VULNERABILITY OF BANGLADESH TO CLIMATE CHANGE AND SEA LEVEL RISE

Concepts and Tools for Calculating Risk in Integrated Coastal Zone Management

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VULNERABILITY OF BANGLADESH
TO
CLIMATE CHANGE AND SEA LEVEL RISE

CONCEPTS AND TOOLS FOR
CALCULATING RISK IN
INTEGRATED COASTAL ZONE MANAGEMENT

SUMMARY REPORT

Dhaka, Bangladesh
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# CONTENTS

<table>
<thead>
<tr>
<th>Study Team</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Preface</td>
<td>v</td>
</tr>
<tr>
<td>Abbreviations</td>
<td>vii</td>
</tr>
<tr>
<td>Glossary</td>
<td>viii</td>
</tr>
<tr>
<td>ix</td>
<td></td>
</tr>
</tbody>
</table>

1 Introduction and background 1

2 The problem: climate change and sea level rise 4
   2.1 Climate change 4
   2.2 Sea level rise 5
   2.3 Agents of climate change and sea level rise for Bangladesh 6

3 Methodology and framework for analysis 7
   3.1 Introduction and overview 7
   3.2 Development options for Bangladesh in the year 2010 10
   3.3 Upstream development conditions 11
   3.4 Cases for analysis and impact assessment 12
   3.5 Comparison of cases and vulnerability profile 12

4 Primary physical effects of climate change and sea level rise 13
   4.1 Inundations 13
   4.2 Low water flows 13
   4.3 Salt water intrusion 14
   4.4 Flash floods 14
   4.5 Drought 15
   4.6 Storm surges 18
   4.7 River and coastal morphology 18

5 Impacts on human and natural ecosystems 20
   5.1 Impacts on human systems 20
   5.2 Impacts on natural ecosystems 23

6 Response strategies 26
   6.1 Introduction 26
   6.2 Retreat 26
   6.3 Accommodation 26
   6.4 Protection 26
   6.5 Integrated coastal zone management and corresponding institutional arrangements 29

7 Vulnerability profiles 31

8 Conclusions 35

9 Recommendations 37

References 39
1. Introduction and background

The International Panel on Climate Change (IPCC)

In response to growing international concerns about the threat of climate change, in 1988 the World Meteorological Organization (WMO) and United Nations Environment Programme (UNEP) jointly established the Intergovernmental Panel on Climate Change (IPCC). The IPCC drew together many hundreds of world's leading scientists and policymakers, from both developed and developing countries. In 1990, IPCC published its First Assessment Report, representing the consensus views of all the scientists involved: that unless something is done to limit greenhouse gas emissions, the planet will undergo global warming and consequent sea level rise. The report examined a number of possible scenarios of future greenhouse gas emissions: “business-as-usual” (BAU), low and high. Under the BAU scenario, the report warned that mean global temperature could increase by 0.2-0.5°C per decade, and that global mean sea level could rise by 3-10 cm per decade, over the next century.

The IPCC’s First Assessment Report was formally adopted by the UN General Assembly (New York, 1990) and by the Second World Climate Conference (Geneva, 1990). A second assessment report is in preparation and is expected to be published at the end of 1995.

BOX 1.1: The Intergovernmental Panel on Climate Change (IPCC)

Task:
To advise policy makers by assessing all relevant scientific information about climate change, ranging from emissions, atmospheric chemistry and changes in the radiation balance, to international and socio-economic impacts of climate change, possible response strategies, and the macro-economic consequences of implementing measures.

Structure:
Originally IPCC formed three Working Groups (WGs). WG-I assessed the available scientific literature on the causes and probability of human-induced climate change and has established a number of scenarios, including accelerated sea-level rise. Based on these scenarios, WG-II assessed the environmental and socio-economic impacts. WG-III formulated feasible response strategies. The outputs of all three WGs culminated in the First Assessment Report published in 1990.

New Structure:
In preparation of the Second Assessment Report IPCC decided to modify its structure in such a way that its activities would be in line with the activities under the United Nation’s Framework Convention on Climate Change (FCCC). In addition to its original tasks, WG-II is now also developing methodologies for emission inventories. The former WG-II (impacts) and WG-III (response strategies) have been merged into a new WG-II, which should assess all available scientific, technical, environmental, social and economic information regarding impacts of climate change and response options to adapt to and/or mitigate climate change. In addition, WG-II is also developing generic technical guidelines for impact assessment and adaptation. A newly established WG-III should, in consultation with WG-I and WG-II, deal with the macro-economic consequences of climate change and implementing measures.

Subgroup B of the new WG-II, co-chaired by the Netherlands, deals with the impacts of climate change on, and possible response strategies to, oceans, large lakes and their ecosystems; coastal zones and small islands; fisheries; and financial services including insurance. Hence, this subgroup includes the Coastal Zone Management Subgroup of the former WG-III.

IPCC vulnerability assessments

Following the recommendations of the 1990 report, the Coastal Zone Management (CZM) Subgroup of former WG-III developed and implemented an operational methodology to assess the vulnerability of coastal and island nations to sea level rise in the context of coastal zone management and planning. This common methodology could be used by nations to conduct their own vulnerability assessments (VAs). The methodology incorporates clearly defined procedures, and yet is sufficiently flexible to allow individual national needs and circumstances to be addressed. The VA studies were coordinated by the IPCC-CZM subgroup (CZMS) with active participation of several coastal nations like Argentina, Australia, Bangladesh, France, Gambia, Japan, Kiribati, The Netherlands, Saudi Arabia, the United Kingdom, the United States of America, Venezuela and UNEP’s Regional Seas Programme.

The IPCC-CZMS, co-chaired by the Netherlands, agreed to provide technical assistance to carry out VA case studies. Bangladesh was one of the countries selected as a case study area. In The Netherlands, the Coastal Zone Management Centre of the Ministry of Transport, Public Works and Water Management and the environmental programme of the Directorate-General for International Cooperation (DGIS) of the Ministry of Foreign Affairs are aiming at increasing the CZM capabilities of low lying coastal nations. DGIS expressed its willingness to consider financing several VA case studies in countries, including Bangladesh.

The Bangladesh Case Study was initiated in 1991. The first results have been presented in Venezuela in preparation for United Nation’s Conference on Environment and Development (UNCED). It was concluded at UNCED that vulnerability studies should form the basis for Integrated Coastal Zone Management (ICZM) as it was specified in chapter 17 of Agenda 21. This recommendation was given due consideration and the vulnerability study has been expanded to a pilot study.

Tentative conclusions and recommendations of this pilot study have been presented in the World Coast Conference, held in Noordwijk, the Netherlands, in November 1993. This report is the summary version of the Final Technical Report of the Bangladesh pilot study.
### Purpose of the pilot study

The pilot study responds to fulfill the obligation of the Government of Bangladesh — which is a signatory to the Framework Convention on Climate Change (FCCC) — to support the international community in understanding the vulnerability of the country to climate change and sea level rise and at the same time, to assist IPCC in formulating ways to mitigate the hazards and find modalities in developing institutions in dealing with the issues. It analyzes climate change issues in the context of integrated coastal zone management, considering other long-term impacts as well, and focuses on quantitative analysis. It is a pilot study in the sense that new methodologies are developed and applied in assessing the vulnerability of a country or a region for climate change and sea level rise.

One of the objectives of the pilot study was to develop tools and techniques for use by the Government of Bangladesh for future coastal resource planning and management. Another objective was to identify both the policies and the technical capacity that will be needed within Bangladesh in order to deal with climate change related issues and problems on an ongoing basis. In particular, the study addressed the following questions:

- What are the likely primary physical effects of climate change and sea level rise on the coastal areas of Bangladesh?
- What will be the likely consequences of these primary physical effects on the population, the physical infrastructure, agriculture and natural ecosystems of Bangladesh?
- What institutional arrangements and capabilities exist within Bangladesh to deal with and respond to the challenges of climate change and sea level rise?
- What are the interactions and sensitivities of different development options within and outside Bangladesh to the possible threats of climate change and sea level rise?
• What needs to be done in the future in order to reduce the vulnerability of Bangladesh to effects of climate change and sea level rise?

The study places climate change in the context of other long- and short-term developments, both within Bangladesh and in upstream countries. The methodology developed has general application in analysing long range impacts in support of short term management decision. It provides an operational tool to account for such impacts.

While the technical study attempts to quantify many of the possible effects of climate change and sea level rise, such as changes in inundated areas, flood depths and agricultural production, the conditional nature of the analysis should be stressed. The study examines the likely consequences for Bangladesh if certain climate changes and sea level rise should occur. The study concentrates on several major agents of climate change using a set of assumptions that are admittedly highly uncertain. The results of these analyses should therefore not be regarded as predictions of situations that will occur; they merely indicate the magnitude of changes that are possible. Results should be used in comparative analyses only.

Outline of the summary report

The summary document highlights the main analyses and findings of the technical and institutional components of the pilot study, which are reported in separate documents. In subsequent chapters attention will be paid to the problems addressed, the approach followed, the results obtained and the conclusions and recommendations drawn.

Chapter 2 introduces the worldwide climate change problem and concern, and discusses the consequences for Bangladesh in more detail. The general IPCC approach - - which formed the starting point for the Bangladesh pilot study -- was adapted in accordance with the specific conditions and concerns for Bangladesh. An overview of the approach followed is presented in chapter 3, while more details can be found in chapters 4 and 5. These chapters present main components of the impact analysis: the assessment of primary physical effects; and the impacts on human and eco-systems.

Special reference is made to the establishment of the vulnerability profile of Bangladesh in chapter 7. This chapter introduces a new methodology to integrate the impacts on natural and human systems and to account for the capability of Bangladesh to implement responsive strategies. Such strategies and problems with their implementation are discussed in chapter 6. Chapters 8 and 9, finally, give the conclusions and recommendations.
2. The problem: climate change and sea level rise

With its low lying deltaic landmass, high population density and low level of development, Bangladesh already has to cope with a number of physical and man-made problems. These include natural hazards such as cyclones, floods and droughts, and socio-economic problems such as low levels of literacy, poor health delivery systems, high unemployment and poverty. In the future, Bangladesh will also have to face adverse impacts of developments across its borders — which, among other things are expected to reduce availability of water during low river flows — and has to deal with the possibility of climate change and sea level rise. This chapter outlines the problems that will arise from climate change and sea level rise, and the existing problems within Bangladesh that are likely to be compounded.

2.1 Climate change

Global climate change is likely to threaten the delicate balance among ecological, social and economic systems and their environments. Although the magnitude of such change can not be predicted with a high degree of accuracy, the process is likely to be irreversible, and potential effects can not be ignored.

The Earth’s climate is changing at an unprecedented rate, due to the warming of the atmosphere by the so-called greenhouse effect, whereby heat is trapped at the surface of the Earth by the atmosphere. Under normal conditions, energy from the Sun passes through the atmosphere, some of which warms the surface of the Earth, and the rest is then reflected back into space. However, certain "greenhouse gases" are now accumulating in the atmosphere and acting like the glass in a greenhouse, trapping this radiation, causing the surface of the Earth to heat up even further.

Over the last 200 years there has been a gradual increase in concentrations of the main greenhouse gases such as carbon dioxide (CO₂), methane (CH₄), and the oxides of nitrogen and sulphur (NO₂ and SO₂) in the atmosphere. These are produced as a result of the burning of fossil fuels, deforestation and certain agricultural practices. Until the early 1960s, the greenhouse effect of CO₂ was the major source of anthropogenic impact on climate; but this picture has changed dramatically. In the last 30 years, the concentrations of synthetic trace substances such as chlorofluorocarbons (CFCs) have increased rapidly (see Box 2.1). These substances are significantly more effective in enhancing the greenhouse effect: the addition of one molecule of CFC to the atmosphere can have the same radiative effect as more than 10,000 molecules of CO₂. The rate of increase of the total heating of the planet is now about five times greater than the mean rate for the period 1850-1960. The trace gas contribution to the greenhouse effect is estimated to have caused an increase in the radiative heating of the planet by an amount equivalent to an increase in the sun’s brightness by about 0.75%.

