – Adaptation, vulnerability and finance (India Team);
- Task 3 – Carbon markets, policy coherence and institutional coordination (South Africa Team);
- Task 4 – Designing international climate change policy and enhancing negotiations skills (Brazil Team); and
- Task 5 – Creation of developing country expert group/mechanism on a long term basis (All Teams).

Funding for BASIC has been provided by Environment Directorate of the European Commission with additional support from the UK, Department for Environment, Food and Rural Affairs and Australian Greenhouse Office. For further information about BASIC go to: http://www.basic-project.net/

About this Paper

The views and opinions expressed in this Handbook have been put forward by the BASIC Task 2 Team to contribute to capacity development and to advance discussions about vulnerability and adaptation and do not express the views or opinions of the funders or the BASIC Project Team as a whole. Task 2 is coordinated by the BASIC India Team which comprises: Sumana Bhattacharya and Aditi Dass, Winrock International, India, Amit Garg, Ashish Rana and PR Shukla, Energy Environment Analytics, Ahmadabad, India, K Narayanan and D Parthasarathy, Indian Institute of Technology, Bombay, India, Manmohan Kapshe, Maulana Azad National Institute of Technology, India, Anand Patwardhan and Meeta Ajit, Technology Information Forecasting and Assessment Council, India. The authors of the Handbook would like to thank the BASIC Team and participants at the BASIC International Workshop, “Vulnerability and Adaptation to Climate Change: From Practice to Policy” held in India, in May 2006, for their contributions and comments to the work under Task 2. This does not imply support for the views expressed in this Handbook by these individuals and organizations.

Other papers produced by BASIC Task Team 2 include:

- Vulnerability to Drought, Cyclone and Floods in India, Sumana Bhattacharya and Aditi Das, Winrock International, India
- Disaster Prevention, Preparedness and Management, and Linkages with Climate Change Adaptation, Anand Patwardhan and Meeta Ajit, Technology and Information Forecasting Assessment Council, India
- Lessons Learnt for Vulnerability and Adaptation Assessment from India’s First National Communication, Sumana Bhattacharya, Winrock International, India
- Proceedings of the BASIC India Workshop, Vulnerability and Adaptation to Climate Change: From Practice to Policy, May 2006, Winrock International

Abstract

This paper is an introductory Handbook or guide to frequently used vulnerability and adaptation assessment (VA) tools so that users can make better informed decisions about which tools to use. By looking at the strengths and weaknesses of commonly used tools and providing an independent critique of their merits, the Handbook *complements* other guides to tools that are available, such as the 2005 Compendium of tools and methods for VA provided by the UNFCCC. Three kinds of tools are covered in the Handbook: impact and vulnerability tools; adaptation policy assessment tools and integrated vulnerability and assessment tools.

The review of current methods and tools to measure vulnerability and adaptation in chapters 2, 3 and 4 of the Handbook and their applicability to India in chapter 5 reveals several gaps and limitations. Most indices & measurements of VA use a very narrow definition of vulnerability and have constructed a common set of proxies or variables at the macro and micro level which ignore the specificities of local or regional factors that are crucial in determining vulnerability and adaptive capacity. However vulnerability is due to several factors. The final chapter of the Handbook develops a comprehensive framework for vulnerability assessment that encompasses various dimensions and suggests an index that can be quantified and compared over a period of time. The new method focuses on indicators that measure (a) the dynamic context of livelihoods, demography, agro-climatic aspects and infrastructure (b) the state of development of a region or population and (c) a population's capacity to progress in economic and social terms. The new conceptual framework, if modified and extended, could give a richer, more complete picture of socio-economic vulnerability and adaptive capacity and is thus an important contribution to moving forward with concrete formulation and implementation of adaptation policies, programmes and projects worldwide.

CONTENTS

Chapter 1: Introduction **1**

1.1 Overview of the Purpose and Structure of the Handbook 1

1.2 Impact and Vulnerability: Conceptual issues and their implication for assessment tools 3

1.3 Adaptation: Conceptual issues and their implication for assessment tools 5

1.4 Need for assessment tools 7

1.5 Qualities of a good tool 8

1.6 Types and classification of tools 10

Chapter 2: Impact and Vulnerability Assessment Tools **15**

2.1 Introduction 15

2.2 Agriculture sector 15

2.2.1 Process crop models 16

2.2.2 Irrigation models 18

2.2.3 Economic models 18

2.2.4 Integrated models for agriculture 18

2.2.5 Other models (e.g. Tools for Climate Risk Assessment in Mountain Agriculture) 19

2.3 Water resources 19

2.3.1 WaterWare 20

2.3.2 Water evaluation and planning system (WEAP) 21

2.3.3 RiverWare 21

2.3.4 Interactive river and aquifer simulation (IRAS) 22

2.3.5 Aquarius 23

2.3.6 RIBASIM 23

2.3.7 MIKE BASIN 24

2.3.8 Spatial tool for river basin environmental analysis and management (STREAM) 24

2.3.9 Soil and water assessment tool (SWAT) 25

2.3.10 Some other tools 25

2.4 Coastal resources 26

2.5 Human health 29

2.5.1 Modelling Framework for the Health Impact Assessment of Man-Induced Atmospheric Changes (MIASMA) 29

2.5.2 Environmental burden of disease assessment 30

2.5.3 CIMSiM and DENSiM (Dengue Simulation Model) 30

2.5.4 UNFCCC guidelines 31

2.5.5 LymSiM 31

2.5.6 Mapping Malaria Risk in Africa (MARA) Low-end Information Tool (LITe) 32

2.6 Forestry, natural ecosystems and biodiversity 32

2.6.1 Empirical - Statistical Models *33*
2.6.2 Simulation Models *33*
2.7 Energy and environment 34
2.8 Infrastructure and industry 38

Chapter 3: Adaptation Policy Assessment Tools **41**
3.1 Introduction 41
3.2 Decision tools 42
3.2.1 Policy exercise *42*
3.2.2 Benefit-cost analysis *42*
3.2.3 Cost-effectiveness *43*
3.2.4 Multicriteria analysis (MCA) *43*
3.2.5 Tool for Environment Assessment and Management (TEAM) *44*
3.2.6 Adaptation decision matrix (ADM) *45*
3.2.7 Screening of adaptation options *45*
3.3 Stakeholder approaches 46
3.3.1 Stakeholder networks and institutions *46*
3.3.2 Scoping *47*
3.3.3 Vulnerability indices *47*
3.3.4 Agent based social simulation *48*
3.3.5 Livelihood sensitivity exercise *49*
3.3.6 Multistakeholder processes *49*
3.3.7 Global sustainability scenarios *50*
3.4 Other multisector tools 50
3.4.1 Climate change and variability *51*
3.4.2 Expert judgement *51*
3.4.3 Historical or geographic analogs: Forecasting by analogy *52*
3.4.4 Uncertainty and risk analysis *52*
3.4.5 Estimating adaptation costs: M-CACES *53*

Chapter 4: Integrated Vulnerability Assessment and Adaptation Tools **55**
4.1 Introduction 55
4.2 Integrated Assessment 55
4.3 Scope and possibilities of integration 56
4.4 Integrated Assessment Models and frameworks 56
4.4.1 PRIMES (Energy System Model) *59*
4.4.2 POLES (Prospective Outlook on Long-term Energy Systems) *59*
4.4.3 ExternE (Externalities of Energy) *60*
4.4.4 ICLIPS (Integrated Assessment of Climate Protection Strategies) *60*

4.4.5 RICE (Regional Integrated model of Climate and the Economy) and DICE (Dynamic Integrated model of Climate and the Economy) 61

4.4.6 IGSM (The MIT Integrated Global System Model) 62

4.4.7 MERGE 62

4.4.8 MAGICC/SCENGEN 63

4.5 General strengths and weaknesses of IAMs 64

Chapter 5: Assessment of Tools and their Applicability in India 69

5.1 Introduction 69

5.2 Future climate projections 69

5.3 Future emission projections 70

5.4 Water resources 72

5.5 Agriculture 72

5.6 Forestry, land use and natural ecosystems 73

5.7 Coastal zones 74

5.8 Energy and infrastructure 75

5.9 Human health 75

5.10 Conclusion 75

Chapter 6: Next Generation Tools for Assessing Vulnerability and Adaptation 80

6.1 Introduction 80

6.2 Vulnerability: Assessment and Measurement Issues 81

6.3 Description of Indicators and Proxies 84

6.3.1 Demographic indicators 84

6.3.2 Climatic indicators 84

6.3.3 Agricultural indicators 84

6.3.4 Occupational indicators 85

6.3.5 Infrastructural indicators 85

6.3.6 Inequality and Poverty indicators 86

6.4 Adaptation: Assessment and Measurement Issues 88

6.5 Summary and Conclusion 91

Chapter 1: Introduction

1.1 Overview of the Purpose and Structure of the Handbook

Climate change is recognized as the biggest market failure ever (Stern Commission, 2006). It is projected to have severe and wide ranging impacts on natural and man-made systems, especially in developing countries. Impact and vulnerability assessments therefore are important prerequisite to formulate appropriate adaptation policy responses for climate change. Myriad impact, vulnerability and adaptation (IV&A) tools are available for this assessment. These assessments are also useful in fulfilling the mandate of Article 12 of the UNFCCC which says "developing country Parties that are particularly vulnerable to the adverse effects of climate change" (UNFCCC, 1992) are to be compensated by the developed country Parties. Thus, an assessment of the impact of the projected climate change on the natural and socio-economic systems is central to the whole issue of climate change.

The purpose of this Handbook is to provide an explanation and a critique of the most frequently used IV&A tools so that users are better informed and can take a more conscious decision in selecting appropriate tools for their use. The Handbook also maps out a conceptual approach and framework for the next generation of tools that remedies the shortcomings of current tools.

This Handbook has been designed so that it *complements* other sources of information about commonly used analytical tools for climate change V&A (UNFCCC, 2005; Burton et al., 2002; UNFCCC, 2002). For this reason a full description of each tool has not been provided since these are also available in other guidelines. Instead the Handbook provides a short description of the main tools and what they are most useful for followed by a section on their respective strengths and weaknesses, we hope this structure will enable users to quickly gauge their comparative advantages thus facilitating selection of tools appropriate to the purpose in question.

Any climate change impact assessment generally involves the following steps:

- Identifying, analyzing and evaluating the impact of climate variability and change on natural ecosystems, socio-economic systems and human health
- Assessing the vulnerabilities, which also depend on the institutional and financial capacities of the affected communities, such as farmers, forest-dwellers and fishermen
- Assessing the potential adaptation responses
- Developing technical, institutional and financial strategies to reduce the vulnerability of the ecosystems and populations.

Because of the complexity of the relationships of natural and man made systems, developing a single tool addressing all aspects of vulnerabilities and impacts, at the same time covering adaptation possibilities is extremely difficult if not impossible. Making decisions about adaptation, requires analysis of specific adaptation measures, projects, and programs. Therefore, information related to tools addressing vulnerability and adaptation have been compiled separately in this Handbook.

The tools described in the Handbook have been taken form various sources and efforts have been made to refer to all possible references. **Chapter 1** of the Handbook outlines what can be considered a "good" tool and provides an overview of tools grouped in three sections:

1. Impact and vulnerability (I&V) assessment tools
2. Adaptation policy assessment tools
3. Integrated vulnerability assessment and adaptation tools

Chapter 2 provides a guide to commonly used impact and vulnerability assessment tools. The first step in addressing impacts of climate change is to assess the vulnerability of the systems affected by it and develop adaptation strategies for them. Various methodologies, tools and techniques are used for these purposes. This chapter provides an overview of different methodologies, generic approaches and sectoral tools available for impact assessments. The sectors covered are agriculture, water resources, coastal resources, human health, forestry, natural ecosystems and biodiversity, energy and environment, and infrastructure and industry.

Chapter 3 covers adaptation policy assessment tools. These include decision tools, stakeholder approaches and other multisector tools. Adaptation assessment process is becoming more sophisticated over the years. Adaptation responses are now seen as integral to the developmental process and growth of a society. This has broadened the scope and extent of adaptation tools that have to not only assess individual policies for their capability to enhance adaptive capacities of the target population and systems, but also have to consider the link with the overall sustainable development paradigm of the host nation. This, therefore, is a fast expanding field of research and practical guidance, where one could become obsolete very quickly.

An explanation and critique of the current integrated assessment tools is provided by **Chapter 4**. Integrated Assessment (IA) considers the interaction between climate change and other change processes to assess the social, economic and environmental impacts of climate change. It requires a wide understanding of natural and human systems, such as demographic profile, economic development and land use of a region, since these have a significant influence on how changes in climate are likely to impact and the capacity to adapt to any such future changes. The chapter discusses IA models and key issues around possible integration across sectors, regions and time.

Chapter 5 covers assessment of tools and their applicability in India. Preliminary studies were carried out under the aegis of India's Initial National Communication (NATCOM, 2004) to assess the impacts of climate change on water resources, agriculture, forests, natural ecosystems, coastal zones, human health and energy and infrastructure. This activity also included development of climate change projections and future emission scenarios for India. These efforts represent the extant scientific capacity, methodological coverage, data availability and constraints, besides shedding light on the vulnerability of different regions of the country to climate change and the need for devising adaptation responses.

Chapter 6 covers next generation tools for assessing vulnerability and adaptation. Most of the earlier studies have used a very narrow definition of vulnerability and constructed an index to suit that definition. However, vulnerability is due to several factors, and also of various kinds. This concluding chapter develops a comprehensive framework of vulnerability assessment that encompasses various dimensions, and suggests an index which can be quantified and compared over a period of time. Using dynamic indicators and combining them into an index is a departure from existing methods and tools. Also, extending the framework to analyze the determinants of adaptations and developing an adaptive efficiency tool is an important contribution of this chapter.

1.2 Impact and Vulnerability: Conceptual issues and their implication for assessment tools

Over the years the definition of vulnerability has undergone many changes as scholars from different disciplines and perspectives contribute to changing needs of policy-makers. As with other similar concepts, it may be very difficult to agree on a single definition of vulnerability. The following section traces the evolution of the concept of vulnerability in a climate change context over the years. The implications of different definitions from different perspectives on the choice of tools to assess vulnerability are also explained.

- Vulnerability is the extent to which climate change may damage or harm a system (IPCC, SAR, 1996). Vulnerability depends not only on a system's sensitivity, but also on its ability to adapt to new climatic conditions.
- In a presentation made at the Sixth Conference of the Parties to the UNFCCC (COP-6), Robert T. Watson, Chair of the IPCC, defines "Vulnerability as the extent to which a natural or social system is susceptible to sustaining damage from climate change, and is a function of the magnitude of climate change, the sensitivity of the system to changes in climate and the ability to adapt the system to changes in climate".
- Vulnerability is the presence of factors that place people at risk of becoming food insecure or malnourished (FAO, 1999). This concept of vulnerability includes hunger vulnerability, which refers to the vulnerability of individuals or households rather than that of regions or economic sectors. This type of definition would therefore focus on tools to estimate capacity of households to afford food, such as income levels, share of food in monthly expenditure, poverty traps, income generating activities (adaptation studies) etc.
- From a natural hazards perspective, Blaikie et al. (1994) define vulnerability as "the characteristics of a person or group in terms of their capacity to anticipate, cope with, resist and recover from the impact of a natural hazard" (9). This concept argues that vulnerability is a measure of a person or group's exposure to the effects of a natural hazard, including the degree to which they can recover from the impact of that event. Correspondingly, the vulnerability assessment tools here would consider adaptation that has already taken place while conducting an I&V analysis. The capacity of households and individuals to adapt becomes the starting point for impact analysis. It is argued that households that have access to resources and social networks are less vulnerable. Although they may experience greater losses (in absolute terms) than the poor, it can be argued that resource-rich households are more resilient in that they recover more quickly from a stress/stimulus.
- Kelly and Adger (2000: 328) define vulnerability as "the ability or inability of individuals or social groupings to respond to, in the sense of cope with, recover from or adapt to, any external stress placed on their livelihoods and well-being."
- Social scientists and climate scientists often mean different things when they use the term "vulnerability"; whereas social scientists tend to view vulnerability as representing the set of socio-economic factors that determine people's ability to cope with stress or change (Allen, 2003), climate scientists often view vulnerability in terms of the likelihood of occurrence and impacts of weather and climate related events (Nicholls et al., 1999). The corresponding tools used for their analysis of vulnerability have therefore developed on different paradigms. The first relies more on economic assessment of I&V and the associated risks; while the latter focus more on physical impacts due to a changing climate without considering people's capacities to withstand such impacts.

- Definitions of vulnerability in the climate change related literature tend to fall into two categories, viewing vulnerability either (i) in terms of the amount of (potential) damage caused to a system by a particular climate-related event or hazard (Jones and Boer, 2003), or (ii) as a state that exists within a system before it encounters a hazard event (Allen, 2003).This combined vulnerability, a function of hazard, exposure and sensitivity, may be referred to as physical or biophysical vulnerability. The term “biophysical” will be used here, as it suggests both a physical component associated with the nature of the hazard and its first-order physical impacts, and a biological or social component associated with the properties of the affected system that act to amplify or reduce the damage resulting from these first-order impacts.
- Jones and Boer (2003) are therefore referring to biophysical vulnerability when they state that “Vulnerability is measured by indicators such as monetary cost, human mortality, production costs, [or] ecosystem damage…” These are indicators of outcome rather than indicators of the state of a system prior to the occurrence of a hazard event.
- For many human systems, vulnerability viewed as an inherent property of a system arising from its internal characteristics may be termed “social vulnerability” (Adger, 1999; Adger and Kelly, 1999). For vulnerability arising purely from the inherent properties of non-human systems or systems for which the term “social” is not appropriate the term “inherent vulnerability” might be used. Social vulnerability is determined by factors such as poverty and inequality, marginalisation, food entitlements, access to insurance and housing quality (Blaikie et al., 1994; Adger and Kelly, 1999; Cross, 2001). It is social vulnerability that has been the primary focus of field research and vulnerability mapping projects, which are generally concerned with identifying the most vulnerable members of society, and examining variations in vulnerability between or within geographical units that may experience similar hazards (Downing and Patwardhan, 2003).
- In this formulation, it is the interaction of hazard with social vulnerability that produces an outcome, generally measured in terms of physical or economic damage or human mortality and morbidity (Brooks and Adger, 2003). Such tools view social vulnerability as one of the determinants of biophysical vulnerability. These tools therefore describe the nature of social vulnerability as a dependence function on the nature of the hazard to which the human system in question is exposed. Although strictly speaking, social vulnerability is not a function of hazard severity or probability of occurrence, certain properties of a system will make it more vulnerable to certain types of hazard than to others. Certain factors such as poverty, inequality, health, access to resources and social status are likely to determine the vulnerability of communities and individuals to a range of different hazards (including non-climate hazards). We may view such factors as “generic” determinants of social vulnerability, and others such as the situation of dwellings in relation to river flood plains or low-lying coastal areas as determinants that are “specific” to particular hazards, in this example, flooding and storm surges.
- The IPCC Third Assessment Report (TAR) describes vulnerability as “the degree to which a system is susceptible to, or unable to cope with, adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude, and rate of climate variation to which a system is exposed, its sensitivity, and its adaptive capacity.” (IPCC, 2001, p. 995) (IPCC Def. 1). Exposure is defined in the same report as “the nature and degree to which a system is exposed to significant climatic variations.” Sensitivity is “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 is “The ability of a system to adjust to climate change (including climate variability and extremes) to moderate potential damages, to take advantage of opportunities, or to cope with the consequences.”

- These definitions are probabilistic in nature, relating either to (i) the probability of occurrence of a hazard that acts to trigger a disaster or series of events with an undesirable outcome, or (ii) the probability of a disaster or outcome, combining the probability of the hazard event with a consideration of the likely consequences of the hazard. These concepts promote tools to capture the probabilistic nature of I&V through modelling.
- Jones and Boer (2003) define hazard explicitly in physical terms. Stenchion (1997) and UNDHA (1992) implicitly define hazard in a similar manner, as an event that might precipitate a disaster but which does not itself constitute a disaster. Risk defined as a function of hazard and social vulnerability is compatible with risk defined as probability x consequence, and also with risk defined in terms of outcome. The probability of an outcome will depend on the probability of occurrence of a hazard and on the social vulnerability of the exposed system, which will determine the consequence of the hazard.
- The principal difference between the natural hazards risk-based approach and the IPCC biophysical vulnerability approach is that risk is generally described in terms of probability, whereas the IPCC and the climate change community in general tend to describe (biophysical) vulnerability simply as a function of certain variables. Nonetheless, the determinants of both biophysical vulnerability and risk are essentially the same - hazard and social vulnerability.

It is therefore clear that different paradigms and disciplines lead to different choices about tools. What is essential is to assess vulnerability as an integral part of the causal chain of risk and to appreciate that altering vulnerability is one effective risk-management strategy. The conceptual framework of vulnerability presented here can be applied in various ways. First of all, it allows communicating clearly which interpretation of vulnerability is used in a specific assessment. Second, it facilitates the discussion of how and why different vulnerability concepts differ from each other. Third, it provides a framework for reviewing existing terminologies of vulnerability.

1.3 Adaptation: Conceptual issues and their implication for assessment tools

Adaptation definitions and their implications for tools are similar to those for impact and vulnerability assessment. The following are some of the examples of the several definitions of adaptation found in the climate change literature:

- Adaptation to climate is the process through which people reduce the adverse effects of climate on their health and well-being, and take advantage of the opportunities that their climatic environment provides (Burton 1992, quoted in Smit et al. 2000).
- Adaptation involves adjustments to enhance the viability of social and economic activities and to reduce their vulnerability to climate, including its current variability and extreme events as well as longer-term climate change (Smit 1993, quoted in Smit et al. 2000)
- The term adaptation means any adjustment, whether passive, reactive or anticipatory, that is proposed as a means for ameliorating the anticipated adverse consequences associated with climate change (Stakhiv 1993, quoted in Smit et al. 2000)

- Adaptation to climate change includes all adjustments in behaviour or economic structure that reduce the vulnerability of society to changes in the climate system (Smith et al. 1996, quoted in Smit et al. 2000)
- Adaptability refers to the degree to which adjustments are possible in practices, processes or structures of systems to projected or actual changes of climate. Adaptation can be spontaneous or planned, and can be carried out in response to or in anticipation of change in conditions (Watson et al. 1996, quoted in Smit et al. 2000).
- According to the IPCC Third Assessment Report, adaptation "has the potential to reduce adverse impacts of climate change and to enhance beneficial impacts, but will incur costs and will not prevent all damages." Furthermore, it is argued that human and natural systems will, to some extent, adapt autonomously and that planned adaptation can supplement autonomous adaptation. However, "options and incentives are greater for adaptation of human systems than for adaptation to protect natural systems" (IPCC 2001: 6-8).

There are also various typologies and distinctions related to the process of adaptation which appear in the literature. For example, according to some of the typologies considered, adaptation can be planned or spontaneous; passive, reactive or anticipatory. The propensity of systems (e.g., socio-economic systems) to adapt is influenced by certain system characteristics that have been called "determinants of adaptation" in the literature. These include terms such as "sensitivity," "vulnerability," "resilience," "susceptibility" and "adaptive capacity," among others. The occurrence as well as the nature of adaptations is influenced by these. As Smit et al. (2000) point out there is some overlap in the concepts captured in these terms. The same authors argue that sensitivity, vulnerability and adaptability capture the broad concepts. Definitions of terms that describe system characteristics that are relevant for adaptation include the following (IPCC, 2001):

- Sensitivity: the degree to which a system is affected, either adversely or beneficially, by climate-related stimuli.
- Adaptive capacity: the ability of a system to adjust to climate change (including climate variability and extremes) to moderate potential damages, to take advantage of opportunities, or to cope with the consequences.
- Vulnerability: the degree to which a system is susceptible to, or unable to cope with, adverse effects of climate change, including climate variability and extremes. [It] is a function of the character, magnitude and rate of climate variation to which a system is exposed, its sensitivity, and its adaptive capacity.

Adaptation policy assessment tools therefore link with I&V tools, especially for sector specific tools. Many I&V tools can in fact be used for assessing alternative adaptation policies as well. These are covered in subsequent chapters.

Adaptation tools are also intricately linked with hazard assessment. Once we accept that risk, vulnerability and adaptive capacity are hazard-specific, we must then recognise that there are many different kinds of climate hazard, operating over a variety of different timescales and requiring a variety of adaptation responses. A system may have the capacity to adapt to certain types of hazard, but not to others. Three broad categories of hazard may be identified:

- Category 1: Discrete recurrent hazards, as in the case of transient phenomena such as storms, droughts and extreme rainfall events.
- Category 2: Continuous hazards, for example increases in mean temperatures or decreases in mean rainfall occurring over many years or decades (such as

anthropogenic greenhouse warming or desiccation such as that experienced in the Sahel over the final decades of the 20th century (Hulme, 1996; Adger and Brooks, 2003).

- Category 3: Discrete singular hazards, for example shifts in climatic regimes associated with changes in ocean circulation; the palaeoclimatic record provides many examples of abrupt climate change events associated with the onset of new climatic conditions that prevailed for centuries or millennia (Roberts, 1998; Cullen et al., 2000; Adger and Brooks, 2003).

The tools to assess these are very different. For example, the first category hazard such as disruption to a hilly rail network from excessive rainfall on a single day could be assessed based on interaction of climate parameter and system conditions through an impact matrix framework (Kapshe et al, 2003). While a category 2 hazard assessment would require a long-term impact assessment modelling tool (Kainuma et al., 2002). The damage to a system resulting from a discrete hazard event such as a storm or flood occurring tomorrow would not be a function of the system's ability to pursue future adaptation strategies – it is existing adaptations resulting from the past realization of adaptive capacity that determine current levels of vulnerability. The likelihood of a system adapting responsively to (as opposed to coping with) a sudden short-lived event such as a hurricane is negligible. However, a system's vulnerability to more gradual, longer-term change will be a function of its ability to adapt incrementally and responsively, and its vulnerability to discrete hazards occurring in the future will be a function of its ability to anticipate and pre-empt those hazards via appropriate planned adaptation strategies.

Some studies have also concluded that today's poverty is yesterday's unaddressed vulnerability (Yamin and Huq, IDS Bulletin, 2005). Climate variability and extreme events play a large role in the "basket" of vulnerabilities faced by the poor due to their disproportionate dependence on natural resource-based livelihoods and location at high-risk of natural disasters. Such studies link development with climate change related risks. However there are very few tools to capture these linkages. However there are a few model based studies that define and estimate sustainable development indicators to link development, climate change (Halsnæs and Garg, 2006; Halsnæs et al., 2006). Further research on vulnerability – who is vulnerable, to what risks, and why and how this links with climate vulnerability – particularly from the perspective of communities themselves – could play an important role in re-orientating development policy and researchable questions elaborating on these issues (Yamin et al., IDS Bulletin, 2006).

1.4 Need for assessment tools

IV&A assessment tools are needed for various reasons starting from awareness generation to planning and implementing action on ground. The IPCC's 2007 Fourth Assessment Report and international negotiations on burden sharing on climate change mitigation and adaptation actions underline the need for more informative and credible IV&A assessment. These assessments have to be:

- consistent across regions, sectors and time scales;
- comparable across alternative policy options and responses;
- conducted in a transparent manner;
- enable integrate across sectors, time and space; and
- capture realities as accurately as possible.

All these requirements imply that we need to have appropriate assessment tools. These tools have therefore developed along with our understanding of IV&A over the years. Some tools that were used even before climate change emerged as an issue and have been modified to suit climate change assessment needs. Integrated assessment is one such concept.

