Economic Modeling of Climate Change Adaptation Needs for Physical Infrastructures in Bangladesh

June 2009

Printing supported by:

Comprehensive Disaster Management Programme
Ministry of Disaster Management and Relief

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Climate Change Cell
Department of Environment

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Published by
Climate Change Cell
Department of Environment, Ministry of Environment and Forests
Component 4b
Comprehensive Disaster Management Programme, Ministry of Food and Disaster Management
Bangladesh

Date of Publication
June 2009

The study has been conducted by **Center for Environmental and Geographic Information Services (CEGIS),** commissioned by the Climate Change Cell.

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Citation

CCC, 2009. *Economic Modeling of Climate Change Adaptation Needs for Physical Infrastructures in Bangladesh.* Climate Change Cell, DoE, MoEF; Component 4b, CDMP, MoFDM. June 2009, Dhaka.

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ISBN: 984-300-003322-4

Acknowledgement

Climate Change Cell of the Department of Environment expresses gratitude to the collective wisdom of all stakeholders including experts, professionals and practitioners dedicated to the service of climate change risk management particularly in climate change adaptation and modeling.

Mention of the research team, Center for Environmental and Geographic Information Services (CEGIS) is obvious.

Cell also likes to mention Ian Rector, CTA, CDMP, Khondaker Rashedul Haque, PhD, former DG, DoE, Mohammad Reazuddin, former Director, DoE and Component Manager of the Cell, and Ralf Ernst, former Technical Adviser, Climate Change Cell for their support and inspiration provided during initial stages of the research programme.

Acknowledgement is due to Technical Advisory Group (TAG) of the Cell for their valuable contribution in identification of concepts, evaluation of concept proposals, development of methodology and finalizing the research reports.

Views of government officials, civil society members and development partners in several stakeholders' consultation workshops enriched the research outcome.

Special gratitude to the distinguished experts Dr. Asaduzzaman, Research Director, Bangladesh Institute of Development Studies (BIDS) and Dr. Atiq Rahman, Executive Director, Bangladesh Centre for Advanced Studies (BCAS), who as peer-reviewers, provided valuable insight on research methodology, analysis and findings.

Cell is grateful to the Department of Environment, Ministry of Environment and Forests for the initiative for publication of the research paper. In this respect, Md. Nojibur Rahman, former Director General, DoE supported the Cell throughout the initiative and provided much needed directives for the publication.

Contribution of Dr. Fazle Rabbi Sadeque Ahmed, Director, DoE in finalizing the research document is invaluable.

Mirza Shawkat Ali and Md. Ziaul Haque, Deputy Director, DoE extended their allout support during whole period of the research programme.

Acknowledgement is due to the Department for International Development (DFID) and United Nations Development Programme (UNDP) for their continued support to the Climate Change Cell in its effort to facilitate the climate change research programme.

Finally, Cell gratefully acknowledges the contribution of Abu M. Kamal Uddin, Programme Manager and Mohammad Showkat Osman, Research Officer, Climate Change Cell who were involved in the over all management of the research program; Md. Nasimul Haque, Information and Communication Expert who provided valuable insight in development of the research program and Md. Mezbanur Rahman, Research Officer who provided valuable assistance in preparing the report for publication.

Foreword

The impacts of global warming and climate change are worldwide. For Bangladesh they are most critical because of its geographical location, high population density, high levels of poverty, and the reliance of many livelihoods on climate-sensitive sectors, such as agriculture, fisheries.

To address current impacts and manage future risks of climate change and variability towards development of a climate resilient Bangladesh, the government has established the Climate Change Cell (CCC) in the Department of Environment (DoE) under the Comprehensive Disaster Management Programme (CDMP). Climate change research, covering modeling and adaptation is one of the major activities of the Cell.

CCC in association with its Technical Advisory Group (TAG) and other stakeholders identified a set of research activities related to climate change in Bangladesh through a number of consultations. The activities have been prioritized and a number of projects have been commissioned in last few years.

Climate change impacts can undermine countries' efforts to achieve the goal of sustainable development. Sustainable development depends on economic growth, social justice, and environmental integrity. It is hard to estimate the market value of impacts of climate change (and variability) on environmental integrity. However, these needs to be monetized to the best possible way to bring policy makers and planners on board. It will provide them with an instrument that enables in interpreting economical, social and environmental cost while planning development program.

The economic analysis and modeling for Bangladesh's vulnerability and susceptibility to climate change, disaggregated across sectors, could indicate investment requirements to protect past development and to assure climate resilient future development. The adaptation deficit for Bangladesh can be determined to a large extent from such analysis and modeling. Considering the physical impacts of climate change on the economy, the climate change cell intends to develop economic assessment framework for Bangladesh.

The study developed economic model for three sectors, water management infrastructures in the coastal zone, health sector and roads and Highways. Using the model, the study revealed that the net investment cost for raising the coastal embankment for the probable Sea Level Rise (SLR) would be around Tk. 34,828 million. For transportation sector, a total of Tk. 8794 million would be required for flood-proofing of roads and highways by raising these infrastructures above the highest ever-recorded flood levels. Adaptation costs for health care, both private and public, have been estimated to be around Tk 1265 million per year.

It is expected that the research will open a window to dive deeper into the issues of cost of climate change with respect to land, water and environment. More integrated approach towards assessing cost of impacts of climate change will be undertaken by researchers to facilitate policy makers and planners to formulate viable adaptation policies, strategies and action plan.

Zafar Ahmed Khan, PhD
Director General
Department of Environment

Acronyms and Abbreviations

AOGCM	Atmosphere-Ocean Global Circulation Models
BCAS	Bangladesh Centre for Advanced Studies
BRTC	Bureau of Research, Testing and Consultation
BUET	Bangladesh University of Engineering & Technology
CCC	Climate Change Cell
CDMP	Comprehensive Disaster Management Program
CEGIS	Center for Environmental and Geographic Information Services
CERP	Coastal Embankment Rehabilitation Project
DoE	Department of Environment
DEM	Digital Elevation Model
ENSO	El-Nino Southern Oscillation
FFWC	Flood Forecasting and Warning Center
GCM	General Circulation Models
GDP	Gross Domestic Products
GoB	Government of Bangladesh
IPCC	Intergovernmental Panel on Climate Change
IWM	Institute of Water Modeling
LDC	Least Developed Countries
LGED	Local Government Engineering Department
MoFDM	Ministry of Food and Disaster Management
MPO	Master Plan Organization
MOEF	Ministry of Environment and Forests
NAPA	National Adaptation Programme for Action
NIPSOM	National Institute of Preventive and Social Medicine
NWMP	National Water Management Plan
RCM	Regional Climate Model
RHD	Roads and Highways Department
RRAP	Risk Reduction Action Plan
RVCC	Reducing Vulnerability to Climate Change
SLR	Sea Level Rise
UNDP	United Nations Development Program
US$	United States Dollar
WARPO	Water Resources Planning Organization
WB	World Bank

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Executive Summary

Global climate risks have now started to take concrete shapes and it is widely predicted that Bangladesh is one of the countries most vulnerable to climate change. Adaptation to climate change risk has already started putting additional strain on development efforts of a country like Bangladesh. The economic cost is expected to be significant not to mention the social and environmental cost. Developed countries have made commitments to share adaptation costs with developing countries.

The need for developing economic model is central to the debate on climate change and adaptation to the changes, which will be extremely burdensome for developing economy like Bangladesh. Understanding the urgency of this fact, a forward-looking economic modelling exercise has been carried out under this study to develop the methodology to enumerate the economic cost of adaptation for physical infrastructural needs due to climate change. The overall study has been divided into three phases; activity and output from each phase is listed below:

- ✓ Phase-I
  - o Assessing the present information base, compiling them, filling the knowledge gap and developing a compensation computational framework.
- ✓ Phase-II
  - o Development of physical adaptation model.
  - o Development of economic model for water management infrastructures in the coastal zone
- ✓ Phase-III
  - o Development of economic models for two more sectors (e.g. Health, Roads and Highways)

The first phase of the study identified relevant knowledge gaps and developed a knowledge base from secondary literature review. This phase provided an outline of the framework (Figure 4.1) to analyze climate change phenomena, primary and secondary parameters of climate change impacts, sectors which are potentially vulnerable to climate change and notion of economic costs of adaptation measures.

The second phase of the study developed an economic model for the water management infrastructural needs for the coast of Bangladesh, which is especially vulnerable to the predicted sea level rise (SLR) due to climate change. Here, raising of existing 138 polders has been considered as key adaptation option and the cost of this option has been compared with expected benefit i.e. saving the expected damage of agricultural crops. The proposed economic model is based on the hypothetical model suggested by Gunasekera and Ford (2005) on climate change. Following this model, a four-step process has been adopted:

- Step-1: risk analysis of exposed situation;
- Step-2: estimation of expected damage due to climate change;
- Step-3: estimation of physical adaptation costs and benefits;
- Step-4: modelling the economics of adaptation.

Enumeration of economic cost has been derived from two modelling outputs – one physical adaptation model and one economic model. The physical adaptation model has been used to simulate two SLR scenarios; 27 cm SLR at the end of year 2050 and 62cm at the end of year 2080 as per IPCC-III assessment. Against each scenario, depth of flooding has been estimated and net change in the inundated area for different land types have been calculated.

Using the output of the physical model, a forward-looking economic model has been developed, incorporating the risk-based framework combining data on hazard (e.g. sea level rise) and considering the damage to standing crop due to overtopping of polders as key vulnerability indicator to estimate the risk. It has been calculated that the net investment cost for raising the embankment for the probable SLR of 27cm (year 2050) and 62 cm (year 2080) will be around Tk. 34,828 million (US$ 500 million approximately). In this regard, it has been assumed that the investment cost for adaptation will occur progressively from year 2010 against the risk of probable SLR. Annual benefit that can be expected from this adaptation will be Tk 574 million/year up to 2050 and Tk. 1,148 million/year onwards up to 2080. It has been found that the incremental B/C ratio of raising embankment will be 2.17 and IRR will be 28%.

Phase-III continues developing the economic model for two other vulnerable sectors: health and transportation following the same methodological steps as adopted in Phase-II.

Climate change induced high intensity events pose huge threats to existing physical infrastructure, specially the roads and highways. In the 1998 and 2004 flood, for example, the direct damage to roads sector is estimated as TK 15,272 and TK 10,031 Million, accounting for 15 and 9 per cent of the total damage respectively. The situation is expected to be deteriorating in the days to come, with the increased extent and intensity of flooding due to potential climate change and sea level rise in future. In this study, risk possessed due to flood vulnerability has been assessed and normalized using the backward looking approach (using past damage data) and the future risk has been estimated in terms of change in the probability of occurrence of regular and extreme flood events.

One option considered is the flood-proofing of roads and highways by raising this infrastructure above the highest ever-recorded flood levels as suggested by the DFID-sponsored programme “Roads and Highways Policy Management, budgetary and TA Support” (RHD). Specifically, some 170 Km of national and regional roads and some 518 Km of district (feeder) roads in high risk areas will be raised by 1m. Further, about 124km of national and regional roads in low risk area will be raised by 0.5m. In total, about TK 8,794 Million will be required for the implementation of the option. The costs estimates have also considered an average of two culverts per Km (for cross-drainage facilities) for each category of roads, instead of currently practiced 0.71 culverts per Km.

For transportation sector, simulation of climate change risk scenarios reveal that if no adaptation is pursued, an annual average loss could increase to 3% of GDP due to increased frequency of flood over next 100 years. Expected damage has come up to the tune of an annual amount of Tk. 52,725 million. If adaptation is pursued, a total of Tk. 8794 million would be required for raising the road height for a length of 811 km. Comparing the costs and benefits of such adaptations, EIRR (at a discount rate of 12%) shows a positive impact (63%). Delays in implementation of adaptation measures or increase of costs may produce risks, but resilience of project impact to these risks have been tested and found that the EIRR still remains around 39% under the most risky assumptions.

Similar exercise has been carried out for health sector. Available literature (NIPSOM, BCAS) reveal that vector and water-borne diseases have been a constant threat to Bangladeshi population, particularly, to the lower income groups. Average number of diarrhoea and skin disease victims is 2.6 to 2.8 million annually, according to those studies. Climate change is supposed to further increase the burden of diarrhoeal diseases at the year 2050. Remaining in the most conservative side, assuming no adaptation scenarios, an additional burden of 7% diarrhoeal patients and 1% dengu patients is envisaged in Bangladesh at 2050 due to change in climate. Adaptation costs for health care, both private and public, have been estimated to be around Tk 1265 million per year. On the other hand, benefit has been estimated in broad terms: saving of private health expenditure and wage savings for the poor. Over a period of 40 years, the cash flow analysis shows that base-case EIRR stands out around 41%. Sensitivity analysis against the risks of (i) increase of 20% costs, (ii) decrease of 20% benefits and (iii) gestation gap increased by 2 years shows only a 10% fall of EIRR from the base-case.

The study has opened a window to dive deeper into the issues of climate change with respect to land, water and environment. More integrated approach towards assessing impacts of climate change may be a welcome attempt for the government as the challenge has marked strokes on the economy through erratic extremes of disasters in Bangladesh.

Definite needs for future research in this respect may be identified as:

- Integrated 1st order physical modeling of climate change: This modeling will establish linkage between magnitudes of difference in elements of climate change and levels of impacts on biotic and abiotic components of environment for medium and long term considerations
- Integrated 2nd order physical modeling of climate change: This modeling will link the results of 1st order modeling with macro-economic implications of such results under medium and long term.

Policy formulation phase will require further research on (i) change in climate change adaptation needs, (ii) reforms in land and water use profiles, (iii) reconstitution of terms of international trade with respect to abatement and adaptation costs and benefits.

A wider forum for brainstorming on these issues is urgent because the climate change factors are incipient and impacts are undercutting our economic strength in terms of drawing more and more resources to repair the severe dents.

1. Introduction

1.1 Background

Change in the global climate is obviously not a nature driven phenomenon; human induced changes in the global climate and associated sea level rise are now widely accepted by policy makers and scientists. The Intergovernmental Panel on Climate Change (IPCC) concluded that "the balance of evidence suggests a discernible human influence on global climate". The exact magnitude of the changes in the global climate is still uncertain and subject of worldwide scientific studies. It is broadly recognized that Bangladesh is very vulnerable to these changes.

Bangladesh is exclusively a climate-dependent economy. This country has historically been wrecked by numerous natural hazards like riverine flooding, severe tropical cyclones and associated storm surges, drought and earthquakes, flash flooding, tornados and river-bank erosion. The man-made hazard, climate change, is a recent but silently growing member joining this already large family of disasters in Bangladesh.

It was envisaged in late 1990s that global climatic change could exacerbate some of the physical consequences of natural hazards (Warrick and Ahmad, 1996). According to the Third Assessment Report of IPCC, South Asia is the most vulnerable region of the world to climate change impacts (McCarthy et al., 2001). Observing the repetitive attack of natural disasters over Bangladesh, it has internationally been argued that Bangladesh, as a country, may suffer the most severe impacts from the man-made hazard climate change.

The international community also recognizes that Bangladesh ranks high in the list of most vulnerable countries on earth. Bangladesh's high vulnerability to climate change is due to a number of hydrological, geological and socio-economic factors. Geographical location in South Asia, flat deltaic topography with very low elevation, extreme climate variability which is governed by monsoon resulting in acute temporal and spatial distribution of water, high population density, high poverty incidence, climate-dependent crop agriculture etc. make up the utterly volatile regime of vulnerability. A review on Bangladesh disaster and public finance (Benson and Clay, 2002) remarked that the effects of rising sea-level on low-lying coastal areas, where there is elevation in progress and in interacting with high flood levels, were clearly complex and uncertain. It is, therefore, most important to understand its vulnerability in terms of population and sectors at risk. Climate change phenomena like temperature rise; sea-level rise, erosion, precipitation, drought etc. impact the primary variables like physical, biological and human systems. These, in turn, impact the secondary variables like aquatic, terrestrial and marine environments. Its final incidence falls upon the various economic sectors like agriculture, livestock, poultry, wildlife, livelihood and health, affecting GDP of the economy.

Four reasons are generally cited for creating adverse impacts of climate change in Bangladesh:

- Increase in number and extent of floods and erosion
- Longer period of floods due to increased precipitation in monsoon and rising sea level
- Increase in period of drought due to reduced rainfall in winter
- Increase in number and intensity of cyclones, tropical storms

The Climate Change Cell of the Government of Bangladesh has been pursuing the efforts to build capacity of the government, strengthen existing knowledge and information base, awareness raising and improving adaptation measures for livelihoods of population. Its publications are rich with issues like: (i) possible impacts and vulnerabilities, (ii) impact modeling, (iii) workshop reports, (iv) climate risk management and adaptation, (v) climate variability and change in Bangladesh etc.