Estimates of future rates of global warming and climate change are made by sophisticated climate models, such as three-dimensional general circulation models. Recent studies conducted at various national research centres suggest that the surface of the Earth will heat up by 3.5-4.5°C for a doubling of CO₂.

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**BOX 2.1: Greenhouse effect**

Building up of GHGs in the atmosphere over time as shown both pictorially and graphically.

![Diagram of greenhouse effect]

The effect of this is to warm the surface and the lower atmosphere.

**Source:** IPCC, WMO, UNDP, 1992
2.2 Sea level rise

One of the most important consequences of an increase in mean global temperatures will be a possible rise in the sea level around the planet. The reasons for this rise in sea level include:

- The expansion of the ocean's volume when water temperatures increase. Although small, such thermal expansion can translate to a considerable rise in mean sea levels.
- Mountain glacier melt will also contribute a sizeable amount of water to the oceans, which will also contribute to sea level rise. It should be noted that such mountain glacier melt will not only contribute to sea level rise once the water reaches the sea, but will also contribute to increased flooding in floodplains.
- Meltwater from the land is expected to be the third component.

In addition to the rise in sea level due to increased temperatures, as described above, the land surface of the planet is also undergoing changes in elevation due to a number of factors, including tectonic changes, sedimentation, etc. The actual amount of sea level rise at any given point along a coast will always depend on the movement of the land surface and be felt as relative sea level rise. In the case of Bangladesh it is believed that the coast, or at least parts of it, may in fact be subsiding; thus the relative sea level rise may be greater than the change in sea levels due to global warming. However, in the absence of hard data to quantify such subsidence, this factor has not been considered in this study.

The IPCC has estimated that by the year 2100, as a result of global warming mean sea level will rise by between 30 and 100 cm, which corresponds to maximum rates of 3.5-15 mm per year. These estimates were based on IPCC's "business-as-usual" scenario, assuming that greenhouse gas emissions will continue, leading to an increase in mean global temperature of 0.2-0.5°C per decade. According to IPCC even if CO₂ concentrations would stabilize around the year 2030, sea levels would continue to rise, though at a lower rates.

These sea level rise (SLR) conditions are recommended for use in all case and pilot studies conducted under the auspices of the IPCC's Coastal Zone Management Subgroup.

**Box 2.2: Global warming scenarios and rise in global mean sea level under scenario A**

IPCC has forecast that global warming will indeed occur, and has assessed four possible scenarios [IPCC, 1992]:

Scenario A: "Business as Usual" i.e., a continuation of current trends in greenhouse gas emissions, which will produce a rate of warming in terms of global mean surface temperatures of 0.2°C - 0.5°C per decade in the 21st century, with a "best guess" of 0.3°C. This would produce a 1 degree rise in temperature by 2025 and 3 degrees by 2100, compared to 1990 levels.

Scenario B: Deforestation is halted, natural gas is increasingly substituted for coal, energy conservation occurs, but temperatures still rise by 2°C by 2100 compared to today, i.e., a rise of 0.2°C per decade.

Scenario C: A greater switch to renewable energy sources in the second half of the 21st century holds the temperature rise to a little above 0.1°C per decade.

Scenario D: Assumes that the switch to renewables occurs in the first half of the 21st century, which stabilizes gas concentrations in the atmosphere.

Three scenarios are shown in the figure below. In the scenario A, temperatures are expected to be higher than the mean in Southern Europe and Central North America, with reduced summer rainfall and soil moisture. By 2030, winter temperatures could rise in these regions by 2°C, and summer temperatures by 2-3°C. In the Sahel, warming will increase by 1-3°C. Southern Asia might experience temperature rises of 1-2°C, and Australia some 1-2°C in summer and 2°C in winter.

Sea level rise in the "business as usual" scenario by some 6 cms per decade due to thermal expansion of the oceans, and the melting of some land ice, producing a rise of some 20 cms by 2030, and 65 cms by 2100.
2.3 Agents of climate change and sea level rise for Bangladesh

Changes in climate and sea levels are expressed in terms of variables such as: temperature, evaporation and river discharges. These variables are called agents of change. In the Bangladesh pilot study, the following agents of change are considered, because of their assumed effect on the natural systems of Bangladesh:

- sea level rise
- temperature
- precipitation
- evaporation
- river discharges
- cyclone intensity

**BOX 2.3 : Agents of climate change and their variations considered in the pilot study**

<table>
<thead>
<tr>
<th>Agents of changes</th>
<th>Moderate changes</th>
<th>Severe changes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sea level rise (cm)</td>
<td>+ 30</td>
<td>+ 100</td>
</tr>
<tr>
<td>Precipitation (%)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Monsoon</td>
<td>+ 18</td>
<td>+ 33</td>
</tr>
<tr>
<td>Winter</td>
<td>+ 12</td>
<td>+ 22</td>
</tr>
<tr>
<td>Evaporation (%)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Monsoon</td>
<td>+ 8</td>
<td>+ 15</td>
</tr>
<tr>
<td>Winter</td>
<td>+ 10</td>
<td>+ 20</td>
</tr>
<tr>
<td>River discharges¹ (%)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Peak flows</td>
<td>+ 6</td>
<td>+ 13</td>
</tr>
<tr>
<td>Low flows</td>
<td>- 12</td>
<td>- 22</td>
</tr>
<tr>
<td>Cyclone intensity (%)</td>
<td>+ 10</td>
<td>+ 25</td>
</tr>
</tbody>
</table>

¹ Only as result from climate change, no upstream developments

Estimates of these agents of change are based on IPCC’s *Business As Usual* scenario [IPCC, 1992]. Information for the estimates on other agents of change has been obtained as well from a study of climate change and its implication for China, which provide the most recent estimate of regional climate changes in East Asia [WWF, 1992]. Values of upper and lower bound estimates for the year 2100 are given in box 2.3. For easy identification, the upper and lower bound sets of climate variabilities will be named severe and moderate climate change scenarios, respectively.

No local and seasonal variations are assumed in sea level rise. The values of 30 and 100 cm correspond with maximum rates of 3.5 and 15 mm per year.

Precipitation and evaporation is expected to increase in the winter and monsoon period. They are closely related to changes in temperature. Seasonal changes increase the deficit in the water balance during the dry period. In absolute terms of millimeters of rainfall, a 12 to 22 % increase of precipitation is much less than a 10 to 20 % increase of evaporation in the dry period as the amount of rainfall is low. This results in a further decrease of low flows, estimated at 12 and 22 % for the two climate scenarios, respectively.

With global warming, the sea surface temperature will rise, which is likely to affect the formation of cyclones. This is a complex process in which a certain threshold temperature of 27°C of surface water is considered to be important. However, there is little evidence that increased sea surface temperatures will increase the possibility of the formation, and thus the frequency of cyclones. On the other hand, once formed, the intensity is expected to increase.
3. Methodology and framework for analysis

3.1 Introduction and overview

Agents of climate change and sea level rise first affect the natural system in Bangladesh. Such primary physical effects are experienced in Bangladesh in the form of increased inundation, reduced low river water flows, increased salt water intrusion, a higher intensity of flash floods, increased droughts and a higher intensity of cyclones. These primary effects affect the country's ecological and human systems. Important ecosystems in Bangladesh which are affected include the Sundarbans in the southwest, the Haors in the northeast, and the wetlands along the coasts. Impacts on human systems which are considered in the study focus on population, infrastructure and food grain production. A full overview of the considered study components and their relations is presented in box 3.1.

In accord with the approach and definitions of IPCC, vulnerability not only depends on the dimension of the impacts on the natural and human systems, but as well on the capability of the society as a whole to cope with these impacts in a social, economic, financial, technical and administrative sense and to develop and implement response strategies. The combination of these impacts and the feasibility to implement response strategies composes the vulnerability profile.

The country was divided into 9 vulnerability zones (VA-zones) to be able to investigate regional vulnerabilities. The demarcation of the VA-zones is presented in box 3.2.

The agents of change, their likely impacts and possible response strategies are examined for a number of climate change scenarios and development conditions in- and outside of Bangladesh.

(a) Three climate change scenarios (based on IPCC estimates): no change and moderate and severe climate changes.

(b) Three development conditions for Bangladesh: the situation in 1990 and projections for 2010, assuming two development options: a "business-as-usual" (BAU) and a "high-development option" (HDO). Detailed specification is given in section 3.2.

**BOX 3.1: Relations considered between agents of change and their impacts**

<table>
<thead>
<tr>
<th>AGENTS OF CHANGE</th>
<th>SEA LEVEL</th>
<th>TEMPERATURE/DENATURATION</th>
<th>PRECIPITATION</th>
<th>RIVER DISCHARGE</th>
<th>CYCLONE</th>
<th>FLOOD PROTECTION/EMBANKMENT</th>
</tr>
</thead>
<tbody>
<tr>
<td>IMPACTS ON NATURAL ECOSYSTEM</td>
<td></td>
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<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>IMPACTS ON SOCIAL ECONOMIC SYSTEM</td>
<td></td>
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</table>

**PRIMARY PHYSICAL EFFECT**

- Inundation
- Low flow
- Salt water intrusion
- Flash floods
- Drought
- Storm surge
- Wet and coastal mangrove

**IMPACTS ON NATURAL ECOSYSTEM**

- Sundarbans
- Wetlands
- Deciduous forests
- Rain forests
- Peat bogs
- Aquatic ecosystems
- Coastal zones

**SOCIOECONOMIC IMPACTS**

- Population
- Infrastructure and capital assets
- Agriculture
Box 3.2: Delineation of study area and zonation

The zones were selected based on the agro-ecological zones and water planning zones using Geographical Information System (GIS). Because the impacts of climate change are likely to be felt almost in the entire country only the Chittagong Hill Tracts have been excluded from the study area.

SB  The Sunderbans zone. This coastal zone is a mangrove-type coast. Possible impacts: flooding due to SLR, storm surges and severe salinity intrusion.

SW  The South West zone, consisting of the Ganges tidal plains used for agriculture. Possible impacts: flooding due to SLR and storm surges, salinization of surface and groundwater, and moderate to severe drought.

SC  The South Central zone, including the offshore islands and the Meghna estuarine floodplain. The area, which is built up by alluvial deposits, is subject to impacts of severe tropical storms and cyclones. Cyclonic Storm Surge usually occur in the transition between the dry and monsoon seasons, generally in the period April/May and October/November. Morphologically this zone is extremely active, caused by the changing flow and silt and mud carried by the major rivers. Possible impacts are: flooding due to SLR, salinity intrusion in soil, surface and groundwater sources and cyclonic storm surges.

SE  The South East zone. The part runs more or less North/South and forms the Eastern boundary of the delta. Impacts: flooding due to cyclonic storm surges.

CW  Central West zone. Middle and higher floodplains of the Ganges. Impacts: flooding and droughts.

CC  Central deltaic and inner zone, consisting of the Ganges, Meghna and Brahmaputra lower floodplains. The rivers are extremely dynamic in hydrological and morphological respect. Their hydrologic regimes are characterized by extremely high discharges in the monsoon season, when high local monsoon rainfall adds to large discharges from the Himalayan catchments. In the dry season the river runoff reduces to only small values. Impacts: flooding due to ASLR and peak river discharges, drainage congestion leading to flash flood and salinity intrusion.