1.5 Qualities of a good tool

A good tool should be able to perform the objective appropriately for which it was deployed. The goals of an assessment should be specified at the outset since they determine to a large extent the problem definition, scope, and boundaries of the assessment. Many climate change IV&A assessments are designed to serve the policy interests of national governments. Other levels of jurisdiction, from local to regional, may also be interested in the results. Often there are multiple objectives, where, for example, a national government may wish to have impact research results to inform its own policy, and at the same time contribute to an international assessment (for example, meeting a Party's obligations under the UNFCCC to address adaptation by, e.g., reducing vulnerability to climate change). Therefore the first quality of a good assessment tool is to provide specific answers to the objectives set out for the assessment.

The wish list for a good assessment tool could cover the following indicators:

- ***Credible:*** The tool should be able to provide credible analysis that is seen as realistic and plausible. However sometimes the climate change impacts could be enormous and common sense could be at loss to explain the results coming out of a tool. However if the tool is able to provide reasons for the analysis, basis for the assumptions, and justify the results in an open and transparent manner, then the tool is considered credible. Credibility therefore does not mean accuracy alone, it means a whole lot of other qualitative constructs around which the tool analyses the problem and addresses the objectives.

- ***Transparent:*** This quality flows from the previous one. Transparency is a pre-requisite to establish credibility. This is especially the case for tools that are based on mathematical modelling. The assumptions in the tool design and operation should be clearly stated, especially since many of these tools are developed by industrialized countries while they are used for developing countries which could have totally different circumstances.

- ***Acceptable to the stakeholders:*** IV&A assessment have strong policy linkages – policies for mitigating adverse impacts of climate change and to strengthen adaptation to climate change. Diverse sets of stakeholders are therefore directly or indirectly involved in this process. Any IV&A tool has to be therefore credible and acceptable to these stakeholders. Of course it may be at times difficult to satisfy all of them but then a majority of stakeholders have to consider the tool as acceptable. This will make policy implementation that much easier.

- ***Relevant:*** As indicated above, the first quality of a good assessment tool is to provide specific answers to the objectives set out for the assessment. The tool has to be therefore relevant to the assessment objectives. In turn the objectives themselves have to be relevant to majority of stakeholders and policymakers. Selection of tools therefore presents a double bind on relevance – relevance to objectives, and relevance of these objectives to stakeholders.

- ***Accurate:*** Projection of future impacts and vulnerability due to climate change could be a very difficult exercise. Multiple variables and their associated uncertainties lend further complexity to the process. However IV&A tools have to provide answers to some very basic policy questions faced by the policymakers and diverse stakeholders and these are linked to implementation now. The tools therefore have to provide plausible answers to these questions. However the uncertainty principle implies that one cannot be completely accurate and completely certain at the same time. Therefore the tools have to be accurate within permissible limits of uncertainty in such estimates.

- ***Measurable:*** This is a real challenge for most of the IV&A assessment tools in the climate change context. Quantification of impacts and relative quantifiable assessment of alternative adaptation measures could be a difficult task, especially since many parameters may be intrinsic where putting a monetary value could be difficult if not impossible such as value of lost habitats, coping capacity of an individual, value of lost biodiversity that is not even documented. Qualitative comparison could also be equally tricky.

- ***Reproducible analysis:*** The results from scientific tools have to be reproducible. This enhances credibility and acceptance of the tool.

- ***Comparable:*** Cross sectoral, regional and temporal assessments are a common trend presently. Therefore if a tool is designed for such an analysis, it should be able to provide a comparable analysis across these variables, duly taking their individual circumstances into consideration. Of course sector specific tools can not compare across sectors and they are not expected to do so. Similarly region specific tools can not compare across regions without being set up for different regions.

- ***Cost effective:*** A balance must be struck between the level/extent of assessment and the resources required for the assessment. Generally tools that are very resource intensive do not tend to acquire wider applicability since many can not afford these resources.

- ***Flexible enough to adapt and/or replicate:*** The tool should be replicable to assess other regions than those already modelled using it. In fact it is desirable that the tool should be able to assess similar regions without much additional inputs. The tool should also be able to document and learn from these assessment and subsequent assessments should therefore become easier.

- ***Capable of identifying trends:*** Many tools depend on historical data to project future. While this is generally acceptable for an initial assessment, it may not capture the many transitions that are taking place around the issue being assessed. For example, while identifying the extent of impact of draught on poor farmers in a developing country like India, the past trends would suggest conventional and traditional strategies only. While in reality, remote sensing and information technology, which are already making their presence felt in other areas in India, could be judiciously deployed to work out an early warning system and information mechanism. A tool should be able to identify and capture such trends.

- ***Readily understood:*** This is one of the most important requirements for a tool. If its analysis is not easy to communicate to policymakers and the various stakeholders, then the efforts expended in reaching these results may be wasted. Generally GIS interface lends good communication strength to a tool. However even if a tool does not have GIS interface, if it meets the above criteria and presents the results in a simple and easy to understand manner, it could become very popular. On the contrary, complexity does not always ensure higher understanding. Over-simplification can also cause problems.

Choosing an appropriate tool therefore becomes very critical for any IV&A analysis. Different tools will be appropriate for different purposes. Each tool has specific characteristic that makes it useful for addressing specific concerns. For example, if global implications of different greenhouse gas (GHG) emission mitigation targets on GDP and carbon prices are to be analyzed over medium term, SGM may be a suitable modelling tool. Alternately, if city level implications of low sulphur diesel use on local pollutant emissions in the short to medium-term are to be analyzed, AIM/Local may be an appropriate tool.

Sometimes alternate models may be deployed to address the same question. There are also instances where a model may be used to address questions beyond its original intended domain. These extensions indicate the art of assessment. Analytical tools are just tools and it requires a seasoned and experienced analyst to employ them judiciously to achieve robust and consistent analysis. Knowledge of the region being analyzed is another important requirement for the art of IV&A assessment.

1.6 Types and classification of tools

IV&A tools can be classified in different ways. They may be simply classified as qualitative and quantitative tools. They may also be classified as sectoral, regional or temporal tools. Another possible classification could be based on the type of policy issues they address, for example food security, water security etc. This classification would be cross cutting and for instance, the tools addressing food security would also capture water availability, socio-economic parameters, regional food trade and supply-chains, while taking the traditional agriculture inputs. We suggest a practical classification as below.

- ***Quantitative models:*** The inputs and outputs of the quantitative models can be expressed in precise terms and can be subjected to various kinds of tests such as sensitivity tests. However, the outputs of these models should not be considered to be very definitive as the underlying assumptions for the inputs to these models such as socio economic scenarios, climate scenarios and processes included are most of the time not robust enough. Quantitative models are of three types, namely, biophysical models, socio-economic models and integrated system models. The biophysical models are the first order models, which analyse the physical interaction between climate and an exposure unit. Biophysical models are again of two types -Empirical statistical models and process based model. The first one relates climate parameters with particular sectoral parameters and assess impacts based on past behaviour, and hence can be extended into the area of adaptation where the policy makers can decide upon the method of adaptation depending on strategies used in the past. The process based models deal with the actual physical laws, first principles about the workings of a system or assumedly universal regularities.

- ***Economic models:*** These models relate the impact of socio-economic activities on environmental parameters like emissions, energy use etc. The economic impacts like GDP change due to climate policies, marginal costs, investment requirements and fuel prices are also model outputs. These are used to estimate the second order effects and beyond such as those on production of cereals, on water supply, or on industrial outputs.

- ***Integrated systems models:*** They represent interactive complexity of climate impact phenomena. It analyses the key interactions within and between sectors of a particular exposure unit and between this unit and outside world. It generates a comprehensive assessment of the totality of impacts rather than the separate sectoral impacts. The second purpose of the integrated assessments is to enable researchers to place climate change impacts in a broader context such as natural resources management, sustainability of ecosystems, economic development and associated broader questions.

- ***Impact Matrix Approach:*** This approach facilitates the identification of indicators, which may have impacts for a particular case study. Matrix approach with indicator analysis is also preferable because, indices make it possible to compare two or more complex, multifaceted systems at one time by analysing the interactions among the systems and converting the information related to varied impacts in a single observable outcome. While this process of reductionism enhances understanding about the phenomenon, it works contrary to both the complex behaviour of the system and potentially disparate nature of impacts. This approach has been used in Kapshe et al. (2003).

- ***Expert and stakeholder judgment:*** This is a method for obtaining rapid assessment of the state of knowledge concerning the likely impacts of climate change solicited from experts in the area of concern. These experiences are built on historical perspectives and are useful for devising adaptation strategies as these judgments also take into consideration the traditional methods of adaptation. Systems combining dynamic simulation with expert judgment are very useful tool for policy analysis.

- ***Remote sensing and GIS:*** Remote sensing along with GIS can help in a storing, combining and analyzing the geographic information used and developed in different assessments for depicting the past, present and the future scenarios

- ***Sectoral Models:*** Tools for assessing the impacts of climate change on agriculture, forestry, coastal zones, natural ecosystems, human health, energy and infrastructure are also available, some in great detail while some as for infrastructure are still under development. Adaptation policy assessment can also be performed using some of these or other available sectoral models.

The subsequent sections of the hand book provide a brief description discuss the technical issues including technical characteristics and limitations of each of the tool used for assessing climate change IV&A.

References

Adger, W. N. (1999) Social Vulnerability to Climate Change and Extremes in Coastal Vietnam, World Development, 27 (2), 249-269.

Adger, W. N. and Brooks, N. (2003) Does environmental change cause vulnerability to natural disasters? In Pelling (ed.), Natural Disasters and Development in a Globalising World, 19-42.

Adger, W. N. and Kelly, P. M. (1999) Social vulnerability to climate change and the architecture of entitlements, Mitigation and Adaptation Strategies for Global Change, 4, 253-266.

Allen, K. (2003) Vulnerability reduction and the community-based approach, in Pelling (ed.), Natural Disasters and Development in a Globalising World, 170-184.

Blaikie, P., Cannon, T., Davis, I., Wisner, B. (1994) At Risk: Natural Hazards, People's Vulnerability, and Disasters. Routledge, London, 333–352.

Brooks, N. (2003).Vulnerability, risk and adaptation: A conceptual framework Tyndall Centre Working Paper 26: www.tyndall.ac.uk/publications/working_papers/wp38.pdf

Brooks, N. and Adger, W. N. (2003) Country level risk measures of climate-related natural disasters and implications for adaptation to climate change, Tyndall Centre Working Paper 26: http://www.tyndall.ac.uk/publications/working_papers/wp26.pdf).

Burton 1992, quoted in Smit et al. 2000

Burton, I. and van Aalst, M., 2004, Look Before You Leap: A Risk Management Approach for Incorporating Climate Change Adaptation into World Bank Operations, Washington, D.C.: World Bank

Burton, I., Huq, S., Lim, B., Pilifosova, O., Schipper, E.L. 2002. From Impacts Assessment to Adaptation Priorities: the Shapping of Adaptation Policy. Climate Policy, Amsterdam, Vol.2, 145-159.

Cross, J. A. (2001) Megacities and small towns: different perspectives on hazard Vulnerability, Environmental Hazards, 3, 63–80.

Cullen, H. M., deMenocal, P. B., Hemming, S., Hemming, G., Brown, F. H., Guilderson, T. and Sirocko, F. (2000) 'Climate change and the collapse of the Akkadian empire: Evidence from the deep-sea', Geology, 28 (4), 379-382.

Downing, T. E. and Patwardhan, A. (2003) Vulnerability assessment for climate adaptation, Adaptation Policy Framework: A Guide for Policies to Facilitate Adaptation to Climate Change, UNDP, in review, see http://www.undp.org/cc/apf-outline.htm).

FAO, 1999. The State of Food Insecurity in the World, Food and Agriculture Organisation, United Nations.

Feenstra Jan F. Ian Burton Joel B. Smith Richard S.J. Tol, (eds) (1998) Handbook on Methods for Climate Change Impact Assessment and Adaptation Strategies, Editors: Jan F. Feenstra Ian Burton Joel B. Smith Richard S.J. Tol, Version 2.0 October, 1998

Halsnæs, K. and Garg, A., 2006. Sustainable Development, Energy and Climate: Exploring synergies and tradeoffs. A publication of UNEP Risoe Centre, Denmark. ISBN 87-550-3542-6.

Halsnæs, K., Garg, A., Denton F. and Olhoff, A., 2006. Practical Guidance Material for the Development, Energy and Climate Country Studies. A publication of UNEP Risoe Centre, Denmark. ISBN 87-550-3543-4.

Hulme, M. (1996) 'Recent climatic change in the world's drylands', Geophysical Research Letters, 23, 61-64.

IPCC (Intergovernmental Panel for Climate Change), (2001a). Climate Change 2001: Impacts, Adaptation, and Vulnerability, Cambridge University Press, Cambridge.

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

Jones, R. and Boer, R. (2003) Assessing current climate risks Adaptation Policy Framework: A Guide for Policies to Facilitate Adaptation to Climate Change, UNDP, in review, see http://www.undp.org/cc/apf-outline.htm).

Kainuma, M., Matsuoka, Y. and Morita, (Eds.), 2002. Climate Policy Assessment: Asia-Pacific Integrated Modelling. T. Springer-Verlag, Tokyo, Japan.

Kapshe, M., Shukla, P. R. and Garg, A., (2003). Climate change impacts on infrastructure and energy systems. In: Shukla, P. R., Sharma, Subodh K., Ravindranath, N. H., Garg, A. and Bhattacharya, S., (Eds.), Climate Change and India: Vulnerability Assessment and Adaptation. Universities Press (India) Pvt. Ltd, Hyderabad.

Kelly, M. and Adger, N. 2000. "Theory and Practice in Assessing Vulnerability to Climate Change and Facilitating Adaptation." Climatic Change, 47: 325 – 352.

NATCOM, 20045. India's Initial National Communication to the United Nations Framework Convention to Climate Change, Ministry of environment and Forests, government of India.

Nicholls, R. J., Hoozemans, F. M. J. and Marchand, M. (1999) Increasing flood risk and wetland losses due to global sea-level rise: regional and global analyses, Global Environmental Change, 9,S69-S87.

Roberts, N. (1998) The Holocene: An Environmental History, Oxford, Blackwell

Smit 1993, quoted in Smit et al. 2000

Smit, B., Burton, B., Klein, R.J.T., and Wandel, J. 2000. "An Anatomy of Adaptation to Climate Change and Variability." Climatic Change, 45: 223 – 251.

Smith et al. 1996, quoted in Smit et al. 2000

Stakhiv 1993, quoted in Smit et al. 2000

Stenchion, P. (1997) Development and disaster management, Australian Journal of Emergency Management, 12 (3), 40-44.

Stern (2006). Stern Commission Report

UNDHA (1992) Internationally Agreed Glossary of Basic Terms Related to Disaster Management, United Nations Department of Humanitarian Affairs, Geneva.

UNFCCC, 1992. United Nations Framework Convention on Climate Change, United Nations.

UNFCCC, 2002. Handbook on Methods for Climate Change Impact Assessment and Adaptation Strategies Editors: Jan F. Feenstra Ian Burton Joel B. Smith Richard S.J. Tol, Version 2.0 October, 1998

UNFCCC, 2005. Compendium on methods and tools to evaluate impacts of, and vulnerability and adaptation to, climate change, a report prepared by Stratus Consulting Inc. for UNFCCC Secretariat.

Watson et al. 1996, quoted in Smit et al. 2000

Yamin, F. and Huq, S., Ed. Vulnerability, Adaptation and Climate Disasters, IDS Bulletin, Volume 36,Number 4, October 2005, Institute of Development Studies, Brighton available at: http://www.ids.ac.uk/ids/bookshop/bulletin/index.html#bull2005

Yamin, F., Mitchell T., and Tanner T. , in Yamin, F. and Huq, S., Ed. Vulnerability, Adaptation and Climate Disasters, IDS Bulletin, Volume 36,Number 4, October 2005, Institute of Development Studies, Brighton available at: http://www.ids.ac.uk/ids/bookshop/bulletin/index.html#bull2005

Chapter 2: Impact and Vulnerability Assessment Tools[1]

2.1 Introduction

The first step in addressing impacts of climate change is to assess the vulnerability of the systems affected by it and develop adaptation strategies for them. Various methodologies, tools and techniques are used for these purposes. Climate change impact assessments help in identifying where the key effects of climate change are likely to occur, what character these effects have, what research is needed for improved understanding of these effects, and to design appropriate adaptation strategies and measures to reduce the anticipated damages. Impact assessments also help determine the kind of climatological information needed to serve short and medium-range decision-making intended either to decrease adverse effects of unfavourable climate or to take advantage of favourable conditions with reference to a given natural or human system. Impact assessments, however, are not merely tools for identifying what climate change may do to human activities and the environment; they are also tools of communication to the policymakers for their effective implementation.

This chapter provides an overview of different methodologies, generic approaches and sectoral tools available for impact assessments. The following sectors are covered: agriculture, water resources, coastal resources, human health, forestry, natural ecosystems and biodiversity, energy and environment, and infrastructure and industry. Additional guidance can be found in other sources of information in particular the UNFCCC Compendium on methods and tools to evaluate impacts of, and vulnerability and adaptation to, climate change (UNFCCC, 2005).

2.2 Agriculture sector

Impacts on agriculture can be addressed at various levels such as on crop yields, on farm and village level output s and income, on regional and national production and on global production and prices. Each level will require different sets of research methods. The inputs of the crop response can be fed to farm level modelling and then the output of the farm level modelling can be an input to the regional and national assessment and the output of which then can be the input to global crop production assessments. Here we focus on only the crop models as these can also be used for climate change impact assessments because they take into account:

- Response of plants to weather
- Effect of CO_2enrichment on growth and yield of crops, in terms of plant processes, water and nitrogen uptake etc.
- Capable of simulating the processes for cropping systems in different agro-ecologies.
- Screening of crop varieties, identification of appropriate agronomic managements like sowing date, inputs such as irrigation, fertilizer, pesticides etc.
- Understanding of the crop growth under variable soil environment, including physical, chemical and biological characters

[1] The descriptions of the tools in chapters 2 and 3 are based on the Compendium on methods and tools to evaluate impacts of, and vulnerability and adaptation to, climate change, prepared by Stratus Consulting Inc. for UNFCCC Secretariat, 2005 available at:
http://unfccc.int/files/adaptation/methodologies_for/vulnerability_and_adaptation/application/pdf/consolidated_version_updated_021204.pdf

- Can be linked to decision support systems, remote sensing tools and GIS for extrapolating the results

The most commonly available and used agriculture sector tools can be broadly classified into the following categories;

1. Process crop models
   a) WOFOST (any crop)
   b) ORYZA series (rice growth models)
   c) ICASA and IBSNAT family of models
   d) GAPS 3.1 (crop management)
   e) EPIC (crop growth, evaluating adaptation to climate change)
   f) Alfalfa 1.4 (alfalfa plant)
   g) AFRC-Wheat
   h) RICEMOD
   i) GOSSYM/COMAX
   j) GLYCIM
   k) WTGROWS (wheat)
   l) INFOCROP (many crops)

2. Irrigation models
   a) CROPWAT

3. Economic models
   a) Econometric models
   b) Input-Output modelling (with IMPLAN)
   c) Relative Risk Index (RRI)
   d) Government support in agriculture for losses due to climate variability

4. Integrated models for agriculture
   a) Agriculture Catchments Research Unit (ACRU)
   b) CENTURY
   c) Agriculture Production Systems Simulator (APSIM)
   d) Model of Agricultural Adaptation to Climate variation (MAACV)
   e) Decision Support Systems linking agro-climatic indices with GCM-originated climate change scenarios
   f) IDSS-SESA climate change Decision Support Systems (DSS)

Each of these model categories have many representative models used globally – some more than the others. Some models are crop specific while some can be adapted for any type of cropping systems. Some models use locale specific climate, soil, water and crop data and support GIS representation, while some are more general economic models. Some are more tuned for adaptation response assessment based on crop vulnerability analysis, while some provide a more integrated approach.

2.2.1 Process crop models

All these models are process based, mechanistic and dynamic models, which predict yield, phenology, and leaf area index of the crops. The outputs of these models can be used for assessment of water use efficiency of the crops and nitrogenous intake by the plant, based on which, the farmer can be advised to save on nutrient input. Though these Crop growth models, initially developed for assessing local demands, can be modified and used for assessment of yield of crops under the climate variability as well as climate change conditions. The details of these models and their limitations are presented in the following paragraphs. The basic inputs to all these models are:

- Daily weather parameters such as maximum and minimum temperatures, precipitation, solar radiation, relative humidity and wind speed
- Information on physical, chemical and biological properties of soil (layer-wise)
- Agronomic and other management inputs, such as water, nitrogen, pesticides, date of sowing, seed rate etc.
- Crop characters (in terms of phenology, physiology and genetic)
- Initial conditions of soil and crop.
- Capability of linking the climate change with the model to evaluate its impact

The outputs of the models can be used for making crop management decisions as these models:

- Simulate temporal trends of growth and yield of crops in terms of biomass component, water uptake, nitrogen uptake and water and nitrogen stress effects.
- Simulate differential responses of crop in relation to variable water supply, nitrogen dosing and climate variability
- Assess the dynamic course of the Organic Carbon content during the crop growing period
- Assess nutrient availability for crop growth
- Develop alternate management and agro economic practice to maximize the agricultural production
- Develop alternate options for resource management and
- Forecast yield by linking crop growth models with related databases of soil, crop, agro economic management etc.

Strengths

- These are the basic models for agriculture sector impact assessment and therefore their use is the first step in climate change impact assessment for a country's agriculture sector.
- Normally these models are specific to a crop. Models such as ORYZA and WTGROWS have been used to model major crops in a country and analyzing the impacts of climate change such as doubling of CO_2emissions, temperature increase etc.
- Can be used at sub-regional scale using GIS interface.
- National policies can be included in the model to capture realities.
- Many of these models have been used globally and therefore expertise and experience is available to set up a new modelling application for a new region.
- Training is also available for most models.
- Also useful for developing countries.
- Results from a country/region could be used to assess potential in similar situations in nearby regions, even if detailed modelling is not conducted for those regions.

Weaknesses

- Data intensive.
- Needs training.
- May not include other factors effecting yield, such as socio-economic parameters.
- Linkages with adaptation policy assessment remain weak, although models such as EPIC can also provide adaptation analysis.

2.2.2 Irrigation models

Strengths

- Helpful for planning and testing impacts of alternative crop irrigation schemes and schedules.
- Useful for planning adaptation methods.
- Useful research tool for water stressed agriculture dependent regions, such as in many developing countries and LDCs.
- The model CROPWAT already has an extensive database for 144 countries and many irrigation schemes and schedules. Therefore only incremental efforts may be needed to fine tune the model for a specific application in any sub-region and cropping pattern.

Weaknesses

- Can not directly integrate climate variables such as doubling of $CO_2$to simulate change in crop water use.
- May not include other factors effecting yield, such as socio-economic parameters.
- Data intensive.

2.2.3 Economic models

Strengths

- Can interface with climate change scenarios and socio-economic parameters such as land prices, production and revenues, food demand etc.
- Based on economic paradigms to estimate adaptation costs.
- National policies can be included in the model to capture realities.
- Also useful for developing countries.
- Results could be used to assess potential in similar situations in nearby regions, even if detailed modelling is not conducted for those regions.
- Linkages with adaptation policy assessment remain weak, although models such as EPIC can also provide adaptation analysis.

Weaknesses

- Generally a new econometric model has to be created for specific regional application based on local circumstances. This may need high resources.
- Data intensive.
- It is advisable to use these in conjunction with the other process crop models for a more robust and holistic analysis. For instance, the results from a process crop model in case of projected failure of a crop under climate change, could be fed-into the economic model to get a more robust results such as food import requirements etc.

2.2.4 Integrated models for agriculture

Strengths

- These models can integrate research and results across sectors and regions, thus providing a more holistic view.
- Some integrated models such as APSIM and CENTURY can also take detailed inputs on factors of agriculture production, such as soil type, plant nutrients, fertilizer application, seeds, water availability etc.

- Can be used at sub-regional scale using GIS interface.
- National policies can be included in the model to capture realities.
- Training is also available for most models.
- Also useful for developing countries.
- Results from a country/region could be used to assess potential in similar situations in nearby regions, even if detailed modelling is not conducted for those regions.

<u>Weaknesses</u>

- Data and resource intensive.
- Needs training.
- May not be able to analyze the impacts of climate change specific parameters such as doubling of CO_2concentrations etc. Therefore could provide more robust results if used in conjunction with appropriate process crop models.

2.2.5 Other models (e.g. Tools for Climate Risk Assessment in Mountain Agriculture)

Climate risk assessment in agriculture is based on point estimate of climatic events and their impacts on agricultural productivity. In mountain environments where the landscape is highly variable, point-estimates and the domain they may represent are meaningless. In order to cope with this gap of geospatial data, a series of tools have been developed and tested. The first tool presented deals with interpolation techniques. Based on the physical processes that rule the climate behaviour, the interpolator software, parameterized with point climatic data, generates daily high-resolution maps on minimum and maximum temperatures, solar radiation and rainfall. The series of maps generated, in addition to soil and topography maps, fulfil the input requirements for process-based models used to assess the impact of climatic variation on agricultural productivity or environmental processes. Two applications of these interfaces are presented. Using the interface with the “Decision Support System for Agrotechnology Transfer” (DSSAT), the impact of climatic variation on crop productivity is assessed. The second example shows the soil vulnerability to climate and soil management by interfacing the climate interpolator with the “Water Erosion Prediction Project” (WEPP).

2.3 Water resources

The water sector tools are mathematical models for assessing water resource adaptations to climate change, focusing on regional water supply and demand analysis of managed water systems. The following models mainly from the UNDP report (http://www.undp.org/cc/apf_outline.htm) are covered;

- WaterWare
- Water Evaluation and Planning System (WEAP)
- RiverWare
- Interactive River and Aquifer Simulation (IRAS)
- Aquarius
- RIBASIM
- MIKE BASIN
- Spatial tool for river basin environmental analysis and management (STREAM)
- Soil water analysis tool (SWAT)

Some of these are long-range simulation models (WEAP and IRAS) while some are short-range simulation models (RiverWare and WaterWare). Models such as SWAT have been originally designed for a daily water run-off modelling. However their use has been extended to model climate change over long time horizons as well.

In the water resources sector, models are available to make an assessment of

- The various components of the land phase hydrological cycle
- The Biophysical impacts of climate change on hydrological resources in terms of water quantity, quality and aquatic ecosystem effects
- The socio-economic impacts of climate change on both water demand and water resources management

For assessing the response of hydrological cycle and hence the hydrological resources to climate change, scenarios for climate changes derived from GCMs/RCMs form an input to a hydrological model. The three key steps here are constructing scenarios that are suitable for hydrological impact assessments, developing and using realistic hydrological models, and understanding the linkages and feedbacks between climate and hydrological systems. Precipitation, evapotranspiration, soil moisture retention capability, and ground water recharge processes are some of the driving forces of the hydrological cycle.

So far the largest number of hydrological assessment studies looking into the effects of climate change have concentrated on potential changes on stream flow and runoff. Stream flow means the water within a river channel, usually expressed as a rate of flow past a point—typically in m3/sec and runoff is the amount of precipitation that does not evaporate, usually expressed as an equivalent depth of water across the area of the catchments. A simple link between the two is that runoff can be regarded as stream flow divided by catchment area, although in dry areas this does not necessarily hold because runoff generated in one part of the catchment may infiltrate before reaching a channel and becoming stream flow. Over short durations, the amount of water leaving a catchment outlet usually is expressed as stream flow; over durations of a month or more, it usually is expressed as runoff. In some countries, "runoff" implies surface runoff only or rapid response to an input of precipitation and does not include the contribution of discharge from groundwater to flow.

We provide a critique of these below.