1.2 Global Climate Risk

Global climate risks have now started to take concrete shape. IPCC (2001) remarked, "There is new and stronger evidence that most of the warming observed over last 50 years is attributable to human activities." The study made the following particular points:

- longer and more closely scrutinized temperature records and new model estimates of variability exist
- warming over last 100 years is unlikely to be due to natural variability of the climate alone, as estimated by current models
- observed warming over last 30 years is unusual, compared to the reconstructed climate data for past 1000 years

Working Group -II summary report of IPCC-IV spells out the projected changes and their impacts during the 21st century, causing global climate risks. The changes are divided into simple extreme and complex extreme categories as follows:

Table-1.1: Climate changes and corresponding impacts

Projected changes	Projected Impacts and risks
Simple extremes	
Higher maximum temperature, more hot days and heat waves	• Increased incidence of death, illness among older groups and urban poor • Increased heat stress in livestock and wildlife • Shifting of tourist resorts • Increased damage to crops • Increased cooling demand for electrical plants and reduced energy supply
Increasing minimum temperature	• Decreased cold-related human • morbidity and mortality • Decreased damage risks for some crops • Reduced heating energy demand • Increased risk to some crops • Extended range of some pest and disease vectors
More Intense rainfall	• Increased flood disasters • Increased soil erosion • Increased fiscal burden on governments • Increased recharge of some floodplain aquifers

Projected changes	Projected Impacts and risks
Complex extremes	
Increased summer drying	• Decreased crop yields • Increased damage to civil constructions due to ground shrinkage • Decreased water resources quality and quantity • Increased risk of forest fire
Increase in tropical cyclone peak wind and rainfall intensities	• Increased risk to human life, infectious diseases, epidemics • Increased coastal erosion and associated risks • Increased damage to coastal ecosystems
Intensified droughts and floods with El Nino events	• Decreased agricultural and rangeland productivity • Decreased hydropower potential in drought-prone regions
Increased Asian summer monsoon rainfall variability	• Increased flood and drought magnitude and damages
Increased intensity of mid-latitude storms	• Increased risk to human life and health • Increased loss of assets • Increased damage to coastal ecosystems

Global climate risks with respect to the resource taxonomy are, inter alia, the following:

- mobility of adverse environmental qualities across borders
- contribution of production, trade and trade policies in environmental intensive goods, factors and services to environmental damages
- deforestation or decreasing wetland (over-exploitation of renewable resources)
- depletion of exhaustible resources in the world
- disposal of human and toxic wastes in globally common places
- loss of bio-diversity and ecosystems damage

How far these concerns will exceed some critical level of consequences constitutes the basis of risk estimation.

1.3 Local-Global Interactions of Climate Change

Large number of small and marginal changes in climate parameters at local or regional level has global impacts while global trends also lead to local effects. Carbon dioxide emissions from the US thermal power plants have been observed to be crossing over to Canada through the regional air loop and have allegedly caused acid rain in Canada.

A significant damage to economic resources results from wrong rights and privileges, pollution regulatory acts, differing inter-temporal rates of return from use and conservation of economic or environmental resources, differing private and social costs and benefits among different countries. So, the impacts of climate change due to human interventions and manipulations flow back and forth from local to global scale or vice versa.

Economic costs of climate change, is, therefore, important to reflect upon for assessing the extent of loss of welfare, human health and productivity due to ozone depletion and climate change.

1.4 Bangladesh's Vulnerability and Key Concerns

Floods, especially the high intensity floods, often devastate physical infrastructure such as road networks, educational centres, market places, public buildings etc. Even flood protecting embankments are threatened to be breached during high intensity floods. The high intensity cyclone of 1970 associated with high tidal surge ravaged the whole coastal belt and took away more than 300 thousand lives and another high intensity cyclone of 1991 caused large-scale destruction to coastal embankments along the Patenga area in Chittagong, destroyed runways of Chittagong airport, ceased port activities by sinking a number of ships in the Patenga channel and also in offshore anchorage. Deluge of 1998 floods rendered most parts of Dhaka inaccessible by motorized vehicles, while the floodwaters of 1988 penetrated the runways of Dhaka International Airport and disconnected it for about 11 days from the rest of the world. The telecommunication network was torn off during the cyclone of 1991 and the entire coastal belt was disconnected for weeks. The catastrophic impact on human health, agriculture and infrastructures caused the economy to suffer negative macroeconomic performances for subsequent years.

Key concerns around climate change in Bangladesh are, inter alia, the following:

- adaptative capacity of human systems is low, but vulnerability is high
- extreme climatic events (floods, droughts, cyclones) are increasing
- economic strength to accommodate adaptation measures is low
- systematic knowledge about ongoing and imminent impacts of climate change and adaptation needs in social, physical and economic terms is only emerging

1.5 The Price of Ignorance about Climate Change

There is, so far, some notions that tropical storms in the Bay of Bengal are increasing in frequency and intensity, that floods are increasing similarly or rainfall amount and distribution are changing. Irregularity in all those natural events has already shown up. But this notion cannot be pursued unscientifically. It is undergoing professional investigation. Because, irony in Bangladesh is that such changes will be only clearly demonstrated after the disaster has taken place!

It is strongly envisaged that climate change- induced high intensity events pose huge threats to existing physical infrastructure. Damage to national highways due to flood alone is estimated at 1011 and 3,315 kilometers by the year 2030 and 2050, respectively. The corresponding damage to embankments is estimated at 4,271 and 13,996 kilometers by the year 2030 and 2050, respectively. The aggregated damage, as estimated by BRTC-BUET in 2005, for health centers and hospitals due to floods, cyclones, sea-level rise and salinity intrusion is estimated at 1,682 and 5,212, respectively, for the above two time horizons.

These natural hazards due to climate change cause significant budgetary pressure with short term fiscal impacts (construction and rehabilitation expenditure) and long term adverse implications for development.

1.6 Economic Cost of Climate Change

Climate change is relatively a new phenomenon in cost-benefits analyses. But the fact remains: cost is anything that reduces an objective. Bangladesh is a welfare country. It has a set of welfare objectives for its population. Poverty reduction is one of the most cherished national objectives. The results of research in Bangladesh and abroad demonstrate that Bangladesh is a clear victim to adverse impacts of climate change, which will drastically reduce its welfare objectives as such. The magnitude and extent of such reduced welfare objectives due to climate change in particular; therefore, constitute the components of cost of climate change.

It is difficult to identify the components of reduced welfare in terms of quantity and quality of lost opportunities due to climate change alone. Climate change creates irreversibility in natural system which increases entropy (in terms of increasing degree of uncertainty in production, consumption and distribution system). To define what the elements of those impacted are or potentially impacted components requires close monitoring of behavior of change patterns in those systems. For example, green house gases dumped into the environment have increased entropy and the decision to pollute the fresh environment has irreversible consequence, bewildering the planners of the affected economies globally. No warning was hoisted about the dangers of climate change from the polluting nations. Nor the affected nations have the definite signals as to what interactions have been taking place between atmosphere and land/soil biota due to CO_2 exchange along the timeline since half a century last.

Besides irreversibility, nature has its own uniqueness which is more than any worth on earth. It is difficult to assess the amount of loss of this uniqueness in environment. Snowmelt on the peaks of the Alps started due to climate change. How much density and thickness it lost nobody cared. But it has finally endangered the earth's surface with all black faces of disasters.

What boils down is the need for identifying the elements of losses due to climate change in order to arrive at some notions of costs.

1.6.1 Important cost considerations for climate change

The "reasons for concern" as described by IPCC (2001) are not all expressed in economic terms. There are non-market impacts too. The important considerations before identifying costs are:

1. Observed temperature change with changes in physical and biological systems;
2. Expected temperature change with changes in physical and biological systems;
3. Observed changes in the frequency and severity of extreme climatic events causing damages to ecosystems, crops and society
4. Expected changes in the frequency and severity of extreme climatic events causing damages to ecosystems, crops and society
5. Expected increased inequality between countries due to differentials in distribution of climate change impacts over the globe
6. Observed and expected impacts of both low and high warming on the macro-economic variable like GDP (mentioning even those impacts which cannot be expressed objectively in monetary terms)

At this moment impacts from future large scale and irreversible changes in earth-systems have not been considered, but these are not redundant. Global scale ocean circulation, El-Nino Southern Oscillation (ENSO) are apprehended to be possible in this current century whereby long term melting of Greenland and west Antarctic ice sheets may happen (IPCC, 2001).

Impacts and changes assessed in the above line will guide the economist to assume the depth and magnitude of losses for the threatened and unique entities of the economy for estimation of climate change costs.

1.6.2 Thresholds of changes

Thresholds are important to register because Bangladesh has direct physical limits and barriers determined by the society or economics. Climate thresholds include frost, snow or monsoon onset. Biophysical thresholds represent a distinct change in conditions of, say, drying of wetland, increase of floods, adverse breeding events, increased wind speed etc. Behavioral thresholds are set by, say, crop yield/ha. or net income per household etc. Operational thresholds are set by design standards for buildings, flood management infrastructures, irrigation infrastructures, heights of levee banks or dam spillways. These thresholds give us a limit beyond which the consequences will be much larger.

1.6.3 Climate change cost, adaptation costs and mitigation costs

Allegorically, if cost of climate change is the sky, cost of adaptation is the roof-top. More explicitly, adaptation cost is a small fragment of climate change cost. One example can be given for clarity of the statement: Bangladesh is visualized to have lost its large area along its coast (overwhelmingly stated to lose sovereignty, see ECF, 2004) as a consequence of sea level rise which is caused by climate change phenomena. This is economically a loss to a degree of infinity. In contrast, adaptation cost is a response-oriented estimate built on planning and investment in new technology, infrastructure and/or new habits and lifestyles needed. Adaptation cost involves those costs which a nation cannot avoid now and in the near future while climate change cost involves all economic, environmental and social losses incurred due to climate change.

Mitigation costs refer to the costs to limit the extent of future climate change. These costs are relevant for the agents which are polluting the atmosphere and which want to reduce the emissions for betterment of the environment at large.

1.7 International Conventions for Compensation

Climate change poses a serious threat to development and poverty reduction in the poorest and most vulnerable regions of the world. According to an estimate by OXFAM, developing countries may need in the order of $50 billion per year to adapt to climate change. Obviously this is beyond the financial reach of the developing countries. Developed countries have a legal obligation under Art 4(4) of UNFCCC to, "assist the developing country Parties that are particularly vulnerable to the adverse effects of climate change in meeting costs of adaptation to those adverse effects." In 2005, the G8 Plan of Action included an agreement to assist developing countries to adapt to climate change.

The socio-economic environment of Bangladesh is characterized by high population density (about 900 persons per sq. km) and relatively low rates of economic growth (around 5%). Adaptation needs for climate change will be hard to finance from the stringent budgetary position of the government. Besides the irreversible and catastrophic impacts, only routine impacts of climate change will need assessment of potential loss derived from a systematic modeling exercise based on economic and physical parameters. Here lies the rationale for developing economic model, based on pragmatic assumptions and scenarios.

1.8 Objective and Scope of the Study

The overall study has been divided into three phases. Overall objective of the study is to develop an economic model for climate change adaptation needs for physical infrastructures in Bangladesh. Under the present scope of the study, only the water management infrastructures, transportation and health sector has been brought under consideration.

Instrumental objectives for different phases are as follows:

- Phase-I
  - Assessing the present information base, compiling them, filling the knowledge gap and developing a compensation computational framework.
- Phase-II
  - Development of physical adaptation model.
  - Development of economic model for water management infrastructures in the coastal zone
- Phase-III
  - Development of economic models for two more sectors (e.g. Health, Roads and Highways)

2. Climate Change Risk to Bangladesh

2.1 General

Bangladesh suffers from many climate dependent natural hazards, such as: riverine and coastal floods, riverbank erosion, tropical cyclones and droughts. The 1998 riverine flood, one of the worst this century inundated two-thirds of the country, damaged crops, physical infrastructure and assets of over US$ 2.5 billion and caused hundreds of deaths and hundreds of thousands of cases of diarrhea. According to the latest GoB MoFDM Situation report, as of 21st November the total number of affected people for 30 districts was 6,737,815. A recent devastating incidence named SIDR in November 2007, which had arrived as a Category-4 Super Cyclone with peak winds at 250 km/hr. A preliminary assessment of UNDP shows that approximately 4.7 million people and a further 2.6 million people (most of them the poorest of the poor) living on 30 of Bangladesh's 64 districts were affected by the storm mainly within the coastal regions of Barisal and Khulna.

Apart from this, the country is known for its high sensitivity to natural calamities. According to the third assessment report of IPCC, South Asia is the most vulnerable region of the world (McCarthy et al., 2001) and the international community also recognizes that Bangladesh ranks high in the list of most vulnerable countries on earth (Ahmed, 2006). The case of Bangladesh is unique in the sense that: unlike other vulnerable island countries, this country will eventually face the multidimensional manifestations of climate change (e.g. flood, cyclone, sea level rise, drainage congestion, salinity, drought etc (WB, 2000). Researchers (Ahmed and Haque, 2002; Ahmed, 2006) have identified a number of hydro-geological and socio-economic factors responsible for Bangladesh's high vulnerability as listed below:

- Its geographical location in South Asia
- Its flat deltaic topography with very low elevation
- Its extreme climatic variability that is governed by monsoon and which results in acute water distribution over space and time
- Its high population density and poverty incidence; and
- Its majority of population being dependent upon crop agriculture, which is highly influenced by climatic variability and change

Other than this, burdened by social and economic problems such as low levels of literacy, poor health delivery systems, low per capita income and high unemployment, Bangladesh faces many difficulties in achieving sustainable development (WB, 2000). It is therefore of utmost priority set by the CDMP (as well as Government) to understand climate change variability in terms of population and sectors at risk and it potential for adaptation to climate change. In addition to this, IPCC-IV concluded that adaptation and mitigation are not stand-alone processes, they should go together and thus the economic Modelling of climate change should address the risk, vulnerability and corresponding mitigation in terms of spatial, temporal and demographic variability. In this chapter, an effort has been made to address the individual and aggregated effect of each climate change parameters disaggregated by different sectors like agriculture, health and infrastructure etc.

2.2 Climate Change Variability: Hydro Morphological Aspects

Geographically Bangladesh is located on the Bengal Basin between 20^0 34' to 26^0 38' North latitude and 88^0 01' to 92^0 42' East longitude. It is bordered on the west, north and east by India, on the south-east Myanmar and on the south by the Bay of Bengal. The country occupies an area of 147,570 sq. km (BBS, 2005). A network of river originated in the eastern Himalayas - The Ganges, The Brahmaputra, and the Meghna (GBM), their tributaries and distributaries crisscross the floodplain over the country. Bangladesh has around 700 km of coastline from the Sundarbans to Teknaf and its prominent deltaic geophysical characteristics have made it one of the most water related disaster prone countries within the world.

Bangladesh is endowed with both surface and groundwater resources and on a per capita basis it has one of the highest quantum available in the world (Ahmed, 2006). Its surface water system is dominated mainly by the GBM rivers, covering about 7% of the surface of the country and constituting a huge outfall only second to that of the Amazon system. Combined discharge of the rivers into the Bay of Bengal is about 142 thousand cubic meters per second at peak periods. It is estimated in average year availability if surface water flows is 1,350 billion cubic meters (BCM), of which 85% of the water flows to the Bay of Bengal (Rahman et al., 1990) carrying a huge amount of Himalayan and GBM flood plain sediments as building blocks of the landmass of the delta.

2.2.1 Temperature and precipitation change

Past and present climate trends and variability in the South East Asia are generally characterized by increasing surface air temperature, which is more pronounced during winter than in summer. IPCC-IV has reported that an increasing trend of about 1°C in May and 0.5°C in November has been observed during the 14-year period from 1985 to 1998 in Bangladesh (Mirza and Dixit, 1997; Khan et. al., 2000; Mirza, 2002). They have also reported decadal rainfall anomalies above long-term averages since 1960s. Since climate change is a dynamic phenomenon, changes will occur over time, and implications will only understood in future, it is not possible ‘to define a changing climate’ that might occur ‘within a definite period in future’. In this regard, researchers (Mahtab, 1989; BCAS-RA-Approtech, 1994; Huq et. al., 1996) have used ‘expert judgment’ to ‘define one or more scenarios of a changing climate’ in relation to the area in question.

Mahtab (1989) speculated that a general surface warming of 0.3 to 5^0C would occur by the year 2050 and they also thought that rainfall would increase by 5 to 20%. Another effort from BCAS-RA-Approtech (1994) speculated the rise of 2^0C and 4^0C change in average temperature for defining ‘moderate’ and ‘severe’ climate change scenarios respectively. The two scenarios also speculated a rise in peak monsoon rainfall be 18 and 33% respectively. Another speculation has been made by Ali (1999), who has considered 2^0C and 4^0C change in average temperature as lower and upper bound thresholds for 2010 respectively.

In the early stages of assessing climate change impacts, in absence of appropriate models and Modelling facilities, researchers have used ‘Expert judgments’ to come up with climate scenarios. With the proliferation of computer assisted Atmosphere-Ocean Global Circulation Models (AOGCM), scientifically more rigorous and acceptable scenarios have been developed in the second stage (Ahmed 2006). Only in recent times, with further development of regional models as well as strengthening of computational capabilities, scenarios have been developed by using regional climate models (RCM).