NW  North West zone. Piedmonts of the Himalayan range and middle and higher floodplains of the Brahmaputra. Possible impacts: flooding and drainage congestion due to peak river discharges, severe drought.

NC  North Central zone. Higher area around Mymensingh. Possible impacts: drainage congestion due to peak river discharges combined with excessive rainfall, droughts during dry season.

NE  North East zone. Middle and higher floodplains of the Meghna river. Possible impacts: flash flood due to drainage congestion and inundations due to peak river discharges.

Vulnerability zones shown in the map of Bangladesh
(c) Three flow conditions: present, sharing and non-sharing water from the rivers which flow into the country across the Indian border are considered. Changes in the discharges of these rivers reflect their upper watershed conditions with respect to forestation and water consumption as well as the level of agreement with India on sharing the available water specially during the dry period. More detail is given in section 3.3.

The methodology followed in this pilot study aims at generating overall *indices of vulnerability*, which consider both the above mentioned impacts and the feasibility to implement possible response strategies. These indices are based on a set of selected concrete and specific *indicators*. Examples of such indicators are flood depth, number of people affected by droughts, capacity of the Sunderbans to adapt to the rate of sea level rise, and technical feasibility to implement protection measures against river floods.

The specific indicators are structured in a hierarchy of importance. For example, the indicators "flood vulnerable area", "flood depth" and "flood risk" represent a higher aspect "inundation". "Inundation", together with "low flow", "drought" and others belong to the main impact category "Primary Physical Effects". Four such main impact categories are considered: Primary Physical Effects; Impacts on Natural Ecosystems; Socio-economic Stress Factors; and Implementation of Response Strategies. Box 3.4 presents the main structure of the hierarchical tree of impact categories for each VA-zone. An overview of specific indicators is presented in Box 7.1.

For each of these impact categories aggregated indices are determined by adding up the individual indicators after a proper scaling and weighting procedure. They represent a

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**BOX 3.3: Overview of the ten selected cases**

<table>
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<tr>
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<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>No change (CCS0)</td>
<td>CASE 1</td>
<td>CASE 4</td>
<td>CASE 6</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Moderate change (CCS1)</td>
<td>CASE 2</td>
<td>CASE 10</td>
<td>CASE 7</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Severe change (CCS2)</td>
<td>CASE 3</td>
<td>CASE 5</td>
<td>CASE 8</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Notes:
1. BAU: Business As Usual future development scenario for Bangladesh.
2. HDO: High Development Option future scenario for Bangladesh.
3. Sharing/non-sharing refers to future regional development and water sharing with upstream countries.

Combinations of the climate change and sea level rise scenarios and the internal and external development options create the cases for analysis for which the values of certain chosen indicators, as categorized below, can be assessed. Pragmatically, not all possible combinations of scenarios and development options have been analysed. Box 3.3 gives an overview of the ten selected cases and corresponding case numbers.

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**BOX 3.4: Analytical hierarchy tree for the vulnerability of Bangladesh**

![Analytical hierarchy tree](image)

**Structure similar for each of the 9 VA-zone**
level of vulnerability or sensitivity for the considered changes. Further aggregation of these main categories leads to an overall vulnerability index, which is done for the nine VAs - zones and for the country as a whole.

First the values of such indicators are assessed for the 10 individual cases through quantitative analysis and/or expert judgements. In a next step a pairwise comparison of cases is made to assess the changes in the criteria due to climate change and sea level rise under a specified set of development conditions. In total, six pairs of cases have been selected for comparison. Four of them refer to a high climate change scenario. These represent the vulnerability profile (VP) of Bangladesh; their comparison will give an indication how the vulnerability of Bangladesh will change under different development options inside Bangladesh and with respect to the quantities of water flowing from across the border. Two additional comparisons refer to a low climate change scenario; these allow a sensitivity analysis of this vulnerability profile for the assessed values of the climate changes and sea level rise, 100 and 30 cm. The main characteristics of the compared cases are presented in Box 3.5.

### BOX 3.5: Main characteristics of the compared cases

<table>
<thead>
<tr>
<th>Comparison of cases</th>
<th>3-1</th>
<th>9.8</th>
<th>5-4</th>
<th>7-6</th>
<th>2-1</th>
<th>10-4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scenario condition</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Climate change and</td>
<td>CCS2-</td>
<td>CCS2-</td>
<td>CCS2-</td>
<td>CCS1-</td>
<td>CCS1-</td>
<td></td>
</tr>
<tr>
<td>sea level rise</td>
<td>CCS0</td>
<td>CCS0</td>
<td>CCS0</td>
<td>CCS0</td>
<td>CCS0</td>
<td></td>
</tr>
<tr>
<td>Development</td>
<td>BAU</td>
<td>BAU</td>
<td>BAU</td>
<td>HDO</td>
<td>BAU</td>
<td></td>
</tr>
<tr>
<td>Bangladesh Indian</td>
<td>1990</td>
<td>1990</td>
<td>1990</td>
<td>1990</td>
<td></td>
<td></td>
</tr>
<tr>
<td>rivers</td>
<td>SH</td>
<td>NSH</td>
<td>NSH</td>
<td>NSH</td>
<td>present</td>
<td>NSH</td>
</tr>
<tr>
<td>Purpose</td>
<td></td>
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<tr>
<td>Vulnerability profile (VP)</td>
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<tr>
<td>Sensitivity VP</td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>CCS2/CCS1</td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Sensitivity VP</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BAU/HDO</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sensitivity VP</td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SH/NSH</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

CCS0, 1 and 2: Climate change and sea level rise scenarios (CCS0: no change, CCS1: moderate and CCS2: severe change)

BAU, HDO: Business-as-Usual and High Development Options for Bangladesh (in 2010)

SH, NSH: Sharig and non-sharing of waters from Indian rivers

It is stressed that the comparison of different developments in and outside of Bangladesh should be made with extreme care. Comparison of different development options has NOT been a purpose of the project. Their specification served only the vulnerability assessment for climate change and sea level rise under different conditions of the Bangladesh society and not the evaluation of alternative developments.

### 3.2 Development options for Bangladesh in the year 2010

The main aspects of development in Bangladesh stem from the low resource to man ratio, demographic characteristics and the major contribution of agriculture sector to the national GDP. The efficiency and ability of agricultural output to continue to outpace the increase in population is an important consideration in the future development of the country. The other important considerations include the ability to continue the downward trend in the rate of increase in population which in turn is tied to improved education, particularly of women and the employment prospects of the youth who represent half of the present population. The economic growth also has to increase at a substantially better pace which will entail higher investments in infrastructure such as roads, communications, water developments and irrigation as well as in industries.

Development options have been specified for the year 2010. As it does not make sense to make realistic predictions over a twenty year period, it was decided to take two development options only.

(i) An optimistic development option in which all the best known development options are implemented. This is known in the study as the High Development Option (HDO). It incorporates an improvement in investments, a demographic transition with much lower birth rate, much improved education particularly of women, major improvements in agriculture technology leading to higher yields and a considerable increase in infrastructure such as flood protection works, roads, bridges and provisions for irrigation.

(ii) A pessimistic development option in which all the present (rather poor) development trends in economic development and population are continued for the next two decades. This option is called the Business As Usual (BAU) development option.

A summary of the formulated development options for Bangladesh is presented in Box 3.6. The box includes as well a comparison of development options considered in this study and the projections given in the Task Force report [Task Force, 1991] and by World Bank up to year 2010 [World Bank, 1993].
3.3 Upstream development conditions

Assessment of the possible effects of upstream developments on the river discharges is rough and tentative. These are based on ongoing developments and on existing plans and ideas for major infrastructure works.

A picture of ongoing developments and potential further watershed development shows that deforestation is concentrated mainly in the southern hill slopes of the Himalayas in the Ganges catchment and in the Assam region in the Brahmaputra middle reaches and in the eastern rivers. Demographic and economic developments are most pronounced in the already densely populated Ganges plain and the catchments of the northwestern rivers. The middle Brahmaputra plain, which is hilly and belongs to the most rainy parts of the world, has less potential for intensive development.

Major infrastructure works which are in discussion are the following:

- A dam on the Brahmaputra near the Indian-Chinese border which will block all sediments entering India through the river.
- Development of a link-channel between the Brahmaputra and the Ganges to augment the waters of the Ganges from the Brahmaputra with a discharge capacity of 3000 m$^3$/s (about 70% of the Brahmaputra low flow).
- Completion of flood embankment projects in the Ganges flood plain in India.
- Development of further dam projects on the Ganges and the Meghna in India and Nepal.

Two additional scenarios for developments in the upstream watersheds of the rivers flowing into Bangladesh are defined.

First, a first-come, first-served scenario, which considers that the upper riparian will continue to interfere with the rivers without consideration to the concerns of the lower riparian and that the proposed constructions will occur. This option is referred to as the non-sharing (NSH) option. It deals with growing water consumption, deforestation and flood protection and lack of agreement on water sharing, resulting in much reduced water flows principally through the Ganges and also in increased high water flows due to increased deforestation upstream.

The second scenario assumes a lower level of impacts. In this sharing (SH) option it is postulated that some sort of integrated water sharing agreement is reached between the riparian countries whereby the rights of the lower riparian Bangladesh to its fair share of water is protected. This refers principally to the low flow conditions of the Ganges. This option also considers that the dam on the Brahmaputra and the Indian link-channel are not constructed. The percent increase in river flows in monsoon and decrease in winter are given in Box 3.7 for the two major rivers: Ganges and Jamuna.


3.4 Cases for analysis and impact assessment

As mentioned, ten cases have been selected which consider different agents of change representing combinations of climate change scenarios and development conditions. These cases for analysis are specified in Box 3.3.

Case 1 Reference case: Existing conditions will continue, with no change in climate, and no development options.

Case 2 Impact of moderate climate change on current development conditions.

Case 3 Impact of severe climate change on current development conditions.

Case 4 Impact of moderate climate change on business-as-usual (BAU) and non-sharing development options.

Case 5 Impact of severe climate change on business-as-usual (BAU) and non-sharing development options.

Case 6 Impact of moderate climate change on high-development option (HDO) and non-sharing development options.

Case 7 Impact of severe climate change on high-development option (HDO) and non-sharing development options.

Case 8 Impact of moderate climate change on business-as-usual (BAU) and sharing development options.

Case 9 Impact of severe climate change on business-as-usual (BAU) and sharing development options.

Case 10 Impact of moderate climate change on business-as-usual (BAU) and non-sharing development options.

In total, six pairs of cases have been selected for comparison. Four of them refer to a high climate change scenario. These represent the vulnerability profile of Bangladesh; their comparison will give an indication how the vulnerability of Bangladesh will change under different development options inside Bangladesh and with respect to the quantities of water flowing from across the border. Two additional comparisons refer to low climate change; they allow a sensitivity analysis of this vulnerability profile for the assumed values of the climate changes and sea level rise. For example, by comparing 3-1 (severe climate change, 1990 development condition) with 2-1 (moderate climate change scenario, 1990 development condition), impacts of 100 cm and 30 cm sea level rise and corresponding climate changes can be assessed.

To a limited degree, assessments can be made on the impacts of different development options. By comparing, for example, cases 6 (no climate change / HDO/ non-sharing) and 4 (no climate change / BAU/ non-sharing), an assessment can be made of the impacts of different developments in Bangladesh, while through the comparison of cases 8 (no climate change / BAU / sharing) and 4 (no climate change / BAU / non-sharing) different options of upstream developments can be compared.