2.3.1 WaterWare

This UNIX based software package is an advanced water resource simulation tool that incorporates numerous models and analyses for easy access to advanced tools of data analysis, simulation modelling, rule-based assessment, and multicriteria decision support for a broad range of water resources management problems. WaterWare includes a number of simulation and optimization models and related tools, including a rainfall-runoff and water budget model, an irrigation water demand estimation model, dynamic and stochastic water quality models, a groundwater flow and transport model, a water resources allocation model, and an expert system for environmental impact and assessment.

<u>Strengths</u>

- Provides a holistic view since it integrates many models.
- Databases could be shared across these models, thus providing a more consistent analysis.
- Can provide real-time operational support.
- Can be used for scientific assessment of adaptation policy options.

Weaknesses

- Data intensive
- Training needed
- Water systems are locale specific and therefore the model may require adjustments to capture these details.
- Cost-benefit analysis for comparing across alternative adaptation policies and issues such as water markets are not captured in the model.

2.3.2 Water evaluation and planning system (WEAP)

This is a PC based surface 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. WEAP is designed as a comparative analysis tool. A base case is developed, and then alternative scenarios are created and compared to this base case. Incremental costs of water sector investments, changes in operating policies, and implications of changing supplies and demands can be economically evaluated.

Strengths

- Useful for integrated water sector policy analysis, including for adaptation.
- Can allocate limited water resources between agricultural, municipal and environmental uses through integration of supply, demand, water quality and ecological considerations.
- Locale specific parameters such as location of dams, river systems, reservoirs, industrial locations etc can be easily set up for all locations.
- Technology representation in the model could also be achieved through costs.
- Can take policy inputs such as differential water use rates for different sectors, reservoir operating rule modifications, and environmental goals etc.
- Results are easier to communicate with policymakers since it can use a long-tern planning horizon, compare alternative scenarios, water allocation across sectors, as well as provide cost comparisons.
- Relatively easy to use.
- Training available on line.
- Diverse stakeholders could be involved due to an open and transparent modelling process and sharing of assumptions.
- Useful for developing countries as well. Moreover license fee has been recently waived off for governmental, academic, and not-profit institutions in developing countries.

Weaknesses

- Data intensive
- Training needed
- Cost-benefit analysis for comparing across alternative adaptation policies and issues such as water markets are not well captured in the model.
- Water systems are locale specific and therefore the modeller should know these details for a more realistic modelling.

2.3.3 RiverWare

A general UNIX based river and reservoir modelling application with both operational and planning applications. This system offers multiple solution methodologies that include simulation, simulation with rules, and optimization. RiverWare can accommodate a variety of applications, including daily scheduling, operational forecasting, and long-range planning. Modelling framework is non-spatial (not GIS based). Because of its object-oriented nature, the modelling framework allows for the generation of new modelling methods that could include economically driven demand modelling.

Strengths

- Engineering model useful for planning, designing, and simulating a water system.
- Can provide real-time operational support.
- Can be used to test alternative engineering solutions for water augmentation in a specific region.

Weaknesses

- Data intensive as well as requiring knowledge of water system of the region being modelled such as various reservoirs, water flows, diversions, groundwater assessments etc.
- Training needed.
- Cost-benefit analysis for comparing across alternative adaptation policies and issues such as water markets are not captured in the model.
- May not be very easy to explain to climate and developmental policymakers.
- May not be the best tool for climate change policy analysis for the water sector. Its results could however be used in conjunction with other models such as WEAP to provide a more robust analysis.

2.3.4 Interactive river and aquifer simulation (IRAS)

This tool is a PC based surface water resource simulation tool, based on water balance accounting principles that can test alternative sets of conditions of both supply and demand. The river system is represented by a network of nodes and links, with the nodes representing aquifers, gauges, consumption sites, lakes, reservoirs, wetlands, confluences, and diversions. Links are river reaches or water transfers to the nodes. The model can simulate up to 10 independent or interdependent water quality factors at a sub-monthly time step. Through data interfacing, IRAS can link to various external modules such as rainfall-runoff and to economic and ecological impact prediction programs.

Strengths

- Useful for planning, designing, and simulating a water system.
- Can also be used to test alternative adaptation policy options.
- Can be tailored to a specific location and water flows.
- Ease of use once set up.
- Has been applied across the world, so expertise is available for help and benchmarking.
- Has better water quality modelling capability than WEAP.

Weaknesses

- Data intensive as well as requiring knowledge of water system of the region being modelled such as various reservoirs, water flows, diversions, groundwater assessments etc.
- Training needed.

2.3.5 Aquarius

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 focuses on optimization of a nonlinear system, where supplies and requested demands are prescribed on the system. Water resource systems are described in node-link architecture, with river reaches, reservoirs, lakes, and demand objects describing the system. A drag and drop user interface helps define the system layout, which is then translated into a quadratic objective function with linear constraints.

Strengths

- Uses economic optimization framework balancing demand and supply of water.
- Can also be used to compare alternative water allocation policies through associated costing estimates. This capability could be used for comparing alternative adaptation policies as well.
- Water markets can be also analyzed since demand functions of various water users competing for water are a model input.
- Can be set up for any location, national or site-specific systems.
- Has separate datasets for physical and economic parameters of water systems. This permits better comparability across regions. This feature could also be useful when similar water system management policies are compared across a country (e.g. in similar cities).
- This model can also provide a link between climatic models (alternative hydrological patterns) and energy models (required hydro power projections) through supply-demand management of water flows using an optimization framework. It could then, for example, help to evaluate whether the increased water availability in a region due to climate change would be better utilized for hydro power generation or for irrigation systems or for storage for drinking purposes in dry summer seasons etc.

Weaknesses

- Data intensive as well as requiring knowledge of water system of the region being modelled such as various reservoirs, water flows, diversions, groundwater assessments etc.
- Training needed.
- Estimating demand functions for various water users could be a tricky proposition, especially in developing countries where formal water markets are non-existing; costs are skewed across user groups and may not represent the actual scarcity value of water.

2.3.6 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. RIBASIM can also generate flow patterns that provide a basis for detailed water quality and sedimentation analyses in river reaches and reservoirs. Demands for irrigation, public water supply, hydropower, aquaculture, and reservoir operation can be taken into account. Surface- and groundwater resources can be allocated. Minimum flow requirements and flow composition can be assessed.

Strengths

- RIBASIM allows for the assessment of infrastructure, and operational and demand management measures.
- This could be an excellent tool for impact assessment of, for example, melting of Himalayan glaciers on Himalayan rivers water flows and associated infrastructures such as reservoirs, bridges, low lying villages, large demand centres (cities and canal irrigation systems) along the river route etc. Alternative hydrological conditions that are based on climatic model projections could be used to simulate these impacts. The model could then be used to assess suitable adaptation policies.

Weaknesses

- Data intensive as well as requiring knowledge of water system of the region being modelled such as various reservoirs, water flows, diversions, groundwater assessments etc.
- Training needed.

2.3.7 MIKE BASIN

For addressing water allocation, conjunctive use, reservoir operation, or water quality issues, MIKE BASIN couples GIS with comprehensive hydrologic modelling to provide basin-scale solutions. For hydrologic simulations, it builds on a network model in which branches represent individual stream sections and the nodes represent confluences, diversions, reservoirs, or water users. It is a quasi-steady-state mass balance model, however, allowing for routed river flows. The groundwater description uses the linear reservoir equation.

Strengths

- Optimizes basin level water allocation and distribution across various demands and multiple sectors.
- Keeps modelling simple and intuitive, yet provides in-depth insight for planning and management.
- Uses mass balance approach. Decay during transport can be modelled.
- GIS interface makes result presentation, especially to policymakers, much more focused.
- Can be set up for national as well as site specific applications.

Weaknesses

- Data intensive as well as requiring knowledge of water system of the region being modelled such as various reservoirs, water flows, diversions, groundwater assessments etc.
- Training needed.

2.3.8 Spatial tool for river basin environmental analysis and management (STREAM)

STREAM is a spatial hydrological model that allows for assessing hydrological impacts due to changes in climate and socio economic drivers. STREAM is set up according to a policy analytic framework and ensures a structured approach for an entire river basin including the coastal zone. STREAM uses hydrological input data, scenarios, adaptive strategies and provides output data on water availability and (salt water) quality. It integrates within this frame several types of interactions between effects of river management on the coastal zone, land and water uses such as short term deforestation and dam building, and long term impacts of climate change. Water use and withdrawals can be simulated such as the spatial distribution of agriculture and urbanization use and the storage of water in the open flood plain and groundwater aquifers. The main advantage of STREAM is that it primarily uses public domain data from the internet providing a very first order of estimates on impacts. This makes the STREAM instrument very flexible for future extensions and adjustments.

Strengths

- Provides a structured approach to the entire river basin including on the coastal zones.
- Integrates several systematic interfaces in a consistent manner.
- Provide GIS interface.
- Uses data that is available in the public domain (generally on the internet), thus making it easier to set up and handle.

Weaknesses

- Could provide macro level results since data may not be very site specific. Therefore it would require calibration and validation in close cooperation with local stakeholders, using local time series of in and output data increasing the level of reliability.

2.3.9 Soil and water assessment tool (SWAT)

SWAT water balance model (Arnold et al., 1990) is a distributed, continuous, daily hydrological model with a GIS interface for pre and post processing of the data and outputs. It simulates the hydrological cycle in daily time steps. The SWAT model routes water from individual watersheds, through the major river basin systems. The system has been used for the assessment of the climate change impacts on water resources availability.

Owing to the fact that the dynamics of the hydrological processes cannot be well represented by models used with temporal scales of more than a day, it is imperative that wherever possible (due to factors such as data availability) continuous hydrological models with daily time step be used.

SWAT simulates the physical processes of the hydrologic cycle in a watershed through a water balance approach. Besides providing the various sub-components of the hydrological cycle such as surface runoff, sub-surface runoff, recharge to ground water, evapotranspiration, etc. It can also predict impact of land management practices on water quantity, water quality, sediment yields, and agricultural and chemical yields. SWAT can be applied to large and small watersheds with varying soil conditions, land use changes, and agricultural management treatments. SWAT is a continuous time model and uses a daily time for water balance computations. It is not designed to simulate a single event but can integrate and project for a long time periods (100 yrs or more). It can study long-term impacts of agricultural practices on large watersheds.

2.3.10 Some other tools

Vulnerability Self-Assessment Tool (VSAT-Water & Wastewater) provides a comprehensive assessment tool that could be used and understood by every water utility manager. Software and related on-line training opportunities are available free of charge. This program is best suited to facilities that serve populations between 10,000 to 100,000 (www.vsatusers.net).

Simplified State Assessment Tool is a simplified VA tool for smaller water and wastewater utilities (under development). This tool includes a simplified overview of the scope and purpose of a VA, similar to the Kansas model. The overview would be accompanied by a series of VA and security planning templates. This will provide a simplified and common tool for the fulfilment of the VA and ERP requirements.

National Rural Water Association is a vulnerability assessment engine to assist small water utilities (www.vulnerabilityassessment.org).

Risk Assessment Methodology for Water Utilities (RAM-W) by provides a methodology for conducting vulnerability assessment programs for water utilities.

Assessment Tools Available to Public Water Systems are tools available to help community public water systems meet the new Safe Drinking Water Act requirements of the USEPA. These include tools such as Security Vulnerability Self-Assessment Guide for Small Drinking Water Systems Serving, Vulnerability Self Assessment Tools, Risk Assessment Methodology for Water Utilities etc. These could also be used to analyze alternative water management policy options.

Automated Geospatial Watershed Assessment (AGWA) tool is a GIS-based multipurpose hydrologic analysis system for use by watershed, land, water, and biological resource managers and scientists in performing watershed- and basin-scale studies. It uses readily available spatial data sets to parameterize, run, and visualize results from two widely used watershed runoff and erosion models: the Kinematic Runoff and Erosion Model (KINEROS), and the Soil & Water Assessment Tool (SWAT). It is also designed to facilitate the assessment of hydrologic impacts associated with landscape and land-use change by allowing the user to compute and visualize the difference between simulation results. The utility of AGWA in joint hydrologic and ecological investigations has been demonstrated on such diverse landscapes as south-eastern Arizona, southern Nevada, central Colorado, and upstate New York.

Policy Dialogue Model (PODIUM) is a PC based model that maps the complex relationships between the numerous factors that affect water and food security, and displays information clearly, in both graphic and tabular formats (www.iwmi.cgiar.org/tools/podium.htm).

2.4 Coastal resources

The coastal zone (the interface of land and sea) is one of the most dynamic natural environments on earth. A large variety of goods and services are produced by different types of coastal systems, attracting many people and major investments. It also one of the most climate-sensitive regions, as it is subjected to a range of climate-related forcing drivers, including sea level change, local precipitation, ocean currents as well as local ecosystems. Coastal populations are both urbanizing and growing more rapidly than global mean trends and are therefore at major risks due to climate change.

The coastal resources tools include decision-support and qualitative to semi-quantitative methods focused on climate change (http://www.undp.org/cc/apf_outline.htm). The focus is on the impacts of climate related coastal hazards, mainly sea level rise, rather than modelling projections of sea level rise.

Three striking features of the research on impacts of climate change on coastal zones can be identified in literature. First, the Third Assessment Report of IPCC (2001b) illustrates very clearly that neither substantial nor very comprehensive progress has been made in evaluating potential socioeconomic impacts of climate change on coastal zones when compared to progress on biogeophysical impacts.

Second, most of the research on socioeconomic impacts of climate change on coastal zones has had a greater emphasis on the potential impacts of sea-level rise but little on any other climate variables. A number of studies have detailed the socioeconomic impacts of sea-level rise. For instance, an assessment by Nicholls et al., (1999) indicated that by the 2080s, the potential number of people flooded by storm surge in a typical year will be more than five times higher than today (using a sea-level rise of 0.38 m from 1990 to 2080) and that between 13 million and 88 million people could be affected even if evolving protection is included. Klein and Nicholls (1999) have categorized the potential socioeconomic impacts of sea-level rise as follows - direct loss of economic, ecological, cultural, and subsistence values through loss of land, infrastructure, and coastal habitats, increased flood risk of people, land, and infrastructure. Other impacts related to changes in water management, salinity, and biological activities.

Third, most of the studies have emphasized the economic effects, rather than impacts on social and cultural systems. This may have been due to limitations in quantifying the impacts of climate change on social and cultural aspects of the society and constraints on data availability. In the 1990s, several studies (Saizar, 1997; Olivo, 1997; Zeider, 1997) examined the cost of sea-level rise in the United States and other parts of the world under various assumptions of protection (Titus et al., 1992) and non protection from sea level rise (Yohe, 1990); and inclusion and non inclusion of cost offsetting factors where Yohe et al. (1996) conclude that considering cost-reducing potential of natural, market-based, adaptation measures or the efficiency of discrete decisions to protect (or not to protect) small tracts of property on the basis of individual economic merit can provide more realistic estimates of costs of sea level rise.

Several different methods such as cost-benefit with adaptation foresight (CBWAF), cost-benefit absent adaptation (CBAA), and protection guaranteed (PG) have been used to estimate economic costs (Yohe and Neumann, 1997). Some studies (e.g. Yohe and Neumann, 1997) assume that sea level rise would be a gradual process and when “Adaptation foresight” is adopted, storm impacts will not change. Whereas other studies (e.g. West and Dowlatabadi, 1999) suggest that although a rise in sea level may be gradual and predictable, the effects of storms on coastal shorelines and structures are often stochastic and uncertain, in part because of sea-level rise effects. Many large cities are located near the coast and Nicholls and Mimura (1998) have argued that the future of the subsiding mega cities in Asia, particularly those on deltas, is among the most challenging issues relating to sea-level rise.

Some attempts have been made to express the value of coastal features that are normally regarded as nonmarket goods (Costanza et al., 1997; Alexander et al., 1998). Several assessments of mangrove and reef ecosystems have highlighted their economic value on the basis of ecosystem goods and services, as well as natural capital value (e.g., Moberg and Folke, 1999).

Patterns of human development and social organization and cultural values in a community are important determinants of the vulnerability of people and social institutions to coastal hazards. This does not imply that all people in a community share equal vulnerability; social factors determine how certain categories of people will be affected. For instance, poverty is directly correlated with the incidence of disease outbreaks (CHGE, 1999) and the vulnerability of coastal residents to coastal hazards. Some methodologies have been developed that include traditional social characteristics, traditional knowledge, subsistence economy, close ties of people to customary land tenure, and the fact that these factors are intrinsic components of the coastal zone (e.g., Yamada et al., 1995; Solomon and Forbes, 1999).

An important issue with respect to the research on climate impact assessment is the scale of the study. In the Second Assessment Report of IPCC (1996b), data on socioeconomic impacts were derived from country and global vulnerability assessment studies. Figures for several countries were given relating to the population affected, capital value at loss, and adaptation/protection costs (Bijlsma et al., 1996). In the recent years, there have been several summaries of the socioeconomic results of the vulnerability assessment studies, presenting data at local, regional, and global levels. Examples include case studies of Poland and Estonia (Kont et al., 1997 and Zeider, 1997), the Philippines (Perez et al., 1999), Bangladesh (Ali, 1999), Egypt (El-Raey et al., 1999), as well as the regional analyses and global synthesis of Nicholls and Mimura (1998).

The sub-national and national vulnerability assessments produced by a large number of countries over the last decade have been collected and reviewed in the European Union ENRICH project SURVAS ("Synthesis and Upscaling of Sea-Level Rise Vulnerability Assessment Studies"), with the goal of providing bottom-up regional and global aggregations of coastal vulnerability (Nicholls and De la Vega-Leinert, 1999).

DINAS-COAST (Dynamic and Interactive Assessment of National, Regional and Global Vulnerability of Coastal Zones to Climate Change and Sea-Level Rise), which in the recent times has been one of the biggest international efforts on coastal zones impact assessment, is a top-down modelling effort to complement the information developed by the bottom-up approach of country studies and SURVAS. It aims to assess coastal vulnerability to climate change at different spatial and temporal scales, which will be of use to EU policies on climate change and on integrated coastal zone management. As regards climate change, it aims to enable researchers and policy makers to explore the effects of climate-change mitigation on the one hand, and adaptation in coastal zones on the other, and assess the results in terms of the trade-offs between mitigation costs, adaptation costs and residual impacts in coastal zones. With respect to integrated coastal zone management, it aims to help identify particularly vulnerable coastal areas and allow for the evaluation of a range of alternative responses.

An important issue brought to fore in a study by Yohe and Schlesinger (1998) is that sea level rise is unlikely to be a important consideration for the developed world at least in the near future, due to, one, the long term nature of the sea level rise hazard, and second, that the developed countries have the resources to manage the impacts of sea level rise in the long term. Also, the data on geomorphological and other coastal features required for accurate estimates of local level studies on sea level rise are not easily available. Therefore focus of research community on impacts of other climate related coastal hazards become important especially in the short term.

2.5 Human health

The health tools differ significantly in their scope and application. Some facilitate the investigation of multiple or overall disease burden and how this burden responds to a number of environmental stressors, including climate change (MIASMA and Environmental Burden of Disease Assessment). Others are more narrowly focused and model the health impacts or transmission dynamics of particular diseases (CIMSiM and DENSiM, LymSim, and MARA LITe). They aid in identifying areas of high risk, and are particularly useful for areas currently endemic to diseases like malaria, dengue fever, and Lyme disease or in close proximity to such areas. Modelling adaptation strategies in the health sector is an emerging field, so the number of tools and approaches available explicitly designed for this purpose is still limited. The UNFCCC Guidelines is one such example. However, all the human health tools detailed in this section are suited to examining impacts of climate change on human health and potential adaptations.

- MIASMA (Modelling Framework for the Health Impact Assessment of Man-Induced Atmospheric Changes)
- Environmental Burden of Disease Assessment
- CIMSiM and DENSiM (Dengue Simulation Model)
- UNFCCC Guidelines: Methods of Assessing Human Health
- Vulnerability and Public Health Adaptation to Climate Change
- LymSiM
- Mapping Malaria Risk in Africa (MARA) Low-end Information Tool (LITe)

2.5.1 Modelling Framework for the Health Impact Assessment of Man-Induced Atmospheric Changes (MIASMA)

MIASMA is a Windows-based modelling application that models several health impacts of global atmospheric change and include simulation for several modules: 1) vector-borne diseases, including malaria, dengue fever, and schistosomiasis; 2) thermal heat mortality; and 3) UV-related skin cancer due to stratospheric ozone depletion. The models are driven by both population and climate/atmospheric scenarios, applied across baseline data on disease incidence and prevalence, climate conditions, and the state of the stratospheric ozone layer.

Strengths

- Can model several diseases.
- Can be linked with climatic scenario projections.
- Useful for regional and global analysis.
- Modular in form, therefore easy to add/ delete disease modules.
- Easy to learn and train
- Uses data that is available in the public domain (generally on the internet), thus making it easier to set up and handle.

Weaknesses

- Does not include socio-economic parameters that affect diseases, such as income, hygiene, public health awareness and systems etc.
- Requires familiarity with modelling
- Not yet linked with GIS.

2.5.2 Environmental burden of disease assessment

The global burden of disease attributable to climate change was recently estimated as part of a comprehensive World Health Organization (WHO) project. The project sought to use standardized methods to quantify disease burdens attributable to 26 environmental, occupational, behavioural, and life-style risk factors in 2000 and at selected future times up to 2030. The Environmental Burden of Disease (EBD) tools include guidelines on how to estimate the approximate magnitude of the health impacts of various environmental factors, including climate change, at national or regional level, to help determination of priorities for action.

Strengths

- Based on sound medical science principles and management concepts
- Excellent databases and disease assessment framework.
- Comparative analysis possible for regions (countries, regions and continents) and diseases around the world
- Annual updates available
- Useful for benchmarking focused national or sub-regional studies
- Does include a few socio-economic parameters that affect diseases, such as income and public health systems etc.
- Well documented and available in public domain for easy access

Weaknesses

- Does not project for future
- Not linked with IPCC climatic scenarios
- Not yet linked with GIS.

2.5.3 CIMSiM and DENSiM (Dengue Simulation Model)

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 1 ha area. DENSiM is essentially 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.

Strengths

- Locale specific models
- Based in medical science
- Useful for comparing and optimizing adaptation strategies to control dengue
- Uses detailed daily weather data (such as temperature, rainfall and humidity) to assess dengue transmission windows
- Estimates the “supply” side of dengue (vector bearing mosquito population) and their effectiveness
- Includes a few demographic parameters that affect diseases, such as population and age-profile etc.

Weaknesses

- Does not project for future
- Not linked with IPCC climatic scenarios
- Does not include socio-economic parameters that could affect final incidence of diseases, such as incomes and public health systems etc.

- Not yet linked with GIS.
- Data intensive
- Locale specific, needs site surveys and weather data to parameterize the model.

2.5.4 UNFCCC guidelines

Provides information on qualitative and quantitative methods of assessing human health vulnerability and public health adaptation to climate change. Objectives and the steps for assessing vulnerability and adaptation are described. For a range of health outcomes, methods are presented for evaluation of evidence that climate change could affect morbidity and mortality; projection of future impacts; and identification of adaptation strategies, policies, and measures to reduce current and future negative effects. The health outcomes considered are morbidity and mortality from heat and heat-waves, air pollution, floods and windstorms, and food insecurity; vector-borne diseases; water- and food-borne diarrhoeal diseases; and adverse health outcomes associated with stratospheric ozone depletion.

Strengths

- Practical and quick assessment tools
- Can project future impacts due to climate change
- Can be set up for any region or country
- Useful for conducting a basic assessment using available data and information in public domain
- Projections and insights could be drawn across similar regions
- Could be used to assess adaptation policies at national level

Weaknesses

- Needs current detailed disease specific data
- Needs complimentary model use for a more in-depth analysis
- Does not include socio-economic parameters that could affect final incidence of diseases, such as incomes and public health systems etc.
- Little training available
- Not yet linked with GIS.

2.5.5 LymSiM

LymSiM simulates the population dynamics of the blacklegged tick, Ixodes scapularis, and the dynamics of transmission of the Lyme disease agent, Borrelia burgdorferi, among ticks and vertebrate hosts. LymSiM models the effects of ambient temperature, saturation deficit, precipitation, habitat type, and host type and density on tick populations. The model accounts for epidemiological parameters, including host and tick infectivity, transovarial and transstadial transmission, such that the model realistically simulates the transmission of the Lyme disease spirochete between vector ticks and vertebrate hosts.

Strengths

- Locale and disease specific model
- Based in medical science
- Estimates the “supply” side of diseases (vector bearing population) and their effectiveness
- Integrates the impact of environmental parameters such as vegetation on vector population

- Useful to simulate and optimize the effects of management technologies on population of tick vectors, could therefore be used to evaluate adaptation strategies

Weaknesses

- Does not project for future
- Not linked with IPCC climatic scenarios
- Data intensive

2.5.6 Mapping Malaria Risk in Africa (MARA) Low-end Information Tool (LITe)

MARA is a biological model of Falciparum malaria transmission that sets decision rules which govern how minimum and mean temperature constrains the development of the parasite and the vector and how precipitation affects survival and breeding. MARA determined the decision rules by reviewing laboratory and field studies throughout Sub-Saharan Africa and looking at current malaria distribution maps.

Strengths

- The model estimates the current biological boundaries of malaria in Africa quite well. Therefore it is a realistic model.
- Uses climatic data for malarial region estimation. Also uses sound principles of fuzzy logic to resolve the uncertainty in malarial and non-malarial regions in a district. Therefore results are more robust.
- Implemented in GIS format
- Comprehensive on line help available for using this tool

Weaknesses

- Can be easily linked to project for future using projections of climatic parameters such as mean monthly temperature, winter minimum temperature and total cumulative monthly precipitation.
- Does not include socio-economic parameters that affect diseases, such as income, hygiene, public health awareness and systems etc.
- Does not integrate impacts across other sectors such as vegetation
- Not yet validated outside Sub-Saharan Africa.

2.6 Forestry, natural ecosystems and biodiversity

Impacts of climate change on forests can be studied in terms of the anticipated -

- Changes in the location of the optimal growth areas for given species which may result into shifts in species composition, and changes in the size of the forest state
- Assessment of the changes in carbon stored in the forests
- Disturbances of the ecosystem functions like change in nutrient retention or litter decay rate and determine the bud break, flowering or leaf fall out of phase with climate change
- Changes in biodiversity and natural ecosystems
- Shift in the location, type, or number of forest sector jobs
- Assessment of afforestation or deforestation due to as a result of competition with agriculture needs.
- Assessment of occurrence frequency of pests and disease and the likely location where these might occur

Sector specific impact and vulnerability assessment tools could also be expanded to assess adaptation policies. These however have to be supported adequately by other tools described in the next chapter. Different types of models have been used to study the impacts of climate change on forests. Most of these models consider biome at equilibrium. The models developed to explore the impact of climate change on vegetation fall into two broad categories:

2.6.1 Empirical - Statistical Models

These are an attempt to elucidate the relationship between existing climate and the existing vegetation. Some of these look at broad vegetation type (e.g., evergreen forest, deciduous forest, etc.), and try to delineate the range of climatic factors (rainfall, temperature, etc.) favourable to these types. Once such a correspondence is obtained with a reasonable degree of reliability, it is possible to use it to project the distribution of these vegetation types for any future climate scenario. A comparison of such a projected distribution with the existing one can then serve as a basis for assessing the impact of climate change as expected under that scenario. A similar approach is also attempted for specific species. By examining the existing and projected patterns of distribution of assemblages of such species, a more detailed evaluation of the impact is possible, since qualitative as well as quantitative differences in the species composition of the assemblages can also be included in the analysis. Recently, more sophisticated methods of pattern recognition (e.g., use of neural networks, genetic algorithms etc.), originating in the field of artificial intelligence are also being applied to the problem of the impact of climate change.

The study of vulnerability and subsequent adaptation is fundamental to forestry and forest genetic conservation. Forest geneticists have long used common-garden experiments and, to a lesser extent, molecular markers to study patterns of adaptation in forest trees. Phenotypic assessments are time consuming and expensive, and provide no information about variation in the genes controlling adaptive variations.