In early 1990s, several attempts have been made to generate climate change scenarios by the use of available General Circulation Models (GCM). The BUP-CEARS-CRU (1994) study reported 0.5^0C to 2.0^0C rise in temperature by the year 2030 under the ‘business as usual’ scenario of IPCC. The same Modelling effort estimated 10 to 15% rise in average monsoon rainfall by the year 2030. ADB (1994) study also made use of four GCMs: CSIR09, CCC, GFDLH and UKMOH. The high estimating GFDL model (GFDLH) projected 59% higher rainfall in South Asian monsoon with a corresponding withdrawal of dry monsoon rainfall by 6%. Modelling outputs of IPCC IS92a showed a rise in temperature of 0.3^0C and 1.5^0C for 2010 and 2070 respectively. But the above-mentioned Modelling outputs haven't tried validation of GCM outputs for Bangladesh.

Another major attempt has been made to generate a model-driven climate change scenario under the 'Climate Change Country Studies Programme' (Ahmed et. al., 1996; Asaduzzaman et. al., 1997 and Huq et. al., 1998). A number of GCMs (CCCM, GFDL, GF01) have been used and the outputs of the three GCMs for the 1990 base year were validated against long-term 'climate normal', as provided in published report (FAO-UNDP, 1988). Applying the same methodology, Ahmed and Alam (1998) reproduced the climate change scenarios, which were largely used for a number of subsequent national assessments. Their outputs of the GCM exercise using GFD 01 transient model is given below:

Year	Average Temperature			Temperature Increase			Average Precipitation			Precipitation Increase		
	W	M	Ave	W	M	Ave	W	M	Ave	W	M	Ave
	(^{0}C)			(^{0}C)			mm/month			mm/month		
1990	19.9	28.7	25.7	0.0	0.0	0.0	12	418	179	0	0	0
2030	21.4	29.4	27.0	1.3	0.7	1.3	18	465	189	6	47	10
2075	22.0	30.4	28.3	2.1	1.7	2.6	00	530	207	-12	112	28

Other than this, Mirza (2002) considered an ensemble of GCMs, and considered three 'temperature change scenarios' with 2^0C, 4^0C and 6^0C changes in average temperature and then computed its response in relation to changes in precipitation over the South Asian subcontinent. They have found huge variations in output results, varying from 0.8% to 13.5% increase in mean annual rainfall for the Ganges basin and –0.03% to 6.4% change of the same for the Brahmaputra basin for a 2^0C temperature change scenario. Agrawal et. al. (2003) have used another ensemble of a dozen GCMs, which were driven by MAGICC model using SCENGEN database. The core findings have been found consistent with the findings of Ahmed and Alam (1998). The output is shown below:

Year	Temperature Change in ^{0}C Mean (Standard deviation)			Precipitation Increase Mean (Standard deviation)		
	Annual	DJF	JJA	Annual	DJF	JJA
2030	1.0 (0.11)	1.1 (0.18)	0.8 (0.16)	3.8 (2.3)	-1.2 (12.56)	+4.7 (3.17)
2050	1.4 (0.16)	1.6 (0.26)	1.1 (0.23)	+5.6 (3.33)	-1.7 (18.15)	+6.8 (4.58)
2100	2.4 (0.28)	2.7 (0.46)	1.9 (0.40)	+9.7 (5.8)	-3.0 (31.6)	+11.8 (7.97)

Note: DJF represents the months of December, January and February, usually the winter months;
JJA represents the months of June, July and August, the monsoon months.

The latest attempt has been made by NAPA (GoB, 2005) and they have adopted the results obtained by Agrawala et al. for changes in temperature and modified the results of Agrawala et al. regarding changes in precipitation.

Year	Temperature Change in ^{0}C Mean (Standard deviation)			Precipitation Increase Mean (Standard deviation)		
	Annual	DJF	JJA	Annual	DJF	JJA
2030	1.0	1.1	0.8	5	-2	6
2050	1.4	1.6	1.1	6	-5	8
2100	2.4	2.7	1.9	10	-10	12

Efforts are now being made to analyze the climate models specifically for Bangladesh. In the recent past, one attempt has been made under a South Asia regional Modelling programme to develop climate change scenarios for the Brahmaputra basin of Bangladesh (Chowdhury et al., 2005). The surprising results were obtained for winter rainfall: unlike other model results, an increase in winter and pre-monsoon rainfall were observed for 2020 and 2050. Overall, the changes in rainfall and temperature for 2020 were 9.1% and 1.4^{0}C with a corresponding increase by 22.7% and 2.8^{0}C respectively by the year 2050.

Although no direct correlation has been found between the Southern Oscillation and consequent temperature anomaly in the oceanic systems and the extreme weather events in Bangladesh, some studies report that the El Nino Southern Oscillation (ENSO) events influenced the record-breaking floods of 1987, 1988 and 1998 (Chowdhury, 1998). The rapid transformation of La Nina from El Nino phase in early monsoon in 1998 is said to have influenced high rates of precipitation over the entire GBM catchment basin. As a result, after a prolonged dry season, the wettest monsoon came along with extremely high levels of precipitation eventually resulting in the deluge of the century. Such global events could therefore intensify some of the extreme climate change related weather events even further (WB 2000).

2.2.2 Sea level rise

Bangladesh has 710 km long coastline. The landward distance of the delineated coastal zone from the shore is between 30 and 195 km whereas the exposed coast is between 37 and 57 km. Other part of the country has an elevation of less than 10 meters above sea level. With the exception of the Chittagong Hill Tracts in the southeast and the Modhupur tract in the central region, the country is located in the floodplains of three main rivers namely Ganges, Brahmaputra and Meghna. The coastal zone is low-lying with 62% of the land have an elevation of up to 3 metres and 86% up to 5 metres. The Bay of Bengal is a northern extended arm of the Indian Ocean. In the north of Bay of Bengal, .Swatch of No Ground., a submarine canyon present at 25 km south of the western coastline of Bangladesh (Mohal et. al. 2006).

A number of previously published studies examined the potential impacts of climate change on Bangladesh (e.g., Qureshi and Hobbie, 1994; Huq et al., 1996; Warrick and Ahmad, 1996; Huq, Karim, Asaduzzaman and F. Mahtab eds. 1999), assuming certain changes in the climate and corresponding sea level rise. Islam (2001) identified some of the changes in global mean sea level induced by several processes on different time and space scales. The processes include glacio-isostatic rebound, oceanographic, atmospheric, and tectonic effects.

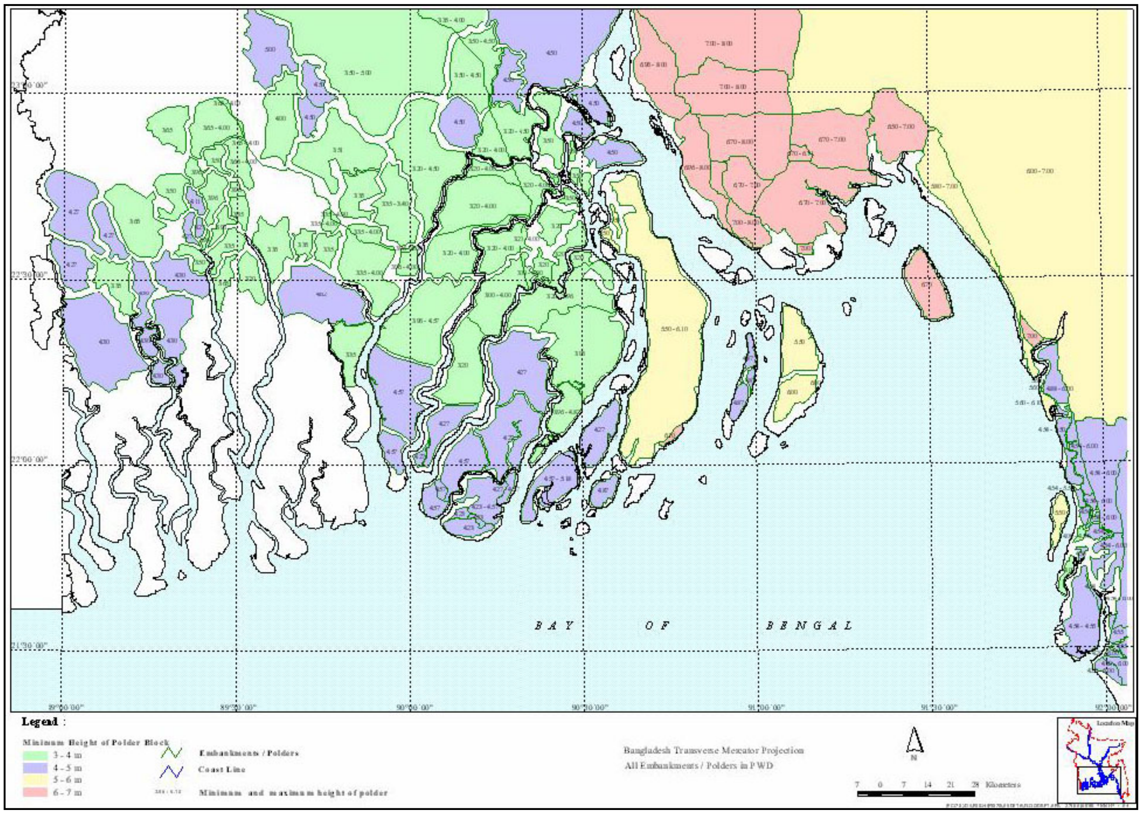

Figure 2.1: Coastal region of Bangladesh

Eustatic sea level variation is associated with the volume change of seawater and relative sea level rise can be different due to local uplift and subsidence. Sea level rise due to sedimentation, although significant near river deltas, is negligible on a global scale.

Sea level rise (SLR) on a short time scale (several years) is associated with El Nino/ Southern oscillations. IPCC-IV study has referred to various researchers who have reported that in the coastal areas of Asia, the current rate of SLR (1 to 3mm/yr) is marginally greater than the global average. In addition to this, the rate of sea level rise of 3.1 mm/yr as reported over the past decade has been accelerated relative to the long-term average taken over the 20th century as a whole (1.7 to 2.4 mm/yr). Future climate change scenarios research by a pilot study of Department of Environment mentioned a potential future sea level rise for Bangladesh is 30-50 cm by 2050 (DoE, 1993). An increasing tendency in sea level rise from west to east along the coast has also been observed. Ahmed and Alam (1998) has projected the SLR value for the year 2030 and 2050, which have been constructed by using general circulation models (GCM) that was superimposed on long-term climatic patterns over ten locations in Bangladesh. Their estimate was one-meter change of sea level by the middle of 21st century; it combines a 90 cm rise in sea level and about 10 cm local rise due to subsidence. These values were obtained by correlating model output data with observed data considering the base year as 1990 and its average winter temp: 19.9 °C & avg. monsoon temp: 28.7 °C. The SAARC Meteorological Research Centre (SMRC) analysed sea level changes of 22 years historical tide data at three tide gauge locations in the coast of Bangladesh. The study revealed that the rate of sea level rise during last 22 years is many fold higher than the mean rate of global sea level rise over 100 years. SMRC projected figures of sea level rise are 18 cm, 30cm and 60 cm for the year 2030, 2050 and 2100 respectively. National Adaptation Programme for Action (GoB, 2005) Team is fully compliant with the Third Assessment Report (TAR) regarding probable SLR, which indicates that the global sea level rise is 9 cm to 88 cm from 1999 to 2100. Another notable study by Mohal et. al (2006) is also agreeable with the IPCC-III prediction and their result shows that, in the year 2100 at 88 cm SLR, about 11% area (4,107 km^2, as shown in Figure 2.2) of the coastal zone will be inundated in addition to the inundated area in the year 2000 under same upstream flows.

But it should be noted that the IPCC rates of change of sea level are only indicative and accurate predictions could not be made due to inherent weaknesses of the models. In addition to this, there is a wide range of variation concerning the extent of such changes in the above-mentioned and other literatures (Yohe and Schlesinger, 1998; Greenpeace, 1999).

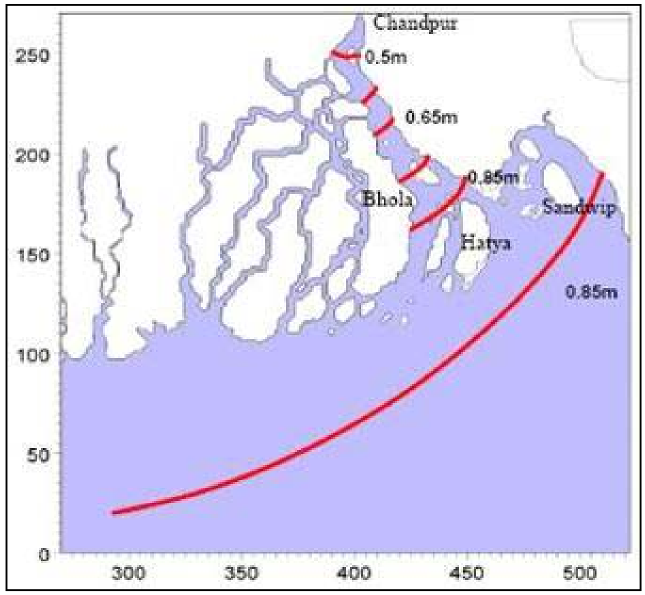

Figure 2.2: Probable depth of flooding in the coastal region

Direct rainfall and river runoff water may be significant factors in short-term changes (seasonal) in sea level along some coasts. Rainfall and runoff water contribute significantly to producing the 100 cm sea level variation seen in the Bay of Bengal. The seasonal sea level changes in the Bay is remarkable and one of the highest in the world. Due to its funnel shaped geometry the maximum seasonal variation can be seen along the northeast coast of the Bay. Along Chittagong coast the annual variation is 1.18m. In the Bay of Bengal during the last 9,000 years, five periods of marine transgressions, each followed by regression, have been recorded. A maximum relative sea level rise rate of 3.65mm/yr-1 has been estimated between 6315 and 5915 years BP; the average rate for the Bengal basin, during the Holocene, was 1.07 mm/yr-1

Table 2.1: Climate Change scenarios for Bangladesh

Year	Temperature change (^{0}C) mean		Precipitation change (%) mean		Sea level rise (cm)		
	Monsoon season	Dry season	Monsoon season	Dry season	SMRC	NAPA scenario	3rd IPCC (upper range)
2030	0.8	1.1	+6.0	-2.0	18	14	14
2050	1.1	1.6	+8.0	-5.0	30	32	32
2100	1.9	2.7	+12.0	-10.0	60	88	88

The focus of this study is on examining the needs and possibilities for addressing adaptation. The aim is to reduce Bangladesh' vulnerability to climate change and sea level rise impacts, and enhance the country's potential for sustainable development.

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2.2.3 Cyclones and storm s

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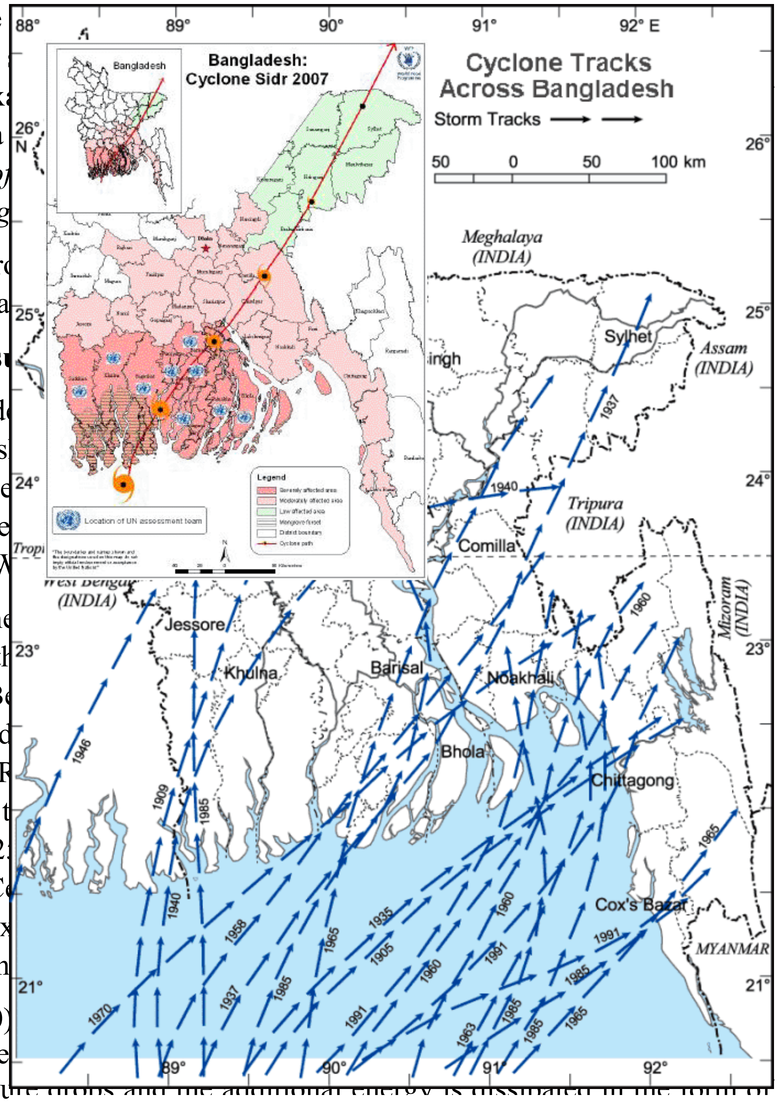

Figure 2.3: Directional movement of historical cyclones in Bangladesh, including cyclone SIDR.