For the six comparisons, vulnerability indices have been developed using a Multi Criteria Analysis (MCA) technique. These indices represent an aggregation of scores on individual criteria and enable a ranking of vulnerability for the six comparison of cases. Aggregation follows the hierarchical paths uptree in box 3.4. Scores on individual criteria or nodes are multiplied with weights and added up to scores on a node on a higher hierarchical level. Through such weights, the importance of the underlying changes are assessed in terms of their contribution to the overall vulnerability.

The indices first have been assessed per VA-zone and for the four main impact categories separately. A combination of these categories results in an overall vulnerability index for each of the VA-zones. These vulnerability indices per VA-zone has been added up for the Vulnerability Profile (VP) of the whole of Bangladesh.

<table>
<thead>
<tr>
<th></th>
<th>Ganges</th>
<th>Jamuna</th>
</tr>
</thead>
<tbody>
<tr>
<td>Non-sharing</td>
<td>Increase (%)</td>
<td>Decrease (%)</td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>100</td>
</tr>
<tr>
<td>Sharing</td>
<td>5</td>
<td>50</td>
</tr>
</tbody>
</table>
4. **Primary physical effects of climate change and sea level rise**

The primary physical effects (PPEs) of the agents of climate change which are considered in the study are the following:

- **Inundations** in the main flood plains of the Bangladesh rivers, characterized by the extension of the flood vulnerable area, the depth of flooding in unprotected areas and the risk of flooding in protected areas. Inundations are affected by climate changes and also by regional developments in watersheds and developments within the country.

- **Low flow conditions**, which mainly are a function of the upstream developments and the subsequent water flows across the Indian-Bangladesh borders. They are represented by: the length of time during which water levels fall below certain critical values and the minimum water levels.

- **Salt water intrusion** along the major rivers, as a function of sea level rise and the reduction of fresh water discharge in the rivers during the dry periods.

- **Flash floods**, considered to be a function of changes in monsoonal precipitation and drainage congestion in the river systems.

- **Drought.** Two special indices represent the drought sensitivity of Bangladesh in the Kharif and the Rabi-seasons. They are a function of changes in temperature, evapotranspiration and local precipitation, assuming full water availability in the surface and groundwater systems.

- **Storm surges** caused by cyclones are assumed to change in intensity.

- **River and coastal morphology.** The physical agents of climate change have impacts on coastal and river erosion and accretion processes measured as changes in the erosion / accretion balance.

The following sections present the brief methodologies and the results of the pilot study for each of these Primary Physical Effects. Elaborated methodologies and results are made available in the Technical Report [BCAS, RA, CZM-Centre and Approtech, 1994].

**4.1 Inundations**

To determine the impacts of inundation on the study area, all nine VA-zones were categorized with respect to their land use and flood type. Box 4.1 gives an overview of the study area which consists of Sundarbans, upland areas, perennially flooded areas and the impact areas. The impact areas are divided into net cultivable areas and settlement areas. Both the NCA and SET are classified in five categories with respect to their flood depths as described in the glossary. F0 lands are defined as the dry land, i.e.: never practically threatened by flooding. Other areas are defined as flood vulnerable areas (FVA). In the case of SET, only the F0 and F1 lands are considered to be impacted since practically no settlement is found in lands below 90 cm of flooding. In both NCA and SET unprotected areas are prone to greater depths of flooding and also more areas may come under floods. With respect to the protected area including the settlement areas these are susceptible to higher risk of flooding.

The extent to which flood characteristics will change, is determined by following a step-wise analysis as presented in the Box 4.2.

The results of inundation analysis, as presented in Box 4.3, show that climate change increases the flood vulnerable area considerably, but that in the case of sharing its impacts are less than under the non sharing scenario. In the case of flood depth and flood risk the impacts of climate change are again very considerable but here the impact of high development increases the risk even further. The explanation for this is that the high development option includes construction of embankments, which enhances the vulnerability of non-protected areas for future floods.

The impacts of these changes by VA-zone were then calculated on populations at risk, agriculture at risk and infrastructure at risk. These results are described in section 5.1.

**4.2 Low water flows**

Low water flow conditions are important for navigation and for surface water extraction for public water supply, agriculture (irrigation) and other economic activities. Both irrigation and navigation have special significance in the national economy. As it has been postulated that, in a changed climatic scenario the low water discharges in the main river systems will be reduced, the resulting water levels in the main rivers and its distributaries and tributaries will also be lowered. Lower flows of water results as well in an increased salt water intrusion from the sea, which again reduces water availability for irrigation.

Low flows are characterized by minimum water levels and by the length of the period during which water levels are below a critical level making it unsuitable for specific economic activities. Two following indicators have been selected for impact assessment:

- **Standard Low Water levels (SLW),** defined as the water level in a specific station which has not exceeded during 5% of the time in an average year (i.e., 18 days).
- Low Water Period which is defined for each station as the period for which in a selected (dry) year water levels are below SLW.

As in the case of inundation analysis, results of the MIKE11 runs have been used to assess the changes in water levels and are presented in Box 4.4.

### 4.3 Salt water intrusion

At least 1.4 million ha of the coastal and offshore areas of Bangladesh -- inhabited by about 15% of the population -- are directly affected by the intrusion of salt water into the surface and groundwater systems. High degree of salinity is seriously affecting the agricultural potential of the saline prone area. The irrigation potential is reduced, crops may be damaged by saline water flooding, and the increased soil salinity reduces plant growth and thus crop yields. It is also causing a problem for large coastal communities in obtaining saline free drinking water supplies. In addition to these, salinity is affecting productivity of the industries within the area, specially during the dry season.

A rise in sea level will increase the area that will be subjected to salt water intrusion into the estuarine surface water system. Box 4.5 shows the changes in the surface water intrusion in Bangladesh that would occur under the two climate change scenarios. The map shows the effects of a rise in sea level of 30 and 100 cm. Since both the ground water and soil salinity are functions of surface water salinity, the former two will also be experienced due to climate change and sea level rise.

These impacts only account for sea level rise and not for changes in the low water flows. Lower minimum flows would compound the problems of salt water intrusion. The effects of sea level rise and changes in river flows may be of the same order of magnitude, but in combination, their impacts on the socio-economic conditions of the whole of Bangladesh would be disastrous.

### 4.4 Flash floods

Flash floods are caused by heavy rainfall in a mountainous or hilly river catchment area, resulting in a sharp rise in water levels in the rivers, followed by a comparatively rapid recession. In Bangladesh, flash floods occur in the North and East, particularly in the Meghna River basin and the southeastern headwaters of streams in the districts of Chittagong, Noakhali and Chittagong Hill Tracts (Box 4.6). The Meghna River originates in the hills of Shillong and Meghalaya near the Indian border. About 4000 km² area is affected in NE zone, followed by the SE zone with an area of about 1400 km².

A flash flood can be caused by a 10-day period of rainfall of more than 300 mm. Rainfall statistics taken at ten stations in the Surma-Kushiyara-Manu-Khowai River systems in the north for the month of May show that this

---

**BOX 4.1: Land types within the study area showing area impacted by inundation**

<table>
<thead>
<tr>
<th>STUDY AREA (9 VA - ZONES)</th>
<th>IMPACT AREA (105.3)</th>
<th>SETTLEMENT AREA (SET) TOTAL OF UNCULTIVABLE AREA (18.4)</th>
<th>PERENNIALY FLOODED (1.7)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SUNDBARBANS (5.5)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>UP LAND (7.5)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NET CULTIVABLE AREA (NCA) (86.9)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>F0 cm &lt; 30 cm</td>
<td>F1 30-90 cm</td>
<td>F2 90-180 cm</td>
<td>F3 &gt; 180 cm</td>
</tr>
<tr>
<td>DRY LAND (26.4)</td>
<td>FLOOD VULNERABLE AREA (FVA) (60.5)</td>
<td>DRY LAND (12.9)</td>
<td>P (2.4)</td>
</tr>
<tr>
<td>PROTECTED (17.2)</td>
<td>UNPROTECTED (17.2)</td>
<td>FVA</td>
<td>UP (3.1)</td>
</tr>
</tbody>
</table>

Area expressed in thousand square kilometers
VULNERABILITY OF BANGLADESH TO CLIMATE CHANGE AND SEA LEVEL RISE

BOX 4.2: Calculation of inundation changes

<table>
<thead>
<tr>
<th>Steps</th>
<th>Inputs</th>
<th>Purpose</th>
<th>Technique/Tool</th>
<th>Output</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Scenarios • Climate change and sea level rise (Box 2.3) • Upstream Development • Development in Bangladesh (Box 3.6)</td>
<td>To assign boundary conditions for river flows</td>
<td>Manually</td>
<td>Changed boundary conditions for 10 cases</td>
</tr>
<tr>
<td>2</td>
<td>Changed boundary conditions for river flows</td>
<td>To obtain water levels at 17 selected stations in major rivers</td>
<td>Hydrodynamic model runs using MIKE 11</td>
<td>New water levels for 17 selected stations in major rivers</td>
</tr>
<tr>
<td>3</td>
<td>New water levels for 17 selected stations in major rivers</td>
<td>To correct for bed level changes (17 selected stations in major rivers)</td>
<td>Geomorphological model runs using WENDY</td>
<td>Adjusted water levels (17 selected stations in major rivers)</td>
</tr>
<tr>
<td>4</td>
<td>Adjusted water levels (17 selected stations in major rivers)</td>
<td>To calculate water level changes in each VA-zone based on 17 selected stations in major rivers</td>
<td>Hydraulic calculations</td>
<td>Average water level changes in floodplain by VA-zone</td>
</tr>
<tr>
<td>5</td>
<td>Floodplain water level changes by VA-zone • To calculate floodplain inundation depths for unprotected areas • To calculate flood risk for protected areas</td>
<td></td>
<td>Frequency distribution of floods</td>
<td>Change in flood frequency in protected areas by VA-zone</td>
</tr>
</tbody>
</table>

Notes: 1) MIKE 11 is a Hydrodynamic Simulation Model 2) WENDY is a Geomorphological Model

occurs about once in every 2-3 years. Flash floods may occur at any time during May and June. The duration of a flash flood can be measured in hours, rather than days.

Flash floods predominantly damage agriculture and to a lesser degree, infrastructure. Present agricultural practices in the affected areas is to grow high-yield rice variety Boro which gets ready for harvesting around May 15. The time almost coincides with that of the flash floods. If flash floods occur after this date, there is generally no damage to crops; only to the infrastructure. But if the flash floods occur before the harvest, crops may be completely destroyed.

Under both the moderate and severe climate change scenarios the incidence of flash floods are expected to increase. The average precipitation is assumed to increase by 18 and 33%, respectively, under monsoon conditions. At present, flash floods and damage assessment in the vulnerable areas are not systematically monitored, so it is impossible to make accurate estimates of likely levels of damage.

4.5 Drought

Drought, in the present study, refers to 'phenological drought' where the plants are responsive to certain level of moisture stress in the top soil affecting vegetative growth. During the Kharif season (monsoon, July-September) precipitation exceeds evapotranspiration. Droughts in this season refer mainly to shortages of rainfall in the late growing period of Transplanted Aman rice. Such shortages can cause serious yield reductions and will delay harvesting time, thus affecting the cultivation of subsequent crops in the Rabi and pre-Kharif season (October-April). During the Rabi season, evaporation exceeds rainfall and the soil moisture content is heavily dependent on the water remaining after the Kharif season. Water stress is frequently felt after mid-Rabi. During the pre-Kharif period, drought conditions depend on the rainfall pattern, which is erratic.