2.6.2 Simulation Models

Simulation models, both deterministic as well as stochastic, explicitly evaluate the temporal changes in the various components of the system (such as root/shoot biomass, soil moisture levels, and concentrations of different pools of nutrients) from one time step to the next. Equilibrium models predict the final composition, biomass etc expected at a location based on the input parameters (such as precipitation, temperature, radiation, soil carbon). Dynamic models, on the other hand, enable one to track the changes expected during the course of the time interval used in the simulation. These models vary greatly in their spatial scales, fundamental processes included in the model, degree of complexity, etc.

BIOME is one such model, which uses GIS interface as well on a gridded scale the model determines equilibrium state vegetation combinations for each location. It combines screening of biomes through application of climatic constraints with the computation of net primary productivity (NPP) and leaf area index (LAI), both based on fully coupled photosynthesis and water balance calculations.

Another process-based model HYBRID simulates the “daily cycling of carbon, nitrogen and water within the biosphere and between the biosphere and the atmosphere”. HYBRID too is based on the competition between plant functional types for light, water as well as nutrients at a location. Mortality as well as regeneration is also taken into account. HYBRID is ideally suited to explore even the transient changes in the vegetation brought about by the changes in the climate during a relatively short time-span of a few decades.

Although such models could provide a depth of analysis, their results have to be calibrated to generate the current biome patterns based on input climate data. The locale specific nature of the forest species makes output interpretation an art, which could be both strength or a weakness - strength in the hands of an experienced modeller, and a weakness if in the hands of a novice.

Decision Support Systems (DSS) are also used to extend conservation planning to the thousands of institutions that impact biodiversity through their routine planning and management. With the help of the DSS, planners, conservation groups, and local governments are better able to integrate biodiversity information into their land use planning. The DSS is a collection of desktop and Internet software tools and information resources, supported by a network of experts to apply them to real-world land use and conservation decisions. These tools allow users to harness the power of advanced geographic information systems (GIS) to visualize the environment and evaluate alternative scenarios for the future. The result is an overlapping continuum among scientists, planners, and stakeholders that allows for iterative planning and evaluation using best available data and conservation planning theory.

Another domain tool concerns climate change related impacts on biodiversity and wildlife populations. Program to Assist in Tracking Critical habitat (PATCH) is a spatially-explicit, individual-based, life history simulator designed for terrestrial landscapes. It is available now, but is also undergoing active development. PATCH is presently a females-only model, and is useful for evaluating the impacts of landscape alteration on wildlife populations. The model includes environmental stochasticity and dynamic landscape change, and incorporates limited density dependence. PATCH reads GIS habitat maps, and is parameterized using species-habitat preferences, territory size, vital rates, and estimates of movement ability. The model outputs include measures of population size, projected habitat occupancy and movement patterns, and identification of demographic sources and sinks.

There are also a few species specific models that track the historical population of the particular species in a region, link it limited socio-economic parameters such as habitat shrinkage rates etc, and then projects population in near-term future. These models however do not consider climate change induced long-term parameters such as vegetation patterns, rainfall, and food availability for these species etc. It is therefore advisable to use these models in conjunction with broader forest and vegetation models to arrive at more robust results. Information on wildlife preservation efforts by the local and national governments should also be included to strengthen the results.

2.7 Energy and environment

Energy environment models can be classified as Top-down, Bottom-up, and Integrated models. Figure 2.1 shows how these models are further classified based on the theory on which they are built or the methodology that they typically follow. Top-down models can be of partial or general equilibrium type, and further, they can be either single-country or global models. Bottom-up models are based on optimization theory and geared for technology assessment. Macro-optimization models classified under this category are largely bottom-up models with economic feature of macro or top-down models. These types of models are built for energy system optimization or specific sector optimization. Local models employ varied methodologies since their focus is on micro-level and local area. Integrated models follow a multidisciplinary approach and are used for integrating knowledge from individual disciplines. Virtually any two or more disciplines can be involved in integrated models. Integrated models can be at global level dealing with issues such as climate change. Local level integrated models integrate issues such as emissions, air quality assessment, and health impacts.

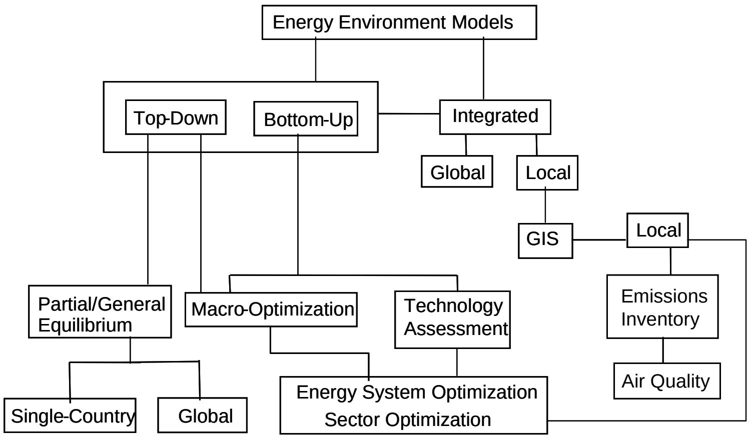

Figure 2.1: Classification of Energy Environment Models

These models can be distinguished on a number of characteristics. The most important of these is the system representation. Other differences concern modelling paradigm, planning horizon, data type, and geographical spread (Table 2.1). All these distinctions highlight the policy questions that a model is best suited to answer.

Table 2.1: Top-down and bottom-up approaches

Attributes	Top-Down	Bottom-Up
Paradigm	Economic: Energy an abstract input to economic growth	Engineering: Energy a physical means to particular ends
Primary Issue Addressed	Evaluation of the overall economic cost of carbon abatement	Evaluation of specific energy technology options
Exogenous variables	Elasticity of Substitution, Autonomous Energy Efficiency Improvement	Energy service demands, Primary energy prices
Flow in the model	Money	Energy Forms
Abatement cost Estimates	Pessimistic	Optimistic
Market assumptions	Considers existing market as optimal	Assumes a technically efficient market
Nature of solution	General equilibrium	Partial equilibrium on energy markets

Each model has specific characteristic that makes it useful for addressing specific concerns. Table 2.2 provides model characteristics, while table 2.3 gives the objectives, typical outputs and policy questions addressed by various models. For example, if global implications of alternate greenhouse gas (GHG) emission mitigation targets on GDP and carbon prices are to be analyzed over medium term, SGM may be a suitable modelling tool. Alternately, if city level implications of low sulphur diesel are to be analyzed over short to medium term on local pollutant emissions, AIM/Local may be an appropriate tool.

Table 2.2: Model characteristics

Models	Space/sector aggregation	Time horizon	Climatic interface
ERB	Global/regional	Long term (100 years)	GHGs
SGM	Global/National	Medium to long-term (50-100 years)	GHGs
AIM/Material	National	Short to medium term (10-30 years)	Solid waste, water pollution, air emissions
GEMA	National	Short to medium term (10-30 years)	CO_2
End-use Demand Projection	National/ Demand Sector	Short to medium term (10-30 years)	Energy use
AIM/Trend	National	Short to medium term (10-30 years)	CO_2
AIM/Enduse	National/ Demand Sector	Short to medium term (10-30 years)	CO_2, local air pollutants
MARKAL & Stochastic MARKAL	National/Sub-national	Medium to long-term (40-100 years)	CO_2, local air pollutants
Electricity Sector LP	National/Sub-national / Supply Sector	Short to medium term (10-20 years)	CO_2, local air pollutants
AIM/Local	City/County/ Point Source	Short to medium term (10-30 years)	CO_2, local air pollutants
AIM, MiniCAM	Global	Long term (100 years)	Climate Change

Typical outputs from top-down models are global/regional trends of energy prices, economic growth and GHG emissions. The bottom-up models have technology focus and their typical outputs include technology and fuel mix, energy system investments, sectoral and fuel level emissions. Integrated models project emissions, concentrations, sea-level rise, temperature changes, land use changes, physical impacts on sectors, mitigation costs, carbon tax for GHG concentration stabilization, usually at global level and therefore lack micro-level detailing. The top-down models also have these constraints. On the other hand, the outputs from bottom-up optimization models provide a detailed disaggregated picture, however GDP, energy prices and sectoral demands are exogenous to them.

Table 2.3: Objectives, typical output and policy questions addressed

Model	Objective	Output	Policy Analysis
ERB	Determine Global / Regional Energy Prices and Energy Use	Global/regional trends of long-term energy prices, economic growth and GHG emissions	Implications of carbon tax on energy prices and economy Implications of regional energy trade restrictions
SGM	Determine market clearing prices for economic sector outputs	Global/national trends of energy prices, economic growth, GHG emissions Sector prices and growth trends Factor prices	Implications of carbon tax/emission caps on energy prices and economy Long-term energy/technology transitions
AIM/	Projections of	National trends of local	Solid wastes, wastewater

Material	sector level environment pollution loads	pollutants Waste recycling trends Economic growth	and air emissions analysis Environment innovation policies
End-Use Demand Projection,	Demand Projections consistent with macroeconomic scenario	End-use Sector Demand Trajectory	Sectoral investment Technology and infrastructure policies
AIM/ Trend	Energy supply and demand projections	End-use Sector Demand and supply Trajectory	Future environmental burdens based on the past socio-economic trends
AIM/ Enduse	Minimize discounted sectoral cost	Sectoral energy, and technology mix, investments and emissions	Sectoral technology Energy and emissions control policies Sectoral investment
MARKAL	Minimize discounted Energy system cost	National energy and technology mix, energy system investments, and emissions	Energy sector policies like energy taxes and subsidies Energy efficiency Emissions taxes and targets
Stochastic-MARKAL	Minimize expected value of discounted system cost	Energy and technology mix under uncertain future, Value of information	Hedging strategies for energy system investments Identify information needs
Power Sector LP Model	Minimize discounted Power sector cost	Power plant capacity and generation mix, emissions profile, total costs	Grid integration and regional cooperation analysis Power sector technology Energy and emissions control policies Power sector investment
AIM/ Local Model	Determine regional spread of energy and emissions	Regional maps	Linking energy and environment policies across time and space
AIM, MiniCAM	Holistic approach to climate change modelling	Emission projections, concentrations, sea-level rise, temperature changes, land use changes, physical impacts on sectors, mitigation costs, carbon tax for GHG concentration stabilization	Mitigation options Climate change impacts assessment Adaptation strategy

Sometimes alternate models may be employed to address the same question, such as SGM and ERB can both address implications of carbon tax on global energy prices and economy in the long term. There are also instances where a model may be used to address questions beyond its original intended domain. For example, AIM/Local model was initially designed for city and plant level analysis. However its domain was extended for large point and area source analysis for country level applications for India. Similarly methane and nitrous oxide emission projections from coal mining, paddy cultivation, municipal solid waste, livestock, and other informal sectors/sources may also be made using MARKAL model, which is an energy system optimization model. These extensions indicate the art of modelling. Models are analytical tools and it requires a seasoned and experienced modeller to employ them judiciously to achieve robust and consistent analysis. Knowledge of the region being modelled is another important requirement for the art of modelling.

The bottom-up, top-down and integrated economy-energy-environment models could also be used to assess impact assessment on energy systems due to climate change as well as to answer adaptation questions. This latter scope however lies in the art of modelling domain. Energy sector issues that have strong linkages with adaptive capacities of populations at macro-level - such as future projections of energy access and affordability, prices of energy and electricity resources, negative externalities of energy production and use, human health impacts of an energy sector policy such as low sulphur diesel for road transport etc. - could be answered by these models.

Cross-country comparisons are also possible using such models. Alternative adaptation policies can also be compared using sound economic analysis. A few GIS-linked models are also available that could use the gridded output from traditional climate models as their inputs and project gridded status of the above parameters in future. These could be very useful for policymakers to craft suitable energy sector policies that are also beneficial from developmental and climate change perspectives.All such tools however require trained experts and extensive resources (data and time).

2.8 Infrastructure and industry

Infrastructure might be subject to suffering the largest amount of damages due to climate change. Climate change could also affect industries and industrial infrastructure in varying degrees. Industries could be directly dependent on inputs from climate sensitive sectors/resources, or could supply their output to climate sensitive sectors, or could be built in climatically sensitive regions such as cyclone prone coastal areas.

However analyzing such possible damages has not attracted much attention as yet. There are not many tools available for a good assessment. This may be partly due to lack of demand for such tools due to low sensitivity on the part of policymakers and researchers, the cross-cutting nature and wide sectoral coverage of infrastructures. Reverse impact matrix is one such tool (Shukla et al., 2004) which could be extended for adaptation analysis. Other support tools however have to be used to compare and choose from alternative adaptation measures.

There are also specific design tools available to assess an infrastructure's coping capabilities to changing climate. For example to check whether a railway bridge could withstand flash floods due to extensive rainfall – let us say beyond 200 mm in 24 hours. Such micro models have to be however used as supplemental to a macro overview on likely climatic parameters along the railway in a changing climate during the entire life of the infrastructure asset (bridge here). Alternative adaptation options have to be then analyzed for their relative capacities to alleviate the expected extreme event as well as their costs. This would require use of suitable approaches described in previous sections.

References

Alexander, A. M., Last, J. A., Margolis, M. and d'Arge, R. C., 1998. A method for valuing global ecosystem services. Ecological Economics 27, 161-170.

Ali, A., 1999. Climate change impacts and adaptation assessment in Bangladesh. In: Mimura, N. (Ed.), National Assessment Results of Climate Change: Impacts and Responses. Climate Research - Special Issue 6, 109-116.

Arnold, J. G., Williams, J. R., Nicks, A. D. and Sammons, N. B., 1990. SWRRB - A Basin Scale Simulation Model for Soil and Water Resources Management. Texas A&M Press, Texas, pp. 255

Bijlsma, L., Ehler, C. N., Klein, R. .J. T., Kulshrestha, S. M., McLean, R. F., Mimura, N., Nicholls, R. J., Nurse, L. A., Nieto, Pérez H., Stakhiv, E. Z., Turner, R. K. and Warrick, R. A., 1996. Coastal zones and small islands. In: Watson, R. T., Zinyowera, M. C. and Moss, R. H., (Eds.), Climate Change 1995: Impacts, Adaptations, and Mitigation of Climate Change: Scientific-Technical Analyses. Contribution of Working Group II to the Second Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 289-324.

CHGE, 1999. In: Epstein, P. R., (Ed.), Extreme Weather Events: The Health and Consequences of the 1997/98 El Niño and La Niña. Centre for Health and the Global Environment, Harvard Medical School, Boston, MA, USA, pp. 41.

Costanza, R., d'Arge, R., de Groot, R., Farber, S., Grasso, M., Hannon, B., Linburg, K., Naeem, S., O'Neill, R. V., Paruelo, J., Raskin, R. G., Sutton, P., and van den Belt, M., 1997. The value of the world's ecosystem services and natural capital. Nature 387, 253-260.

El-Raey, M., Frihy, O., Nasr, S. M., and Dewidar, K. H., 1999. Vulnerability assessment of sea-level rise over Port Said governate. Egypt. Environmental Monitoring and Assessment 56, 113-128.

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

IPCC, 2001b. Climate Change 2001: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Third Assessment Report of the Intergovernmental Panel on Climate Change (IPCC). Cambridge University Press, Cambridge.

Klein, R. J. T. and Nicholls, R. J., 1999. Assessment of coastal vulnerability to climate change. Ambio 28(2), 182-187.

Kont, A., Ratas, U., and Puurmann, E., 1997. Sea-level rise impact of coastal areas of Estonia. Climatic Change 36, 175-184.

Moberg, F. and Folke, C. 1999. Ecological goods and services of coral reef ecosystems. Ecological Economics 29, 215-233.

Nicholls, R. J. and De la Vega-Leinert, A. C., 1999. Guidelines for Synthesis and Aggregation of National Results. Second draft, Flood Hazard Research Centre, Middlesex University, London, UK, pp. 38.

Nicholls, R. J. and Mimura, N., 1998. Regional issues raised by sea-level rise and their policy implications. Climate Research 11(1), 5-18.

Olivo, M. D., 1997. Assessment of the vulnerability of Venezuela to sea-level rise. Climate Research 9(1-2), 57-65.

Perez, R. T., Amadore, L. A. and Feir, R. B., 1999. Climate change impacts and responses in the Philippines coastal sector. Climate Research (Special Issue) 6, 97-107.

Saizar, A., 1997. Assessment of a potential sea-level rise on the coast of Montevideo, Uruguay. Climate Research 9(1-2), 73-79.

Solomon, S. M. and Forbes, D. L., 1999. Coastal hazards and associated management issues on South Pacific islands. Ocean & Coastal Management 42, 523-554.

Titus, J. G., Park, R. A., Leatherman, S. P., Weggle, J. R., Greene, M. S., Brown, S., Gaunt, C., Trehan, M., and Yohe, G., 1992. Greenhouse effect and sea level rise: the cost of holding back the sea. Coastal Management 19, 172-204

West, J. J. and Dowlatabadi, H., 1999. On assessing the economic impacts of sea-level rise on developed coasts. In: Downing, T. E., Olsthoorn, A. J. and Tols, R. S. J., (Eds.), Climate Change and Risk. Routledge, London, United Kingdom, pp. 205-220.

UNFCCC, 2005. Compendium on methods and tools to evaluate impacts of, and vulnerability and adaptation to, climate change, a report prepared by Stratus Consulting Inc. for UNFCCC Secretariat.

Yamada, K., Nunn, P. D., Mimura, N., Machida, S. and Yamamoto, M., 1995. Methodology for the assessment of vulnerability of South Pacific island countries to sea-level rise and climate change. Journal of Global Environment Engineering 1, 101-125.

Yohe, G. W. and Schlesinger, M. E., 1998. Sea Level Change: The Expected Economic Cost of Protection or Abandonment in the United States. Climatic Change. 38, 447-472.

Yohe, G. W. and Neumann, J., 1997. Planning for sea-level rise and shore protection under climate uncertainty. Climatic Change 37(1), 243-270.

Yohe, G. W., 1990. The cost of not holding back the sea: toward a national sample of economic vulnerability. Coastal Management 18, 403-431.

Yohe, G. W., Neumann, J., Marshall, P. and Ameden, H., 1996. The economic cost of greenhouse-induced sea-level rise for developed property in the United States. Climatic Change 32, 387-410.

Zeider, R. B., 1997. Climate change vulnerability and response strategies for the coastal zone of Poland. Climatic Change 36, 151-173.

Chapter 3: Adaptation Policy Assessment Tools

3.1 Introduction

The adaptation assessment process is becoming more sophisticated over the years. Adaptation responses are now seen as integral to the developmental process and growth of a society. This has broadened the scope and extent of adaptation tools that now have to not only assess individual policies for their capability to enhance adaptive capacities of the target population and systems, but also how these link with the overall sustainable development paradigm of the host nation. This therefore is a fast expanding field of research and practical guidance, where guidance on existing tools could become obsolete very quickly. An emerging literature on sustainable development and climate change has attempted to further develop approaches that can be used to assess specific development and climate policy options and choices in this context (Beg et al., 2002; Munasinghe 2002; Halsnæs and Verhagen, 2005, Markandya and Halsnæs 2002; Munasinghe and Swart, 2005; Simms, 2001). These have included discussions about how distinctions can be made between natural processes and feedbacks, and human and social interactions that influence the natural systems and that can be influenced by policy choices (Barker, 2003).

UNDP's Adaptation Policy Framework (APF), one of the most integrated adaptation policy analysis tool available, provides guidance on designing and implementing projects that reduce vulnerability to climate change, by both reducing potential negative impacts and enhancing any beneficial consequences of a changing climate (http://www.undp.org/cc/apf_outline.htm). It seeks to integrate national policy making efforts with a "bottom-up" movement. The framework emphasizes five major principles: adaptation policy and measures are assessed in a developmental context; adaptation to short-term climate variability and extreme events are explicitly included as a step toward reducing vulnerability to long-term change; adaptation occurs at different levels in society, including the local level; the adaptation strategy and the process by which it is implemented are equally important; and building adaptive capacity to cope with current climate is one way of preparing society to better cope with future climate. The APF is a flexible approach in which the following five steps may be used in different combinations according to the amount of available information and the point of entry to the project: (1) defining project scope and design, (2) assessing vulnerability under current climate, (3) characterizing future climate related risks, (4) developing an adaptation strategy, and (5) continuing the adaptation process. The framework focuses on the involvement of stakeholders at all stages.

National Action Programme for Adaptation (NAPA) is another important source for adaptation tools (http://www.unitar.org/ccp/napaworkshops.htm). Least developed countries (LDCs) may use NAPAs to rank their adaptation measures for funding by the UNFCCC LDC Fund and other sources based on such criteria as urgency and cost-effectiveness. The guiding elements imply that the NAPA process should emphasize 1) a participatory approach involving stakeholders, 2) a multidisciplinary approach, 3) a complementary approach that builds on existing plans and programs, 4) sustainable development, 5) gender equity, 6) a country driven approach, 7) sound environmental management, 8) cost-effectiveness, 9) simplicity, and 10) flexibility based on country specific circumstances. In the NAPA process, much of the work of assessing vulnerability and adaptation is intended to be drawn from existing sources. The Guidelines do stress the importance of conducting a participatory assessment of vulnerability to current climate variability and extreme events as a starting point for assessing increased risk due to climate change.

In the following sections we evaluate commonly used adaptation tools.

3.2 Decision tools

The decision tools analyze and choose from multiple options to meet a common adaptation policy objective. UNDP report (http://www.undp.org/cc/apf_outline.htm) covers the following decision tools;

- Policy exercise
- Benefit-cost analysis
- Cost-effectiveness
- Multicriteria analysis
- Tool for environmental assessment and management (TEAM)
- Adaptation decision matrix
- Screening of adaptation options

We provide a critique of these below.

3.2.1 Policy exercise

A flexible structured method designed to synthesize and assess knowledge from several relevant fields of science for policy purposes directed toward complex, practical management problems. Policy exercise techniques provide an interface between scientists, academics, and policy makers. At the heart of the process are scenario writing ("future histories," emphasizing non-conventional, surprise rich, but still plausible futures) and scenario analyses via the interactive formulation and testing of alternative policies that respond to challenges in the scenario. These scenario based activities typically take place in an organizational setting reflecting the institutional feature of the issues that are addressed.

Strengths

- Policymakers' involvement is easier.
- Ease of use.
- No training required for participants.
- Scope, coverage and involvement of relevant policymakers can be identified based on the adaptation problems being analyzed.
- Useful for developing countries and LDCs.

Weaknesses

- Inexperienced facilitators' could diminish the tremendous possibilities.
- May need a separate economic analysis for weighing alternative adaptation options.
- Experience may drive commonsense, which may both be inadequate in the climate change context. Therefore guard against risk of arriving at wrong policy decisions.

3.2.2 Benefit-cost analysis

This approach uses a conceptual framework for analyzing an adaptation measure by identifying, quantifying, and monetizing the costs and benefits associated with the measure. Spreadsheet software is often used to facilitate analysis; however, the specific approaches used are highly dependent on the measure under consideration.

This tool can be used to determine whether the benefits of the adaptation measure outweigh the costs, whether net benefits are maximized, and how the measure compares to other options.

Strengths

- Proven economic tool.
- Could provide very project/ policy specific assessment.
- Good to compare quantitatively across alternative adaptation options.

Weaknesses

- Needs trained human resources.
- Requires extensive data and analysis.
- Involving policymakers could be difficult.
- Difficult to get cost and benefit data for social parameters involved.
- Arriving at an acceptable discount rate could be tricky.
- Cost-benefit analyses are generally performed from a project/policy-perspective and not from a user (e.g. community needing adaptation measures) perspective. Application of this tool would therefore need special care to keep constant focus on the user perspective – that is costs to the user and benefits to the user.

3.2.3 Cost-effectiveness

Cost-effectiveness analysis takes a predetermined objective and seeks ways to accomplish it as inexpensively as possible. Unlike cost-benefit analysis, the level of the benefit is treated as an external given, and the objective of the analysis is to minimize the costs associated with the achievement of this specified objective.

Strengths

- Proven economic concept.
- Could provide economy-wide policy assessment.
- Good to compare costs of adaptation across countries that have similar circumstances and objectives.
- Good to provide indicative comparison of national adaptation costs with national mitigation costs (worked out from different models).
- Good to quantify adaptation objectives in more concrete terms.

Weaknesses

- Needs trained human resources.
- Requires extensive data and analysis.
- Involving policymakers could be difficult.
- Defining objective function could become subjective for adaptation policy.
- Difficult to get cost data for social parameters involved.
- Requires macro-level assumptions, which could be distant from micro-level adaptation needs and realities.
- Arriving at a common discount rate for different countries could be tricky.

3.2.4 Multicriteria analysis (MCA)

MCA describes any structured approach used to determine overall preferences among alternative options, where the options accomplish several objectives. In MCA, desirable objectives are specified and corresponding attributes or indicators are identified. The actual measurement of indicators need not be in monetary terms, but are often 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. Explicit recognition is given to the fact that a variety of both monetary and non-monetary objectives may influence policy decisions. MCA provides techniques for comparing and ranking different outcomes, even though a variety of indictors are used. MCA includes a range of related techniques, some of which follow this entry.

Strengths

- Proven modelling concept.
- Broader approach and could include economic, social, environmental, technical and financial criteria.
- Could rank different adaptation options on the above multiple criteria.
- Could be linked with Cost-benefit analysis.
- Could generate environmental and social indicators on the side.

Weaknesses

- Needs trained human resources.
- Requires extensive data and analysis.
- Defining multiple criteria and preferences for policy outcomes could become subjective for adaptation policy.
- Requires macro-level assumptions, which could be distant from micro-level adaptation needs and realities.

3.2.5 Tool for Environment Assessment and Management (TEAM)

This software package creates graphs and tables that allow experts to compare the relative strengths of adaptation strategies using both quantitative and qualitative criteria. TEAM assists the user in evaluating issues such as equity, flexibility, and policy coordination. The user lists the strategies across the top of the table and the evaluation criteria down the side, and then enters a score indicating the relative performance of each strategy under the various criteria. This table can then be used to construct a variety of graphs of the data. It will not necessarily identify the optimal strategy (unless one strategy outperforms all others in all criteria), but is instead designed to allow the user to more clearly see the strategies' relative strengths and weaknesses.

Strengths

- Comprehending outputs could be easier for policymakers.
- Supports visual comparison of alternative adaptation policy options through graphs and charts.
- Training needs are not very high.
- Use in conjunction with other tools (such as policy exercise and cost-benefit) could add depth to analysis.
- Good for cross-country comparisons.
- Useful for developing countries and LDCs.

Weaknesses

- Needs trained human resources.
- Needs data to set up for specific country.

3.2.6 Adaptation decision matrix (ADM)

The ADM uses multicriteria assessment techniques to evaluate the relative effectiveness and costs of adaptation options. Users are asked to specify criteria that will be used to evaluate options and weight the criteria. Scenarios of current climate and climate change can also be used. Users are asked to give a score (e.g., 0 to 5) on how well each criterion is met under a particular scenario for each option. The scoring can be based on detailed analysis or expert judgment. Scores can be multiplied by weights and summed up to estimate which options best meet the criteria. The scores can be compared to relative costs to assess cost-effectiveness.

Strengths

- Could be considered as a simplified MCA.
- No training required for participants.
- Ease of use.
- Policymakers' involvement is easier.
- Promising for developing countries and LDCs.
- Broader approach and could include economic, social, environmental, technical and financial criteria.
- Could rank different adaptation options on the above multiple criteria.
- Detailed modelling outputs on relative costs could be used as inputs to lend credence to score and criterion weightage.