A storm surge during a cyclone inundates coastal areas and offshore islands, which causes most of the loss of life and property. Information on storm surge height is very scarce in Bangladesh. Available literature provides a range of 1.5 to 9.0 meter high storm surges during various severe cyclones (Haider et al., 1991). However, a SMRC report shows the surge height for 1876 cyclone was 13.6 m at Bakerganj and the surge height for 1970 cyclone was 10m. Locations of these surge heights are not known. Therefore, it is difficult to compare maximum wind speed and corresponding surge heights. Displacement of water surface during a cyclonic storm surge also depends on the height of tide, which is a function of lunar attraction and wind-factor. There is considerable difference in tide-height depending on the season and position of the moon relative to the sun.

Another important factor is the path of cyclones. Due to its geographic location, cyclones hitting the Khulna region in the southwest have comparatively lower storm surges than those hitting the Meghna estuary. The paths of a few recent cyclones that hit Bangladesh are shown in Figure 2.3. These include the recent SIDR path and other historical incidences up to 1997 cyclone. From time immemorial, cyclones have visited the delta and caused extensive damages to the lives and properties of millions of people in the coastal districts of Bangladesh. In 1584, about 200,000 people were reportedly killed in Barisal by a cyclone storm surge. Another cyclone that hit in 1822 killed more than 70,000 people in Barisal and 95 percent population of the Hatiya Island. Considering the much smaller populations during those times, the numbers of deaths give an indication to the severity of the cyclones. A cyclone in November 1970 hit the southern districts of Bangladesh (the then East Pakistan) forcing a 9 m high storm surge and killing approximately 300,000 people (Haider et al., 1991). The cyclone of 1991 caused 138,000 lives. In more recent years, however, number of deaths caused by the cyclones with severe intensity has declined due to the growing successful institutional arrangements for disaster management and the fact that there are now over 2000 cyclone shelters spread along the coast (which are being utilized during the cyclones).

In terms of climate change, warmer sea surface temperatures are correlated with tropical cyclone activity. Some studies have concluded that a 1°C increase in sea surface temperatures could increase tropical cyclone intensity by 10 percent (e.g., Henderson-Sellers and Zhang, 1997). Lal et al. (1995) have found that higher temperatures may not increase tropical cyclone activity.

However, even with similar intensity, the destructive effects of cyclones would be intensified by sea level rise induced increased water depths in the shallow continental shelf of the Bay of Bengal. Assuming there is a positive correlation between sea surface temperature and tropical cyclone intensity, Ali (1996) calculated the effect of a repeat of the 1991 cyclone with a 10 percent increase in intensity and sea level rise. He concluded that this could result in storm surge 2 m higher and inundating 13 percent more land than the 1991 cyclone. Another modelling exercise from Mohal et al. (2006) indicated that the cyclone induced storm surges along with sea level rise (32 cm) inundated delta area would increase from 42% to 51.2% in case of occurrence of 1991 cyclone, which had erased about 150,000 people from its coastal region. The team also concluded that a 10% increase in wind speed of 1991 cyclone along with 32 cm SLR, would increase the surge height by 1.2-1.7 m near Kutubdia-Cox's Bazar, eastern coast of Bangladesh. Ali (1999) in a Bangla publication mentions that during the years 1877-1995, 365 cyclones were recorded in the Bay of Bengal, which died before hitting the coast. He suggests that: in a warmer world, some of such cyclones could actually hit the land. Therefore, even if the total numbers of cyclones do not increase, the number of cyclones hitting the land, with resulting damages, may increase. He reiterates the point on increased intensity of cyclones under climate change.

2.2.4 Cross-boundary river flows

The country's geographical location, high dependence on the GBM regional hydrology, spatial and temporal distribution of water resources-all contribute to the high degree of susceptibility of Bangladesh to water related extreme events (Ahmed et. al., 1998a).

Bangladesh has been sharing a total of 54 Transboundary Rivers, which are mostly originated from Himalayan glaciers located on upper riparian countries. Himalayan glaciers cover about three million hectares or 17% of the mountain area as compared to 2.2% in the Swiss Alps. They form the largest body of ice outside the polar caps and are the source of water for the innumerable rivers that flow across the Indo-Gangetic plains. Himalayan glacial snowfields store about 12,000 kml of freshwater. About 15,000 Himalayan glaciers form a unique reservoir which supports perennial rivers such as the Indus, Ganga and Brahmaputra which, in turn, are the lifeline of millions of people in South Asian countries like Pakistan, Nepal, Bhutan, India and Bangladesh. The Gangetic basin alone is home to 500 million people, about 10% of the total human population in the region (IPCC-IV).

Figure 2.4: Melting of Gangotri glacier

It is expected that climate change induced alterations in temperature would affect the timing and rate of snow melt in the upper Himalayan reaches. Recent study shows that glaciers in the Himalaya are receding faster than in any other part of the world and, if the present rate continues, the likelihood of them disappearing by the year 2035 and perhaps sooner is very high if the Earth keeps warming at the current rate. Its total area will likely shrink from the present 500,000 to 100,000 km^2 by the year 2035 (WWF, 2005). As a result, the hydrological aspects of the eastern Himalayan rivers and the Ganges-Brahmaputra-Meghna(GBM) river basins could change significantly.

The receding and thinning of Himalayan glaciers can be attributed primarily to the global warming due to increase in anthropogenic emission of greenhouse gases. The relatively high population density near these glaciers and consequent deforestation and land-use changes has also adversely affected these glaciers. The 30.2 km long Gangotri glacier has been receding alarmingly in recent years (Figure 2.4). Between 1842 and 1935, the glacier was receding at an average of 7.3 in every year; the average rate of recession between 1985 and 2001 is about 23 in per year (Hasnain, 2002). The current trends of glacial melts suggest that the Ganga, Indus, Brahmaputra and other rivers that criss-cross the northern Indian plain could likely become seasonal rivers in the near future as a consequence of climate change and could likely affect the economies in the region. Some other glaciers in Asia - such as glaciers shorter than 4 km length in the Tibetan Plateau - are projected to disappear and the glaciated areas located in the headwaters of the Changjiang River will likely decrease in area by more than 60% (Shen et al., 2002).GBM river systems would begin to swell early, while increased precipitation in monsoon would generate additional volumes of runoff. With only 7 percent of GBM catchment area, the country receives over 90 percent of the water discharged through the GBM river systems, and already suffers from repeated floods. Problems concerning drainage congestion will aggravate further with increasing volumes of water coming through the cross-boundary rivers during the monsoon.

During the winter period, however, flows in the GBM rivers might decrease because of lower rainfall and higher surface evaporation. Developments and climate change induced moisture stress in the upstream areas of the river basin will result in an increase of the rate of water withdrawal for agricultural, domestic and industrial activities. This might lead to even lesser availability of water flow in the cross-boundary rivers in Bangladesh during the winter months. There are 57 cross-boundary rivers in Bangladesh, 54 are shared with India and the rest are shared with Myamnar. Bangladesh is the common lower riparian for all these cross-boundary rivers. In December 1996, the governments of Bangladesh and India came to an agreement on sharing the low Ganges flows. Discussions on sharing of cross-boundary river flows need to include contingencies for changes in runoff, and demand due to climate change.

2.2.5 Flooding

The most common water-related natural hazard in a deltaic floodplain such as Bangladesh is flood. Flooding in Bangladesh is the result of complex series of factors. Ahmed (2006) has identified four major types of flood in this country, viz. in country rainfall floods, flash floods in the eastern hill basin, major river floods, and the floods caused by tidal storm surges during cyclones. Of these four types, river flood is of the greatest concern to the people.

Analysis of past floods suggests that, about 26 percent of the country is subject to annual flooding and an additional 42 percent is at risk of floods with varied intensity (Ahmed and Mirza, 1998). The projected increase in rainfall during monsoon would be reflected in the flow regimes of the rivers of Bangladesh. Increased flooding and drainage congestion, therefore, are the expected consequences of increased rainfall from a warmer and wetter condition. A 10 percent increase in monsoon precipitation in Bangladesh could increase runoff depth by 18 to 22 percent, resulting in a sevenfold increase in the probability of an extremely wet year (Qureshi and Hobbie, 1994). Since it is found that monsoon precipitation will increase by 11 and 20 percent, surface runoff will increase in the order of 20 to 45 percent, respectively (Ahmed and Alam, 1998). They also reported that, by the year 2030, an additional 14.3 percent of the country will become extremely vulnerable to floods, while the already flood-vulnerable areas will face higher levels of flooding. It is also reported that, even if the banks of the major rivers are embanked, more non-flooded areas will undergo flooding by the year 2075.

Furthermore, rise in sea level along the coastal belt would not only inundate low-lying areas along the coast, it would also create a favourable condition for saline waters to overtop the flood protecting coastal embankments, especially when induced by strong winds (CEGIS, 2006). Breach of existing coastal embankments will also inundate land with saline waters.

Mirza and Dixit (1997) estimated that a 2°C warming combined with a 10 percent increase in precipitation would increase runoff in the GBM Rivers by 19, 13, and 11 percent respectively. Increased depth of flooding will be pronounced in the lowlands and depressions in the Faridpur, southwest Dhaka, Rajshahi-Pabna, Comilla, and Sylhet-Mymensingh greater districts. New work undertaken by this study (and referred to previously) reported that an increase in precipitation over the GBM basins of about 5 percent combined with a temperature increase of around 1°C could result in small changes in peak discharge, but up to a 20 percent increase in area flooded (Kenny et al., 1998). Additional area flooded would tend to have small flood depth (flood category F_0), but would still cause additional destruction compared to current floods. Severity of extreme floods, such as the 20-year flood event, is estimated to increase marginally.

Different researchers (ADB, 1994; BUP-CEARS-CRU, 1994; Warrick and Ahmad, 1996, Alam et al., 1998) have identified the of lack information on susceptibility to flash-floods under climate change induced hydrological regime, it is difficult to comment on how it would affect the country. Similarly, no targeted research has so far been undertaken to understand whether new areas will become more prone to water- logging as a response to increased monsoon intensity under climate change regime.

2.2.6 Drainage congestion and sediments

Flooding would be exacerbated by climate change induced sea level rise, which would limit runoff discharge due to enhanced backwater effect, as was seen in the floods of 1998 (Ahmed and Mirza, 1998). Moreover, due to prolonged discharge of floodwaters; the rate of sedimentation will increase. As a result, both the riverbed and the bed of the adjacent floodplains will rise leading to further drainage congestion, and possibly more intense flooding in the following years. Such a cyclic course of events would intensify flood problem in the already flood prone areas of the country.

Major sources of the sediments carried by the region's rivers are in the upstream areas in India, China, Nepal, and Bhutan and the average annual sediment load that passes through the country to the Bay of Bengal ranges between 0.5 billion to 1.8 billion tons (Ahmed,

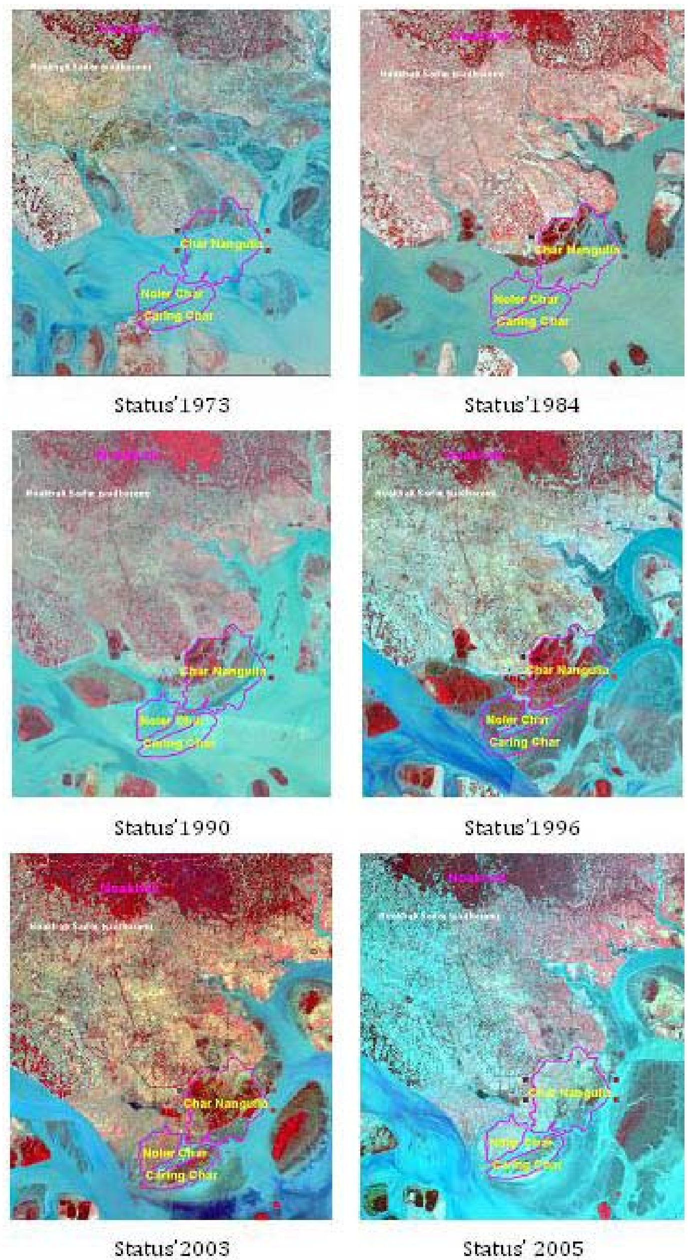

Figure 2.5: Development of Char Nangulia, Noler Char and Caring Char of Noakhali

2006). Increased rainfall runoff in the vast GBM region, comprising a total catchment area of 1.41 million km^2, also contributes to enhanced sediment flows along the GBM river systems. Sediments generally originate in the mountainous areas. In recent years, increased deforestation in the mountains has exposed topsoil, and eventually might have increased the sediment load in the rivers (Goswarni, 1985). This is likely to increase the rate of bed level rise in the channels and the floodplains. Moreover, instead of fertile silt, if infertile sand or coarse sediments are deposited with flooding of the Brahmaputra, it will severely reduce productivity of the top soil. Climate change induced higher sedimentation rates will, therefore, have serious social and economic implications for the future. Recent remote sensing analysis of CEGIS revealed that coastal land areas have been increasing due to huge sedimentation and subsequent land development scenarios (Char Nangulia, Noler Char and Caring Char of Noakhali district) in the coastal zones of Bangladesh.

Sediment rating curves developed by the Master Plan Organization (MPO) for its National Water Plan, Phase I (1986) and Phase II (1991), indicated an increase in sediment load in the Ganges and the Brahmaputra between the two periods. There was a sediment discharge increase of 16 per cent at Bahadurabad (on the Brahmaputra) and 46 per cent at Hardinge Bridge (on the Ganges). Not all of the sediment that flows into the country travels down to the Bay of Bengal; a part is deposited within the channels. The consequence is progressive siltation and decrease of channel depth, thereby increasing the flood ability of the alluvial plain.

2.2.7 Low river flows and salinity ingress

In a normal hydrological cycle, rivers suffer from low flow conditions when there is no appreciable rainfall runoff. As mentioned earlier, lower precipitation in combination with higher evaporation will lead to increased withdrawal of surface water. Low flow conditions of the rivers will be subsequently accentuated. This will also reduce the cross-boundary river flows, and the availability of fresh water for irrigation, livestock and people.

Typically low flow condition starts to occur in the post monsoon period and continues till early April, March being the critical month. During low flow surface salinity penetrates further inland due to lack of adequate flushing. Under climate change scenarios low flow

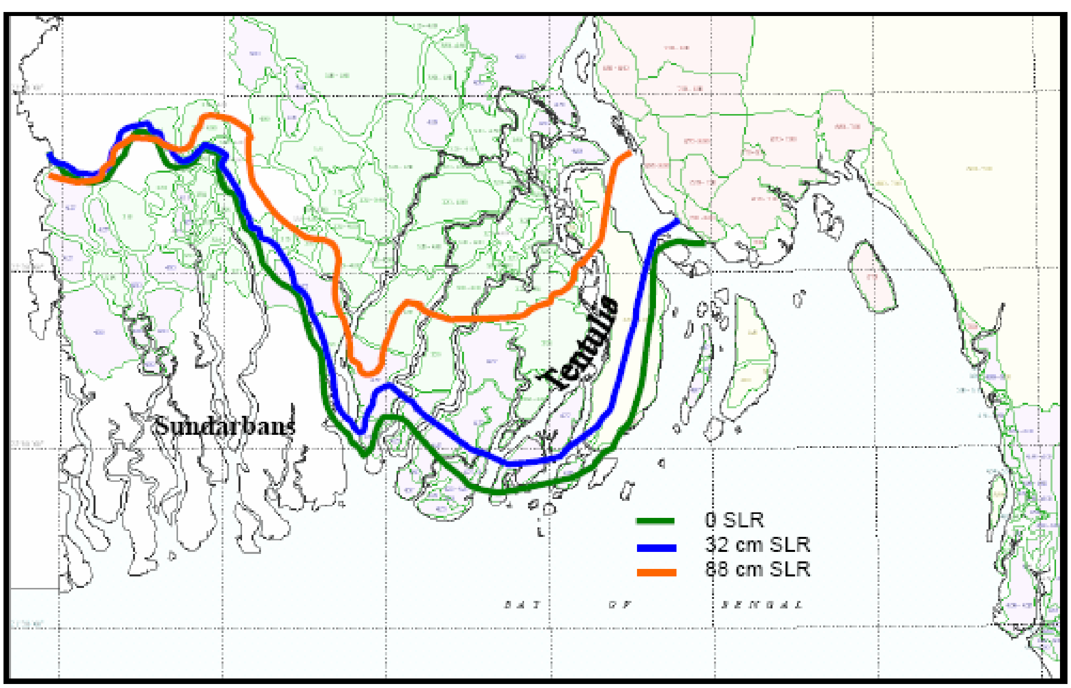

Figure 2.6: Line of equal salinity (5 ppt) for different SLR during dry season

(Source: Mohal et. al., 2006)

conditions are likely to aggravate with the possibility of withdrawal of appreciable rainfall in winter (Ahmed et al., 1998a). The southwestern parts of the country will be particularly vulnerable, since the region depends on freshwater flows along the Ganges and its major distributary, Gorai. People in the southwestern region have expressed their concerns regarding increasing salinity (RVCC, 2003). Study from Mohal et. al. (2006) almost complied with the same finding that was derived from mathematical Modeling. They found that as sea level continues to raise, the associated effects of permanent inundation is likely to increase the salinity near coastal areas. The study also shows that 5 ppt saline front will penetrate about 40 km inland for SLR of 88 cm which is going to affect the only fresh-water pocket of the Tentulia River in Meghna Estuary as shown in Figure 2.6. A big chunk of the fresh-water zone that will be disappearing due to sea level rise near to the estuary will have a far reaching effect on the country's ecology and will extinct some of its endangered species (marked by IUCN) for ever.