Drought affects the entire population of the affected areas. Drought conditions force the landless and the marginal farmers to relocate themselves, where job are readily available. Lower food production in combination with unemployment, compound poverty situation and result in creating social vices.

Under both the moderate and severe climate change scenarios, the intensity of droughts will increase in comparison with no climate change situation. During the Rabi season, the area severely affected by drought could triple from 4000 to about 12,000 km² under the severe climate change scenario. During the Kharif season, the area subject to severe, and moderate to very severe drought, could quadruple, affecting both irrigated and rainfed crops. The areal change regarding very severe to moderate drought in severe climate change with respect to no climate change for the Kharif season is shown in Box 4.7.
BOX 4.3: Impacts of inundation

- Changes in flood vulnerable area
  - 1990: 66 km², 2010 BAUSH: 66 km², 2010 BAUNISH: 66 km², 2010 HDOONISH: 86 km², 2010 BAUNISH: 66 km².

- Changes in flood depth

- Changes in flood risk

Severe change refers to 100 cm SLR
Moderate change refers to 30 cm SLR.

BAU and HDO refer to Bangladesh development options.
NSH and SH refer to water sharing agreement with India.
BOX 4.4 : Changes in low water periods

<table>
<thead>
<tr>
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<th></th>
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<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>NO CHANGE</td>
<td>18</td>
<td>36</td>
<td>91</td>
<td>100</td>
<td>18</td>
<td>91</td>
</tr>
<tr>
<td>MODERATE CHANGE</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SEVERE CHANGE</td>
<td>11</td>
<td>20</td>
<td>42</td>
<td>40</td>
<td>10</td>
<td>79</td>
</tr>
</tbody>
</table>

BAU and BD refer to Bangladesh development options.
NSH and SB refer to water sharing agreement with India.

BOX 4.5 : Salinity affected areas

- International Boundary
- VA Zone Boundary
- Major Rivers
- Saline Front at 2ds/m, CCS2
- Saline Front at 2ds/m, CCS1
- Saline Front at 2ds/m, CCS0

BOX 4.6 : Areas affected by flash floods

- International Boundary
- VA Zone Boundary
- Major Rivers
- Flash Flood Prone Areas

Bay of Bengal

Scale
50 100 150 200 km
4.6 Storm surges

Storm surges are associated with cyclones. Formation of cyclones is a complex process where a certain threshold surface water temperature of 27 degrees Celsius at the location of their origin plays an important role. In Bangladesh, cyclonic storm surges are observed twice a year: in late May and in early November. The present day cyclone affected areas are shown in the Box 4.8. Since global climate change will also cause an increase in mean sea surface temperature, it may be expected that both the frequency and intensity will be affected by the changes, although little evidence is found that the frequency of cyclones will be increased. Once the cyclone is formed, it is more likely that its intensity will be increased due to higher sea water temperatures.

An increase in intensity might result in increase in affected areas. However, there is a lack of data on the historic cyclonic processes and their damages. For the vulnerability assessment it is assumed that the cyclone intensity will rise only in the presently affected areas for both the climate change scenarios: 10% for moderate climate change and 25% for severe climate change.

4.7 River and coastal morphology

The total length of the Bangladesh coastline is about 650 km, of which about 125 km is covered by the Sundarbans and 85 km by Cox's Bazar beach in the South. The coast can be broadly divided into the East-West oriented deltaic coastline, and a North-South oriented non-deltaic coastline. The deltaic coastline comprises the Ganges tidal plain, which represents abandoned deltas of the Ganges River, and the dynamic Meghna deltaic plain, which is the present conduit of the major rivers. The non-deltaic Chittagong coastal plain is dominated by mud in the North and by sand in the South.

Historically, the coastline has been undergoing erosion and accretion probably in a dynamic equilibrium. The impact of climate change and sea level rise is expected to result in an increase in erosion and a decrease in accretion in the deltaic part of the coast. From an assessment of changes in erosion and accretion of the Meghna estuary over the last 20 years using remote sensing data and GIS (see Box 4.9), it was observed that erosion has in fact increased over time. The Chittagong coast is also likely to recede due to increased sea level rise. For a 2 cm per year sea level rise it is estimated that the coast will recede by 2-3 m per year or 80-120 m by the year 2030. This means that the Cox's Bazar beach will completely disappear.
BOX 4.9: The dynamics of shoreline of the Meghna river delta: A GIS presentation

Geographical Information Systems (GIS) allow geographical and spatial data to be digitized and stored for analysis either with databases or with changes in the geography. GIS allows overlays to be done of the same area at different times to see the changes over time. GIS exercises were carried out using data on the Meghna estuary at 3 different times namely, 1977, 1984 and 1991. The results clearly show the change in land accretion and erosion that has occurred in the Meghna estuary over that period.
5. Impacts on human and natural ecosystems

Changes in the physical environments have profound impacts on both the human and ecosystems of Bangladesh. Box 3.1 shows how the changes in Primary Physical Effects affect the socio-economic and ecological aspects. In this chapter the likely effects of some selected PPEs on human and natural ecosystems are briefly presented.

5.1 Impacts on human systems

Regarding human systems three aspects have been selected: population; physical immobile infrastructure and capital assets; and agriculture. Limitations are mainly due to practical considerations as availability of time and data. Box 3.1 refers to the considered impacts, not to the possible impacts.

The poverty driven large population are already vulnerable to any extreme climatic event and its impact is always felt in terms of large-scale migration soon after the event. It is, therefore, important to evaluate how many people would be under certain degree of risk in a changed climatic condition. Population impacted by inundation, salinity intrusion, drought, flash floods and cyclones are considered in this pilot study.

Although the existing physical infrastructure are inadequate to provide better amenities of life to most of the Bangladeshi, their existence is nevertheless extremely important for all socio-economic activities of the population. PPEs, especially inundation, affect these physical infrastructure and immobile ones suffer the most since these can not be moved in any extreme climatic event. This is why the impacts of inundation on fixed physical infrastructure are considered for evaluation.

Livelihood of a large fraction of the population in Bangladesh revolves around agriculture and it is considered as the single most important human activity in the society. Impacts on agriculture only due to inundation and drought have been considered in this pilot study.

Impact of inundation on population

Some 71 million people or 65% of the total population of Bangladesh are already affected every year by inundation of slight to moderate intensity. This proportion is likely to increase under the conditions of climate change and sea level rise, as presented in the Box 5.1 (case 9). Assuming that the water sharing option is adopted, under the BAU scenario, 84% of the total population will be affected out of which about 9.3 million people will be affected by severe floods of 90-180 cm. But for the non-sharing option (case 5), the flood-affected population increases to 94%. Thus, under the BAU/non-sharing option, the entire country will face floods of varied intensity. It is also found that about 20 million people (13% of the total) will be affected by severe floods of 90-180 cm. These results emphasize the importance of sharing of water options from the common rivers with the upper riparian countries.

Under the high development option (HDO) scenario, due to the presence of large-scale infrastructure
installations on river banks viz. embankments etc., the impacts of flooding on the population would be greater, 41% to face floods of 90-180 cm. Under this scenario (case 7), about 4 to 5 million people (3% of the total) would be at extremely high risk of flooding.

**Impact of inundation on infrastructure**

The total value of capital assets in Bangladesh is estimated at about Tk 1,800 billion (1990 value). This number includes all mobile assets, which have been excluded from the pilot study as they are assumed not to be vulnerable to inundations. For the pilot study, the immobile physical infrastructure are categorized into five groups: water works, mainly for flood protection and irrigation; houses and settlements; transport network; utilities; and industries. Capital values for each of these categories are calculated, based on their 1990 replacement values. The total value in 1990 thus considered in this study is Tk 284 billion. This value does not include land developments, farm houses and private buildings because of lack of data. Almost 70% of the Tk 284 billion is invested in houses and settlements. Most of the investments have been made in the northwest and central central zone. Capital values in 2010 have been estimated at Tk 410 and 610 billion for the low and high development scenarios, respectively.

Through expert judgment, the considered physical infrastructure has been allocated to different land type categories (F0 to F3; protected and unprotected) and assessments were made of expected annual damage due to inundations for each of these land categories. These assessments were based on a flood which occurs once in every 20 years. Since the change in areas due to inundation for each land type are known as a Primary Physical Effects (PPE), the total expected damage can be estimated for each of the cases. Box 5.2 presents the results. Comparison should take into account the different capital values on which these figures are based for the different development options.

The numbers roughly show a increase in damage due to climate change and sea level rise for the 1990 situation and the low development 2010 conditions between 15 and 21%. For the high development option, the increase in loss is substantially higher and expected at Tk 252 billion (i.e., 297-45), or about 41% of the capital value estimated in the year 2010 (this is about 12% of the GDP in 2010).

Comparison of the numbers of box 5.3 shows as well that the additional loss of physical infrastructure, due to inundations under the moderate climate change scenario of 30 cm is not significant.

**Impacts of inundation on agriculture**

The Master Planning Organization (MPO) of the government has classified all the land of Bangladesh in five land type categories depending upon their relative flood depths (F0 to F4). Since the crop yield varies according to the flood vulnerability status (F0-F4) of land, any change in F0 to F4 distribution of cultivatable land would change the total production of Aman rice. Changes in the distribution of F0-F4 areas for the 10 cases are estimated using the change in flood depth (box 4.3) due to inundation. Comparisons between cases are presented in Box 5.3.

Under the business-as-usual development scenario, the inundation resulting from severe climate change would result in a 13.6 million metric tons (Mmt) reduction in Aman rice production when water is shared, compared with a 10.5 Mmt reduction if water is not shared.

Under the high development option it is assumed that larger areas would be irrigated and that flood control embankments would be built, hence it is expected that Aman production would increase. If no climate change is considered then production would be higher than under present conditions. This increase is attributed mainly to the increase in production of local cultivars, namely BL Aman and LT Aman; although the production of HYV Aman is reduced because this can not be grown in F2 areas. Under the severe climate change scenario production would fall to 70% of current levels (about 19 Mmt of paddy). Obviously the non-sharing of water would contribute to this huge loss of production – even improvements in irrigation conditions and flood control infrastructures could not compensate for such a loss of rice production.
Impacts of drought on population and agriculture

With moderate climate change, the area regarded as severely affected will increase from 3,600 km\(^2\) to 12,000 km\(^2\) during the Rabi season. During the Kharif season, the moderately to severely affected areas that will be reclassified as very severely affected will increase fourfold.

At present about 73 million people, about 67% of the population, live in areas that are prone to moderate or severe drought. Of these, about 25% live in areas that are severely and very severely affected during Kharif season. The proportion of the population living in severe drought-prone areas would increase from 4% to 9% and 18% under the moderate and severe climate change scenarios, respectively.

The impact of drought in Kharif season is currently most severely felt in the northwest zone of Bangladesh. However, going from no climate change to severe climate change conditions, the vulnerability to drought will increase in central west and southwest zones. It is estimated that no wheat cultivation will be possible in southcentral and southwest zones. Potato production will also be affected.

Under the severe climate change scenario, overall rice production could be reduced by about 25% for all development scenarios considered (see Box 5.5), with the maximum reduction in HYV Aus. This reduction would be due to both the decrease in the area suitable for growing rice and the reduction in yields by more than 60%. The fall in production would be even more pronounced for irrigated crops.

The total drought-affected populations in Bangladesh for the three climate change scenarios are given in Box 5.4.

Because of the increase in the intensity of drought there would be more demand for water for irrigation. The irrigation water requirements may increase from the existing 200 cm up to 310 cm per hectare for HYV Boro in very severely drought-affected areas. The requirements of HYV Aus will also increase by more than 50% from the present level. Under both climate change scenarios, the prospects for growing more irrigated crops will be reduced by the limited availability of irrigation water. This will lead to a reduction in cropping intensity in many parts of the country, particularly in the most severely affected areas as illustrated in the maps in Box 4.7.