Weaknesses

- The users have to be knowledgeable about various adaptation options, criteria used to evaluate them and the relative weightage of these criteria. An ignorant user could skew the analysis.
- The coordinator has to be especially knowledgeable in cross-cutting and cross-sectoral issues.
- Defining multiple criteria and preferences for policy outcomes could become subjective for adaptation policy

3.2.7 Screening of adaptation options

This matrix-based decision-making tool sets up a series of criteria that allow the user to narrow the list of appropriate adaptation measures. The user sets up a table with evaluation criteria across the top: Will the measure target a high-priority area? Will it address targets of opportunity? Is it likely to be effective? Will it generate other benefits (e.g., economic, environmental)? Is it inexpensive? Is it feasible? The user can insert or substitute other criteria if they are more appropriate. The user then evaluates each measure against these criteria, entering a simple "yes" or "no" in the cells. This tool is frequently combined with expert judgment.

Strengths

- Could be considered to have some similarities with policy exercise, MCA, and ADM.
- Ease of use.
- No training required for participants.
- Policymakers' involvement could become easy if this exercise is conducted in two-stages. In the first stage, relevant national and international experts set up the series of criteria for different adaptation options. In the second step, policymakers are given these criteria and asked to evaluate various adaptation options on these criteria, inserting or substituting other criteria if they consider them more appropriate, which should be rare after the first step. The results from

the second step could then be used in conjunction with some cost assessment to make the analysis more robust.
- Scope, coverage and involvement of relevant experts can be identified based on the adaptation problems being analyzed.
- Useful for developing countries and LDCs.

Weaknesses
- Evaluation criteria could be too aggregate and therefore lead to wrong policy conclusions.
- Sectoral expertise required.
- Inexperienced coordinator could diminish the results.

3.3 Stakeholder approaches

Stakeholder approaches in general emphasize the importance of ensuring that the decisions to be analyzed, how they are analyzed, and the actions taken as a result of this analysis are driven by those who are affected by climate change and those who would be involved in the implementation of adaptations. UNDP report (http://www.undp.org/cc/apf_outline.htm) covers the following stakeholder approaches;

- Stakeholder Networks and Institutions
- Scoping
- Vulnerability Indices
- Agent Based Social Simulation
- Livelihood Sensitivity Exercise
- Multistakeholder Processes
- Global Sustainability Scenarios

We provide a critique of these below.

3.3.1 Stakeholder networks and institutions

The stakeholder networks and institutions approach focuses on understanding those who make the decisions and how they relate to one another. Building adaptive capacity over long time scales depends on understanding these relationships. Institutions can be viewed as the collective rules, norms, and shared strategies that define stakeholder behaviour. This approach posits that understanding present capacity is the key to predicting how it is likely to evolve in response to future risks. These relationships can be complex, and unravelling them can require the use of a number of tools (see below). Each stakeholder has different objectives, resources, and responsibilities, all of which must be investigated. Some stakeholders may have little voice in the process or may be assigned responsibilities in only part of the issue. New stakeholders may emerge and relationships may alter, particularly in a crisis.

Strengths
- Useful analysis to understand and apply decision making tools in a better way.
- Ease of use.
- Useful to understand possible institutional constraints in implementing a specific adaptation policy.
- Could be used to sensitize stakeholders about other stakeholders' perspectives and their role in implementing an adaptation policy. Therefore in a slightly modified approach, this type of stakeholder consultation could be used before

choosing decision tools and then again before/during implementing the chosen adaptation policy. This could improve the chances of the policy's acceptance by the various stakeholders and its subsequent successful implementation.
- More appropriate at local level since stakeholder relationships could be governed by very locale specific constraints. However lessons learnt could have national and global applicability.

Weaknesses
- Participants may need special training in policy analysis and stakeholder consultations. However practitioners can easily adopt these.
- Inexperienced participants may not be able to capture the nuances of sensitive relationships between various stakeholders and how to use these relationships constructively to facilitate choosing an adaptation policy and how to promote consensus around a chosen adaptation policy.

3.3.2 Scoping
A major step in designing an assessment of climate impacts, vulnerability, and adaptation is to scope the elements of the study. A spreadsheet has been developed to aid project teams in the scoping phase. The spreadsheet has a list of potential methods — over 70 general techniques that are appropriate in various stages of an assessment. A simple form allows users to choose answers to eight scoping questions. The answers are then used to screen the choice of potentially useful tools. A section of the spreadsheet has common flowcharts of projects (e.g., NAPA and APF) and a set of building blocks that users can link to make their own project diagram.

Strengths
- Useful for initiating a scoping exercise to assess suitable tools for climate change impacts, vulnerability and adaptation in a policy context.
- Useful for researchers, especially beginners trying to frame adaptation policy for a project design.
- Supportive tool to make project diagrams and flowcharts for demonstration.

Weaknesses
- The tool is difficult to access since not available on the website.
- More designed for researchers and not for practitioners and realists.

3.3.3 Vulnerability indices
Formal vulnerability indices can be helpful as part of an adaptation strategy. Vulnerability is defined by the IPCC as the combination of sensitivity to climatic variations, the probability of adverse climate change, and adaptive capacity. For each of these components of vulnerability, formal indices can be constructed and combined. Methods of aggregating across sectors and scales have been developed in other contexts (e.g., the Human Development Index) and are beginning to be applied to climate change. However, substantial methodological challenges remain — in particular estimating the risk of adverse climate change impacts and interpreting relative vulnerability across diverse situations.

Strengths
- Based on current vulnerability, perceived risks, and existing adaptive capacities.

- Uses quantified indices and therefore good to compare across alternative policy options.
- Useful to identify vulnerable regions, populations and sectors to target adaptation policy. The tools can also facilitate ranking these in order of vulnerability in a consistent framework, and therefore facilitate directing limited resources to the most needy, especially in a developing country or LDC context.

Weaknesses

- Needs trained manpower.
- Not easy to use.
- Needs considerable data and analysis to estimate indices.
- Difficult to estimate the risks of adverse climate change impacts and interpreting relative vulnerability across diverse situations.

3.3.4 Agent based social simulation

A computer assisted technique for knowledge elicitation assists in building rules of how people respond to a variety of stimuli and scenarios of environmental and social conditions. Agent based social simulation is a relatively formal approach to stakeholder and institutional analysis. It is a computer programming method that uses software agents to represent the positions, boundaries, and actions of stakeholders. This approach is one of the few means to realistically simulate the behaviour of stakeholder networks in the context of the rules, norms, and shared strategies from social and economic institutions. This approach can be applied at various stages of an assessment. One example is that agent based social simulation can incorporate socioeconomic scenarios that are constructed as sets of rules regarding, for example, environmental values, regulation, and economic goals. An advantage of this approach is that the realization of socioeconomic scenarios is the outcome of stakeholder behaviour rather than being exogenously imposed in a way that bears little relation to actual decision making processes.

Strengths

- Based on actual behaviour of stakeholders and not imposed by persons outside the target region/population/sector. This could also facilitate reducing implementation barriers later.
- Brings in realism to adaptation policy assessment and implementation. Such reality checks could be very useful and desirable for successful implementation of an adaptation policy.
- Applicable at various stages of designing, selecting and implementing an adaptation strategy.
- Stakeholder involvement is consistently high through out the process.
- More appropriate at local level since stakeholder responses could be governed by very locale specific circumstances. However lessons learnt could have national and global applicability.

Weaknesses

- Needs trained manpower and resources.
- Very little information on training sources is available.
- Good to establish realistic background conditions and requires further tools in choosing and deciding on adaptation policy responses.
- A relatively new entrant in the climate change adaptation policy assessment arena. Therefore sufficient experience is not available.

3.3.5 Livelihood sensitivity exercise

Livelihood sensitivity mapping exercise is a means of integrating existing knowledge of climate vulnerability with livelihood analysis. It commonly involves stakeholder participation. Initially the exercise can be conducted in the context of rapid workshop breakout group, but eventually can be formalized via the inclusion of expert analysis, impact models, or historical analogues: The exercise involves developing a matrix with three blocks of rows — beginning with ecosystem services (e.g., soil moisture), then livelihood activities (such as crop production) and finally a synthesis based on livelihoods themselves. Climatic stresses (e.g., drought) are listed as columns. Users then fill in the cells — rating the sensitivity of ecosystem services, activities and livelihoods to a range of hazards and stresses. Exposure across the hazards and impacts across the services/activities/livelihoods can be calculated as aggregated indices.

Strengths

- Useful to identify livelihoods that could be sensitive to climate change related impacts.
- More appropriate for local level and regional analysis.
- More useful for research purposes.

Weaknesses

- More often than not, it would identify the obvious. For example, the livelihoods of poor and marginal farmers are very sensitive to natural stresses such as droughts and floods. Therefore it may not be very helpful to provide any new insights to policymakers, especially in developing countries and LDCs. However could be marginally more effective if it also estimates the extent and level of problem, for example by linking with independent surveys that estimate the number of households having various types of livelihoods etc.
- It is not directly linked to actual adaptation policy response analysis and decision making. It could only suggest target populations and types of their vulnerabilities.

3.3.6 Multistakeholder processes

Multistakeholder processes aim to promote better decision making by ensuring that the views of the main actors concerned about a particular decision are heard and integrated at all stages through dialogue and consensus building. The process takes the view that everyone involved in the process has a valid view and relevant knowledge and experience to bring to the decision making. The approach aims to create trust between the actors and solutions that provide mutual benefits (win-win). The approach is people-centred and everyone involved takes responsibility for the outcome. Because of the inclusive and participatory approaches used, stakeholders have a greater sense of ownership for decisions made. They are thus more likely to comply with them.

Strengths

- A practical approach to decision making and implementation.
- More likely to develop trust, consensus building and ownership of adaptation policy and measures amongst various stakeholders. An internal dynamic mechanism could also develop as an off-shoot that could facilitate stakeholder reflection and feedback at various stages of policy implementation. This increases the odds in favour of successful implementation of an adaptation policy.
- Involves more of a problem solving approach than a problem analysis approach.

- More appropriate for local level. However lessons learnt could have regional, national and global applicability in similar circumstances.

Weaknesses

- Inexperienced facilitators' could diminish the many possibilities.
- The process requires mutual understanding, patience and a give-and-take approach amongst various stakeholders. Tough and uncompromising stakeholders could therefore scuttle the process, and so can selfish local politics.
- May need a separate economic analysis for weighing alternative adaptation options to facilitate an educative decision making.
- The process is based on collective common sense. Experience may drive such common sense, which may both be inadequate in the climate change context. Therefore guard against risk of arriving at wrong policy decisions.
- This is still a new and evolving field.

3.3.7 Global sustainability scenarios

Scenarios of future vulnerability are poorly framed by existing scenarios developed for bracketing future greenhouse gas emissions. Alternative scenarios of sustainability have been developed in various forms, and these correspond to many of the conditions of vulnerability and adaptive capacity that are of concern to development planners and practitioners. A major suite of sustainability scenarios was developed by the Global Scenarios Group (GSG). These include a conventional wisdom of market forces, a world of increasing degradation and impoverishment, and a sustainability transition. They are similar to scenarios developed for the UNEP Geo assessment. The GSG suite of scenarios includes storylines and quantified indicators for major world regions using the PoleStar scenario tool developed by SEI-Boston.

Strengths

- Useful for articulating global storylines and integrating adaptation issues in a consistent framework.

Weaknesses

- It is not strictly a stakeholder approach tool.
- Adaptation policy assessment is locale specific, and the global scenarios may not be able to cover the distance in a consistent manner. One needs to convert the global storylines to national and locate specific storylines for consistency.
- Needs training and extensive data resources.
- Difficult to involve policymakers and adaptation practitioners.
- May need a separate economic analysis for weighing alternative adaptation options.

3.4 Other multisector tools

The tools described in this part of the Handbook, listed in Table 3.4, are applicable to more than one sector. They provide a general evaluation of adaptation options, are easily adapted to numerous regions and situations, and are frequently used in conjunction with sector-specific tools to develop a comprehensive analysis or in support of a complete framework. UNDP report (http://www.undp.org/cc/apf_outline.htm) covers the following other multisector tools;

- Climatic Change and Variability (CCAV)
- Expert Judgment

- Historical or Geographic Analogs: Forecasting by Analogy
- Uncertainty and Risk Analysis
- Estimating Adaptation Costs: M-CACES

We provide a critique of these below.

3.4.1 Climate change and variability

It is a methodology of descriptive statistics to illustrate the changing average conditions and the variability in conditions over time. Climate time-series data can be described according to their average conditions, but of particular importance for vulnerability are the impacts of adaptation to the variability of conditions from year to year. Within the range of climatic conditions is a range of conditions with which humans can cope. This range can be changed with adaptive responses. The climatic conditions can also be described and compared according to the variation of conditions over a particular time period (indicated by the variance).

Strengths

- Useful for understanding the climate variability; which in turn could lead to estimating coping range of humans (or even other species) under a changing climate; which in turn could be used to draft suitable adaptation policies to change this coping range to suit the possible climate change induced ranges.
- Tool permitting replication under similar circumstances elsewhere.
- Flexible and could be designed by the user as per the needs of analysis.
- Useful for vulnerability assessment as well.
- Could provide good indicative target regions/population for taking adaptation measures. However further tools may be needed for a deeper and comparative analysis of alternative policy options.
- Its effectiveness could be enhanced if adapted to integrate developmental aspects into purely climatic parameters. For example, incidence of malaria is not only a function of climatic variables (such as humidity and temperature) but also depends upon socio-economic status and development of the target population - governing the extent of preventive measures against breeding of malarial parasites and protection against the existing mosquitoes.

Weaknesses

- Needs time-series climate data.
- Future climate change may not depend upon past climate variability. Therefore basing adaptation responses on past data alone may be insufficient, inappropriate and could lead to inadequate adaptation measures.
- Does not compare alternative adaptation policies for which separate tools have to be used.
- It may also be difficult to decide on a “suitable” range of coping responses in a changing climate. Too small expansion of the existing coping range may not mitigate impacts, while too much expansion may result in additional costs.
- Above constraints could erode its authenticity and practical applicability. Therefore it may be difficult to involve policymakers actively.

3.4.2 Expert judgement

Expert judgment is an approach for soliciting informed opinions from individuals with particular expertise. This approach is used to obtain a rapid assessment of the state of knowledge about a particular aspect of climate change. It is frequently used in a panel format, aggregating opinions to cover a broad range of issues regarding a topic. Expert judgment is frequently used to produce position papers on issues requiring policy responses and is integral to most other decision-making tools.

Strengths

- Widely used and established tool in many other contexts.
- Saves time vis-à-vis a full scale study.
- Flexibility to choose on specific problem to investigate.

Weaknesses

- Adaptation policy assessment is locale specific, and if experts are not aware of the local conditions and circumstances, the results could be very distant from reality.
- Expert judgement intrinsically has some subjectivity.
- The facilitator/coordinator need to be trained in assembling an expert panel, formulating questionnaires, and interpret and aggregate expert opinions.
- The coordinator need to have a good understanding/grasp of the situation and adaptation problem under investigation, and should be able to access other tools to strengthen/compare the results from expert judgement, such as using cost-benefit analysis.

3.4.3 Historical or geographic analogs: Forecasting by analogy

This qualitative tool is a method for evaluating the effectiveness of potential adaptation strategies by comparing observed adaptations to past climate extremes in different geographic locations, sectors, or time periods. This method compares events that have had a similar effect in the recent past to the likely impact of future events associated with climate change, assuming that lessons can be learned from such past experience and then applied to future situations. These compared situations can generally share several important characteristics such as time scale, severity, reversibility, impacted sector, or aggravating factors, and point out how well actual adaptation response worked or did not work.

Strengths

- Useful for initial research and to narrow down feasible adaptation options for more in-depth analysis.
- May be useful specifically for societal and community-based responses to climate variability and to assess the effectiveness of traditional coping strategies.

Weaknesses

- Does not compare alternative adaptation options quantitatively.
- Past experience may not be applicable in a changed future situation especially in the climate change context where many parameters and their interactions could change simultaneously.
- Not used much currently.
- Needs extensive information on past adaptation responses.

3.4.4 Uncertainty and risk analysis

This approach can be applied through critical review of available literature and data or through data analysis using software programs. Uncertainty and risk analysis allows the user to address the errors and unknowns often associated with data and information used to evaluate climate change adaptation measures. A key element of uncertainty and risk analysis is defining the decision criterion that is most appropriate for the question at hand. Uncertainty and risk can be assessed qualitatively, using probability ratings such as slight, moderate, and high. Uncertainty can also be assessed quantitatively, using decision analysis tools (e.g., decision trees) or sensitivity analyses such as Monte Carlo analysis. This method is often used in conjunction with other assessment techniques.

Strengths

- Uses established economic concepts.
- Estimation of uncertainty and risk are important inputs in choosing a specific adaptation option from alternative choices.

Weaknesses

- Needs specific training if using software packages like Monte Carlo etc.
- Quantitative analysis could be more demanding on resources.
- Needs other tools for fully comparing alternative adaptation policy options.

3.4.5 Estimating adaptation costs: M-CACES

M-CACES, a Windows-based software program, is required by the U.S. Army Corps of Engineers for the preparation of water resources construction and rehabilitation cost estimates for projects with federal costs exceeding US$2 million. The Unit Price Book associated with M-CACES provides production rates, unit costs, and crew composition for the United States. Price escalation for inflation is used to adjust pricing to the project schedule and to fully fund the estimate.

Strengths

- Provides costs estimates for natural resources projects (long-life assets).
- Useful for project level analysis.

Weaknesses

- Useful for final cost analyses (and not initial cost analyses) due to amount of data and time required.
- Needs extensive cost data related with the project.
- Needs training.

References

Barker, T., 2003: Representing global, climate change, adaptation and mitigation. Global Environmental Change, 13, pp. 1-6.

Beg, N., J.C. Morlot, O. Davidson, Y. Afrane-Okesse, L. Tyani, F. Denton, Y. Sokona, J.P. Thomas, E.L.L. Rovere, J.K. Parikh, K. Parikh, and A. Rahman, 2002: Linkages between Climate Change and Sustainable Development. Climate Policy, 2(5), pp. 129-144.

Burton, I., Huq, S., Lim, B., Pilifosova, O., Schipper, E.L. 2002. From Impacts Assessment to Adaptation Priorities: the Shaping of Adaptation Policy. Climate Policy, Amsterdam, Vol.2, 145-159.

Burton, I., S. Huq, and B. Lim. In Preparation. Adaptation Policy Framework. United Nations Development Programme. New York.

Cohen, W., and D. Levinthal, 1989: Innovation and learning: The two faces of R&D. The Economic Journal, 99, pp. 569-596.

Halsnæs, K., and J. Verhagen, 2005: Development Based Climate Change Adaptation and Mitigation - Conceptual Issues and Lessons Learned in Studies in Developing Countries. Mitigation and Adaptation Journal, Forthcoming

Markandya, A., and K. Halsnaes, 2002: Climate Change and Sustainable Development. Earthscan, London.

Munasinghe, M., 2002: The sustainomics trans-diciplinary meta-framework for making development more sustainable: applications to energy issues. International Journal of Sustainable Development, 4(2), pp. 6-54.

Munasinghe, M., and R. Swart, 2005: Primer on Climate Change and Sustainable Development. Cambridge University Press, UK.

Shukla, P.R., Kapshe, M. and Garg, A. (2004), Development and Climate: Impacts and Adaptation for Infrastructure Assets in India. OECD Global Forum on Sustainable Development: Development and Climate Change, ENV/EPOC/GF/SD/RD(2004)5/FINAL, OECD, Paris.

Simms, A., 2001: Special Edition, IMPACT October 2001

UNFCCC, 2005. Compendium on methods and tools to evaluate impacts of, and vulnerability and adaptation to, climate change, a report prepared by Stratus Consulting Inc. for UNFCCC Secretariat.

Chapter 4: Integrated Vulnerability Assessment and Adaptation Tools

4.1 Introduction

Integrated Assessment (IA) considers the interaction between climate change and other change processes to assess the social, economic and environmental impacts of climate change. It requires a wide understanding of natural and human systems. This is important because demographic profile, economic development and land use of a region have a significant influence on how changes in climate are likely to impact and the capacity to adapt to any such future changes. It is also necessary to take in to account the concerns of the stakeholders and priorities of the policymakers because the extent of impacts and scope of adaptation are strongly influenced by their actions.

The Integrated Assessment studies on energy and environment policy and implementation have attracted considerable attention internationally. Linking global climate change concerns with local policymaking and sustainable development are presently the major driving forces. The present study focuses on integrated assessment tools for impact assessment. However, relationship with future emissions and possibility of adaptive actions widen the scope of integrated assessment. Here we are reviewing the literature on IA and various methodologies for IA including models and frameworks. This is followed by the discussion on the energy and environment linkage and long-term environmental changes.

4.2 Integrated Assessment

Definition of IA has generated a lot of discussion in contemporary literature. ‘Integration’ has a vague definition in social science literature. It indicates combining parts into a whole or bringing together various components to make something perfect or complete which is imperfect or incomplete. Similarly, ‘assessment’ means assembling, summarising, organising, interpreting, and possibly reconciling pieces of existing knowledge, so that policymakers will find them relevant and helpful in their deliberations.

Combining these two unclear concepts becomes rather difficult and thus various authors have put forward different definitions of IA (Parson, 1995; Weyant et al., 1996; Risbey et al., 1996; Rotmans and Dowlatabadi, 1998). All these definitions have three elements in common: interdisciplinary problem, knowledge structuring approach and decision-support for policymaking. Thus, IA can be defined as an interdisciplinary process of structuring knowledge elements from various scientific disciplines in such a manner that all relevant aspects of a social problem are considered in their mutual coherence for the benefit of decision-making (ICIS, 1999).

After accepting such a broad definition, the question still remains what is it that is being assessed and what is it that is integrated? The answer to this question is context specific. Therefore, for the present research work we define IA in the context of energy and environment.

We define IA as a framework to represent interactions between natural and socio-economic systems, for understanding the cause-effect chains including feedback loops, for the purpose of addressing policy questions. The integration here relates to sectoral, spatial and temporal issues.

4.3 Scope and possibilities of integration

Integration requires the combination of multiple elements in an assessment system. It is primarily needed to represent complex interactions across spatial and temporal scales, processes and activities. ‘Vertical integration’ deals with process integration while ‘horizontal integration’ involves bringing together knowledge form different disciplines. Integrated assessments may involve qualitative as well as quantitative tools. Integrated models range form simple to extremely complex representation of systems. Simple models are better at representing uncertainty, whereas scenarios and projections from complex models will be more precise if not more accurate. The integration in the models results from:

- Sectoral Integration
- Processes Integration
- Integrating Policy priorities and Implementation mechanism
- Integrating Mitigation, Impacts and Adaptation

IAs can be run at varied levels depending upon the objectives of the assessments. At the first level, IA should be based on consistent databases and scenarios. The second level of integration can establish a relationship between various sectors, systems, and regions affected by climate change. At the third level, different models are linked so that important feedbacks are taken into consideration.

The integration provides an opportunity for linking wide scientific knowledge and interests to distinctly differing, socio economic and political interests and opinions. These assessments are very much needed not only to provide a platform for the scientists to link their own area of research with other scientific disciplines but also to apprise the policy makers about the likely impacts of climate change and the ranges of adaptation strategies available. Therefore in the final analysis, IAs are essential for facilitating the optimal development of institutional and research linkages, projects and policy recommendations as they synthesize the best available synthesis of current scientific, technical, economic, and socio-political knowledge

4.4 Integrated Assessment Models and frameworks

The literature on definitions of IA and IA modelling reveals several different kinds of goals. For instance, in Morgan and Dowlatabadi (1996), IA models are viewed as research tools, where a model provides an organising framework for conducting research by ensuring consistency and pointing to substantive areas where more information is required. The actual research program emerges iteratively from the insights that the model provides and from investigations in the substantive domains of the sub-components. In Rotmans et al. (1998) the definition of IA emphasises that IA should provide useful information for policy decisions. This is a more ambitious goal, though it seems to be in accord with the general intent of IA modelling as carried out by most IA modelling groups. A conceptual framework showing complexities and multidisciplinary nature of IA is shown in Figure 4.1.

In the process of running IA models to develop useful information for policymakers, IA modellers usually make a distinction between use of IA models as ‘forecasting tools’ and ‘heuristic tools’. The researchers are of the opinion that the models should not be viewed as forecasting tools for policymaking, rather, as heuristic tools. In the heuristic approach, less confidence is placed on the actual model results and quantitative model outputs are used to make qualitative judgments about impacts (e.g., large, small), abatement (e.g., high, low) and dynamics (e.g., now, later), and about the interplay of processes in the model. These qualitative judgments have been termed 'insights' provided by the models for the policymakers. None of the integrated models developed so far have an inbuilt heuristic approach. However, the scenario analysis done using these models works as a close substitute for providing the alternate future options to the policymakers.

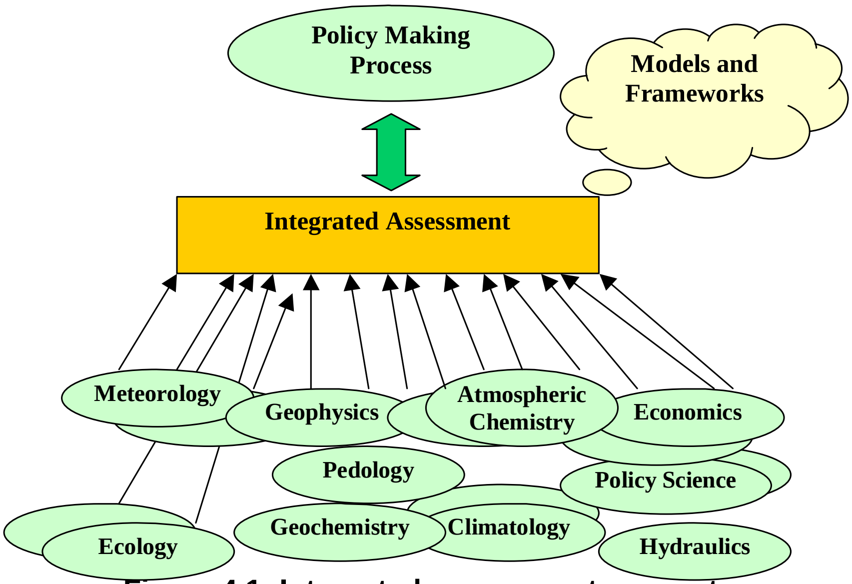

Figure 4.1: Integrated assessment concept
Source: Matsuoka (2001)

These integrated assessment models provide analysis of alternate policy approaches and their impacts on various performance indicators. For example, alternate GHG emission trajectories in the twenty-first century due to different global policy scenarios are indicated in the IPCC reports (IPCC, 2000). This report also elaborates the key driving forces for the modelling exercises and provides useful information for the policymakers to visualise the future impacts of their decisions today.