The world heritage and declared Ramsar site Sundarban will be hugely affected by the salinity ingress. Actually, the Sundarbans has already been affected due to reduced freshwater flows through Ganges river system over the last few decades particularly during the dry season. This has led to a definite inward intrusion of the salinity front causing the different species of plants and animals to be adversely affected. Increased salt-water intrusion is considered as one of the causes of top dying of Sundari trees. The impact of sea level rise will further intrude the saline water to landward. Sea level rise of 32 cm will intrude 10 to 20 ppt salinity level more in the Sundrabans. The rate of salt-water intrusion will also affect the ability of the ecosystem to adapt (Mohal et.al, 2006).

Bangladesh NAPA document has also highlighted the concerns regarding salinity ingress, especially for the southwestern region (GOB, 2005).

2.2.8 Droughts

Bangladesh will also be at higher risk from droughts. High index of aridity in winter, especially in the western parts of the country may be compensated by increased withdrawal from the surface water sources. If that is the case, despite the minimum flow in the Ganges as provided by the Ganges Water Sharing Treaty (GOB-GOI, 1996) it would be extremely difficult to provide adequate freshwater flows in the downstream of the Ganges dependent areas, particularly during the dry season. The issue of drought has also been reiterated in the Bangladesh NAPA document. It is reported earlier that, combating excessive aridity will require either augmented inflows of the Ganges from the upstream or increased ground water withdrawal in those areas (Halcrow et al., 2001).

Karim et al. (1996) reported the effect of climate change induced moisture stress and resulting phonological drought impacts. A geographical distribution of drought prone areas under climate change scenarios shows that the North Western parts of the country will be at greater risk of droughts, during both the Kharif and pre- Kharif seasons. It is found that, under a moderate climate change scenario, Aus production would decline by 27 percent while wheat production would be reduced to 61 percent (Karim et al., 1998). Under a severe climate change scenario (with 60 percent moisture stress), yield of Boro might reduce by 55-62 percent. Moisture stress might force farmers to reduce the area for Boro cultivation.

In case of a severe drought, forced by a change of temperature by +2°C and a reduction in precipitation by 10 percent, runoff in the Ganges, Brahmaputra, and Meghna rivers would be reduced by 32, 25, and 17 percent respectively (Mirza and Dixit, 1997). This would limit surface irrigation potential in the drought-vulnerable areas, and challenge food self-sufficiency programs of the country.

2.2.9 River erosion and accretion

Rivers in Bangladesh are morphologically highly dynamic. The main rivers are braided, and forms islands or char in between the braiding channels. These chars, of which many are inhabited, "move with the flows" and are extremely sensitive to changes in the river conditions. Erosion processes are highly unpredictable, and not compensated by accretion. These processes also have dramatic consequences in the lives of people living in those areas. A four year study concluded in 1991 reported that: out of the 462 administrative units in the country, 100 were subject to some form of riverbank erosion, of which 35 were serious, and affected about 1 million people on a yearly basis (REIS, 1991).

A study by EGIS (1997), analyzing remote sensing images from 1973 to 1996 of the 240 km long Brahmaputra-Jamuna River between the Indian border, and the confluence with the Ganges concluded that the river has been widening at an average rate of about 130 m per year. This corresponded to a loss of about 70,000 ha in 23 years, while only 11,000 ha had been accreted. With the exception of 10 percent of stable charlands, which were more than 20 years old, the average age of a given area of charland was found to be only four years. The same EGIS study concluded that the observed erosion during the flood years 1987 and 1988 was 8,000 ha per year, against an average of 3,000 ha per year during the mentioned 23-year period - this gives some indication of how sensitive these processes are. However, the net erosion rate was therefore estimated at 8,700 hectares per annum. In addition to this, erosion of border riverbanks is serious because it can cause loss of land to neighboring countries (Halcrow et al., 2001).

Changes in the river flows and sediment transport due to multi-dimensional impacts of climate change are expected to increase the dynamics of these rivers even more. While the consequences are highly uncertain, they give rise to major concern especially given the related loss of land and property.

2.3 Sectoral Impact of Climate Change

2.3.1 Impact on agriculture

Agriculture is a major sector of Bangladeshi economy, providing about 22 percent of total GNP. Perhaps more important is the fact that almost two-thirds (65 percent) of the labor force is employed in agriculture (Faruquee, 1998). Rice is by far the major crop in Bangladesh. In 1992- 1995, average annual production was 18 Mmt. In contrast, only 1.2 Mmt of wheat was produced annually in the same period (BBS, 1998). But IPCC-IV has stated that Results of recent studies suggest that substantial decreases in cereal production potential in Asia could be likely by the end of this century as a consequence of climate change. However, regional differences in the response of wheat, maize and rice yields to projected climate change could likely be significant (Parry et al., 1999; Rosenzweig et al., 2001).

Farmers in Bangladesh are quite poor, even in comparison with its neighboring countries. The average size of farms is very small. A recent estimate show that over 70 percent of farm families have less than 1.0 hectares (2.5 acres) and 80.3 percent has less than 2 ha (5.0 acres) land. The farms are undercapitalized, and lack the usual inputs of quality seed, fertilizer, pest control etc. (Ahmad and Hasanuzzaman, 1998). In addition, Bangladeshi farmers have little mechanized agricultural tools. For example, in the early 1990s, there were 5,300 tractors in Bangladesh, whereas Pakistan with about twice the area for agriculture had more than 54 times the number of tractors (WRI, 1998).

Published sources on the effect of climate change on rice yields tend to show minor negative to positive effects at low temperature changes associated with slight CO_2 fertilization effect. For example, Karim et al. (1996) estimated that an increase of 2°C with unconstrained water supplies (no moisture stress) would increase rice yields only slightly. A temperature increase of 4°C (higher than projections for 2050) results in mixed yield changes. Rice yields for 2020 and 2050 were calculated based on the results of Karim et al. (1996) and assuming no moisture stress, and relatively strong CO_2 fertilization effect. The results, presented in Table 2.2, show a small positive change in yields. Wheat yields are projected to decrease at both temperature changes, even with optimistic assumptions on the CO_2 fertilization effect.

Table 2.2: Percent change in rice yields (Chittagong)

Scenario	Aus	Aman	Boro
2020: +0.7^{0}C; 410 ppm CO2	+3	+2	+4
2050: +1.5^{0}C; 510 ppm CO2	+9	+4	+11

Notes: Calculations are based on Karim et al., 1996; without considering moisture stress.

Previous agricultural yield estimates were based on information published on the positive effects of higher atmospheric carbon dioxide levels on plant growth at the time the studies were carried out. Recent analyses have shown that increased CO_2 levels essentially help to attain higher leafarea index, and do not contribute to increased rice yields (Abrol, 1998). These results have supplemented the findings of Walker and Steffen (1997). It may be too early to come to a conclusion regarding the direct effects of climate change on food-grain production. There are, however, indirect effects in relation to induced changes in floods and salinity.

At present, western parts of Bangladesh are periodically being affected by droughts in winter months. Since the temperature will rise, and there exists a strong possibility that the winter precipitation will decrease further, it is likely that the moisture content of topsoil would decrease substantially leading to severe moisture stress. Higher temperature would, furthermore, induce higher rates of evapo-transpiration leading to acute (phenological) drought conditions in winter months. Consequently, a late Kharif II drought in December would adversely affect Aman

crop at the ripening stage, while an early Rabi drought would more severely affect wheat and Boro crops at both germination and vegetative growth stages (Karim et al., 1998). Furthermore, increasing moisture stress in early Kharif I would affect Aus production significantly. Increased drought will increase capillary action and salinity build up in the top soil as well. Detailed processes of salinity build up are explained in Karim et al (1990). On an average year, increased salinity not only causes a net reduction of about 0.2 Mmt of rice production, but also diminishes potentials of Boro and wheat cultivation in saline affected soils of the coastal areas. With the possibility of increasing soil salinity under climate change scenarios, it is highly likely that food-grain production in those areas would be extremely vulnerable. It is reported that, the effect of soil salinity on Aus production would be detrimental, and Aman, when grown under a severe climate change scenario, could also suffer over two-fold yield reductions (Habibullah et al., 1998). Recently, CEGIS (2006) has shown sea level rise along the southwestern region of Bangladesh Aman suitability decrease significantly.

Together with the possible reduction in Aman rice area (as a result of greater spread of flood waters, and longer duration of flooding) and a reduction in the Boro rice area (which will be limited by available surface and groundwater for irrigation), the total area suitable for rice production may in the future stagnate or possibly decrease.

Another influence on the total available area for agriculture is that: climate change is expected to disturb the sediment balance. It is difficult to forecast whether there will be net accretion or erosion. However, it is important to remember that newly accreted land along the coast may take up to 15 years to develop full production potential, whereas land lost to erosion is in most cases valuable agricultural land. Despite this fact, average accretion in Bangladesh is close to one thousand hectares per year of valuable agricultural land. At present this land is 'state-owned'. A coherent land use policy with appropriate support services (for example, access to information) for this state-owned land is urgently needed to avoid (the often illegal) settlements before the soils have developed their full productive capacity.

Floods affect agricultural production significantly. The 1988 flood caused reduction of agricultural production by 45 percent (Karim et al., 1996). Similarly, Aman production potential of some 2 to 2.3 Mha could not be realized due to the devastating floods in 1998 that lasted for about 67 days. Since seedlings could not be planted in the flood affected areas, the resulting estimated shortfall of foodgrain production exceeded 3.5 Mmt. Higher discharge and low drainage capacity, in combination with increased backwater effects would increase frequency of such devastating floods under climate change scenarios. Prolonged floods would tend to delay Aman plantation, resulting in significant loss of potential Aman production, as observed during the floods of 1998.

Considering all the direct and induced adverse effects of climate change on agriculture, one may conclude that crop agriculture would be even more vulnerable in Bangladesh under a warmer world.

2.3.2 Impact on roads and highways

Floods, especially the high intensity floods, often devastate physical infrastructure such as road networks, educational centres, market places, administrative buildings etc (Nizamuddin *et al*., 2001; Siddiqi, 1997; Siddique and Chowdhury, 2000). Among this, a large road and highway network is criss-crossing the whole Bangladesh like veins, most of it traversing through the flood plains of the country. The Roads and Highways Department (RHD) is responsible for a huge number of assets in the form of roads, bridges and culverts. Protecting and maintaining about 20,798 kilometers of roads and 14,712 bridges and culverts with an estimated asset value of TK 727,000 Million is of prime importance for the national economy.

Deluge of 1998 rendered most parts of Dhaka inaccessible by motorized vehicles, while the flood waters of 1988 penetrated the runways of Dhaka International Airport and disconnected it for about 11 days from the rest of the world. The telecommunication network was torn off during the cyclone of 1991 and the entire coastal belt was disconnected for weeks.

Historical records show that the roads, which were raised above the 1988/1998 flood-level, suffered minimum damage in the 2004 floods. After the 1988 flood, for example, national highways such as the Dhaka-Chittagong, Dhaka-Mawa-Khulna, Dhaka-Sylhet and Dhaka-Aricha highways were raised by 1 to 1.5 meters above HFL. As a result, these highways suffered no significant damages during the 2004 flood. Flood loss potentials to roads infrastructure have been huge. In the 1998 and 2004 flood, for example, the direct damage to roads sector is estimated as TK 15,272 and TK 10,031 Million, accounting for 15 and 9 per cent of the total damage respectively. The situation is expected to be deteriorating in the days to come, with the increased extent and intensity of flooding due to potential climate change and sea level rise in future. Hence, it is important to develop flood proofing systems as a response to natural disasters, in designated flood risk zones, to protect life, property and vital infrastructure such as roads.

Climate change induced high intensity events pose huge threats to existing physical infrastructure. Damage to national highways due to flood alone is estimated at 1,011 and 3,315 kilometers by the year 2030 and 2050, respectively. The corresponding damage to embankments is estimated at 4,271 and 13,996 kilometers by the year 2030 and 2050, respectively. The aggregated damage figures for health centres and hospitals due to floods, cyclones, sea-level rise and salinity intrusion is estimated at 1,682 and 5,212, respectively, for the above two time horizons (BRTC-BUET, 2005).

In this regard, removal of impediments of drainage (dredging/re-excavation of choked rivers/khals; drainage canals), construction of drainage structures (culverts, bridges, and regulators), rehabilitation of structures such as roads, embankments etc. should be considered as adaptation measures towards facilitating drainage and reduce flood-related vulnerability (Ahmed *et al.*, 1998, Ahmed, 2005; Faruque and Ali, 2005).

In view of urban flooding, this option will remain as an important adaptation option despite the high cost of its implementation. In increasingly flood vulnerable areas (FVA), efforts should be made for flood proofing of infrastructure, as deemed necessary (Faruque and Ali, 2005).

DFID-sponsored programme “Roads and Highways Policy Management, budgetary and TA Support” (RHD) considered flood as direct disaster and adaptation cost was enumerated considering the flood-proofing of roads and highways by raising this infrastructure above the highest ever-recorded flood levels within the country. Specifically, some 170 Km of national and regional roads and some 518 Km of district (feeder) roads in high risk areas will be raised by 1m. Further, about 124km of national and regional roads in low risk area will be raised by 0.5m. As the option comprises a long-term programme and since the costs would be very high if incurred at one time, it proposes action when a particular road is due for major maintenance or re-surfacing, with priority given to high risk areas.

Flood-proofing of roads and highways by raising road height to the highest recorded flood and provision of adequate cross-drainage facilities. The Roads Master Plan (Government of Bangladesh, 2007) also recently reiterated the maintenance of 1 to 1.2 meter freeboard above a 50 year flood, although directives in this respect have been in existence since the time of the floods back in 1987 and 1988. Notwithstanding the above facts, so far, the efforts and resources of the RHD are meager compared to the enormous dimension of the problem. The proposed option in its entire scope will provide appropriate flood proofing to nearly 800 Km of roads through roads raising across the country.

In recent time, relevant experts suggested that roads constructed along the east-west direction were given extra attention to ensure proper drainage of water, by providing extra spans for adequate passage at the peak flow stage. Experts also warned that the existing bituminous pavements are more susceptible to water than cement-concrete ones. Provision of asphalt concrete topping and hard shoulder can reduce the damage to roads caused by the flow of water over the road surface. Asphalt concrete produce more durable pavements than the usual road with mixed carpeting. Knowledgeable people also opine that in order to minimize the erosion of the road embankments and vulnerable road sections, slopes have to be protected with hard layers (C.C. blocks with geotextile); less vulnerable sections should be protected with flood resistant natural turfs and plants like vetiver (Kashful).

2.3.3 Impact on human health

Human health condition in Bangladesh is quite poor. Average life expectancy is 58 years, which is lower than in its neighboring countries. Two-thirds of children under five are underweight in the country, and infant mortality rate is 78 per thousand, three times higher than the average for all of Asia (WRI, 1998). Major health hazards are communicable diseases (cholera, dysentery, diarrhea, measles, tetanus etc) caused by poor nutrition and sanitation status. Prevalent parasitic diseases include malaria, dengue, filariasis, and helminthiasis. Most diseases are found in rural areas (Heitzman and Worden, 1989), where access to health care is limited. There is only one doctor for every 12,884 people and one nurse for every 11,549 people. Ratio of individuals to doctors deteriorated between the early 1980s and the early 1990s. Only 48 percent of the population has access to adequate sanitation (WRI, 1998).

Existing literature does not provide an assessment of climate change impacts on human health in Bangladesh. Although there is a significant seasonal variation in temperature ranging from 10 to 38°C, heat stress mortality may be observed among elders, especially during mid-April and mid- August. Due to high temperature and humidity, the elders and malnourished children will face dehydration related problems. A temperature increase of 1-2°C would perhaps not cause a significant change, but higher intensity of extreme events (patches of very hot days etc.) may intensify heat stress and associated health hazards.