Impact of flash floods and river morphology on population

Changes in the hydrologic and hydraulic conditions of the Bangladesh rivers include flash floods and river erosion processes. About 12 million people i.e., 10% of the total population now live in areas prone to flash floods (Box 4.5), particularly in the southeast and central central zones. In case of changed climatic conditions, these people will face more frequent flash floods induced by higher precipitations in the monsoon period.

Completely controlling river bank erosion in Bangladesh presently is beyond the technical, financial and institutional capabilities of the country. In many places huge efforts reduce the adverse impacts of this kind of erosion, but still, e.g., in the
years 1993 and 1994, about 110 km² of land has been eroded making 1.2 million people homeless. These erosion processes are expected to increase under climate change conditions, making it even more difficult to control the behaviour of the Bangladesh rivers and putting serious constraints to social and economic developments.

This is to be emphasized here that, the present rate of exploiting resources from these important ecosystems has already made it extremely vulnerable. On top of these human activities, climate change will force these to even more vulnerable situation.

**Impact of salt water intrusion, cyclones and coastal dynamics on Population**

At present, 6% of the total population live in areas close to the coast that are affected by a combination of effects such as salt water intrusion, cyclones and coastal erosion and accretion process. With the 100 cm rise in sea level in the severe case, an additional 25 thousand square kilometer areas would be affected by surface water salinity intrusion, affecting about 35 million people. Intensities of cyclones are expected to increase with about 10 to 25%. The existing coastal accretion/erosion balance is expected to become negative: instead of an equilibrium situation a net erosion might be expected. These changes will seriously and adversely affect the possibilities for development.

**5.2 Impacts on natural ecosystems**

Bangladesh has one of the highest population densities in the world and hence practically all the land area is inhabited. Nevertheless there are still some important natural ecosystems that are of international significance. These include the Sundarbans, which is part of the largest mangrove forest in the world; the rainforests of the Chittagong Hills bordering Myanmar (formerly Burma); deciduous forests in the northcentral and northeast zones; peat basins; aquatic ecosystems; coastal plains and the Haor wetlands. Although the possible impacts of climate change on these natural ecosystems are highly uncertain, an attempt has been made to estimate the impacts of climate change on these ecosystems on a qualitative basis. The results are presented in Box 5.6.

As it is demonstrated in the above Box, two major ecosystems, Sundarbans mangrove ecosystems and Haor wetland ecosystems, will suffer big impacts of climate change. Based on their relative importance and susceptibility to climate change, these two ecosystems are examined with particular emphasis. The findings are presented in Boxes 5.7 and 5.8, respectively.
BOX 5.7: Sundarbans ecosystem

The Sundarbans constitute the largest mangrove forest in the world covering an area of about 1,000,000 ha of which about 60% lies within Bangladesh and the remaining in the state of West Bengal in India. It represents an area with an extremely rich diversity of plant and animal species. About one third of the total area consists of water in the form of rivers, channels and tidal creeks.

The two dominant mangrove species of trees are the Sundri (Heritiera fomes) from which the forest gets its name and Gewa (Excoecaria agallocha). There are a large number of fish and shrimp species occurring in the waters. There are a number of turtles, crocodiles and frog species of importance. The freshwater dolphin (Platanista gangetica) also is found in the rivers. Sundarbans is also known as the home for the Royal Bengal Tigers (Panthera tigris).

Presently the main threat to the Sundarbans come from both man-made interference in the form of tree cutting and overfishing as well as some encroachment. However the bigger threat comes from reduced flows of freshwater through the Ganges during the dry season which has led to a definite inward migration of the salinity front affecting its flora and fauna. The phenomena of top dying of Sundri trees is ascribed in part to the increased salt water intrusion.

The impact of climate change will be to make the salt water front move further upstream and together with lower stream flows the freshwater vegetation will be depleted rapidly. The rate of salt water intrusion will also affect the ability of the ecosystem to adapt. The higher climate change scenario will not allow enough time to adapt.

**BOX 5.8: The Haor basin**

The Haor basin comprising of floodplains of the Meghna river and its tributaries consisted of a rich mosaic of permanent and seasonal lakes, ponds and abundant aquatic vegetation. However, through gradual sedimentation, the basin became shallower leading to the formation of reeds and sedges. This resulted in providing enough food and shelter for fish and other aquatic fauna, and attracted migratory birds which, in their turn, added to the fertility of the water bodies by their excreta promoting rich growth of phytoplankton and macrophytes.

Swamp forests with evergreen trees were once abundant consisting of Hijal (Barringtonia acutangula), Koroch (Pongamia pinnata), Barun (Crataeva nurvala) and Gotamagar (Trewia nudiflora). Also associated with these are the wild rose of Bengal (Rosa involucrata), Ban Tulsi (Lippia guminata), Baldumur (Ficau heterophylla) and other climbers. These swamp forests are adapted to monsoon flooding of up to four months a year. Remnants of these forests are now restricted to areas sloping away from village highland towards the Haor sheltering homesteads from wave erosion. Traditionally these forests have been managed communally by coppicing in a three year rotation beginning when the trees are five to seven years old.

There is an abundance of water fowl and wetland dependent birds occurring in the wetlands of the haor basin. A total of 125 species of waterfowl are known to have occurred in the haor basin. These species of birds depend on the wetlands. The haor wetlands are considered to be an internationally recognized important wintering area for migratory waterfowl, principally ducks and shore birds.

Over half of the 260 species of fin fish and shrimps found in the freshwaters of the country are known to occur in the haor system. The major fin fish include the Indian carps such as Rui (Labeo rohita), Catla (Catla catla), Kalbaas (Labeo calbasu), catfishes like Aire (Aorichthys aor), Pangas (Pangasius pangasius), Boal (Walfago atta) and snakeheads like Shol (Channa striatus) and Gazar (Channa marulius). Of the freshwater prawns, the giant prawn locally known as Golda Chingri (Macrobrachium rosenbergii) occurs in the rivers and floodplains of the haor areas. Millions of people earn their livelihood from fishing in the Haor areas.

Other aquatic animals of importance in the Haor basin include mussels, snails and other gastropods.

There are two main threats to the Haor ecosystem. The first is from natural causes, namely sedimentation and siltation leading to the gradual filling up of the depressed basins and thus converting the permanently flooded area as well as the seasonally flooded areas. The second more important threat to the wetlands is from human interference in the form of construction of embankments. Full embankments allow conversion of the wetlands into drylands and cause complete destruction of the wetland habitats.

The expected impact of climate change in this region is that the water flow regimes of the major rivers may be changed, probably to increase the high flows, thus causing greater inundations but also leading to higher rates of sediment flow which will accelerate the natural rate of deposition. Drought conditions may also hasten the drying up process.
6. Response strategies

6.1 Introduction

Integrated Coastal Zone Management (ICZM) is considered to be the most adequate mechanism to deal with the possible impacts of climate change and sea level rise. It not only provides the tools to identify the short and long term actions in implementing national strategies towards achieving sustainable development, but also provide the framework under which the actors from different strata of the society act together and take appropriate response strategies.

The choices of response strategies against impacts of climate change and sea level rise are limited: limiting emissions and adaptation to changes. Limiting carbon emissions to the level of 1990, which is recommended by the FCCC, not only depends on the government of Bangladesh, but also on other governments. In this case the countries which have high per capita emission of greenhouse gases (GHGs) may act without further delay. In order to limit the emission of GHGs for Bangladesh a complete GHG inventory is a must. Also necessary would be an analysis of the energy use and energy related emissions so that the future development of Bangladesh would not be detered.

Unlike limiting emissions, the adaptive response strategies depend largely on the Bangladesh’s own capability in terms of finance, technology and human resources. IPCC identified three adaptive measures as illustrated in Box 6.1 [IPCC, 1990].

- Retreat: resettle the inhabitants, abandon structures in currently developed areas, and require that any new development be set back specific distances from the shore, as appropriate.

- Accommodate: continue to occupy vulnerable areas but accept the greater degree of flooding (e.g. convert farms to fish ponds). This includes accommodations.

- Protect: defend vulnerable areas, especially population centers, economic activities, and natural resources. This includes building dikes, embankments, sea walls, etc.

Each of these adaptive measures is examined for Bangladesh and are described below.

6.2 Retreat

Retreat in Bangladesh is not a practical solution, because of the country’s high population density and very low resource to man ratio. Relocation of people within the country is not acceptable socially, since that would mean sharing of already low resource-base with the neighbourhood. On the other hand, migration to other countries, especially ones with high resource potential, could only be possible with the consent of international community.

6.3 Accommodation

Accommodation to climate change and sea level rise has been the traditional way of the people of the country, particularly in the most hazard-prone areas along the coast and rivers. The people have already invented many modalities to adapt to these hazardous living conditions. They have learned to live with the adverse conditions, and for a pragmatic planner it is thus important to learn from the people’s ancestral behaviour and their accommodating strategies. Based upon these knowledge and identifying their requirements through participatory planning, appropriate adaptive development strategies may then be formulated.

Some possible strategies may include developing crop varieties and cropping practices that are adapted to local conditions and possible conditions under climate change scenarios including salinity and drought tolerance among others. The possibility of brackish water aquaculture may also be experimented with.

For the case of cyclones, a recurrent hazard in the coast of Bangladesh, the best strategy seems to be the one being followed now, namely to improve forecasting and early warning systems in combination with easily accessible and strong cyclone shelters in sufficient quantities to enable all the cyclone prone population to take shelter upon receipt of a cyclone warning. In order to supplement the existing disaster management programme, the institutional capabilities may be further strengthened.

While accommodation strategies need to be pursued, it must be recognized that they only allow the country to live with the problems of climate change and mitigate but not to solve or eliminate the problems themselves. Thus it would make sense for Bangladesh to make a major effort in the international arena to ensure that the impacts of future climate change are minimized as much as possible. This will mean the speedy adoption and implementation of international conventions, including the Montreal Protocol and the Framework Convention on Climate Change.

6.4 Protection

For some parts of the country, such as the Sundarbans mangrove forest, the best coastal protection measure is presently to preserve and conserve the protecting mangrove forests as much as possible and to allow for future (inland) migration under influence of accelerated sea level rise. In other areas, as in the south central and south east, it would be possible to build embankments or to increase the height
BOX 6.1: Sample response to sea level rise considered in the IPCC methodology

<table>
<thead>
<tr>
<th>Buildings</th>
<th>Wetlands</th>
<th>Crops</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>RETREAT</strong></td>
<td><strong>ACCOMMODATE</strong></td>
<td><strong>PROTECT</strong></td>
</tr>
<tr>
<td>Establish building setback codes</td>
<td>Regulate building development</td>
<td>Protect coastal development</td>
</tr>
<tr>
<td>Allow wetland migration</td>
<td>Strike balance between preservation and development</td>
<td>Create wetland/mangrove habitat by landfilling and planting</td>
</tr>
<tr>
<td>Relocate agricultural production</td>
<td>Switch to aquaculture</td>
<td>Protect agricultural land</td>
</tr>
</tbody>
</table>

Source: IPCC, 1990
BOX 6.2: Integrated coastal zone management for sustainable development: A framework

Benefits of the framework

- improving understanding of common concepts (including common terminology), methodology and approaches to the various tasks involved in the ICZM process, thus strengthening ICZM capacities
- assisting policy makers to deal with both short term and long term needs in order to achieve sustainable use of coastal resources
- providing a common frame for exchange of ICZM experiences
- improving programme evaluation by national governments as well as international funding agencies
- improving understanding of benefits of ICZM thus increasing motivation for and investment in ICZM programmes
- enhancing coordination among the international agencies financing ICZM studies and projects in developing countries, thus enabling more efficient use of available resources
- enabling optimal use of the limited domestic resources available in some countries for ICZM efforts

Source: CZM-Centre, 1994
of existing embankments to prevent inundations. But it is not possible to prevent intrusion of salt water into the waterways and through capillary action into the groundwater. One possible barrier to such salt water intrusion might be the protection and use of freshwater wetlands as barriers to salt water intrusion, as has been done in other parts of the world.