A variety of methods of conducting IA are possible. Current projects have largely pursued integration through a formal integrating model, though the centrality and manner of use of the model vary among projects (Rotmans et al., 1998). Most of the IA frameworks are conceptual in nature and various researchers have suggested different models for IA of climate change. (IPCC, 1996b)

Centre for Integrated Regional Assessment (CIRA) of global climate change at the Pennsylvania State University, developed a comprehensive framework based on the concept of using scientific modelling approaches to understanding how the future of a region would be perturbed by climate change (Knight, 2001). The framework shows that, such effects could emerge from climate change impacts in the region itself and also from changes in other regions providing challenges or opportunities for the region in question. The diagrammatic representation (Figure 4.2) reflects the general flow of scientific investigation and the dialogue with the policy community. The basic framework is a continuous loop from causes to climate changes. It links four general concepts, causes, changes, consequences and responses, as the climate forcing factors resulting from human activity. The framework recognises the way in which each region is embedded in a matrix of contiguous regions of similar resolution as well as larger spatial units through hierarchical relations. (Fisher et al., 2000)

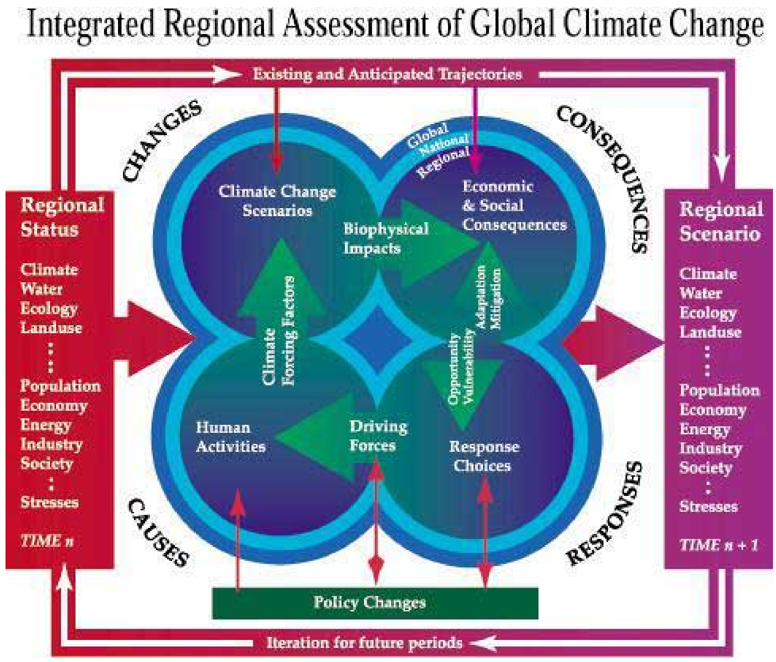

Figure 4.2: Integrated Regional Assessment Framework

IPCC reports (IPCC, 1996b; 2001b) have discussed the IA models in detail. One of the initial attempts of putting together literature on integrated assessment models was done in the IPCC Second Assessment Working Group III report (IPCC, 1996b). This report had a dedicated chapter (Chapter 10) on IA of climate change where various IA models have been explained highlighting the main contribution of IA models as integrators of interdisciplinary knowledge. IPCC special report on emission scenarios (IPCC, 2000) also used in all six different models for generation 40 scenarios. These models are:

- Asian Pacific Integrated Model (AIM) from the National Institute of Environmental Studies in Japan (Morita et al., 1994);
- Atmospheric Stabilization Framework Model (ASF) from ICF Consulting in the USA (Lashof and Tirpak, 1990; Pepper et al., 1992, 1998; Sankovski et al., 2000);
- Integrated Model to Assess the Greenhouse Effect (IMAGE) from the National Institute for Public Health and Environmental Hygiene (RIVM) (Alcamo et al., 1998; de Vries et al., 1994, 1999, 2000), used in connection with the Dutch Bureau for Economic Policy Analysis (CPB) WorldScan model (de Jong and Zalm, 1991), the Netherlands;
- Multiregional Approach for Resource and Industry Allocation (MARIA) from the Science University of Tokyo in Japan (Mori and Takahashi, 1999; Mori, 2000);
- Model for Energy Supply Strategy Alternatives and their General Environmental Impact (MESSAGE) from the International Institute of Applied Systems Analysis (IIASA) in Austria (Messner and Strubegger, 1995; Riahi and Roehrl, 2000); and the
- Mini Climate Assessment Model (MiniCAM) from the Pacific Northwest National Laboratory (PNNL) in the USA (Edmonds et al., 1994, 1996a, 1996b).

A description of each of the above has been provided in the SRES (IPCC, 2000) at http://www.grida.no/climate/ipcc/emission/150.htm

Subsequent to this many different reports have compiled the literature on many more IA models. A brief description of a few selected models is presented here along with their respective strength and weaknesses. Many variants of the above models used for SRES (IPCC, 2000) have also been developed by researchers; however these variants are not being described here. Table 4.1 provides a summary along with possible sources of more information on each of the models. In the end a general discussion on the common strengths and weaknesses of the IAMs is presented.

4.4.1 PRIMES (Energy System Model):

PRIMES simulates a market equilibrium solution for energy supply and demand by finding the market clearing prices of each energy form. The equilibrium is static within each time period but dynamic in a time-forward path. The model has a detailed representation for energy demand and supply technologies and pollution abatement technologies. The considerations about market economics, industry structure, energy/environmental policies and regulation have been conceived so as to influence market behaviour.

PRIMES is conceived for forecasting, scenario construction and policy impact analysis. It covers a medium to long-term horizon.

The model can support policy analysis in the following fields:

- Standard energy policy issues: security of supply, strategy, costs etc
- Environmental issues
- Pricing policy, taxation, standards on technologies
- New technologies and renewable sources
- Energy efficiency in the demand-side
- Alternative fuels
- Energy trade and EU energy provision
- Conversion decentralisation, electricity market liberalisation
- Policy issues regarding electricity generation, gas distribution and refineries.

Strengths:

- Modular nature of the model allows either for a unified model use or for partial use of modules to support specific energy studies.
- Simulates in detail the technology choice in energy demand and energy production.
- Data intensive

Weaknesses:

- A fundamental assumption in PRIMES is that producers and consumers both respond to changes in price. Other behavioural factors receive less importance.
- Due to modular structure, the sectors in different modules may have different level of detailing. This facilitates highlighting of particular issues for the sector but maintaining consistency across sectors may be difficult.

4.4.2 POLES (Prospective Outlook on Long-term Energy Systems)

The POLES model is a global sectoral model of the world energy system. It works in a year-by-year recursive simulation and partial equilibrium framework, with endogenous international energy prices and lagged adjustments of supply and demand by world region.

Strengths:

- This model addresses the issues related to Long-term (2030) simulation of world energy scenarios, national and regional energy balances, and projections and international energy markets analysis.
- It is possible to analyze impacts of energy prices and taxes policies, and costs of international GHG abatement scenarios with different targets.
- Greenhouse Gas emissions and abatement strategies, entitlements, and flexibility systems and Tradable Emission Permit Systems analysis can also be performed using this model.

Weaknesses:

- Application is limited to Energy sector.
- Multi-period optimisation is not considered.

4.4.3 ExternE (Externalities of Energy)

The ExternE methodology provides a framework for measuring the impacts in monetary values. It has five stages which deal with (1) Definition of activity and impact categories; (2) Estimation of impacts in physical units; (3) Monetisation of impacts; (4) Assessment of uncertainties, sensitivity analysis; and (5) Analysis of the results, drawing of conclusions.

The model currently includes (1) Environmental impacts; (2) Global warming impacts; and (3) Accidents as impact categories

Strengths:

- Captures externalities of energy use across sectors and fuels.
- Modelling can start with limited impact categories and more categories can be added later.
- Good for cross-country comparative assessment of social and private costs.

Weaknesses:

- It aims to cover all external effects but the knowledge and data regarding many of the impacts is limited.
- Uncertainties exist about the interactions between causes and effects.
- Set up for industrialized countries only.
- Impact costs are considered at macro levels and therefore may not be acceptable to all stakeholders.
- It is not possible to define interaction between impact categories.

4.4.4 ICLIPS (Integrated Assessment of Climate Protection Strategies)

The ICLIPS project is an international and interdisciplinary research activity whose aim is to provide an Integrated Assessment of Climate Protection Strategies in order to support the decision making community in the realization of the UNFCCC.

Complementary application strategies are suggested to help in deciding about the indicators that are to be involved in the definition of guardrails for defining the “tolerable windows”. The confinement strategy seeks to identify those critical thresholds that are related to large-scale singular and irreversible changes in the qualitative behaviour of the climate system (e.g. global run-away greenhouse effect and shut-down of the ocean conveyor belt). The relaxation strategy proceeds the opposite way by focusing initially on the most sensitive systems or regions. Accordingly, the most binding critical level of climate change is sought below which significant impacts do not occur according to our present scientific knowledge.

Strengths:

- It uses Tolerable Windows Approach (TWA) which consists of a separation of normative settings for "tolerable windows" on climate impacts, negotiable allowances for greenhouse gas emissions, and desirable socioeconomic development scenarios.
- The model takes into account climate impacts, the climate system itself, relevant biogeochemical cycles, emissions of different greenhouse gases, the allocation of emission rights to different nations, possible instruments for emission mitigation, and the dynamics of socio-economic development.

Weaknesses:

- The definition of “tolerable windows” is not universal and may not be acceptable to all stakeholders.

4.4.5 RICE (Regional Integrated model of Climate and the Economy) and DICE (Dynamic Integrated model of Climate and the Economy):

The RICE and DICE models are integrated economic and geophysical models of the economics of climate change. The model contains both a traditional economic sector, similar to that found in many economic models, and a geophysical module designed for climate-change modelling. In the economic sectors, each country or region is assumed to produce a single commodity which can be used for either consumption or investment. In the baseline model, there is no trade in goods or capital, but countries in certain cases trade rights for carbon emissions and receive consumption goods in return.

The basic approach taken in analyzing the economics of climate change is to consider the trade-off between consumption today and consumption in the future. By taking steps to slow emissions of greenhouse gases (GHGs) today, the economy reduces the amount of output that can be devoted to consumption and productive investment. The return for this "climate investment" is lower damages and therefore higher consumption in the future. The purpose of the study is to capture the major tradeoffs involved in climate-change policy.

Strengths:

- DICE models single world region whereas RICE models world in six or ten regions.
- Provides the flexibility of doing the market solution, cooperative solution, and the nationalistic solution analysis.

Weaknesses:

- Population and technology growth and emission decline are exogenously assumed.
- Does not consider possibility of abrupt climate change

4.4.6 IGSM (The MIT Integrated Global System Model)

The MIT Integrated Global System Model (IGSM) is designed for simulating the global environmental changes that may arise as a result of anthropogenic causes, the uncertainties associated with the projected changes, and the effect of proposed policies on such changes.

The IGSM formulation includes an economic model for analysis of greenhouse and aerosol precursor gas emissions and mitigation proposals, a coupled model of atmospheric chemistry and climate, and models of terrestrial ecosystems. All of these models are global but with appropriate levels of regional detail.

The linked IGSM components provide an emissions/chemistry/climate framework that is applied to questions relevant to policy-making. For example, predictions of greenhouse gas emission levels can be linked to uncertainties in future influences such as population growth and economic performance. Further, the effect of various emissions control policies on climate can be pursued, allowing analysis of the sensitivity of policy-relevant outcomes to critical assumptions in all the various components.

Strengths:

- Component model with integrated feedback.
- Global model with regional detailing.
- Linked components provide an emissions/ chemistry/ climate framework for questions relevant to policy-making.
- Analysis of the sensitivity of policy-relevant outcomes to critical assumptions of various model components.

Weaknesses:

- It provides studies of the impact of climate change only on natural ecosystems and agriculture.
- Climate model of IGSM currently does not simulating changes in the sea level.

4.4.7 MERGE:

MERGE is a model for estimating the regional and global effects of greenhouse gas reductions. It quantifies alternative ways of thinking about climate change. The model is sufficiently flexible to explore alternative views on a wide range of contentious issues: costs of abatement, damages from climate change, valuation and discounting.

MERGE contains sub-models governing: (1) the domestic and international economy;
(2) energy-related emissions of greenhouse gases; (3) non-energy emissions of GHG's and; (4) global climate change – market and non-market damages.

Strengths:

- Use of Top-down and bottom-up approaches in one integrated model provides a balance of economy and technology view of the system.
- Abatement choices of ‘when where and what’ to mitigate can be answered.

Weaknesses:

- Learning by doing approach, followed in the model for improvements over time, may result in different local and global optimums. To overcome this problem several different starting and ending points may have to be simulated.

4.4.8 MAGICC/SCENGEN:

MAGICC and SCENGEN are coupled software suites that allow users to investigate future climate change and its uncertainties at both the global-mean and regional levels. MAGICC carries through calculations at the global-mean level. SCENGEN uses these results, together with results from a set of coupled Atmosphere/Ocean General Circulation Models (AOGCMs) and a detailed baseline climatology, to produce spatially-detailed information regarding future changes in temperature and precipitation, changes in their variability, and a range of other statistics.

MAGICC consists of a suite of coupled gas-cycle, climate and ice-melt models integrated into a single software package. This software allows the user to determine changes in greenhouse-gas concentrations, global-mean surface air temperature and sea-level resulting from anthropogenic emissions of carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), reactive gases (CO, NOx, VOCs), the halocarbons (e.g. HCFCs, HFCs, PFCs) and sulfur dioxide (SO_2).

SCENGEN constructs a range of geographically-explicit climate change scenarios for the world by exploiting the results from MAGICC and a set of AOGCM experiments, and combining these with observed global and regional climate data sets.

In addition to climate change scenario construction, SCENGEN produces spatial pattern results for: changes in variability; two different forms of signal-to-noise ratio (to assess the significance of changes); probabilistic output (with the default being the probability of an increase in temperature or, more interestingly, precipitation); and a wide range of validation statistics for individual models or combinations of models.

Strengths:

- Integrated Climate model and scenario generator.
- Global and regional level analysis is possible considering GHGs and local pollutants such as (SO_2).

Weaknesses:

- Due to pattern-scaling for climate change fields, extensive baseline climate data (observed) from actual climate scenario is needed to obtain values for the future time period.

Table 4.1: Integrated Assessment Models

Methods/ Tools/ Models	Brief Description/ Definition	Use/Application	Web Link
PRIMES (Energy System Model)	It is a simulation model focusing on the energy markets of EU	Useful in analyzing the impacts of various forms of carbon emission trading on energy markets	http://www.e3mlab.ntua.gr/manuals/PRIMsd.pdf
Poles	It is partial	Excellent tool to shed light	http://webu2.upmf-

(Prospective Outlook on Long-term Energy Systems)	equilibrium world wide energy market model	on consequences for international energy market of EU	grenoble.fr/iepe/textes/POLES8p_01.pdf
Externe (Externalities of Energy)	A bottom-up methodology	Evaluates the external cost associated with the range of different fuels in different locations	http://www.externe.info/
ICLIPS (Integrated Assessment of Climate Protection Strategies)	Focuses on the long-term dynamics of the interactions between human society and the climate system	Uses tolerable windows approach. Perceived limits to potential climate impacts as well as requirements for an acceptable socio-economic development are specified and a set of emission reduction strategies that obey these constraints are identified.	http://www.pik-potsdam.de/research/past/1994-2000/iclips/
RICE and DICE	Climate-economy model.	Integrated economic and geophysical models of the economics of climate change	http://www.econ.yale.edu/~nordhaus/homepage/dicemodels.htm
IGSM (The MIT Integrated Global System Model)	Simulates the global environmental changes that may arise as a result of anthropogenic cause.	Research tool for analyzing potential anthropogenic global climate change and its social and environmental consequences	http://web.mit.edu/globalchange/www/if.html
MERGE	Model for estimating the regional and global effects of greenhouse gas reductions	Designing strategy for greenhouse gas (GHG) abatement	http://www.stanford.edu/group/MERGE/
MAGICC/SCENGEN (Model for the Assessment of Greenhouse-gas Induced Climate Change/ Regional Climate SCENario GENerator)	Software to investigate future climate change and its uncertainties both at global and regional levels.	To produce spatially-detailed information about GHG induced Climate Change.	http://www.cgd.ucar.edu/cas/wigley/magicc/

4.5 General strengths and weaknesses of IAMs

IAM studies continue to be developed and the direction of these developments can be classified into the following three. First, modelling targets and phenomena are becoming wider and more detailed than before in order to respond to widened audiences, new policy needs, and new scientific knowledge. Very detailed climate change scenarios were prepared for IAMs (Hulme et al. 2002), special dynamic models of land use and land degradation are trying to be integrated with emission and impact models (Hootsman et al. 2001; Groeneveld et al. 2000), technology factors are trying to be introduced as endogenous variables in IAMs (Weyant and Olavson 1999), and pluralism in value system are trying to be operated and reflected to future projection in IAMs (Janssen et al. 1998; van Asselt et al. 2002).

Furthermore, institutional factors such as governmental regulations, international regime and cultural systems have been proposed to be incorporated with IAMs.

The second direction is to apply IAMs to participatory IA process where stakeholders including policy makers and scientists communicate with each other to recognize the priority of information and decisions. The typical examples of the participatory IAM application are ULYSSES (Urban Lifestyles, Sustainability and Integrated Environmental Assessment) project (van Asselt et al. 2001), VISIONS (Integrated Visions for a Sustainable Europe) project (Rotmans et al. 2001), and COOL (Climate Options for the Long Term) project (Berk et al. 1999). These European scenario development processes of long term environmental change and policy introductions with policy makers and citizens.

The third direction of IAM development is to apply IAMs to regional and local assessment rather than global scale assessment. Lorenzoni et al. (2000) downscaled the IPCC global emission scenarios (IPCC 2000) into British impact assessment by means of their IAM, Green et al. (2000) estimated co-benefit of air pollution abatement policies and global warming mitigation policies for several countries, Amann et al. (2001) tries to extend an IAM on acid rain (RAINS) to multi-pollution and multi-effect model including air pollutants of SO_2, NOx, VOC, NH3 and to integrate it with country models (NIAM: National Integrated Assessment Model) to assess environmental impact in a national level (Johansson et al. 2001).

Such new developments of IAMs increase the audience and users, and IAMs are been adopting in many important processes of environmental policy making as core tool to link science frontier to their processes.

Dowlatabadi (1995) has deliberated on the possible contributions of IA models to policymaking in the field of climate change. Kolstad (1998), while reviewing the IA, goes to the extent of defining these models as a research field in itself. Rana and Morita (2000) write that it is extremely difficult to appease the policymakers with the analyses from IA models due to the level of abstraction in them as compared to the disciplinary analysis.

The integrated response to climate change has been discussed extensively at global level and to some extent at regional level. Such broad integrations are likely to help in improving the understanding of appropriate responses to climate change but may not necessarily be the most appropriate for local policymaking. IA may also be of interest to the local policymaker but the focus of integration will have to be across dimensions of impact sector, location, group and time. Hence, it is a common understanding that IA can work as a tool that can analyse and provide implications of alternate policy regimes and that it is best left to the policymakers to decide which policy to choose.

Risbey et al, 1996 opine that most of the IAMs trying to address complex issues are based on rather simple sub-models of natural and social systems. These models cannot, nor do they claim to, represent the real world. It is very important for potential users of IAMs to understand the limitations of these models before using the model results. The CIESIN, 1995 while highlighting the usefulness of the IAMs has also provided a list of limitations:

- The systems modelled are large, complex, and chaotic.
- The complexity of natural and social systems cannot be captured by IAMs.
- The full consequences of policies considered will not be known for decades or centuries.
- Over this span of time, many surprises will occur.
- Scientific knowledge is incomplete or absent in many areas.
- Values of human, animal, and plant life, health and diversity are difficult to quantify.

Usually, models that have complex or moderately complex economic or energy modules have simpler carbon cycle and climate modules. On the other hand, models with complex carbon cycle and climate modules have simpler economic and energy modules. Models that explicitly deal with uncertainty have overall simplistic structures. It is acknowledged in the literature that building a single model capable of addressing all the nuances of the climate change problem is not possible (Dowlatabadi, 1995).

Acknowledging that IAMs are limited in scope does not dismiss their usefulness. IAMs are intended to be tools for furthering our understanding of the climate change problem and not predictive models of what might take place. As such, they can provide insights into the climate change problem that are not available through other analytical and decision-making tools.

References

Burton, I., (1997). Vulnerability and adaptive response in the context of climate and climate change, Climatic Change, (36) 185-196.

Centre for International Earth Science Information Network (CIESIN). 1995. Thematic Guide to Integrated Assessment Modelling of Climate Change [online]. University Centre, Mich. CIESIN URL: http://sedac.ciesin.org/mva/iamcc.tg/TGHP.html

EIA, (2001). International Energy Outlook, Energy Information Administration, Office of Integrated Analysis and Forecasting, U.S. Department of Energy, Washington, D.C. (April 12, 2001).

Garg, A., D. Ghosh and P. R. Shukla, (2001c). Integrated energy and environment modelling and analysis for India, OPSEARCH, 38 (1).

ICIS (International Centre for Integrative Studies), (1999). Integrated Assessment: A bird's-eye view, Introductory guide prepared for the European summer school Puzzle Solving for Policy: Tools and Methods for Integrated Assessment, 30 August - 17 September, Maastricht, The Netherlands.

IPCC (Intergovernmental Panel for Climate Change), (2001a). Climate Change 2001: Impacts, Adaptation, and Vulnerability, Cambridge University Press, Cambridge.

IPCC (Intergovernmental Panel for Climate Change), (2001b). Climate Change 2001: Mitigation, Cambridge University Press, Cambridge.

IPCC (Intergovernmental Panel for Climate Change), (2001c). Climate Change 2001: The Scientific Basis, Cambridge University Press, Cambridge.

IPCC (Intergovernmental Panel for Climate Change), (1996a). Revised IPCC Guidelines for National Greenhouse Gas Inventories: Reference Manual, Vol. 3, Inter Governmental Panel on Climate Change, Bracknell, USA.

IPCC (Intergovernmental Panel for Climate Change), (1996b). Climate Change 1995: Economic and Social Dimensions of Climate Change, Contribution of Working Group III to the Second Assessment Report of the Intergovernmental Panel for Climate Change, Cambridge University Press, Cambridge.

IPCC (Intergovernmental Panel for Climate Change), (2000). Special Report on Emissions Scenarios, Cambridge University Press, Cambridge.

Kainuma, M., Y. Matsuoka, T. Morita and Go Hibino, (1999). Development of an end-use model for analyzing policy options to reduce greenhouse gas emissions, IEEE Trans on Systems, Man, and Cybernetics - Part C: Applications and Reviews, 29 (3) 317-324.

Kane, S. M. and J. F. Shogren, (2000). Linking adaptation and mitigation in climate change policy, Climatic Change, 45 (1) 75-102.

Knight, G. C., (2001). Centre for Integrated Regional Assessment: Progress Report, The Pennsylvania State University, University Park, PA.

Kolstad, C. D., (1998). Integrated assessment modelling of climate change, in W.D. Nordhaus, (ed.), Economics and Policy Issues in Climate Change, Resources for the Future, Washington, DC.

Matsuoka, Y., T. Morita and M. Kainuma, (2001). Integrated assessment model of climate change: The AIM approach, in Matsuno, T. and H. Kida, (eds.), Present and Future of Modelling Global Environmental Change: Towards Integrated Modelling, Terra Scientific Publishing Company, Tokyo. pp. 339–361.

Mayer, Nicola and Wendy Avis, (eds.), (1998). The Canada Country Study: Climate Impacts and Adaptation, Volume VIII: National Cross-Cutting Issues, Environmental Adaptation Research Group, Environment Canada.

Morgan, M. G. and H. Dowlatabadi, (1996). Learning From integrated assessment of climate change, Climatic Change, 34 (3-4) 337-368.

Parry, M., N. Arnell, M. Hulme, R. Nicholls and M. Livermore, (1998). Adapting to the inevitable, Nature, (395) 741-742.

Parson, E. A., (1995). Integrated assessment and environmental policymaking: In pursuit of usefulness, Energy Policy, (23) 463-475.

Parson, E. A., (1996). How Should We Study Global Environmental Problems: A Plea For Unconventional Methods of Assessment and Synthesis, International Institute for Applied Systems Analysis (IIASA), Luxemburg, Austria.

Pielke, R. A., (1998). Rethinking the role of adaptation in climate policy, Global Environmental Change, 8 (2) 159-170.

Rana A. and T. Morita, (2000). Scenarios for green house gas emission mitigation: a review of modelling of strategies and policies in integrated assessment models, Environmental Economics and Policy Studies, 3 (2) 277-289.

Risbey, James, Milind Kandlikar and Anand Patwardhan, (1996). Assessing integrated assessments, Climatic Change, (34) 369-395.

Rotmans, J. and H. Dowlatabadi, (1998). Integrated assessment of climate change: evaluation of methods and strategies, in S. Rayner and E. Malone, Human Choice and Climate Change: an International Social Science Assessment, Washington, USA, Battelle Press.

Schneider, S., (1997). Integrated assessment modelling of climate change: Transparent rational tool for policy making or opaque screen hiding value-laden assumptions?, Environmental Modelling and Assessment, 2 (4) 229-250.

Smith, J. B. and S. S. Lenhart, (1996). Climate change adaptation policy options, Climate Research, 6(2) 193-201.

Weyant, J. and O. Davidson, (1996). Integrated assessment of climate change: An overview and comparison of approaches and results, in IPCC (1996), op cit.

Wigley, Tom M.L., (1999). The Science of Climate Change: Global and US Perspectives, PEW Centre on Global Climate Change, Arlington, USA.

www.eia.doe.gov/pub/pdf/international/0484(2001).pdf

Chapter 5: Assessment of Tools and their Applicability in India

5.1 Introduction

IPCC projects that climate may warm globally by 1.4 to 5.8oC by the next 100 years, and over the Indian region the warming may be about 2.1 to 2.6 °C in the 2050s and 3.3 to 3.8°C in the 2080s (Shukla et al., 2003). The amount of rainfall is projected to increase. However there would be variations in its spatial pattern, with some pockets showing increase and some pockets indicating decrease in rainfall. The global sea level is projected to rise between 0.09 to 0.88 m till 2100 and that extreme events like excessive rain, flash floods, droughts, cyclones and forest fires are likely to increase.

India has substantial reasons to be concerned about climate change. Vast population depends on climate-sensitive sectors like agriculture and forestry for livelihood. The adverse impact on water availability due to recession of glaciers, decrease in rainfall and increased flooding in certain pockets would threaten food security, cause die back of natural ecosystems including species that sustain the livelihood of rural households, and adversely impact the coastal system due to sea level rise and extreme events. This aside, achievement of vital national development goals related to other systems such as habitats, health, energy demand, and infrastructure investments would be adversely affected.

Preliminary studies were carried out under the aegis of India's Initial National Communication (NATCOM) to assess the impacts of climate change on water resources, agriculture, forests, natural ecosystems, coastal zones, human health and energy and infrastructure. This activity also included development of climate change projections and future emission scenarios for India. Annex 1 lists all the studies that have been conducted. These efforts represent the extant scientific capacity, methodological coverage, data availability and constraints, besides shedding light on the vulnerability of different regions of the country to climate change and the need for devising adaptation responses. The subsequent sections analyze the assessment tools and their future applicability in India and the South Asian region as a whole.

5.2 Future climate projections

Rupa Kumar et al (2003) have used a suite of state-of-art coupled Atmosphere-Ocean General Circulation Models (AOGCMs) and a regional climate model (HadRM2) for projecting regional characteristics of rainfall and temperature over Indian sub-continent. Based on AOGCM experiments conducted for three types of future greenhouse gas emission scenarios (IS92a, A2 and B2), extending up to the end of 21st century and a two decade long HadRM2 simulations (only IS92a) pertaining to a future time slice of 2041-60, scenarios of rainfall and temperature are developed for the entire region. Apart from developing scenarios for temperature and rainfall, high-resolution HadRM2 simulations are also used to study extreme climate events and their future projections over India. Lal and Harasawa (2000, 2001), Lal et al (2000), Gadgil and Sajni (1998) have also used similar modelling techniques.

Regional detailing of global climate projections is a challenging task. Research in this direction has been initiated in India. However verification of sub-regional simulations conducted by Rupa Kumar et al (2003) with actual rainfall data over the last 100 years shows promising correspondence. The control simulation of HadCM2 provides a good representation of the mean climate of the south Asian monsoon, though it fails to capture some local details of the surface climate. The positions of the monsoon trough, lower and upper level jets are well simulated, as are the broad features of the surface temperature and precipitation. Upper level divergence, however, is overestimated, coincident with a deeper monsoon trough. The regional model reproduces the large-scale features of the GCM climate and adds realistic local detail. The annual cycles of rainfall and surface air temperature are also remarkably close to the observed patterns, which demonstrate that the regional model is able to overcome the large biases of the GCM in portraying these features.