There are some indirect implications of climate change to human health. It is reported that elevated temperatures would create favorable conditions for vector-borne pathogens (McMichael et al., 1996) and directly influence prevalence of vector-borne diseases. Bangladesh is already exposed to diseases such as malaria and dengue. Many people suffer from malarial diseases each year. Salmonela is a common pathogen that causes large-scale outbreaks of typhoid fever in most parts of Bangladesh. Warmer and wetter conditions would increase the prevalence of such deadly diseases. A study on the number of weeks in a typical year in which dengue could be transmitted in Calcutta, India, found that the length of the period could increase from 44 weeks a year to all year long under a 2°C warming (Jetten and

Focks, 1997). Since the general weather and environmental conditions of West Bengal and Bangladesh are similar, a similar change might be observed in this country.

Mosquito is a menace almost everywhere in Bangladesh. It is also a common vector for the malaria parasite. Stagnant and filthy water bodies are the best breeding grounds for mosquitoes. Since higher temperature and prolonged rainless days during January and February help reducing water volumes in standing water bodies, problems associated with mosquitoes are at its peak during winter months. Under climate change, higher prevalence of mosquito-borne diseases can be expected.

Effect of climate change on other sectors could adversely influence the health situation in Bangladesh. Floods increase the risks associated with diarrhea and cholera -- diseases also associated with high temperatures (Colwell, 1996). Any adverse impact on food production systems would increase the risk of further malnutrition. Increases in the number of tropical cyclones, or flood intensity, or frequency could pose additional risks to human life.

2.4 Adaptation Needs and Strategy

IPCC-IV has already recognized that water and agriculture sectors are likely to be most sensitive to climate change-induced impacts in Asia. Agricultural productivity in Asia is likely to suffer severe losses because of high temperature, severe drought, flood conditions, and soil degradation. They have also identified some of the following adaptation strategies to reduce the vulnerabilities to climate change:

- Increases in income levels,
- Education and technical skills,
- Improvements in public food distribution,
- Disaster preparedness and management, and
- Health care systems

Discussions in this chapter show that Bangladesh is highly vulnerable to climate change. Faced with the indicated impacts, the next issue is: whether and how Bangladesh can adapt to those changes and what will be the economic cost for adaptation will be discussed on the next chapters.

2.5 Steps towards Adaptation

2.5.1 Formulation of NAPA

NAPAs (national adaptation programmes of action) provide a process for Least Developed Countries (LDCs) to identify priority activities that respond to their urgent and immediate needs with regard to adaptation to climate change. The rationale for NAPAs rests on the limited ability of LDCs to adapt to the adverse effects of climate change. In order to address the urgent adaptation needs of LDCs, a new approach was needed that would focus on enhancing adaptive capacity to climate variability, which itself would help address the adverse effects of climate change. The NAPA takes into account existing coping focusing on scenario-based modeling to assess future vulnerability priority activities, rather than focusing on scenario-based modeling to assess future vulnerability and long-term policy at state level. In the NAPA process, prominence is given to community-level inputs as an important source of information, recognizing that grassroots communities are the main stakeholders.

Bangladesh has already formulated its NAPA in the year 2005 (MoEF, 2005). Fifteen adaptation measures have been formulated considering six sectors namely Water, Coastal area, Natural Disaster and Health; Agriculture, Fisheries and Livestock; Biodiversity, Forestry and Landuse; Industry and Infrastructure; Food security, Livelihood, Gender and Local governance; and Policies and Institutes. The total cost of adaptation stands at about US$ 75 million. Bangladesh is now seeking international assistance in implementation of its adaptation programme.

2.5.2 Formulation of Country Framework

Bangladesh has formulated a Country Framework to mainstream Climate Risk Management and Adaptation in 2006 (CCC, 2006). The objective of the country framework is establishing a mechanism that facilitates national development planning and implementation to integrate adaptation to climate change and climate risk management systematically and over time.

Defining risk environment includes current and future climate risks, accommodating peoples' perceptions and using climate modeling facility to enable one to pinpoint risks over time and space. To do so, characterizing the natural conditions, socioeconomic conditions, and institutional environment must be adequately characterized. Responding to the climate risks involves formulation of micro level risk reduction action plan (RRAP), identification of climate related sectoral development plans, social communication, knowledge management, capacity building, demonstration of good practice, implementation of the action plans (piloting), monitoring, evaluation and feedback mechanism and scaling and implementation. Institutional facilitation for adaptation includes creating enabling policy environment, mainstreaming and coordination, partnership building, institutional arrangements and Governance (continuity, transparency, handling political interferences, financing, and enabling implementation.

The country framework on one hand supports pursuing disaster risk reduction through identifying current and future climatic induced hazards, while on the other supports climate resilient development. The Country Framework provides a much necessary platform for implementing NAPAs in LDCs and serves as an example of climate resilient development persuasion.

3. Climate Change Modelling - Tools and Techniques

3.1 Physical Adaptation Modelling

3.1.1 Water sector

Physical Models

The rivers and floodplains of Bangladesh are known for extreme variation in dry and wet seasons making periodic floods and droughts. The development projects for productions and safety nets have considerable interferences in natural flood dynamics in this region. Further, the impact of climate changes on water resources are giving the flood dynamics new shapes which have not been considered during the design and implementation of those development projects and safety nets. Numerous water and related models has been developed and used in Bangladesh to estimate the features of water resources projects over last few decades. The major implementation agencies in water Modelling are BWDB and WARPO. WARPO used water models mainly at national levels, where BWDB used for small to large projects. Main water Modelling institutes in Bangladesh are RRI and IWM. The available and frequently used models are:

Organization	Models	Software Source
WARPO The models in WARPO are not being used currently and have not been updated for long	Groundwater model Surface water model (MIKE11-NAM) Morphological model (MIKE11 Modelling suite) Flood management model (MIKE11-GIS) Salinity model (Rapid assessment model)	Self DHI (through IWM) DHI (through IWM) DHI (through IWM) CEGIS
IWM IWM is providing Modelling supports to BWDB and other organizations	One dimensional Modelling of rivers and floodplains (MIKE11 Modelling suite) Two dimensional Modelling of rivers, estuary and sea (MIKE21 Modelling suite) Three dimensional Modelling of rivers and estuaries (MIKE and Delft 3D series) Distributed hydrological Modelling (MIKE SHE series) Urban drainage and water quality Modelling (MOUSE Modelling series) Water resources management Modelling (MIKE Basin Modelling series). MIKEBASIN provides basin scale solutions for optimizing water allocations, conjunctive water use, reservoir operation, and water quality issues, emphasizing results visualization through a GIS interface.	DHI DHI DHI, Delft DHI DHI DHI
CEGIS	Drought Assessment Model (DRAS) Shrimp crop DSS STREAM (Spatial Tools for River basins and Environmental and Analysis of Management options) Salinity intrusion rapid assessment model River bank erosion short term prediction model Nijhum dwip integrated development DSS	Self Self Self Self Self Self

Data availability

BWDB has a good historical data on water levels from over 300 gauges on all over

Bangladesh. They collected discharges from several locations in major and medium rivers. Modelled water levels and discharge data are also available for big floods in BWDB, FFWC and IWM. For two climate change projects of CEGIS, using sea level rises the hydrodynamic models were run to generate water levels, discharges, salinity and inundations in coastal areas based on several prediction scenarios as follows:

	Year 2010	Year 2050	Year 2050
Water Levels, Discharges, Salinities			
Base (Yr 2000) for flood	+SLR 14 cm	+SLR 32 cm	+SLR 88 cm
Base for dry periods (1997)	+SLR 14 cm	+SLR 32 cm	+SLR 88 cm
100 yr flood (Yr 1988)	+SLR 14 cm	+SLR 32 cm	+SLR 88 cm
Avg flood (Yr 2005)	+SLR 27 cm	+SLR 62 cm	
Extreme flood (Yr 1998)	+SLR 27 cm	+SLR 62 cm	
Storm surge (1991) + 10% increase in intensity	+SLR 27 cm		

The inundation was computed in CEGIS using GIS techniques.

There is a great lacking in observed salinity data. The available data are not sufficient for good modelling to estimate the impact of climate change induced sea level rises. Only indicative results can be generated.

Data on physical infrastructures like polders, embankments, sluices are available in BWDB and IWM. Coastal Embankment Rehabilitation Project (CERP) conducted a survey to produce embankment elevations and sluice information in all coastal polders. This database is useful to estimate the embankment inundations, flooding and drainage capacities inside the polders which can be utilized to estimate the impacts on agricultural, fisheries, livestock, communication and other facilities.

For computing the inundation and infrastructural damages, land elevations have prime importance. CEGIS has computerized topographic maps of whole Bangladesh and prepared the Digital Elevation Model (DEM) using the maps prepared during 1960s. Finnmap developed topographic maps on coastal zone during 1990-2000 for BIWTA using Aerial Photographs. CEGIS has computerized all the Finnmaps which could be used to update the existing DEM. Other physical features like roads, settlements, water bodies etc. could be extracted from the Finnmaps as necessary to find the climate change impacted features.

Other models

Some other models available in water sectors around the world, some of which account climate are:

- WaterWare
- Water Evaluation and Planning System (WEAP)
- RiverWare
- Interactive River and Aquifer Simulation (IRAS)
- STREAM
- RIBASIM
- Aquarius

The models summarized here include long-range simulation tools such as WEAP and IRAS, short-range simulation models like RiverWare and WaterWare, and economic optimization models like Aquarius. RIBASIM allows for the assessment of infrastructure, and operational and demand management measures. Short descriptions of these models are given below:

WaterWare

WaterWare is a UNIX based software package developed by Environmental Software and Services, GmbH, Gumpoldskirchen, Austria (http://www.ess.co.at/WATERWARE). It is an advanced water resource simulation tool that incorporates numerous models and analyses for easy access to advanced tools of data analysis, simulation Modelling, rule-based assessment, and multi-criteria decision support for a broad range of water resources management problems. WaterWare is implemented in an open, object-oriented architecture; it supports the seamless integration of databases, GIS, models, and analytical tools into a common sense, easy-to-use framework. It includes a number of simulation and optimization models and related tools, including a rainfall-runoff and water budget model, an irrigation water demand estimation model, dynamic and stochastic water quality models, a groundwater flow and transport model, a water resources allocation model, and an expert system for environmental impact and assessment.

This model has an extensive data requirement. The main inputs required by this software are: background maps with administrative boundaries, landuse; river network (geometry) graph and segment geometry (cross sections, roughness); River Basin Objects, their location and depending on the type of object, data on water demand, use, consumptive use, and wastewater generation (pollution loads); Time series of basic hydro-meteorological data, temperature and precipitation, optionally relative humidity, wind speeds, cloud cover and solar radiation, potential evapotranspiration; hourly to daily observation data from one or more water quality observation stations; station location and regular time series for each parameter and investment and operational costs for a set of alternative waste water treatment technologies.

This software can be used to generate outputs like:- Water allocations at demand nodes, flows in river reaches, water quality constituents throughout water system, aquifer dynamics, and other water system components.

Water Evaluation and Planning System (WEAP)

WEAP is a PC based surface and groundwater resource simulation tool developed by Stockholm Environment Institute (SEI), SEI-Tellus Institute, Boston, USA (http://www.weap21.org). It is based on water balance accounting principles, which can test alternative sets of conditions of both supply and demand. The user can project changes in water demand, supply and pollution over a long-term planning horizon to develop adaptive management strategies. WEAP is designed as a comparative analysis tool. A base case is developed, and then alternative scenarios are created and compared to this base case. Incremental costs of water sector investments, changes in operating policies, and implications of changing supplies and demands can be economically evaluated.

The key inputs are: spatially explicit demographic, economic, crop water requirements; current and future water demands and pollution generation; Water use rates, capital costs, discount rate estimates; historical inflows at a monthly time step; groundwater sources; Reservoir operating rule modifications, pollution changes and reduction goals, socioeconomic projections and water supply projections.

It can be used to generate outputs like: Mass balances, water diversions, sectoral water use; benefit/cost scenario comparisons; pollution generation and pollution loads.

RiverWare

RiverWare is river and reservoir Modelling application with both operational and planning applications. This system is developed by Center for Advanced Decision Support in Water and Environmental Systems (CADSWES), University of Colorado, Boulder, USA (http://cadswes.colorado.edu/riverware). It offers multiple solution methodologies that include simulation, simulation with rules, and optimization. RiverWare can accommodate a variety of applications, including daily scheduling, operational forecasting, and long-range planning. Modelling framework is non-spatial (not GIS based). Because of its object-oriented nature, the Modelling framework allows for the generation of new Modelling methods that could include economically driven demand Modelling.

The key inputs are: Description of diversion water requirements; historical inflows at multiple time steps, reservoir characteristics, stream reach routing characteristics; operating rules of system given as prioritized operating policy described through a rule-based system.

It can be used to generate outputs like mass balances, detailed flow descriptions throughout the water system, water diversions, water quality descriptions of dissolved solids and water temperature. Currently, Modelling applications have focused on operational strategies of current systems.

Interactive River and Aquifer Simulation (IRAS)

This model is surface water resource simulation tool developed by Resources Planning Associates, Inc., Ithaca, USA (http://www.cfe.cornell.edu/research/urbanwater/project%20description/General/IRAS.htm). It based on water balance accounting principles that can test alternative sets of conditions of both supply and demand. The model can simulate up to 10 independent or interdependent water quality factors at a sub monthly time step. Through data interfacing, IRAS can link to various external modules such as rainfall-runoff and to economic and ecological impact prediction programs.

The key inputs are configuration of system and component capacities and operating policies; demand requirements at various nodes; historical inflows at various time steps, evaporation and seepage losses from system, aquifer recharge rates, wetland characteristics; waste loads; reservoir operating rule modifications, pollution changes and reduction goals.

It can be used to generate outputs like system performance in meeting demand requirements, flows, storage volumes, energy, and water quality throughout system.

RIBASIM

RIBASIM is a generic model package for simulating the behavior of river basins under various hydrological conditions. This package is developed by WL Delft Hydraulics, Delft, The Netherlands (http://www.wldelft.nl/soft/ribasim/int/index.html). The model package is a comprehensive and flexible tool that links the hydrological water inputs at various locations with the specific water users in the basin. It enables the user to evaluate a variety of measures related to infrastructure and operational and demand management, and to see the results in terms of water quantity and flow composition. It can also generate flow patterns that provide a basis for detailed water quality and sedimentation analyses in river reaches and reservoirs. Demands for irrigation, public water supply, hydropower, aquaculture, and reservoir operation can be taken into account. Surface- and groundwater resources can be allocated. Minimum flow requirements and flow composition can be assessed.

The required inputs are: Configuration of system and component capacities and operating policies; spatially explicit demographic, economic, crop water requirements; current and future water demands and pollution generation; water use rates, capital costs, discount rate estimates; Historical inflows at a monthly timestep; groundwater sources, Reservoir operating rule modifications, pollution changes and reduction goals, socioeconomic projections and water supply projections.

It can be used to determine water balance providing the basic information on the available quantity of water as well as the composition of the flow at every location and any time in the river basin. This takes into account drainage from agriculture, discharges from industry and the downstream re-use of water in the basin.

Spatial Tools for River basin Environmental Analysis and Management (STREAM)

STREAM is a spatial hydrological model that allows for assessing hydrological impacts due to changes in climate and socio economic drivers. This software is developed by Institute for Environmental Studies (IVM), Vrije Universiteit Amsterdam, The Netherlands (http://www.geo.vu.nl/users/ivmstream/). STREAM is set up according to a policy analytic framework and ensures a structured approach for an entire river basin including the coastal zone. STREAM uses hydrological input data, scenarios, adaptive strategies and provides output data on water availability and (salt water) quality. It integrates within this frame several types of interactions between effects of river management on the coastal zone, land and water uses such as short term deforestation and dam building, and long term impacts of climate change.

STREAM is a spatial model and uses data from digital GIS maps and satellite observations, in particular land-use related data. The basis of the instrument is a grid or raster-based water balance approach. Water use and withdrawals can be simulated such as the spatial distribution of agriculture and urbanization use and the storage of water in the open flood plain and groundwater aquifers.

The main advantage of STREAM is that it primarily uses public domain data from the internet providing a very first order of estimates on impacts. This makes the STREAM instrument very flexible for future extensions and adjustments. The next stage of development, calibration and validation, is usually performed in close cooperation with local stakeholders, using local time series of in and output data increasing the level of reliability.

Key output is spatial hydrological information on water availability in the form of (monthly) soil-humidity and river discharges. The latter outputs can be both in a hydrograph or in spatial GIS based map.

3.1.2 Roads

Physical Settings

In Bangladesh major types of roads according to the RHD classification are, (a) National

Highway - which connects divisions and important cities and ports with the capital city, Dhaka; (b) Regional Highways - which connects division centers with division head quarters; (c) Zilla Road - which connects districts with Upazilas and (d) Rural Roads - which connects Upazila with Unions and other growth centers.