In the case of cities such as Dhaka, Chittagong and Mongla, porthaving high concentration of capital and infrastructure, it is necessary to build dikes and sea walls to prevent the worst damage from storms and sea water intrusion. Also for the areas of poldered agriculture and aquaculture, small scale embankment, depending on the nature of the area specific problem, may be erected to supplement the already existing ones. However, implementation of these protective measures would require substantial external financial and technical support.

6.5 Integrated coastal zone management and corresponding institutional arrangements

The coastal zone of Bangladesh comprises a rich and complicated mixture of different ecosystems, agricultural practices, industrial activities, fishing habitats and navigation and other activities. All these activities and the natural resources on which they are based need to be developed in a way that allows the maximum possible benefit to the largest number of people, without degrading the resources themselves. Available human resources, local traditions and complicated and often inadequate institutional arrangements create possibilities as well as limitations to solve the short range problems of such developments. The impacts of possible climate change and other long term changes on this already complex problem of resource utilization, makes it even more imperative to develop integrated approaches, technically, economically, socially and institutionally.

As agreed in the declaration of the World Coast Conference in Noordwijk, The Netherlands (1993) and in the Agenda 21 at UNCED in 1992, the need for countries with low lying coastal areas to introduce and implement Integrated Coastal Zone Management (ICZM) approaches is imperative to prepare for and to mitigate the impacts of climate change and sea level rise. An integrated approach enhances sustainable development (box 6.2). It enables, among other things, the assessment if coastal zone developments make the coastal area more rather than less vulnerable to the impacts of possible climate change and sea level rise. Another important characteristic is, that the climate change issues are placed in the proper context of other long range problems — such as the decrease of low water flows in the Ganges — and day to day urgent decision matters.

Proper institutional arrangements are at the kernel of Integrated Coastal Zone Management. It is crucial to gather all actors in a proper institutional structure and to submit them to a set of common procedures for the planning and implementation of coastal zone developments. Before starting to improve present management and institutional arrangements in order to facilitate Integrated Coastal Zone Management, it is necessary to analyze the capacity of the present institutions and identify the possibilities and possible bottlenecks for developing and implementing ICZM activities.

The pilot study made an attempt to analyse the system of Governance in Bangladesh, its planning mechanisms and arrangements, focusing on the water resources sector in relation to coastal zone management. The main issues identified through this analysis are presented below. Box 6.3 gives an overview of the assessment of the capability of Bangladesh to implement response strategies for mitigating the impacts of possible climate change and sea level rise.

<table>
<thead>
<tr>
<th>IMPLEMENTATION ASPECTS</th>
<th>MAJOR PROBLEM</th>
<th>PARTIAL PROBLEM</th>
<th>NO PROBLEM</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>INSTITUTIONAL ARRANGEMENTS</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>* allocation of tasks</td>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td>* linking mechanisms</td>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td>* legislation/organisations</td>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td>* staff capacity</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>* existing CZM plan</td>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>CROSS BOUNDARY ARRANGEMENTS</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>* physical/chemical flows</td>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td>* water sharing agreements</td>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>ECONOMIC &amp; FINANCIAL POSSIBILITIES</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>* national economic capacity</td>
<td>x</td>
<td></td>
<td>x</td>
</tr>
<tr>
<td>* international funding possibilities</td>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>TECHNICAL CAPABILITIES</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>* availability of data</td>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td>* research/technical capability</td>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td>* design/construction capability</td>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td>* general education level</td>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>SOCIAL &amp; CULTURAL ACCEPTABILITY</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>* awareness</td>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td>* people's participation</td>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td>* access to resources</td>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td>* social/cultural constraints</td>
<td>x</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
The main findings of the above mentioned analysis are given below:

**Need for a coherent administrative system**

Bangladesh is yet to develop a coherent system of government and a people-oriented development/administrative setup. It started with a parliamentary system, then shifted to a presidential system, and has again reverted to the parliamentary system. Such frequent changes in policy have impaired development.

**Need for a sustained focal institutional framework for development**

Bangladesh has not yet been able to identify and sustain local institutional networks for spearheading and implementing development and policy decisions. This may be attributed to the abrupt changes in the governmental framework with past changes in the government.

**Centralized system of planning**

The system of planning is centralized and all development schemes are prepared and approved in the capital. Other administrative units such as divisions/districts/thanas lack the power, human resources and the funds to undertake substantial development schemes at the local level. The present system hampers effective, people-based development planning and implementation.

**Need for a legal framework for planning**

The Planning Commission and other related agencies have not been created by law but by administrative decisions and orders. Planning is not a mandatory exercise. The planning agencies should be strengthened by providing appropriate legal mandate.

**Effective mechanism for implementation, coordination, monitoring and evaluation**

The status of implementation of development schemes is very poor. Bureaucratic bottlenecks and inefficiency of the implementing agencies handicaps implementation of any development programme. The existing programmes should allow room for people's evaluation and feedbacks under a mandated coordinated body incorporating local level representation.

**Proper land use planning and effective cost recovery systems**

There is a need for an appropriate land use planning, which is lacking at any level. Such a plan would maximize land and resource use. Also an effective and efficient system of cost recovery has to been developed.

**Bias in favour of the government sector**

The whole planning exercise and all related administrative and financial infrastructure and arrangements are highly biased in favour of the government sector. It is necessary to identify the development actors from all sectors including the informal sector and provide them with necessary support in implementing development programmes.

**The role of the private sector**

Despite the efforts of successive governments, the private sector's contribution to overall economic development has been marginal. Unless the private sector plays a more dominant and effective role the country may not experience a real change in its current rate of development.

**Bias in favour of infrastructure building**

In most development initiatives the building of roads, culverts, embankments etc. are given more emphasis than developments in human resources, health, education, agriculture and water resources. Resource allocation should be prioritized.

**Dependence on donor funding**

Bangladesh is heavily dependent on donor funding for development. Such dependence makes development costly, often irrelevant, and unsustainable in many cases. The overall development strategies, therefore, often fail to reflect the people's needs and priorities.

**People's participation**

The people at large are bypassed in the overall process of development. Their participation in the stages of planning, monitoring and evaluation is practically absent. At the implementation stage the local people are sometimes involved as labourers only. Total participation by the people at all stages of development is essential to make it appropriate and efficient.
7. Vulnerability profiles

Vulnerability for impacts of climate change and sea level rise is not an absolute measure. It is a comparative judgement of differences between two conditions of the same development situation in Bangladesh: one with and one without climate change and sea level rise. Examples of such differences are: an 80 cm increase in high water levels; a 20% extension of periods of low water flows in the Bangladesh rivers; an 18 billion taka value of infrastructure affected by increased inundations; and a 1.5% decrease in national income. These differences can then be compared and judged on their relative importance (weighting). An overview of the considered criteria for which these differences were determined is presented in Box 7.1. They include, in addition to criteria related to impacts of climate change and sea level rise, indicators referring to the feasibility to implement responsive measures.

The total set of these weighed differences for one comparison taking into account the possibilities to take responsive measures is called a vulnerability profile (VP). Such a profile could be related either to the present or to a future development situation of Bangladesh. Overall vulnerability is expressed in terms of critical, high, medium and low analogous to the terminology of IPCC-CZMS, (1992).

For the present study, 5 different development situations have been considered: the 1990 situation; and four different options for 2010, which combine developments within Bangladesh (high and low development) and outside Bangladesh (sharing and non-sharing of water).

As mentioned these five different development situations have been analyzed in ten different cases combining these development situations with climate change scenarios (Box 3.3). Based on these ten cases six pairwise comparisons were made. Estimating the differences between the cases considered in each pair and weighing these differences resulted in a vulnerability profile for that selected pair. An overview of the six selected pairs is presented in Box 3.5. Four out of these six comparisons include vulnerability profiles for a severe climate change scenario (including a 100 cm sea level rise); two present a sensitivity analysis for a moderate climate change scenario. These vulnerability profiles enable a ranking of development conditions in terms of their vulnerability to climate change and sea level rise.

Weighed differences have been combined into aggregated indices; for example, an index for vulnerability due to inundation combines differences in: flood vulnerable area; average flood depths in unprotected areas; and risk of flooding in protected areas. Further weighing and aggregation leads to vulnerability indices for the main impact categories considered; Primary Physical Effects, Natural Ecosystems, Socio-economic Stress and Implementation of Response Strategies. Through a similar procedure the vulnerability indices for the main categories are added to one overall vulnerability index for individual VA - zones. As a final step, these indices can be combined.
into one total vulnerability index for the country as a whole. If desired different VA-zones can be given different weights. These vulnerability indices are calculated using a Multi-Criteria Analysis Technique: the Analytical Hierarchy Process or AHP, which enables both quantitative and qualitative scores to be used.

The approach does not yield physically or economically meaningful indices, but allows ranking and evaluation of different development options with respect to their vulnerability for climate change and sea level rise.

Results are presented graphically in Box 7.2, showing the vulnerability indices per VA zone. These indices are expressed as percentages of maximum scores, which are obtained when scores for all individual indicators represent maximum values for the considered range of possible impacts.

The graph shows a rather uniform vulnerability profile for the four considered situations under the severe climate change scenario (present; BAU/non-sharing; BAU/sharing; and HDO/non-sharing). This implies that the country remains at the same level of vulnerability as in 1990, irrespective of the expected developments within and outside of Bangladesh. Using this characteristic, maps have been composed which show only one vulnerability profile, differentiated by VA-zone and representing different development options (Boxes 7.3 and 7.4). In these maps, a score of more than 50 % of the maximum possible score has been classified critical, between 25 and 50 % highly vulnerable and below 25 % medium vulnerable.

From the results it can be concluded that a substantial part of the country scores around 50 % of the maximum possible vulnerability for most of the considered aspects. The southwest and northwest zones are above the average vulnerability, and the northeast zone below the average.

It is stressed that these vulnerability indices refer to climate changes and are relative to "no-change" values of the climate scenario. These indices refer therefore to relative changes in addition to changes due to developments in and outside of Bangladesh. Major changes and adverse impacts, e.g., on population affected by inundations and the availability of water in the dry period are already expected under the high development and non-sharing option. The climate change impacts add relatively little to these impacts. In some aspects this may result in a low vulnerability to climate change and sea level rise. For example, if ecosystems are expected to disappear anyhow, they are not vulnerable any more to impacts for climate change and sea level rise.

32
BOX 7.3: Vulnerability of Bangladesh for different aspects

a: Primary physical effects

- Critically vulnerable
- Highly vulnerable
- Medium vulnerable

b: Natural ecosystem

- Critically vulnerable
- Highly vulnerable
- Medium vulnerable

c: Socio-economic stress

- Critically vulnerable
- Highly vulnerable
- Medium vulnerable

d: Implementation of response strategies

- Critically vulnerable
- Highly vulnerable
- Medium vulnerable
BOX 7.4: Overall vulnerability of Bangladesh
8. Conclusions

Vulnerability of Bangladesh for climate change and sea level rise considers four categories of impacts and is specified for nine VA-zones. The four categories relate to: a) the physical, ecological and socio-economic impacts of climate change and sea level rise; and b) the feasibility to implement possible response strategies, such as retreat, accommodation and protection. The nine VA-zones divide the country in four southern, two central and three northern regions. This distribution enables a regional differentiation of agents of change of their impacts and of the aggregated vulnerability assessment.