Climate models are very data intensive and also need huge computational resources. The efforts by the Indian researchers are towards making more sub-regional and local (up to 50 km grid) climatic projections. These projections are then to be provided to modellers working on agriculture, forestry and land use, water resources, and coastal zone impact assessment. This is presently lacking.

The climatic projections are made for the entire Indian subcontinent region. For instance, figure 5.1 provides projections of seasonal precipitation for the entire region for the period 2041-60. Therefore it provides rich data and projections that could be used by other countries in South Asia, namely Pakistan, Bangladesh, Nepal, Sri Lanka, Bhutan, Maldives, and Burma for their impact and adaptation studies.

The climate change projections could be further developed for selected SRES emission scenarios using the latest version of the regional Hadley Centre climate regional model (HaDRM3). Future climate scenarios could be extended up to 2100 for suitable time slices as per the requirement of assessment studies.

5.3 Future emission projections

Long term modelling of carbon emissions in India has over a decade of experience and many institutions have well established research groups around these (Shukla, 1992; Loulou et al., 1997; Kanudia and Shukla, 1998; Rana and Shukla, 2001; Nair et al., 2003; Garg et al., 2003; Shukla et al., 2006). These studies have analyzed future CO_2 and non-CO_2 emissions under alternate scenarios.

Different ministries of the Government of India have also developed scenarios for future, which have been used in short-term and long-term policymaking. These include Hydrocarbon Vision 2025, Planning Commission five-year plan documents, Technology Information Forecasting & Assessment Council (TIFAC) reports on Technology Vision 2020 for seventeen sectors, Electric Power Surveys, Railways vision 2050, National Highways plan, Auto Fuel Policy (Mashelkar et al., 2002), and a few state level plans like Delhi 2021. Although, these studies have not been used for emission projections, they provide useful information on key driving forces.

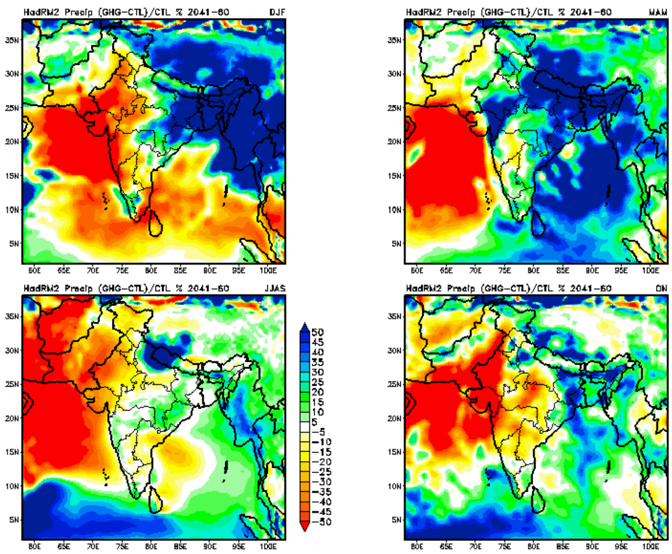

Figure 5.1:. Projections of seasonal precipitation for the period 2041-60, based on the regional climate model HadRM2.

Source: India's Initial National Communication to UNFCCC, 2003

Energy environment models can be classified as Top-down, Bottom-up, and Integrated models (refer figure 2.1). Almost all these models are used in India for policy research (Nair et al., 2003). The critical input and key parameters for these models are indicated in table 5.1.

Table 5.1: Key Inputs and parameters

Models	Key data inputs	Key parameters
ERB	Population, energy supply technology profiles, total resource base, production costs	Labour productivity, energy end use intensity, price elasticity of demand, income elasticity
SGM	Input-output tables, energy balance table, time series data for sectoral capital stock, demographic, land use	Substitution elasticities, Price elasticity of demand, Discount rate, Future technology parameters
AIM/Material	Input-output tables, industrial and municipal wastes, data on energy sector, environmental capital stock	Factor productivity, AEEI, Waste disposal growth efficiency
End-use Demand Projection	Time series data of sectoral production,	Long-term saturation level of sectoral production
AIM/Trend	Population, GDP, demand elasticities, sectoral value added	Energy demand, efficiency improvement projections, electricity and heat shares in various sectors
AIM/Enduse	Sectoral demands, technology profiles	Technology improvement, discount rate, countermeasures
MARKAL/Stochastic MARKAL	Sectoral demands, technology profiles (production efficiency, lifetime, fixed and variable costs, year of introduction), energy	Discount rate, Fuel supply curve characteristics, technology improvement

	prices	
Electricity Sector LP	Electricity demand, fuel availability, renewable energy availability	Technology and fuel characteristics
Emissions Inventory	activity levels	Emissions coefficients
AIM/Local	Large point and area source profiles, sectoral demand projections	Technology improvement, discount rate, countermeasures
Health Impact	Plant emission profiles, epidemiological data	Population distribution profile, stack height
AIM, MiniCAM	Input data for individual models (e.g. ERB, MAGICC and SCENGEN for MiniCAM)	Individual model parameters, interactions between key drivers (population, economy, energy, agriculture, land use, atmospheric dispositions etc.)

5.4 Water resources

At the national level there has not been any significant work on the climatic change impact assessment on Indian water resources, except a few discussions on general impact philosophy (Lal, 2001). A general projection of the water resource demand for 2050 has been worked out (Fig. 5.1) by the Central Water Commission and is provided by Thatte (2000).

Wilk and Hughes (2002) have used a monthly rainfall–runoff model for a large tropical catchment in southern India. Various land-use and climatic change scenarios were tested to assess their effects on mean annual runoff and assured water yield at the Bhavanisagar Reservoir. Owing to the fact that the dynamics of the hydrological processes cannot be well represented by models used with temporal scales of more than a day, it is imperative that wherever possible (due to factors such as data availability) continuous hydrological models with daily time step be used.

Gosain et al (2003) have used the SWAT (Soil and Water Assessment Tool) water balance model for the river basins to carry out the hydrologic modelling for the country. The SWAT model (Arnold et al., 1990) is a distributed, continuous, daily hydrological model with a GIS interface for pre and post processing of the data and outputs. It simulates the hydrological cycle in daily time steps. The SWAT model routes water from individual watersheds, through the major river basin systems. The system has been used for the assessment of the climate change impacts on water resources availability.

However there is much scope for extending the above initial impact assessment. These could include refinement of runoff estimates for the major river basins by incorporating major man-made interventions in the model simulations; identification of hotspots with respect to floods and droughts for current and future climate; conducting pilot studies for determining the stream flow of selected snow-fed rivers; assessment of impacts of current climate variability and climate change on selected glaciers; and assessment of water demand of various sectors under different climate change scenarios.

5.5 Agriculture

Many methods have been utilized by the Indian scientific community for assessing the possible impact of climatic variability and climatic change on agriculture.

Historical data analyses by various statistical tools and analogue approach have traditionally been used to assess the impact of climatic variability. Since environmental control, particularly of CO_2, is very difficult and expensive, there have been only a few studies all over the world in estimating its direct impact on crop plants. Controlled environment facilities such as open top chambers, Phytotron, and green houses are now increasingly being used to understand the impact of temperature, humidity and CO_2 on crop growth and productivity. Greater efforts are now also being made to establish Free Air CO_2 Enrichment (FACE) facilities where CO_2 is artificially increased in field conditions to quantify its possible impacts. One such facility has recently been setup at the Indian Agricultural Research Institute, New Delhi, to study the effect of increased CO_2 on crop photosynthesis and yield.

The interaction effects of CO_2, rainfall and temperature can be best studied through the use of crop growth simulation models. These models simulate the effect of daily changes on weather (including those caused by climatic change) for any location on growth and yield of a crop through understanding of crop physiological and soil processes. Several crop models have also been used in India for impact assessment of climatic variability and climate change. Models of various crops included in the DSSAT shell have been the most popular. For rice, ORYZA series of models have been effectively used. Indian models, such as WTGROWS for wheat, have been the basis of a large number of studies. Greater use of such crop models for impact assessment of climate change is, however, limited due to lack of a user-friendly framework that requires limited inputs and considers yield reduction due to pests and diseases in the tropics. InfoCrop is one such indigenous decision support system based on crop models that has been developed recently at the Indian Agricultural Research Institute to meet the stakeholders need for information on vulnerability of agriculture to climate change and for optimizing crop management. The InfoCrop modelling framework requires limited inputs and also includes databases of typical Indian soils, weather and genotypes. Current version of the model deals with chickpea, cotton, groundnut, maize, mustard, pearl millet, pigeonpea, potato, rice, sorghum, soybean, sugarcane, and wheat.

Further research could include assessment of vulnerability of major crops, livestock, fishery, and agriculture systems to current climate risks and future climate change; development of integrated assessment methodologies for assessing the vulnerability of different agro-climatic regions to climate change; assessment of the impacts of climate change on rain-fed cropping system in Peninsular India.

Promoting adaptation is critical for Indian agriculture system, which is dominantly rain-fed. The government sponsored crop insurance, monsoon forecasting, agriculture extension services to farmers, and enlarging irrigation systems are integral part of agriculture promotion in India. However further research and modelling studies have to be conducted in this area.

5.6 Forestry, land use and natural ecosystems

The models developed to explore the impact of climate change on vegetation fall into two broad categories. The Empirical-Statistical Models attempt to elucidate the relationship between existing climate and the existing vegetation. Once such a correspondence is obtained with a reasonable degree of reliability, it is possible to use it to project the distribution of these vegetation types for any future climate scenario. The comparison of such a projected distribution with the existing one can then serve as a basis for assessing the impact of climate change as expected under that scenario. Recently, more sophisticated methods of pattern recognition (e.g., the use of neural networks, genetic algorithms, etc), originating in the field of artificial intelligence are also being applied to the problem of the impact of climate change. The Simulation Models explicitly evaluate the temporal changes in the various components of the system (root/shoot biomass, soil-moisture levels, the concentrations of different pools of nutrients, etc) from one time-step to the next. The Equilibrium Models predict the final composition, biomass, etc, expected at a location, based on the input parameters (precipitation, temperature, radiation, soil carbon, etc). The Dynamic Models, on the other hand, enable one to track the changes expected during the course of the time-interval used in the simulation. These models vary greatly in their spatial scales, fundamental processes included in the model and the degree of complexity.

The impact assessment is carried out using the BIOME-3 model by predicting the equilibrium composition of different vegetation types under the ‘Control’ and ‘Greenhouse Gas’ (GHG) scenarios. The BIOME-3 model determines the equilibrium state vegetation combinations for each location. It combines the screening of biomes through the application of climatic constraints with the computation of the net primary productivity (NPP) and the leaf area index (LAI), both based on fully-coupled photosynthesis and water balance calculations.

The GCMs are more robust in projecting global mean temperatures compared to their ability for making predictions at regional levels. The uncertainty involved in the projections of temperature and, particularly, precipitation at the regional level is high. The vegetation response model, BIOME-3, is an equilibrium model and does not project the transient phase responses. Also, the database on soil, water and plant physiological parameters as inputs to the vegetation models such as the BIOME-3 is poor. Thus, the findings of the present analysis should be viewed with caution.

The study of natural ecosystems needs to be conducted in tandem with projected climate change scenarios. Mangroves, coral reefs and grasslands deserve special attention.

5.7 Coastal zones

India has over 7500 km long coastline and inhabited by more than a 100 million people. India also has two groups of islands.
The assessment of the vulnerability of coastal zones to projected climate impacts and the development of adaptation strategies include;

- Analysis of the present vulnerability, including representative vulnerable groups
- Assessment of potential vulnerabilities in the future
- Comparisons of vulnerability under different socio-economic conditions, climatic changes and adaptive responses.
- The identification of points and options for intervention, which would lead to the formulation of adaptation responses.
- The final task is to relate the range of outputs to stakeholder decision-making, public awareness and further assessment.

A greater emphasis is placed on the first two components in India, that is, hazard and exposure, and the combination of the two, which are the actual climate impacts in coastal regions. There have been a few independent case studies on sea-level rise and its implications in various regions. GIS techniques and satellite imagery have been used for this purpose. Use of models and modelling techniques has so far been limited. Specific areas for research could be assessment of sea-level rise along the

Indian coast line based on data available from tide-gauge measurements; simulation of sea-level rise along the Indian coast for various climate change scenarios and an assessment of the frequencies & magnitude of occurrences of storm surges; and assessment of impacts of sea-level rise and cyclone/storm surges on coastal settlements and infrastructure.

5.8 Energy and infrastructure

India, as a developing country, is and will be investing heavily in infrastructure development such as coastal power plants and transmission networks, hydroelectric dams, transport in hilly and coastal areas (roads, bridges, and rail networks), coastal industry, coastal settlements etc. These are long-term assets and exposed to nature and therefore to the changing climate. However there is not much research conducted to capture these aspects and include them into national planning. An interesting methodology has however been developed for such impact assessment – termed as "reverse impact matrix" (Kapshe et al., 2003). Future climate scenario analysis has been gainfully employed to analyze the impacts of climate change on a hilly railway network, resulting in identification of critical parameters for future impacts. This methodology could be further expanded to include the role of development in climate related impacts and whether synergies could be utilized for more resilient infrastructure planning.

5.9 Human health

Any projections about the extent and direction of the potential impacts of climate variability and change on human health are extremely difficult to make with confidence because of the many confounding and poorly-understood factors associated with potential health problems. These factors include the sensitivity of human health to various aspects of weather and climate, the differing vulnerability of various socio-economic, demographic, and geographic segments of the population, movement of disease vectors, health sector reforms, and how effectively prospective problems can be dealt with. Modelling the health impacts is therefore that much more difficult. Indian researchers have however analyzed incidence of malaria - existing and future. Projection of climatic parameters, namely average temperature, humidity, precipitation, have been employed to project state-level likely incidence of malaria in future. This approach however does not include effects of other aspects as mentioned above.

Prospective studies could include identification of indicators of vector generation and malaria transmission; impacts of climate change on malaria & dengue at national, state and selected district levels; including effects of socio-economic and health sector developments in future health assessments; heat stress impact assessment; and role of development policies for enhancing resilience of population to adverse health impacts of climate change.

5.10 Conclusion

India is one of the leaders in developing countries in climate change related impact assessment on various sectors. However there is a long way to go for more credible, reliable and consistent assessments. The major thrust areas for future analysis would aim for the following;

- Consistency across climate change scenarios, socio-economic scenarios and sectoral/regional impact assessments

- Development of consistent scenarios and databases at finer grid levels for the above
- Integrated impact assessment
- Identification of critical regions/sectors where severe impacts are likely to occur in short, medium and long terms
- Sensitivity and uncertainty analysis of impact assessment
- Adaptation studies and more use of modelling
- Linking investment needs with impacts and adaptation
- Linking development with climate change adaptation and mitigation
- Capacity building for modelling in all sectors and disciplines

References

Lal, M. and H. Harasawa, 2000: Comparison of the present-day climate simulation over Asia in selected coupled atmosphere-ocean global climate models. Journal of the Meteorological Society of Japan , 78(6), 871–879.

Lal, M. and H. Harasawa, 2001: Future climate change scenarios for Asia as inferred from selected coupled atmosphere-ocean global climate models. Journal of the Meteorological Society of Japan, 79(1), 219–227.

Lal, M., G.A. Meehl, and J.M. Arblaster, 2000: Simulation of Indian summer monsoon rainfall and its intraseasonal variability. Regional Environmental Change, 1(3/4), 163–179.

Annex 1 (for chapter 5)

Future scenarios: Climate and emissions

National Circumstances for a sustainable future
Jyoti Parikh, Kirit Parikh and Seema Roy

Regional climate change scenarios for India
K. Krishna Kumar, K. Rupa Kumar, K. Kamala, V. Prasanna and S. K. Patwardhan

Future scenarios of extreme rainfall and temperature over India
K. Krishna Kumar, N. R. Deshpande, P. K. Mishra, Preethi Bhaskar and K. Rupa Kumar

Emission scenarios and CO2 emission projections
P. R. Shukla, Amit Garg, K. K. Sharma and Manmohan Kapshe

Estimation of present and future emissions of HFCs, PFCs and SF6 from Indian industry
Sukumar Devotta and Saroja Asthana

Future methane and N2O emissions for India
Amit Garg, P. R. Shukla and Manmohan Kapshe

Impacts of climate change on Energy, Industry and Infrastructure
Manmohan Kapshe, P. R. Shukla and Amit Garg

<u>Water resources</u>

Assessment of Vulnerability and Adaptation for Water Sector
A. K. Gosain, Sandhya Rao, Debajit Basuray

GIS based evaluation of the impact of climate change on hydrology for better decision-making at a river basin level in India
Kapil K Narula and Suruchi Bhadwal

Impact of climate change on Chhota Shigri glacier, Chenab basin and Gangotri glacier, Ganga headwater in the Himalaya
Syed I. Hasnain, Sarfaraz Ahmad and Rajesh Kumar

Impact of Climate Change on Himalayan Glaciers
Anjani K.Tangri

Vulnerability Assessment of the Lower Ganga-Brahmaputra-Meghna Basins
Pankaj Kumar Roy, Debasri Roy, Asis Mazumdar & Balaram Bose

Biogeochemical Modelling studies of the Achankovil River Basin
M. Bala Krishna Prasad and AL. Ramanathan

Climate Change and Ground Water Resources of Deccan Basalt and Ganga Basin
Dr. D.K. Chadha

Impact of Climate Change on Water Availability Case Study of City of Delhi
Kalipada Chatterjee, Vivek Kumar & Samrat Sengupta

Increasing Community Resilience for Adaptation to Adverse Impacts of Climate Change: Case Study of a Drought Prone Area in India
Kalipada Chatterjee and Vivek Kumar

<u>Agriculture sector</u>

Correlation between Crop Yields and Climatic Variability/ Change and Adaptation Strategies
Naveen Kalra, P.K. Aggarwal, S. Chander, H. Pathak, R. Choudhary, A. Chaudhary, R.L. Sapra, Sujith Kumar and Mukesh Sehgal

Impact of enhanced CO_2concentration on crop growth
D.C.Uprety, N.Dwivedi, D.C.Saxena, A Raj, G.Paswan, Ranjan Das and K.B.Sujatha

Assessment of climate change impacts on irrigated and rain fed crop production systems
R. Selvaraju

Adaptation strategies for farmers in case of adverse impact of climate change on sorghum cultivation in North Karnataka
H. Venkatesh, K. Krishna Kumar, M.A. Bellakki, S.G. Aski and S.M. Warad

<u>Forestry, land use and natural ecosystems</u>

Spatial Distribution of Forest Species Composition and growing stock - A GIS Approach
J.K. Rawat and Alok Saxena

Vulnerability and adaptation to climate change in the forest sector in India
N. H. Ravindranath, N. V. Joshi and R. Sukumar

Potential Impact of Climate Change on Forests: a case study in Uttaranchal
Varghese Paul, T. P. Singh and Arundhati Das

Assessment of Garhwal Himalayan Forest with Special Reference to Climate Change
Bhupendra S. Adhikari and Gopal S. Rawat

Climate change impact assessment on vegetation structure and composition in wet evergreen and shola forests of Kerala part in the Western Ghats
U.M. Chandrashekara

Impact of climate change on mangrove forests along the southern west coast: A case study from Kasargod, Kerala, India
Tanaji G. Jagtap, Z. A. Ansari, F. B. Coutinho, S. Charulata and D. M. Gaidhane

A case study of sequestration of carbon through afforestation
N.K. Srivastava, L.C. Ram, S.K. Bharati, S. K. Thakur, Joshy George, R.C. Tripathi and G. Singh

Climate change impacts on natural ecosystems in India
R. Sukumar

Assessment of vulnerability of forests, meadows and mountain ecosystems due to climate change
K.G. Saxena, P.S. Ramakrishnan, R.K. Maikhuri, K.S. Rao and S. Patnaik

Limnological studies on the Conservation of Lotic Ecosystem of Tripura with reference to the impact of Climate change
Sukanta Banik

Vulnerability Assessment of Kachchh District of Gujarat
M. S. Bhagwat, B. S. Roy and S Raina

Impact of climate change on marine ecosystems of India
A.G. Untawale

A Preparatory Assessment of Vulnerability of the Ecologically Sensitive Sundarban Island System, West Bengal, in the Perspective of Climate Change
Sugata Hazra, Kaberi Samanta, Rajashree Dasgupta, Gautam Sen

Sea level rise and coastal zones

Vulnerable Areas and Adaptation Measures for Sea Level Rise along the Coast of India
Onkar S. Chauhan, A. S. Unnikrishnan, A. A. A. Menezes T.G. Jagtap, J. Suneethi and R. Furtado

Assessment of Vulnerability of Indian Coastal Zones to Climate Change
Anand Patwardhan and K. Narayanan

The Impact of Sea Level Rise on Surface Inundation and Salt Water Intrusion in Goa
Ligia Noronha, A G Chachadi and B S Choudri

<u>Health</u>

Impact of Climate Change on Malaria in India
A.P. Mitra, Sumana Bhattacharya, C. Sharm, K. Krishnakmar, A.A. Munot, Rekha Tiwari and Manoj Joseph

Impact of Climate Change on Malaria in India with Emphasis on Selected Sites
Ramesh C. Dhiman, Sharmila Bhattacharjee, Tridibesh Adak and Sarala K Subbarao

Chapter 6: Next Generation Tools for Assessing Vulnerability and Adaptation [2]

6.1 Introduction

A growing body of literature in the past two decades has examined climate change as one of the most important issue in global environmental systems, and has analyzed vulnerability and biodiversity loss arising out of the same. The IPCC concludes out that the vulnerability of a region depends to a great extent on its wealth and that poverty limits adaptive capabilities (IPCC, 2000). Furthermore socio-economic systems "typically are more vulnerable in developing countries where economic and institutional circumstances are less favourable". Natural disasters are one of the important causes that increase the vulnerability of regions and populations. Climate change is projected to increase the frequency and magnitude of extreme weather events thereby increasing vulnerability. The natural hazards literature (Cutter, 1996) suggests that vulnerability arises from a combination of factors, such as location, infrastructure, and the socioeconomic characteristics of the population including access to resources, and poverty. It can be described as the combined result of a number of outside stimuli, and the properties of a system. Countries, regions, economic sectors and social groups may differ in their degree of vulnerability to climate change therefore both because of differences in exposure to climate related events, and socio-economic, cultural, and political factors.

Related to the concept of vulnerability is the issue of adaptation. According to the IPCC Third Assessment Report, adaptation "has the potential to reduce adverse impacts of climate change and to enhance beneficial impacts, but will incur costs and will not prevent all damages." Furthermore, it is argued that human and natural systems will, to some extent, adapt autonomously and that planned adaptation can supplement autonomous adaptation. However, "options and incentives are greater for adaptation of human systems than for adaptation to protect natural systems" (IPCC, 2001). Therefore adaptive capacity is defined as "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. The goal of an adaptation measure should then be to increase the capacity of a system to survive external shocks or change".

The foregoing review of current methods and tools to measure vulnerability and adaptation reveals several gaps and limitations. Most indices & measurements of VA use a very narrow definition of vulnerability and have constructed a common set of proxies or variables at the macro and micro level which ignore the specificities of local or regional factors that are crucial in determining vulnerability and adaptive capacity. However vulnerability is due to several factors.

This concluding chapter of the Handbook develops a comprehensive framework for vulnerability assessment that encompasses various dimensions and suggests an index that can be quantified and compared over a period of time. The new method focuses on indicators that measure (a) the dynamic context of livelihoods, demography, agro-climatic aspects and infrastructure (b) the state of development of a region or population and (c) a population's capacity to progress in economic and social terms. As the new conceptual framework gives a richer, more complete picture of socio-economic vulnerability and adaptive capacity, it is an important contribution

[2] This chapter is based on studies of vulnerability and adaptation in India undertaken by members of the BASIC India team D.Parthasarathy, K.Narayanan, and Unmesh Pattnaik (Department of Humanities and Social Sciences, Indian Institute of Technology, Bombay, India).

to BASIC and other countries in moving forward with concrete adaptation policies, programmes and projects.

6.2 Vulnerability: Assessment and Measurement Issues

In assessing and measuring vulnerability, it is important that one understands its socio-economic context, i.e. the socio-economic status of a group is closely linked to the adaptive capacity of that particular group. Many factors contribute to social and economic vulnerability including rapid population growth, poverty and hunger, poor health, low levels of education, gender inequality, fragile, marginal and / or hazardous location, and lack of access to infrastructure, resources and services, including knowledge and technological means. Assessment of current vulnerability can be and has been done using a variety of variables derived from these factors.

However, assessing vulnerability and adaptive capacity is far from being a simple task, given the dynamic shifts that characterize the lives and livelihoods of the poor anywhere in the world. Unlike measurement of ‘states’ – of poverty, well being, health, etc., assessment of vulnerability – by being linked to a composite set of factors impinging on people’s adaptive capacities – is a complex methodological exercise that has to factor in states of flux and dynamic situations rather than measure static contexts, or simple shifts in welfare and well being. Since assessment of vulnerability and adaptation are related to decision making processes and policy shifts, it is essential that the tools used be appropriate and accurate. Much of the literature in this area also make the mistake of confusing exposure to climate related events with vulnerability, which entirely misses the important theoretical point that vulnerability arises out of the failure to manage risks associated with climate related uncertainties, and that adaptation, risk reduction and vulnerability reduction strategies have existed in the past despite exposure to climate related stresses.

A review of methods, tools and techniques to measure vulnerability and adaptation described above reveals several gaps and limitations. Most indices and measurements of vulnerability have a common set of proxies or variables at the macro and micro level which ignore the specificities of local or regional factors that are crucial in determining vulnerability and adaptive capacity. The use of monetary values only to evaluate losses (which are of little relevance in subsistence economies), a lack of attention paid to the resilience and adaptation of many systems to climate related variability, and the assumption of linear responses (positive and negative) across time are some of the other shortcomings.

Measurement techniques also suffer from limitations due to choice of proxies, which are themselves determined by data limitations. Proxies may or may not accurately represent the aspects being assessed – in this case vulnerability. Assessing vulnerability also becomes difficult when temporal variations are inadequately addressed either by giving them too much importance or too little. Since variations in socio-economic systems and climate regimes already exist, the approaches presented in this paper make an important methodological advance by looking at ‘variance in variance’ – significant shifts in trends and variability along selected indicators.

Here we try to construct methods of assessing socioeconomic vulnerability and adaptive efficiency by focusing on indicators that measure a) the dynamic context of livelihoods, demography, agro-climatic aspects, and infrastructure, b) the state of development of a region or population, and c) a population’s capacity to progress in economic and social terms.

The theoretical basis and conceptual framework behind the development of tools (vulnerability index and adaptive efficiency) is given in Figure 6.1 below.

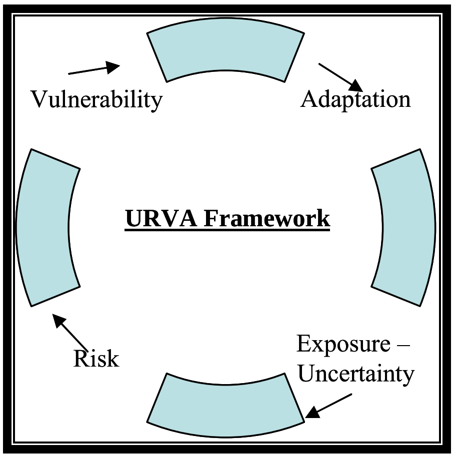

Figure 6.1: Conceptual framework used for development of the tools (vulnerability index and adaptive efficiency)

The conceptual framework starts with exposure to climate change related events which create uncertainties. Uncertainty issues are usually addressed by converting them into risks, which involves gathering knowledge and information regarding the sources of uncertainty. The inability to manage risk effectively due to a variety of factors results in vulnerability. Adaptation essentially is to do with reducing vulnerability and more effectively managing risk through coping strategies which enhance adaptive capacity. A fundamental assumption here is that vulnerabilities arise from and are a function of factors which minimize the ability to convert exposure related uncertainties into risk, i.e., vulnerability does not simply arise due to exposure to climate change related external shocks or stresses. Vulnerability is thus hypothesized as emerging endogenously from within a system even though the endogenous factors may determine how vulnerable a population is to exogenous shocks. Based on this conceptual understanding of the relationships between exposure, uncertainty, risk, vulnerability and adaptation, we have attempted to develop two tools to measure vulnerability and adaptation – a vulnerability index and an adaptive efficiency measurement tool.