The lengths of each class with types are presented below:

Road Length by Classification		
National Highway	=	3,507.51 Km
Regional Highway	=	4,118.72 Km
Zilla Road	=	13,251.42 Km
Total Road Length	=	20,877.65 Km
Road Length by Surface Type according to latest survey		
Bituminous	=	16,766.06 Km
HBB	=	653.02 Km
Earth	=	563.38 Km
Cement Concrete (CC)	=	2.44 Km
Cement Blocks	=	0.37 Km
Total Paved Road Length	=	17,332.25 Km
Total Unpaved Road Length	=	653.02 Km
Total Surveyed Road Length	=	17,985.27 Km
Length of Road Not Surveyed	=	2,892.38 Km

The roads make obstructions to overland flows specially during recession time of flood. The roads are designed using elevation of flood with different recurrence depending on types. National, Regional highways and Zilla road area usually designed for 30,20 and 10 year return period of maximum floods.

Models

As the road elevations are designed based on flood levels, the levels are normally computed using the historic observed water level data as available along the alignment. Recently RHD started using hydrodynamic models like Mike11 (1-D) to estimate the number of openings and height of the crest.

The model is available for major rivers but not for flood plain, which is very important for designing the road elevations. Recently IWM has started Modelling to analyze the impacts of flood on the communication road networks using pseudo 2-D models.

The required data to incorporate the roads in the model is insufficient; only alignment is clearly available in RHD, but the elevations and other section parameters are scattered.

The available topographic data is very old which is applicable for water resources projects but road models require higher resolution data, because it deals with base widths ranging from 10-100 meters only.

3.1.3 Health

Physical settings

Climate change impact on human health is a global concern. Various climate change related events like heat waves, cold waves, flood, drought, Sea Level Rise, salinity intrusion, cyclone etc have direct and indirect adverse impacts on human health. It has been estimated that climate change causes 2.4% of all cases of diarrhea worldwide and 2% of all cases of malaria. Due to climate change, baseline number of people at risk of dengue is 1.5 billion worldwide. Climate change was responsible for at least 150,000 deaths and 5.5 million Disability Adjusted Life Years (DALY) in the year 2000. It was estimated that about 119 million cases of malaria occur every year only in South East Asia.

Bangladesh is already vulnerable to outbreaks of infectious, water borne and other types of diseases. The record shows that malaria incidents increased from 1556 in 1974, 15375 in 1981, 30282 in 1991 to 42012 in 2004. A recent study of Climate Change Cell of the Department of Environment shows that temperature, rainfall and salinity concentration are factors for causing diarrhea, skin diseases, malaria, dengue, kala-azar etc in Bangladesh. It has been found that temperature variation is the main cause of diarrhea, skin diseases and malnutrition. Moreover, skin disease and malnutrition are more or less highly correlated with all three variables. The rise in global temperature and increased instances of water logging due to floods has increased the population of mosquitoes especially in tropical countries. About 26 million people in Banglaedsh are at risk of malaria. In recent years, malaria is staging a come back in Bangladesh. 13 boundary districts in the east and north-east part of Bangladesh including Chittagong Hill Tracts belong to high risk Malaria zone. A brief demographic health status of Bangladesh is presented in following Table 3.1.

Table 3.1: Demography and health status

Population in Million	**129.25 million**
Male	65.84 percent
Female	63.41 percent
Density of Population (per sq. km.)	876
Life expectancy at birth (2000)	64.9 years
Maternal Mortality Rate (per 1000 live birth)	37
Post neonatal mortality rate	19
Infant mortality rate	53 (per 1000 live birth, 2000)
Crude birth rate	23.6
Crude death rate	8
Nutrition (calorie intake)	2244
Malaria death rate per 100000(all ages)	0.5
Tb incidence rate 100000	99
%of <5 children with diarrhea treated with ORT (ORS or homemade solution)	74.6
% of <5 children with symptoms of ARI seeking care from trained provider	20.3

Physical Models

The available physical models for health sector are mainly of two types. Some facilitate the investigation of multiple or overall disease burden and how this burden responds to a number of environmental stressors, including climate change and others are more narrowly focused and model the health impacts or transmission dynamics of particular diseases. Available physical models are as follows:

- MIASMA (Modelling Framework for the Health Impact Assessment of Man-Induced Atmospheric Changes)
- CIMSiM and DENSiM (Dengue Simulation Model)
- LymSiM

MIASMA

Modelling Framework for the Health Impact Assessment of Man-Induced Atmospheric Changes (MIASMA) is a Modelling application that models several health impacts of global atmospheric change and include simulation for vector-borne diseases, thermal heat mortality and UV-related skin cancer due to stratospheric ozone depletion. The models are driven by population and climate/atmospheric scenarios, applied across baseline data on disease incidence and prevalence, climate conditions, and the state of the stratospheric ozone layer.

The required inputs are: For thermal stress, maximum and minimum temperature; for skin cancer, column loss of the stratospheric ozone over the site, maximum and minimum temperature and rainfall; Vector-borne diseases also require other baseline data.

Key Outputs are: For the thermal stress module- cardiovascular, respiratory, and total mortality; for skin cancer module- malignant melanoma and nonmelanoma skin cancer; for vector-borne disease modules- cases and fatalities from malaria, and incident cases for dengue fever and schistosomiasis.

CIMSiM and DENSiM (Dengue Simulation Model)

These simulation models are developed by Infectious Disease Analysis, Gainesville, USA (http://id-Analysis.com). CIMSiM is a dynamic life-table simulation entomological model that produces mean-value estimates of various parameters for all cohorts of a single species of Aedes mosquito within a representative 1 ha area. For each cohort, depending on the life stage, CIMSiM maintains information on abundance, age, development with respect to temperature and size, weight, fecundity, and gonotrophic status. With few exceptions, the various processes are simulated mechanistically.

DENSiM is essentially the corresponding account of the dynamics of a human population driven by country- and age-specific birth and death rates. An accounting of individual serology is maintained, reflecting infection and birth to seropositive mothers. The entomological factors passed from CIMSiM are used to create the biting mosquito population. The survival and emergence values dictate the dynamic size of the vector population within DENSiM while the gonotrophic development and weight estimates influence the rate at which these females bite. The infection model accounts for the development of virus within individuals and its passage between the vector and human populations.

Required inputs are: A pupal/demographic survey for estimating the productivities of the various local water-holding containers; Daily maximum/minimum temperature, rainfall and saturation deficit.

The key output Parameters estimated by DENSiM include demographic, entomologic, serologic, and infection information on a human age-class and/or time basis.

LymSiM

LymSiM is developed by Infectious Disease Analysis, Gainesville, USA (http://id-Analysis.com). LymSiM simulates the population dynamics of the blacklegged tick (Ixodes scapularis) and the dynamics of transmission of the Lyme disease agent (Borrelia burgdorferi) among ticks and vertebrate hosts. LymSiM models the effects of ambient temperature, saturation deficit, precipitation, habitat type, and host type and density on tick populations. The model accounts for epidemiological parameters like host and tick infectivity, transovarial and transstadial transmission, such that the model realistically simulates the transmission of the Lyme disease spirochete between vector ticks and vertebrate hosts. The software features a dynamic life table model of I. scapularis with a weekly time step; rates of development, survival, fecundity, and host finding are based on weather or other environmental variables and vary with time.

Required inputs are: proportions of forested, meadow, and ecotone; weekly average temperature, rainfall total, relative humidity, and saturation deficit and density of the four to six types of hosts.

This simulation can generate outputs like, Seasonal and geographical distributions of the Lyme disease agent and its vectors as a function of climate.

A number of vector and water borne diseases including diarrhea, dysentery, skin diseases etc are common in Bangladesh. In addition, mental disorders, malaria, dengue and malnutrition problems affect many people of the country.

Currently there is no known health model available in Bangladesh to assess the impacts of climate change. But recently BCS-ICCDRB-WHO-CDMP and others started to identify the indicators, sensitivity and thresholds of climate elements (temperature, humidity, rainfall and salinity) for diseases. Based on the finding of the studies CEGIS will develop an indicative model to estimate addition population exposed to diseases.

The intended model will use mainly temperature, rainfall, humidity, flood and salinity data from available sources. The major sources of climate data are IPCC 4th assessment report. Flood and salinity data will be used from CLASSIC and DFID studies and others as available.

3.1.4 Agriculture

Physical Setting

The production of crop in Bangladesh is constrained by too much water during the wet season and too little during the dry season. Presently total irrigated area is 4.4 million ha which is more than 50 % of the potentially irrigable area of 7.12 million ha cultivated area. This area is being irrigated through surface and ground water resource. Irrigation coverage through Shallow tubewells (STWs) during the dry period has grown very fast following a policy of privatization and deregulation. As a result, the groundwater table in Bangladesh is declining at a rapid rate causing STWs non-operating in many parts of the country during dry period. Lack of surface water during the dry season limits the function of Low Lift Pumps. The situation will further aggravate under climate change scenario. On the other hand the Aman crop during the monsoon will become vulnerable to increasing flood threat.

A simulation study conducted under the climate change country study assessed the vulnerability of foodgrain production due to climate change in Bangladesh. Two general circulation models were used for development of climate scenarios. The experiments considered impact on three high yielding rice varieties and a high yielding wheat variety. A rise in temperature of $4^{o}C$ would cause significant decrease in production, some 28 % and 68 % for rice and wheat, respectively. Moreover, doubling of atmospheric concentration of CO_2 in combination with a similar rise in temperature would result into an overall 20 % rise in rice production and 31 % decline in wheat production. It was found that boro rice would enjoy good harvest under severe climate change scenario with doubling of atmospheric concentration of CO_2 . The apparent increase in yield of boro (dry season rice crop generally grown under irrigated conditions and includes high yielding varieties) and other crops might be constrained by moisture stress. A 60 % moisture stress on top of other effects might cause as high as 32 % decline in boro yield, instead of having an overall 20 % net increase. It is feared that moisture stress would be more intense during the dry season, which might force the Bangladeshi farmers to reduce the area for boro cultivation. Shortfall in boro production will severely compromise the food security of poor country.

Physical models for Agriculture Sector

The agricultural sector tools range from sector-wide economic analyses to farm-level crop models. The crop process models address the impact of various management and climate change scenarios on single crops, multiple crops and entire ecosystems. There are also tools that can be used to examine particular ecological factors or processes or support bigger picture strategic adaptation decisions. Available physical models are as follows:

- APSIM (Agricultural Production Systems simulator)
- Process Soil and Crop Models: CENTURY
- ORYZA 2000
- Model of Agricultural Adaptation to Climatic Variation (MAACV)
- Process Crop Models: Erosion Productivity Impact Calculator (EPIC)
- Process Crop Models: RICEMOD

APSIM (Agricultural Production Systems simulator)

APSIM is a Modelling framework with the ability to integrate models derived in fragmented research efforts. This package is developed by Agricultural Production Systems Research Unit, Queensland, Australia (http://www.apsim.info). APSIM enables research from one discipline or domain to be transported to the benefit of some other discipline or domain. It also facilitates comparison of models or submodels on a common platform. This functionality uses a “plug-in-pull-out” approach to APSIM design.

User can configure a model by choosing a set of submodels from a suite of crop, soil and utility modules. Its crop simulation models share the same modules for simulation of the soil, water and nitrogen balance. APSIM outputs can be used for spatial studies linking with (GIS).

APSIM required Inputs are: Soil properties, daily climate data, cultivar characteristics, and agronomic management.

It can generate outputs like, changes in crop and pasture yields, yield components, soil erosion losses, for different climate change scenarios.

Process Soil and Crop Models: CENTURY

CENTURY is a general model of plant-soil nutrient cycling that has been used to simulate carbon and nutrient dynamics for different types of ecosystems, including grasslands, agricultural lands, forests, and savannas. This model is developed by Natural Resource Ecology Laboratory at Colorado State University, USA (http://www.nrel.colostate.edu/projects/century5/).

CENTURY is composed of a soil organic matter/decomposition submodel, a water budget model, a grassland/crop submodel, a forest production submodel, and management and events scheduling functions. It computes the flow of carbon, nitrogen, phosphorus, and sulfur through the model's compartments. The grassland/crop production model simulates plant production for different crops and plant communities. The forest model simulates the growth of deciduous or evergreen forests in juvenile and mature phases. To simulate a savanna or shrubland, CENTURY uses both of these submodels with some additional code to simulate nutrient competition and shading effects.

Main required inputs are: monthly average maximum and minimum air temperature; monthly precipitation; soil texture; plant nitrogen; phosphorus and sulfur content; lignin content of plant material; atmospheric and soil nitrogen inputs; initial soil carbon; nitrogen.

The model can simulate outputs of Changes in soil carbon and nutrient balances, as well as in crop, pasture and forest production, for different climate change scenarios.

ORYZA 2000

ORYZA 2000 is the successor to a series of rice growth models developed by IRRI (http://www.knowledgebank.irri.org/oryza2000). The model combines several modules: aboveground crop growth, evapotranspiration, nitrogen dynamics, soil-water balance, and others.

Required inputs are: daily climate data (irradiation or sunshine hours, minimum temperature, maximum temperature, early morning vapor pressure, mean wind speed, and precipitation), soil properties, and crop management.

ORYZA generates rice yield for different climate change scenarios.

Model of Agricultural Adaptation to Climatic Variation (MAACV)

This model illustrates the endogenous and exogenous forces that influence adaptation responses and classifies those responses into various farms and regional level responses. The biophysical environment, government programs, economic conditions, and other forces are the exogenous considerations and factors such as the attributes of the farmer, the farm family, and the farm, including their experiences, perceptions, location, scale, and finances, are the endogenous considerations made in this model. Farm responses include tactical and strategic decisions.

Major inputs are: system and human agency influences on adaptation responses.

Main outputs are: classification of range of forces and responses to adaptation to climatic variation.

Process Crop Models: Erosion Productivity Impact Calculator (EPIC)

EPIC is an IBM, Macintosh or Sun based generalized crop model that simulates daily crop growth on a hectare scale. Like most process plant growth models, it predicts plant biomass by simulating carbon fixation by photosynthesis, maintenance respiration, and growth respiration. Several different crops may be grown in rotation within one model execution. It uses the concept of light-use efficiency as a function of photosynthetically available radiation (PAR) to predict biomass. EPIC has been modified to simulate the direct effects of atmospheric carbon dioxide on plant growth and water use. Crop management is explicitly incorporated into the model.

The model requires quantitative data on climate, soils, and crop management.

Key Outputs are: response of crop yields, yield components, and irrigation requirements to climate change adaptations.

Process Crop Models: RICEMOD

RICEMOD is a FORTRAN and BASIC based ecophysiological model for irrigated rice production. It is developed by IRRI. It includes a number of physical parameters, including accommodation of subroutines dealing with soil and plant chemistry as well as physical processes of the atmospheric environment. The model is very sensitive to soil parameters and has been expanded to consider soil water deficit. Model components include maximum leaf area index, timings of plant growth initiation and harvest, radiation-use efficiency (RUE), and harvest index (HI).

Required Data are: soil, plant, and atmospheric data (rainfall, pan evaporation, radiation, minimum and maximum temperature, day length).

Key Outputs are: total area index (LA1, leaves and stem), growth rates, dry weights, dry matter partitioning, grain yield, number of grains, CO_2 assimilation, and amount of radiation absorbed by the canopy.

3.2 Cost-Benefit Modelling of Adaptation

3.2.1 General principles

Emergence of cost-benefit concept for adaptation

Adaptations to deal with sea-level rise, more intense cyclones and threats to ecosystems and biodiversity were recommended by IPCC –III as high priority actions in temperate and tropical Asian countries. It was suggested that the design of an appropriate adaptation programme in any Asian country must be based on comparison of damages avoided with costs of adaptation.

The temperature projections for the 21st century, based on IPCC Fourth Assessment Report (AR4) Atmosphere-Ocean General Circulation Models (AOGCMs), and discussed in detail in Working Group I Chapter 11, suggest a significant acceleration of warming over that observed in the 20th century (Christensen et al., 2007). Warming is least rapid, similar to the global mean warming, in South-East Asia, stronger over South Asia and East Asia and greatest in the continental interior of Asia (Central, West and North Asia). In general, projected warming over all sub-regions of Asia is higher during northern hemispheric winter than during summer for all time periods. The most pronounced warming is projected at high latitudes in North Asia. Recent modelling experiments suggest that the warming would be significant in Himalayan Highlands including the Tibetan Plateau and arid regions of Asia (Gao et al., 2003).

Projected changes in surface air temperature and precipitation for sub-regions of Asia under SRES are conjectured under two broad frames: A1FI (highest future emission trajectory) and B1 (lowest future emission trajectory) for three time slices, namely 2020s, 2050s and 2080s.

Context of Cost-Benefit Modelling of Adaptation

Bangladesh has an increasing trend of about 1°C of temperature rise in May and 0.5°C in November during the 14 year period from 1985 to 1998. The same increase has caused decadal rain anomalies above long term averages since 1960s (Mirza and Dixit, 1997; Khan et al., 2000; Mirza, 2002). These negative impacts call for adaptation options at local, regional and national scale. For examining economic viability of adaptation measures to implement, a cost-benefit analysis is justified.