The study considers the following agents of change: sea level; temperature and evaporation; precipitation; river discharge and cyclones. It merits mention that these agents of change not only encompass impacts from climate changes, but as well consider different developments in and outside Bangladesh for the year 2010. Developments outside Bangladesh are related to activities in the upstream watersheds of the rivers flowing into the country and to the arrangements with India on sharing of the available water. Two extremes are considered in the pilot study: a sharing and a non-sharing condition. Developments inside Bangladesh consider a Business-as-Usual and a High Development condition. Reference is made to sections 3.2 and 3.3 for specification of these options.

A total of four development situations have been analyzed on their vulnerability to climate change and sea level rise.

- the 1990 situation inside and outside Bangladesh (present);
- a Business-as-Usual development (BAU) in Bangladesh in the year 2010, assuming a water sharing condition with India (2010BAU/SH);
- a Business-as-Usual development (BAU) in Bangladesh in the year 2010, assuming a non-sharing condition with India (2010BAU/NSH); and
- a High Development (HDO) in Bangladesh in the year 2010, in combination with a non-sharing condition with India (2010HDO/NSH).

Vulnerability to climate change and sea level rise refers to changes in addition to the changes incurred in the four development conditions above. This has important consequences for the evaluation of the results of the vulnerability assessment proper. For example, even without any climate change or sea level rise, the 2010BAU/NSH development might result in considerable adverse impacts, for example, on the number of people affected by droughts and inundations and the damage to infrastructure due to natural hazards. These changes, however, are not included in the changes considered in the assessment of the vulnerability for additional impacts of climate change and sea level rise.

The above approach implies that an outcome of the assessment is possible that, relatively speaking, the vulnerability for climate change and sea level rise would decrease under future development conditions. For example, if the whole country is already flooded, an additional rise of sea levels will not increase the number of people affected by floods.

Taking the above into account, the study yielded the following main conclusions.

- Climate change and sea level rise will affect the whole of Bangladesh and not only the coastal areas. Main impact categories are: inundations; droughts; salt water intrusion; and low flow conditions.

Due to adaptive bed level rises in the morphologically dynamic rivers, water level rises due to sea level rise are expected to extend beyond the border with neighbouring countries. This effect has a strong north-south orientation.

Changes in climatic conditions will affect the whole country. Drought prone areas, however, are mainly found in the western part of Bangladesh, giving these impacts a strong west-east orientation.

Impacts on salt water intrusion and low flow conditions are strongly related and have mainly a north-south orientation. The combination of these impacts probably leads to non-proportional effects on, e.g., the availability of fresh surface water for irrigation purposes. This could not be analyzed at the same level of quantification as the impacts on inundations and droughts.

- Bangladesh in 1990 conditions of development is highly to critically vulnerable for climate change and sea level rise. The main part of the country scores around 50% of the maximum possible vulnerability for most of the aspects. The southwest and northwest-zones are above the average vulnerability and the northeast-zone below the average. The central west-zone is highly vulnerable in terms of primary physical effects and socio-economic stress. However, the overall vulnerability is similar to the southeast and southcentral-zones.

- Bangladesh remains highly vulnerable to climate change and sea level rise, irrespective of future developments in and outside the country. With regard to the primary physical effects, the 1990 situation seems slightly more vulnerable than the three considered future situations, while for the impacts on the natural ecosystems, the non-sharing water conditions result in a slightly higher
vulnerability of Bangladesh. With respect to the aggregated socio-economic aspects and the feasibility of response strategies, differences in aggregated vulnerability indices are negligible.

- Developments in Bangladesh (2010 BAU and HDO developments) and in the upstream watersheds of the main rivers (sharing and non-sharing of available water) bring about changes onto Bangladesh which are similar to those induced by the severe climate changes. The country seems particularly vulnerable for a combination of a high development option for Bangladesh (as defined in this pilot study) and non-sharing of water from the upstream watersheds.

- As mentioned, climate changes and sea level rise in addition to these developments in and outside Bangladesh have -- relatively speaking -- a rather similar impact. This implies that the combination of high development, non-sharing of water and climate change is expected to bring the country in a critical situation with respect to the damage of river floods and storm surges and the availability of freshwater in the dry period. In particular the water availability has major consequences on the country’s potential for foodgrain production.

- A non-proportional combination of effects is pronounced for all aspects related to river flows and water levels. For example, the analysis case 2010HDO/NSH in severe climate change results in an average increase of flood depth of 70 cm, while the accumulation of the individual impacts amount to 35 cm only.

- Another non-proportional combination of effects is identified for the water balance in the dry period. On the one hand more irrigation water will be required to compensate for the expected changes in evaporation and precipitation. On the other hand, the availability of water will be substantially reduced due to lower river flows in the dry period and increased salt water intrusion.

- The conclusion that the high development in Bangladesh just compensates for the adverse impacts of climate change and sea level rise, is most clearly demonstrated for the foodgrain production. Improved management practices are expected to bring the total production from a level of 32 up to a level of about 40 million metric tons per year. Reduction of the production due to drought is expected to be in the same order of magnitude.

- The regional distribution of possible impacts of climate change and sea level rise is dominated by two "groups" of agents of change:
  - changes in sea level, river discharges and cyclone intensity, resulting in impacts which differ in north-south direction; and
  - temperature, evaporation and precipitation changes, resulting in impacts which differ mainly in a west-east direction.

The combination of these effects bring the southwest and northwest-zone in the highest vulnerability class and the northeast-zone in the lowest. the other zones have rather similar vulnerability indices. The southeast, southcentral and central west-zone seem slightly more vulnerable than the Sundarbans and the central central-zones.

- It is stressed that the above conclusions are based on rough assumptions, a limited set of impacts and subjective judgements on vulnerability classifications. Moreover, it is recognized that the flexibility of a society to adapt to gradual changes and future technological developments will help to mitigate the impacts predicted. On the other hand, important adverse impacts could not yet be studied. These include: salt water intrusion into the surface water and groundwater systems and the influence on soil salinity; and the above mentioned combination of effects during the dry period of increased water demand for irrigation and the reduced surface water availability during low flow conditions.

- IPCC considers three categories of adaptive response strategies: retreat, accommodation and protection. For Bangladesh, the retreat option is only considered in the southeast-zone. Accommodation seem the most feasible one, in particular, in the southeast and the central zones, where development is highest.
9. Recommendations

In order for Bangladesh to contain and manage vulnerability to the possible impacts of climate change as well as other long term regional and national developments a number of activities are to be undertaken. The following recommendations are made for implementation at different levels.

National level

- The approach and corresponding analytical framework as developed and applied in the pilot study proved to have the potential to become a powerful planning tool to support strategic decision making in Bangladesh, in issues related to natural resource management. Existing models and available data are sufficient and are able to produce useful information on possible long term impacts of human induced developments inside and outside of Bangladesh and of changes in climate and sea levels.

- The Interministerial Government Review Committee on Climate Change -- chaired by the Ministry of Environment -- played a crucial role in the coordination of the pilot study and the presentation and dissemination of its results and findings. The Review Committee was established under the present project, but its function has been gradually broadened to other issues related to planning of natural resources. It is strongly recommended to further institutionalize its role and function and to provide it with an operational technical assistance. One of its important functions should be to generate information in support of important planning decisions. The Government Review Committee on Climate Change could be seconded by a Committee on Integrated Coastal Zone Management. This High Level Committee could play an important integrating role for short and long term developments of the coastal areas of Bangladesh.

- Effective adaptive responses to the threat of climate changes and sea level rises include such measures as: the creation of support and extension services to improve or change agricultural practices; negotiations on water sharing arrangements with India; efficient mechanisms for disaster management; development and introduction of desalination techniques; and the plantation of mangrove protection belts. Such measures include many different sectors of the Bangladesh society and should be part of integrated coastal zone management.

- Integrated coastal zone management is a complicated issue which requires operational institutional arrangements. To this end it is recommended:
  - to implement efficient land use planning procedures and effective cost recovery systems;
  - to develop operational planning, implementation and evaluation procedures;
  - to distribute corresponding tasks through proper institutional arrangements;
  - to establish an efficient and effective legal framework; and
  - to pay strong emphasis on aspects of training and capacity building of government agencies involved in planning, implementation and evaluation.

In particular in training and capacity building, international cooperation and stimulation of transfer of knowledge is urgently required.

- The presented conclusions justify a high concern for planning agencies with respect to their capacitation and to a continual programme of investigations (preferably coordinated through the Government Review Committee). Such investigations should concentrate on further developing tools for planners to support important strategic decisions in Bangladesh on, e.g., flood protection measures, crop diversification and on rural and urban development. A next round of investigations could concentrate on the following topics.

Extension of the analytical framework

- Salt water intrusion into the surface and groundwater systems and the impacts on soil salinity under different developments inside and outside Bangladesh. This requires, among other things, a more detailed model investigation (MIKE11) as has been performed in the present pilot study. Salt water intrusion should be studied as a function of changes in river discharges and sea levels during low flow conditions.

- Vulnerability to droughts and changes in low flow conditions. Such a study would have two main components. One component will study in more detail the impacts of droughts on future agricultural production for different suitable cropping patterns and would specify the corresponding water requirements. The other component will compare water requirements and water availability, the latter as a function of low flow conditions and salt water intrusion. It is important that the agricultural production accounts for possible limitations in water availability as resulting from the second component.

Social differentiation

- Mitigation of response strategies in Bangladesh refers to the accommodation of the Bangladesh society, mainly on a regional scale. Vulnerability studies up to now concentrated on impacts for the country as a whole or
for specified regions. Indicators developed in the pilot study do not differentiate between different stakeholders or social impact categories. A study is recommended which accounts for the vulnerability of different social groups, e.g., landless people, women and urban poor.

- A possible approach for such a study could be: (i) identify in a specified area the relevant stakeholders; (ii) formulate their needs with respect to the natural resources, e.g., freshwater, soil conditions and mangrove protection; (iii) establish the possible impacts of climate changes and other developments on the availability and accessibility of these resources; (iv) formulate possible measures to enhance and guarantee the access to these resources for the different stakeholders; and (v) evaluate the feasibility to implement these measures.

- It is important to relate the vulnerability of different social groups with other types of vulnerability, such as food shortage and poor ambient environmental quality.

Regional level

- Step up efforts at regional cooperation between the co-riparian countries to ensure a fair share of fresh water flows, particularly during the dry season. This is essential for sustainable development in the region.

- Participate in and encourage regional efforts at assessing climate change impacts as well as mitigation strategies.

International level

- Continue to participate actively in the efforts of the Intergovernmental Panel on Climate Change (IPCC).

- Put forward Bangladesh's activities and particularly vulnerability to climate change to the international community and seek their cooperation in preventing climate change and also mitigating its effects on Bangladesh.

- Participate in developing and implementing the World Coast 2000 plan and also the other commitments under Agenda 21 and the Framework Convention on Climate Change.

- To set up an institution for research and development to contain and manage vulnerability to climate change. Considering that Bangladesh is one of the most vulnerable countries such an institute may appropriately be located in Bangladesh.

- International effort for fair share of regional waters must continue as urgent priority.
BANGLADESH WATER DEVELOPMENT BOARD

Report on the construction of the

FENI RIVER CLOSURE DAM

HASKONING
Royal Dutch Consulting Engineers and Architects

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