In our framework vulnerability arises from the inability to manage risk effectively and efficiently adapt to it. So vulnerability can be termed as the inability to adapt to the extremes. Vulnerability also refers to a situation when certain groups in society are more vulnerable than others to shocks that threaten their livelihood and/or survival. Vulnerable groups may live in a chronic state of impoverishment in which their livelihood is constantly at risk. This concept of vulnerability has two elements:

- the severity of the impact of the shock (the more severe the impact if the risk is not managed, the higher the vulnerability), and
- resilience to a given shock (the higher their resilience, the lower their vulnerability), in other words, resilience is an indicator of adaptive capacity.

Lack of adaptation/vulnerability therefore arises from a lack of opportunity to manage risk. In effect then, a small decline in welfare, or a minor shock or disaster could be life and livelihood threatening, or would at least have permanent consequences for different forms of capital or assets. The vulnerable thus would include not only those who are poor but also those sections of the non-poor who are potentially exposed to severe shocks and have little ability to manage risk, in other words, those likely to find themselves in poverty after a shock has occurred. Vulnerability is often reflected in the condition of the system and the socioeconomic characteristics. Assessment of current vulnerability can be done using a variety of socioeconomic indicators. The socio-economic status of a group is closely linked to the adaptive capacity of that particular group. Many factors contribute to social and economic vulnerability including rapid population growth, poverty and hunger, poor health, low levels of education, gender inequality, fragile, marginal and / or hazardous location, resource degradation, and lack of access to infrastructure, resources and services, including knowledge and technological means. Vulnerable populations have a limited capacity to protect themselves from natural hazards, especially from extreme events such as cyclonic storms, drought and floods. They bear the brunt of the consequences of large-scale environmental change, including land degradation, biodiversity loss, and climate change, which affect the welfare of the most vulnerable populations. Over the long term, vulnerable populations will need to learn to cope with the effects of climate change on their production structures.

The vulnerability index that has been developed in this chapter tries to capture vulnerability in greater depth and on a more comprehensive scale. This is done by carefully choosing a set of variables, by combining variables related to socio-economic and agro-climatic factors, and by combining them in a composite index by modifying existing methodologies. This is done by including many indicators that serve as indicators or determinants of vulnerability. In other words we assume that vulnerability can arise out of a variety of factors. In particular we look at six different sources of vulnerability. The different sources that we consider crucial in determining the vulnerability of people in a particular region are: (1) climatic factors (2)demographic factors (3) agricultural factors (4) occupational factors (5) infrastructure and (6) the level of poverty and inequality. The idea is to prepare an index to map the vulnerability among populations of a chosen region or country. Figure 6.2 shows the framework developed to estimate the extent of vulnerability of people in area exposed to climate change related extreme events, using the proposed vulnerability index.

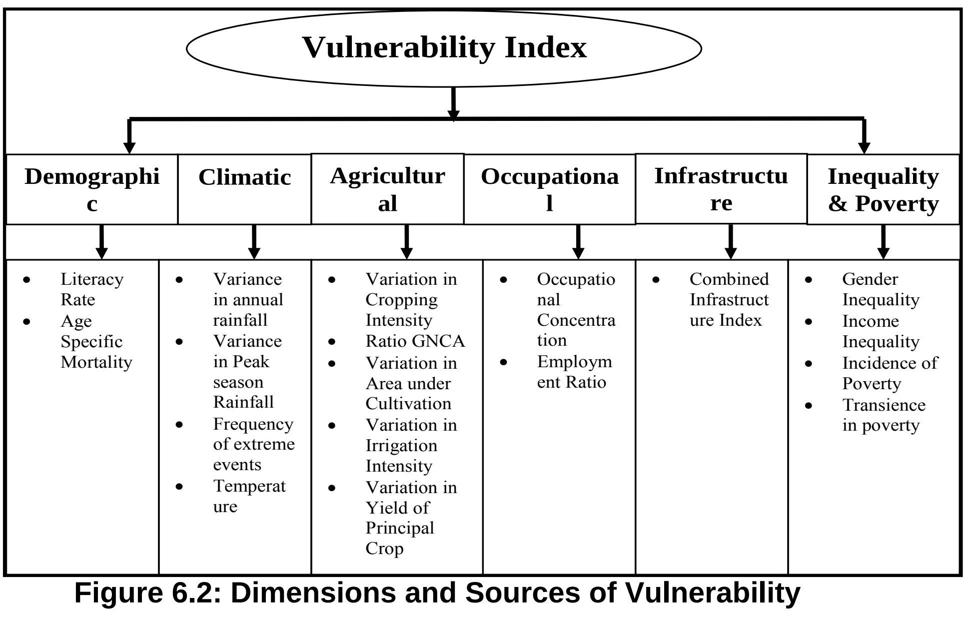

Figure 6.2: Dimensions and Sources of Vulnerability

6.3 Description of Indicators and Proxies

This section explains the rationale for inclusion of these sources in the vulnerability index.

6.3.1 Demographic indicators

The structure of the population plays a key role in determining vulnerability and defining the resilience of the people to environmental shocks. The impact of demographic characteristics on vulnerability is captured by two indicators; literacy rate and age specific mortality. Mortality is quite crucial in assessing the inherent vulnerability of people in hazard prone areas. The level of education of people is highly significant in defining the socioeconomic vulnerability. In terms of our framework this is determined by the actual literacy rate. Education is a provision that not only might help to reduce vulnerability in future generations but also, higher education levels will imply higher human capital. This will be helpful in reducing vulnerability in post disaster situations. Theoretically a population that is literate is more likely to be resilient due to their ability to draw on alternative entitlements in the face of a shock.

6.3.2 Climatic indicators

Climate variability and change have direct impacts on vulnerability of people through flooding, droughts, changes in average temperatures, temperature extremes, and extreme weather events. In addition, climate variability can affect natural resource inputs important to production. Climate variability can affect food sensitivity particularly related to food production. Variability in precipitation affects crop production directly, as well as through impacts on soils, pest and disease outbreaks, and other mechanisms. For example, in an agricultural area with high dependency on climatic conditions due to lack of alternative sources of irrigation, the following four proxies could be used to analyze the impact of climatic factors on current vulnerability. The proxies are (1) variance in annual rainfall (2) variance in peak season rainfall (3) frequency of occurrence of extreme events and (4) variation in temperature. The proxy frequency of occurrence of extreme events accesses the current vulnerability based on historical data. Similarly trends and variance in temperature based on historic data will be crucial for vulnerability. If there is large variability in temperature across different years vulnerability of the region will also be higher.

6.3.3 Agricultural indicators

Agricultural vulnerability refers to food and livelihood security. It is defined as the potential for changes in the availability of food in a particular geographic area (district). Five indicators are used to give a picture about vulnerability arising from agricultural pattern. The indicators used are variation in cropping intensity, variation in the ratio of gross cropped area to net cropped area, variation in irrigation intensity, variation in area under cultivation and variation in yields. Cereals production captures the state of development in the agriculture sector and the access of farmers to production inputs. If the production over years has been sufficiently high then it implies that extreme events can be instrumental in increasing current vulnerability by destroying the standing crops. By stating this we are assuming that there is no buffer storage facility and the harvests of a particular year are consumed in that year itself. This assumption is quite rigid to make but if we are interested in studying the current vulnerability of the people at one point of time this assumption may be necessary. The other three indicators - cropping intensity, area under cultivation and irrigation intensity also reflect the degree of modernization in the agriculture sector and the access of farmers to production inputs. The higher these are, the higher will be the production and hence lower will be the vulnerability.

6.3.4 Occupational indicators

The composition of the labour force is also one of the crucial variables that is not only important from the point of view of current vulnerability but also is important in determining future vulnerability. The composition of the labour force reflects the social and economic resources available for adaptation. Two proxies that could be used are: occupational concentration of workers and employment ratio (ratio of non workers to the total population in a region). This will reflect the adaptability of the labour force in post disaster situations. A highly productive labour force defines a high institutional strength and stability of public infrastructure. A strong institutional setup is likely to reduce social vulnerability. Hence a stable and diverse occupational structure will mean that the labour force is utilized optimally. If there is more concentration of workers in some particular category it indicates a lack of options and higher chance of vulnerability. Similarly a higher number of non workers will also increase the vulnerability of people in disaster prone regions in terms of adaptive capacity.

6.3.5 Infrastructural indicators

The impact of climate change on infrastructure and to the population takes place through a variety of ways. Physical infrastructure is directly affected by climate related changes. The economy of the area in concern can also be affected in an indirect way.

Table 6.1: Summary of the variables used, their data source and the apriori expected functional relationship between the indicator and the vulnerability context

Sources of Vulnerability	Indicator	Description of the Indicator	Hypothesized functional relationship between the Indicator and Vulnerability
Demographic	Illiteracy Rate	Number of illiterates per district population	The higher is the literacy rate higher will be the vulnerability
	Age specific Mortality	Age specific mortality rates (Infant, under 5, and other age groups, gender wise)	The higher is the mortality rates and gender differences the higher will be the vulnerability
Climatic	VAR	Variance in annual rainfall	The higher is the variance higher will be the vulnerability
	VJJA	Variance in Peak Season rainfall	The higher is the variance higher will be the vulnerability
	Events	Frequency of extreme events (severe storms and storms)	The higher is the frequency of extreme events higher will be the vulnerability
	Temperature	Trends and variance in Mean temperature	The higher is the increase and variance the higher will be the vulnerability
Agricultural	Cropping Intensity	Net Cropped Area/ Gross Cropped Area	The higher is the variation in cropping intensity the higher will be the vulnerability

	RGNCA	Gross Cropped Area/ Net Cropped Area	The lower is the ratio the higher will be the vulnerability
	Variation in Area under cultivation	Net Cropped Area/ District Area	The higher is the area under cultivation higher will be the vulnerability
	Variation in Irrigation Intensity	Net Irrigated Area/ Net Cropped Area	The higher is the variation in irrigation intensity the higher will be the vulnerability
	Variation in yield	Variation in Yield per unit area of the major crop	The higher is the variation in yield the higher will be the vulnerability
Occupational	Occupational concentration	Number of workers in different occupations a district	The higher is the concentration in one or more categories the higher will be the vulnerability
	Employment Ratio	No. of non-workers in a district/ Total no. of workers	The higher is the number of non-workers the higher will be the vulnerability
Infrastructure	Combined infrastructure index (CII)	Length of roads banks, schools, hospitals, transport in proportion to area and population	The lower is the index for CII the higher will be the vulnerability
Inequality and Poverty	Gender inequality	Gender inequality in literacy and in workforce	The higher is the gender inequality higher will be the vulnerability
	Income inequality	Gini coefficient	The higher is the Gini coefficient higher will be the vulnerability
	Incidence of Poverty	Head Count Ratio	The higher is the HCR higher will be the vulnerability
	Poverty ratios	Poverty gap and squared poverty gap index	The higher is the poverty higher will be the vulnerability

This is through the change in market demand for goods and services produced in the concerned area. Relief services post extreme events are dependent on physical and social infrastructure such as roads, communication, banks etc., and the lack of these can inhibit effective provision of relief services. Therefore the absence of infrastructure services in a particular region will seriously affect the vulnerability condition of that area. Infrastructure plays a key role in influencing vulnerability and enhancing adaptive capacity. In terms of our framework this aspect is captured by a combined infrastructure index which measures the infrastructure facilities of a region relative to the population and area of that region. Therefore there will be an inverse relationship between the infrastructure index and vulnerability; in other words, the lower is the index higher will be the vulnerability.

6.3.6 Inequality and Poverty indicators

The relationship between vulnerability and poverty is very complex in nature. Poverty can cause vulnerability but can also be an outcome of vulnerability over years. Since our framework is more concerned with estimating current vulnerability we comprehend that greater inequality and poverty over years will result in greater vulnerability. With this framework we have identified some indicators to reflect on the current vulnerability of a region due to inequality and poverty over time. The indicators are - the level of gender inequality, income inequality, incidence of poverty and transition in poverty rates. A higher gender inequality means deprivation of particular section of society and hence higher level of this will mean greater vulnerability. Similarly income inequality indicates that there is an imbalance in the income pattern and consumption power across the various population strata. So this will also mean higher vulnerability for certain strata of population in the hazard prone area. Finally higher levels of poverty and higher levels of stochastic poverty implies that a greater section of the population lives below the per capita income levels and also moves in and out of poverty levels thereby indicating and increasing the vulnerability of that population.

Having selected indicators based on their theoretical role in determining vulnerability (a detailed in Table 1), it is necessary to carry out some form of standardization to ensure that they are comparable. To arrive at a dimensions index for some of the indicators (indicators where we need to calculate the variance in the proxies) simple standardization is carried out which fits variables to relative positions between -1 and 1. This is done by using the formula:

$$\frac{ActualXi - MeanXi}{MaximumXi - MeanXi} \quad (1)$$

The formula departs from standard ones used in composite indices such as HDI by substituting the minimum value in the numerator with the mean value. This is done since the variables are measured dynamically (variation and trends) rather than in a static way. By doing, so we eliminate the possible effects of natural variation, and only consider variation beyond the normal which are due to climate change related effects.

For other indicators we apply a normalization procedure so that rather than refitting the actual range of values across the 0-1 scale, they are fitted to a normative scale of what is deemed high and what is deemed low. For example the actual values are normalized onto a categorical scale such that each indicator is ascribed a value between 0 - 1 in terms of their relative vulnerability position.

For indicators which show an inverse relationship with the state of vulnerability, we carry out a standardization procedure to equate these with other indicators showing a positive relationship with vulnerability levels. This is achieved by simply subtracting the obtained value of the indicators from 1 so that all values lie between 0-1 and the relationship between the direction of movement of an indicator's value and vulnerability levels remain the same for all indicators.

This allows an assessment of relative levels of vulnerability pattern across populations and regions and more specifically rank them according to vulnerability pattern over certain time periods. For this we follow a very simple standardization method. The methodology used to calculate the final vulnerability index follows the basic approach developed by (Anand and Sen, 1994) for the final calculation of the human development index (HDI) after creating the dimensions index. So to construct the final vulnerability index for the different areas we can assign equal weighs to all the indicators listed above and calculate a simple weighted average of all the indicators. This is done by taking a simple average of the indicators in each category.

$$\text{Vulnenability Index}_i = \left(1/N\right) Indicator\ 1 + \ldots\ldots\ldots + \left(1/N\right) Indicator\ J \quad (2)$$

Where,
J = Different indicators representing the different sources of vulnerability
n = Total number of indicators (in the present case n = 18)
i = Represents the population

After the values of the index are calculated for all the populations or regions a ranking of the various units can be done to identify the most vulnerable ones in terms of the indicators used for measurement. This analysis can be repeated for different time periods in order to see how the vulnerability profile has changed over the years for the units in terms of the indicators used to measure vulnerability.

6.4 Adaptation: Assessment and Measurement Issues

The concept of vulnerability and adaptation are deeply related to the amount of threats and risk perception by the people in a system. This perception of risk is dynamic in nature and varied and hence the perception of risk influences adaptation behaviour and vulnerability. The perception of risk is not only dependent on social values, attitudes, social structure and culture but also on livelihood patterns and structures and poverty levels. The concept of adaptive efficiency (AE) introduced by Douglass North (North, 1990) as a theoretical framework provides some insights in understanding the nature of vulnerability but does not provide a comprehensive picture of the true nature of vulnerability of populations. The concept was introduced to overcome the deficiencies in the traditional concept of allocative efficiency. North himself has said that that the concept is insufficiently understood and there exists no model to help us understand or measure it better. Understanding AE requires an understanding of the concepts of uncertainty, risk, and vulnerability and the relationship between them. Uncertainty arises in a dynamic situation where there is no probability distribution of outcomes as we have insufficient knowledge of a system and its behaviour. We cope with uncertainty by reducing it to risk which involves acquiring more information and knowledge about the causes of uncertainty and the system in which uncertainty prevails.

Therefore assessment of vulnerability and adaptation will be considerably enhanced if we use the adaptive efficiency approach which is more appropriate for dynamic systems. A theoretical framework that looks at adaptive efficiency rather than allocative efficiency and that integrates with Amartya Sen (1987) - capabilities approach is perceived as the best one for assessing vulnerability and adaptation of regions and populations. Livelihood diversity and increased access to resources and institutions, combined with freedom from discrimination and policies promoting equity enhance choice and hence the ability to deal with risk better, thus reducing vulnerability. Greater choice, indicated by greater capability levels enables individuals, households and communities to respond and adapt better to short and long term changes. Sociologists and economists argue that risks are socially allocated and distributed, and hence adaptation strategies to mitigate vulnerability by better responding to risk should be based on enhancing choice, flexibility, and equity. The concept of adaptive efficiency defines how economies and societies work effectively in a dynamic time frame thereby helping in assessing adaptive efficiency of population or region to climate change. Vulnerability of population / region can be captured through simple proxy variables (poverty, infrastructure, etc.) or a more comprehensive index. This permits mapping of climate change scenarios with vulnerability scenarios over a period of time. Figure 6.3 describes the conceptual framework of adaptive efficiency by tracing its linkages to the vulnerability context and the ways in which adaptive capacity can be enhanced for a given population.

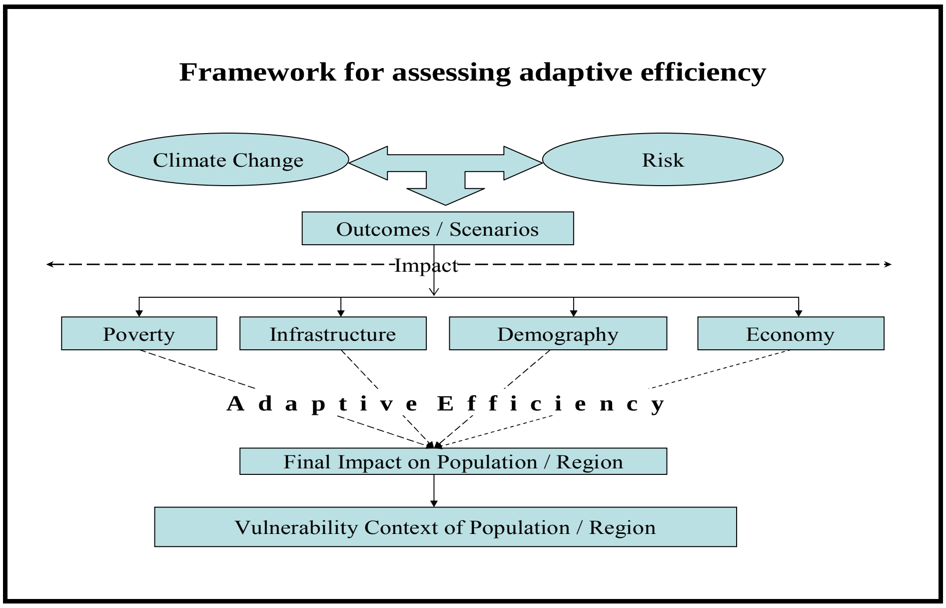

Figure 6.3: Framework for using adaptive efficiency

For the purpose of development of a tool to assess adaptive efficiency, vulnerability is seen to be derived from (i) exposure to risks and shocks and (ii) an inability to manage these risks and shocks (adaptive capacity) due to inadequate assets, infrastructure and social protection mechanisms (such as social insurance and assistance), access and availability of coping mechanisms (including institutional mechanisms, technology and livelihood strategies / options). Figure 6.4 shows the framework for quantifying adaptive efficiency.

Adaptive efficiency = f (income, infrastructure, literacy, poverty, institutions, extremes, occupational distribution, risk)

Vulnerability arising from	Description of Variables	Expected Relationship
Income	Income per capita	Inverse Relationship ↑ proxies ↓ Vulnerability
Infrastructure	Performance measured in terms of composite index of infrastructure	
Literacy	Literacy Rate	
Institutions	Institutional support	
Occupational Distribution	Index of occupational distribution of workforce (composite index)	
Risk	risk bearing capacity based on alternate sources of income support	
Poverty	Incidence of poverty	Direct Relationship ↑ proxies ↑ Vulnerability
Extremes	Number and intensities of extreme events	

Figure 6.4: Framework for measuring adaptation

From the above figure we can see that adaptive efficiency is taken as a function of a set of indicators which are crucial in determining the resilience of people to extreme events. Since adaptive capacity of people is closely related to the vulnerability faced by them many of the indicators used for quantifying it are taken from the earlier set of vulnerability indicators. A higher level of vulnerability itself has a negative relationship with the adaptive capacity of people. Other factors like institutional support mechanisms are helpful in hedging against vulnerability and increasing adaptive efficiency. Therefore we use the following set of indicators for arriving at a measure of adaptive efficiency.

Table 6.2: Summary of the variables used in measuring adaptive efficiency and the apriori expected functional relationship

Measure of Adaptive Efficiency	Description of the Indicator	Hypothesized functional relationship between the Indicator and Adaptive Capacity
Literacy Rate	Number of literates per district population	The higher is the literacy rate higher will be the adaptive capacity
Sex ratio	No. of females per thousand males	The higher is the number higher will be the adaptive capacity
Life Expectancy	Life Expectancy of Males and Females	The higher is the life expectancy higher will be the adaptive capacity
RGNCA	Gross Cropped Area/ Net Cropped Area	The higher is the ratio the higher will be the adaptive capacity
Area under cultivation	Net Cropped Area/ District Area	The higher is the area under cultivation higher will be the adaptive capacity
Irrigation Intensity	Net Irrigated Area/ Net Cropped Area	The higher is the irrigation intensity the higher will be the adaptive capacity
Yield	Variation in Yield per unit area of the major crop	The higher is the yield the higher will be the adaptive capacity
Occupational concentration	Proportion of workers engaged in non agricultural activities	The higher is the concentration in one or more categories the higher will be the adaptive capacity
Poverty	No. of people above poverty line	The higher is the number of people above poverty line higher will be the adaptive capacity
Taxpayers	No. of people paying income tax	The higher is the number of taxpayers higher will be adaptive capacity
Combined infrastructure index (CII)	Length of roads, schools, hospitals, transport in proportion to area and population	The higher is the index for CII the higher will be the adaptive capacity
Housing	No. of people living in pucca (good quality) houses	The higher is number of people living in pucca houses higher will be adaptive capacity
Institutional Support	No. of banks and other financial institutions per region	Higher the level of institutional support higher will be the

	and population	adaptive capacity

From the above table we can see that all the indicators of adaptive efficiency exhibit a positive relationship with the final adaptive capacity. To assess the relative adaptive capacity of different hazard prone regions we have to arrive at a quantitative figure for adaptive capacity. This is done by taking a simple a weighted average of the above listed indicators. A higher value will suggest that the population in concern has a higher adaptive capacity than the ones having a lower value. One thing that needs to be kept in mind is that we can know only the relative positions of hazard prone regions in terms of their adaptive capacity. In other words we only know if one disaster prone region has a better adaptive capacity than another disaster prone region. Alternatively, we can also arrive at a ranking of adaptive capacity of the disaster prone regions (best and worst off regions) in terms of the indicators used to measure adaptive capacity and higher ranked ones can be regarded to have higher levels of adaptive efficiency. A more accurate assessment can be made by comparing the levels of adaptive capacity with occurrence of climate related hazards to evaluate levels of adaptive efficiency.

6.5 Summary and Conclusion

Most of the earlier studies have used a very narrow definition of vulnerability and constructed an index to suit that definition. However, vulnerability is due to several factors, and also of various kinds. This chapter has developed a comprehensive framework of vulnerability assessment that encompasses various dimensions, and suggests an index which can be quantified and compared over a period of time. Using dynamic indicators and combining them into an index is a departure from existing methods and tools. We hope that by extending the framework to analyze the determinants of adaptations and developing an adaptive efficiency tool, we have made a contribution to the development of new tools and methodologies for assessment of vulnerability and adaptation.

References

Anand, S. and A. Sen (1994). “Human Development Index: Methodology and Measurement”, Occasional Paper 12, United Nations Development Programme, Human Development Report Office, New York.

Bohle, H. C., T. E. Downing, and M. J. Watts (1994). “Climate change and social vulnerability” Global Environmental Change 4(1): 37-48

Cutter, S. L. (1996). “Vulnerability to environmental hazards” Progress in Human Geography 20(4): 529-539

IPCC (2000). Presentation of Robert Watson, Chair, Intergovernmental Panel on Climate Change, at the Sixth Conference of the Parties to the United Nations Framework Convention on Climate Change, The Hague, 13th and 20th November, 2000.

IPCC (2001). IPCC Third Assessment Report. Climate Change 2001, in five volumes: Synthesis Report, Working Group I: The Scientific Basis; Working Group II: Impacts, Adaptation and Vulnerability; Working Group III: Mitigation, Geneva: Intergovernmental Panel on Climate Change & Cambridge: Cambridge University Press, Available online at www.ipcc.ch

Kaly, U. Briguglio, L. McLeod, H. Schmall, S. Pratt, C. and R Pal (1999). "Environmental Vulnerability Index (EVI) to summarise national environmental vulnerability profiles" SOPAC Technical Report 275, available online at: http://www.uvm.edu/giee/research/publications/evi.pdf

Ligon E. and L. Schechter (2002). "Measuring Vulnerability", Washington, D.C., USA, September 23-24, 2002, available online at: www.ifpri.org/events/conferences/2002/092302.htm

Mansuri G. and A. Healy (2002). "Vulnerability Prediction in Rural Pakistan", Washington, D.C., USA, September 23-24,2002, www.ifpri.org/events/conferences/ 2002/092302/mansuri.pdf

Moss R.H., A.L.Brenkert and E.L.Malone (2001). "Vulnerability to climate change: A Quantitative approach," U.S Dept. of Energy, September 2001, www.pnl.gov/globalchange/pubs/ vul/DOE%20VCC%20report.PDF

North, Douglass C. (1990). Institutions, Institutional Change, and Economic Performance, New York: Cambridge University Press.

Patwardhan, A., K. Narayanan, D. Parthasarathy and U. Sharma (2003). "Assessment of Vulnerability and Adaptive Capacity in Coastal Zones", in Shukla et. al. (eds) "Climate Change and India Vulnerability Assessment and Adaptation", Hyderabad: Universities Press.

Sen, A. (1981). Poverty and famines: an essay on entitlement and deprivation, Oxford: Oxford University Press

Sen A. (1987). Commodities and Capabilities, New Delhi: Oxford University Press.

Shukla, P. R., S. K. Sharma and P. V. Ramana (eds.) (2002). Climate Change in India Issues, Concerns and Opportunities, Tata McGraw Hill: New Delhi.

Tata Energy Research Institute (TERI). (1996) The Economic Impact of a One Metre Sea Level Rise on the Indian Coastline: Method and Case Studies Report submitted to the Ford Foundation
http://www.ccasia.teri.res.in/country/india/impacts/impacts.htm

Watson, R. T., M. C. Zinyoera and R. H. Moss (1998). The Regional Impacts of Climate Change: An Assessment of Vulnerability. A Special Report of IPCC Working Group II, Cambridge: Cambridge University Press.