Cost-benefit analysis tries to quantify climate change damages in monetary terms as the social cost of carbon (SCC) or time-discounted damages. Due to considerable uncertainties and difficulties in quantifying non-market damages, it is difficult to estimate SCC with confidence. Results depend on a large number of normative and empirical assumptions that are not known with any certainty. SCC estimates in the literature vary by three orders of magnitude. Often they are likely to be understated and will increase a few percent per year (i.e. 2.4% for carbon-only and 2–4% for the social costs of other greenhouse gases (Yohe et al., 2007). SCC estimates for 2030 range between 8 and 189 US$/t$CO_2$-equivalent (IPCC, 2007b, Chapter 20).

Local and international projections of climate change direct finger to the need for adaptation in Bangladesh. Limited treatment of adaptation in climate change assessments, however, is still a problem and a number of reasons explain this.

- First, the focus of the international climate change negotiations has largely been on mitigation (perhaps because attention to adaptation could be viewed as 'giving up' on mitigation) even though the importance of adaptation is underlined in Article 4 of the UNFCCC and Article 10 of the Kyoto Protocol.
- Second, adaptation is largely undertaken at the local scale, by individual households, farmers, companies or local governments; it is thus difficult to target through coordinated international incentives, and is more complicated to handle quantitatively by models in global scenarios.
- Third, it is difficult to generalize the ways that individuals or communities are likely to adapt to specific impacts.

Cost-benefit analysis of adaptation options for (i) flood proofing of roads and highways by raising road-height and for (ii) flood proofing of char area homesteads by raising earthen platforms has been done in an earlier study (Islam and Mechler , 2007). The report provides forward and backward looking framework for cost-benefit analysis. It has assessed costs and benefits following three steps analytical frame: (i) hazard analysis, (ii) vulnerability analysis and (iii) risk analysis. These principles can also be pursued in this study.

Assumptions for Cost-Benefit Analysis

- adaptation to climate change impacts is exclusive of mitigation
- a certain level of temperature rise is assumed over a horizon of roughly 100 years
- three sub-sectors of the economy are studied: health, water resources and roads and highways
- damages due to climate change have been estimated by "backward linkage", or considering empirical data on temperature and consequent impact on the target variables
- non-monetized impacts are not considered in cost estimates

3.2.2 Economic modelling

Health

Health and life are non-market goods. Some indirect method for estimating shadow prices has to be developed. First step is to find out morbidity and mortality caused by climate change (Ahmed, 2006). The author has quoted Agrawala et al. 2003 who inferred that deadly diseases like malaria and dengu would put human health into more risks under climate change. The Bangladesh NAPA comments that health risk of the poor would be disproportionate given the government's spending on health sector. The next step is to find out the total economic value of the degradation of health due to climate change. Specific affected components are: urban water quality, drinking water quality, drainage congestion, solid wastes management and marine environment.

Identify adaptation needs and costs

The said consequences have negative impacts on income and livelihood of the affected population. So, adaptation is the perceived immediate solution (ultimate solution is reduction of emission or mitigation measures). Adaptation needs have, therefore, to be identified against each type of climate change impacts. For example: adaptation to increased morbidity or mortality due to malaria or dengu will need, say:

- research on biological dose-response functions through controlled laboratory experiments
- increased infrastructures for attending and treating patients
- increased preventive measures to reduce infections by parasites
- improved infrastructures to reduce or avoid drainage congestion where mosquitoes grow
- treatment of polluted water
- added infrastructures for solid waste disposal
- mitigation of marine environment
- increased awareness building efforts widely in the country

These physical needs will be translated into financial costs using market prices. Appropriate conversion rates will be used to transfer them to economic costs, representing economic cost of adaptation.

Select approach to valuing impacts

Two approaches to the valuation of human life/health are usually practiced:

- discounted future earnings (opportunity cost, objective standard-based valuation of costs and benefits),

- willingness to pay or willingness to accept (subjective preference-based valuation of costs and benefits).

The first approach is proposed to be followed in the present analysis.

Discounted future earnings/benefits

The cost of various diseases (illness) can be estimated as the sum of:

- direct expenditure for medical care
- forgone earnings attributable to morbidity
- cost of premature death (likely)

These costs are assumed to be equal to the **present value** of future earnings of the population affected by climate change.

The difference between net income saved and cost of adaptation will give net benefit of adaptation. Net income saved will be derived as the difference of income saved with and without adaptation.

This approach has been formalized by the WHO and World Bank through the concept of DALY (Disabled Adjusted Life Years). Brandon and Hommann (1995) calculated the discounted present value of health/life lost due to environmental degradation.

These values will be adjusted with the projected normal GDP values (without impacts of climate change) to derive the reduced values of GDP for the future (with impacts of climate change). GDPs can be estimated either at market price or at factor cost.

Discount rate to be used for deriving present value will be assessed after discussions with notable economists of Bangladesh (particularly of BIDS and Dhaka University)

Two issues must be made clear here:

- present value method as above will leave many non-market impacts (costs) out from the analysis (particularly in health sector), but that should not misguide the policy makers by way of underestimating the adverse impacts of climate change. It is only for simplicity's sake that only market impacts are considered.
- abatement cost on the part of the polluters has not been considered in the cost structure

Water Resources Development Infrastructures

Water resources sector has enormous scope to be addressed for impacts of climate change in Bangladesh. Massive infrastructures have been historically constructed to fight against cyclones, storms and surges in the coastal areas. Drainage systems have also been built to keep the areas free from congestions. Climatic changes over the last decades have been changing the cycles of storms and surges and frequency of disaster events is increasing. Agrawala et al. 2003 envisage threat to a large area of the coast due to sea level rise in Bangladesh over the course of 21st century and beyond. Increased flooding from glacial melt, more intense monsoon and more intense and frequent cyclones would also adversely affect agriculture in the near term by inundating more and more land. Increased salinization also poses a threat to loss of agricultural production.

Food demand is increasing with increase in population. Loss of agricultural products as such would put Bangladesh into a chronically food-deficit nation which is not desirable. Contribution of agriculture to GDP is very vital for the sustainable economy of Bangladesh. Adaptation to climatic changes is essential from economic and social points of view. Specific affected water –related infra-structural components are: coastal embankments, water management structures, irrigation infrastructures, cyclone shelters etc.

Identify adaptation needs and costs

The said consequences have negative impacts on income and livelihood of the affected population. So, adaptation is the perceived immediate solution (ultimate solution is reduction of emission or mitigation measures). Adaptation needs have, therefore, to be identified against each type of climate change impacts. For example: adaptation to increased floods, drainage congestions, storm surges, salinity intrusion etc. will need, say:

- raised embankments and infrastructures for facing higher flood and high tide levels
- more ventage and appropriate levels of drainage structures
- improved infrastructures to reduce or avoid drainage congestion
- appropriate drainage structures across all types of roads in coastal polders
- more drainage and/or conveyance capacity of the coastal rivers
- pumping excess water from pockets particularly where high value properties and infrastructures, urban centers and industrial zones are located.
- development of water reservoir for crisis events like cyclonic disasters (due to climate change) when drinking water becomes a life-saving resource.
- establishing more effective early warning systems for flooding that might result from enhanced cyclone intensity due to climate change

These physical needs will be translated into financial costs using market prices. Appropriate conversion rates will be used to transfer them to economic costs, representing economic cost of adaptation.

Select approach to valuing impacts

Two approaches to the valuation of human life/health are usually practiced:

- discounted future earnings (opportunity cost, objective standard-based valuation of costs and benefits)
- willingness to pay or willingness to accept (subjective preference-based valuation of costs and benefits).

The first approach is proposed to be followed in the present analysis.

Discounted future earnings/benefits

The cost of various damages to infrastructures can be estimated as the sum of:

- direct expenditure for reconstruction or rehabilitation of existing structures
- forgone earnings attributable to damages

These costs are assumed to be equal to the present value of future earnings of the population affected by climate change.

The difference between net income saved and cost of adaptation will give net benefit of adaptation. Net income saved will be derived as the difference of income saved with and without adaptation.

These values will be adjusted with the projected normal GDP values (without impacts of climate change) to derive the reduced values of GDP for the future (with impacts of climate change). GDPs can be estimated either at market price or at factor cost.

Discount rate to be used for deriving present value will be assessed after discussions with notable economists of Bangladesh (particularly of BIDS and Dhaka University)

Two issues must be made clear here:

- present value method as above will leave many non-market impacts (costs) out from the analysis (particularly in health sector), but that should not misguide the policy makers by way of underestimating the adverse impacts of climate change. It is only for simplicity's sake that only market impacts are considered.
- abatement cost on the part of the polluters has not been considered in the cost structure

Roads and Highways

The Roads and Highways department (RHD) has constructed about 21,000 km. of roads and above 14,700 bridges all over the country. LGED also has constructed huge rural and semi-urban roads of different categories. Potentials of loss of roads and highways due to floods and cyclonic surges due to climate change are very high. These have serious social and economic implications. Without safe and strong roads, highways and embankments, the water-marooned people during disaster do not find temporary shelters to save their life. Livestock population also gets endangered. Total economic resources stand still.

Roads and Highways sector has enormous scope to be addressed for impacts of climate change in Bangladesh. Climatic changes over the last decades have been changing the cycles of storms and surges and frequency of disaster events is increasing. Agrawala et al. 2003 envisage threat to a large area of the coast due to sea level rise in Bangladesh over the course of 21st century and beyond. Increased flooding from glacial melt, more intense monsoon and more intense and frequent cyclones would also adversely affect communication sector in the near term by overtopping and breaching more and more roads and highways.

Demand for roads is increasing with increase in urbanization. Roads are serving as blood veins to the mobility of economic resources across the country. Loss of these infrastructures as such would put Bangladesh into a chronically disaster-prone nation, particularly during disaster which is not desirable. Adaptation in terms of raising the height and protecting the roads from damages due to climate change is essential from economic and social points of view. Specific affected water –related road infra-structural components are: flood-proofing of roads, raising of coastal embankments with concrete top to be used as roads, water management for the road-crossing water-courses etc.

Identify adaptation needs and costs

The said consequences of damages to roads infrastructures have negative impacts on economic activities, transportation, income and livelihood of the affected population. So, adaptation is the perceived immediate solution (ultimate solution is reduction of emission or mitigation measures). Adaptation needs have, therefore, to be identified against each type of climate change impacts. For example: adaptation to increased floods, drainage congestions, storm surges etc. will need, say:

- raised roads and embankments and communication infrastructures for facing higher flood and high tide levels
- more ventage and appropriate levels of cross-drainage structures
- improved infrastructures to reduce or avoid drainage congestion
- appropriate drainage structures across all types of roads in coastal polders

These physical needs will be translated into financial costs using market prices. Appropriate conversion rates will be used to transfer them to economic costs, representing economic cost of adaptation.

Select approach to valuing impacts

Two approaches to the valuation of physical facilities are usually practiced:

- discounted future earnings (opportunity cost, objective standard-based valuation of costs and benefits)
- willingness to pay or willingness to accept (subjective preference-based valuation of costs and benefits).

The first approach is proposed to be followed in the present analysis.

Discounted future earnings/benefits

The cost of various damages to infrastructures can be estimated as the sum of:

- direct expenditure for reconstruction or rehabilitation of existing structures
- forgone earnings attributable to damages

These costs are assumed to be equal to the present value of future earnings of the sectors or population affected by climate change.

The difference between net income saved and cost of adaptation will give net benefit of adaptation. Net income saved will be derived as the difference of income saved with and without adaptation.

These values will be adjusted with the projected normal GDP values (without impacts of climate change) to derive the reduced values of GDP for the future (with impacts of climate change). GDPs can be estimated either at market price or at factor cost.

Discount rate to be used for deriving present value will be assessed after discussions with notable economists of Bangladesh (particularly of BIDS and Dhaka University)

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- abatement cost on the part of the polluters has not been considered in the cost structure

3.2.3 Data needs for economic modelling of climate change

General

Economic Modelling of climate change is a complex exercise. An ideal Modelling would need a wide variety of time series and projected data including:

- population, technology, production, consumption
- emission quantum
- temperature
- atmospheric concentrations
- radiative forcing and global climate
- regional climate and weather
- profiles of sea level rise
- climatic thresholds
- direct impacts on crops, health, infrastructures, forests, ecosystems etc.
- income, expenditure, livelihoods, additional risks and vulnerabilities
- price parameters
- discount rates
- key macroeconomic indicators of development

While data on many of the said parameters are available for different regions and countries of the world, many of them are not available as regular, annual or periodic data for a particular region or country. More curiously, assumptions are different for future behavior of climate change (level of future use of fossil oils, emission of methane, fraction of carbon that will remain in the atmosphere etc). Nature and causes of natural variability of climate and its interactions with forced changes are also difficult to obtain. So, much of the available projected climate-related data are either hard to get or hard to rely for good results to come.

Tentative Data needs for the Study

Water Sector

For water sector, following data will be needed for constructing an economic model:

- Hazards and decadal frequency
- Levels of vulnerability per hazard
- Risks per vulnerability
- Existing infrastructures
- Projected loss of water infrastructures (embankments with crest levels, sluices with capacity, irrigation structures with length and capacity etc.)
- Existing production levels in crops, fisheries and livestock
- Projected loss of crops, fisheries and livestock
- Existing households and housing structures (including public and private assets and buildings)
- Projected households and housing structures (including public and private assets and buildings)
- Existing GDP in water sub-sector, growth trend and PRSP goal

Road Sector

Following data on road sector are expected to be used for economic Modelling of climate change:

- Length of road (Type-A)
- Length of road (Type-B)
- Length of Regional Highway
- Length of National Highway
- Hazards and their decadal frequency
- Levels of vulnerability per hazard
- Risks per vulnerability
- Projected loss of road infrastructures (road, bridges, culverts, spillways, protective works etc.) due to climate change disasters

Health Sector

- Population and households
- Existing vulnerabilities and risk levels due to water-borne and vector-borne diseases
- Projected vulnerabilities and risk levels due to water-borne and vector-borne diseases
- Costs of present public sector spending on mitigation of health disasters
- Projected costs of public sector spending on mitigation of health disasters due to climate change impacts
- Existing infrastructures for public drinking water, health and sanitation services
- Projected needs for additional public drinking water, health and sanitation services due to climate change impacts

Agriculture Sector

Following data will be needed to construct economic model for agricultural sector:

- Present net land available for crops round the year
- Expected loss of net land for crops round the year due to climate change impacts
- Present yield levels for all crops
- Projected yield levels for all crops due to climate change impacts
- Price of products (present and future)
- Expected damage frequency and damage profiles for the future
- Salinity levels (present and future)
- Use of fertilizers and pesticides (Present levels and expected future levels)

3.2.4 Integration with planning cycle

Exercise on climate change impacts in Bangladesh should be gainfully used in the planning frame of Bangladesh. Research, theories and recent disaster shocks in Bangladesh signal positive sings of existence of climate change devil. Without a direct link to the planning cycle of Bangladesh, the results of these studies will get lost and adaptation activities will not emerge.

Bangladesh has a regular cycle in economic planning exercise in the Planning Commission under Ministry of Planning. This Commission draws sectoral plans from relevant Ministries once a financial year (July to June), revised every year in March. Adaptation needs are expected to be identified for each sector as such and estimates for economic options for adaptation have to be prepared to incorporate in sector plans and mainstream the issues at national level. This would facilitate imputing the adaptation costs and benefits into the national budget to see the influence of it on macroeconomic indicators like GDP at large.

4. Approach and Methodology

4.1 Overall Approach

Reflections above guide the present researchers towards an approach, which takes step-by-step and progressive model development activities instead of going for the economic model directly. In this regard, as already stated in the study objective, the study has been designed to provide the desired outputs in three phases. In the first phase, it outlines a successive approach to work out a computational framework from assessing the present information base, compiling them, filling the knowledge gap. The second phase start following the methodological steps derived during the first phase and go for developing the physical adaptation model for the water management infrastructure in the coastal zone of Bangladesh. Based on adaptation propositions, economic models has been developed enumerating the cost of damage and benefit from savings through adaptation considering the probable risk and vulnerability in the sectors. The third phase directly developed economic models for two other sectors, i.e., transportation and health sector.

In this study, while developing the economic model, both forward and backward looking approach has been undertaken. Forward-looking approach combines data on hazard and vulnerabilities to an estimate of risk and reduced risk. The sensitivity or exposure of each sector in terms of risk and risk reduced has been assessed considering the increased incidence of climate induced hazards or disasters as key vulnerability indicator.

Towards developing the economic model, suitable answer to the following questions has either been enumerated or justified:

- By what extent specific sectors (water management infrastructure, health and transportation) are sensitive to climate change exposure?
- What are the physical impacts of climate change due to the changes in the hydro-meteorological parameters (e.g. sea level rise, temperature change, flooding etc.)
- What is the expected economic cost of damage in the short and long term?
- How should we balance the net costs/benefits of adaptation against climate change impacts?
- To what extent the adaptation choices are economically viable?
- What will be our ability to refine/improve policy responses with improved information over time?

Overall phasing of the economic model development exercise is outlined in figure 4.1.

4.2 Cost – Benefit Modeling: An Integrated Approach

The proposed economic model is based on the hypothetical model suggested by Gunasekera and Ford (2005) on climate change, which consists of the following determinants:

- Reference case without impacts;
- Climate change damage costs or reference case with impacts;
- Cost of policy;
- Benefits of avoided climate change; and
- Net benefits of adaptation and mitigation.

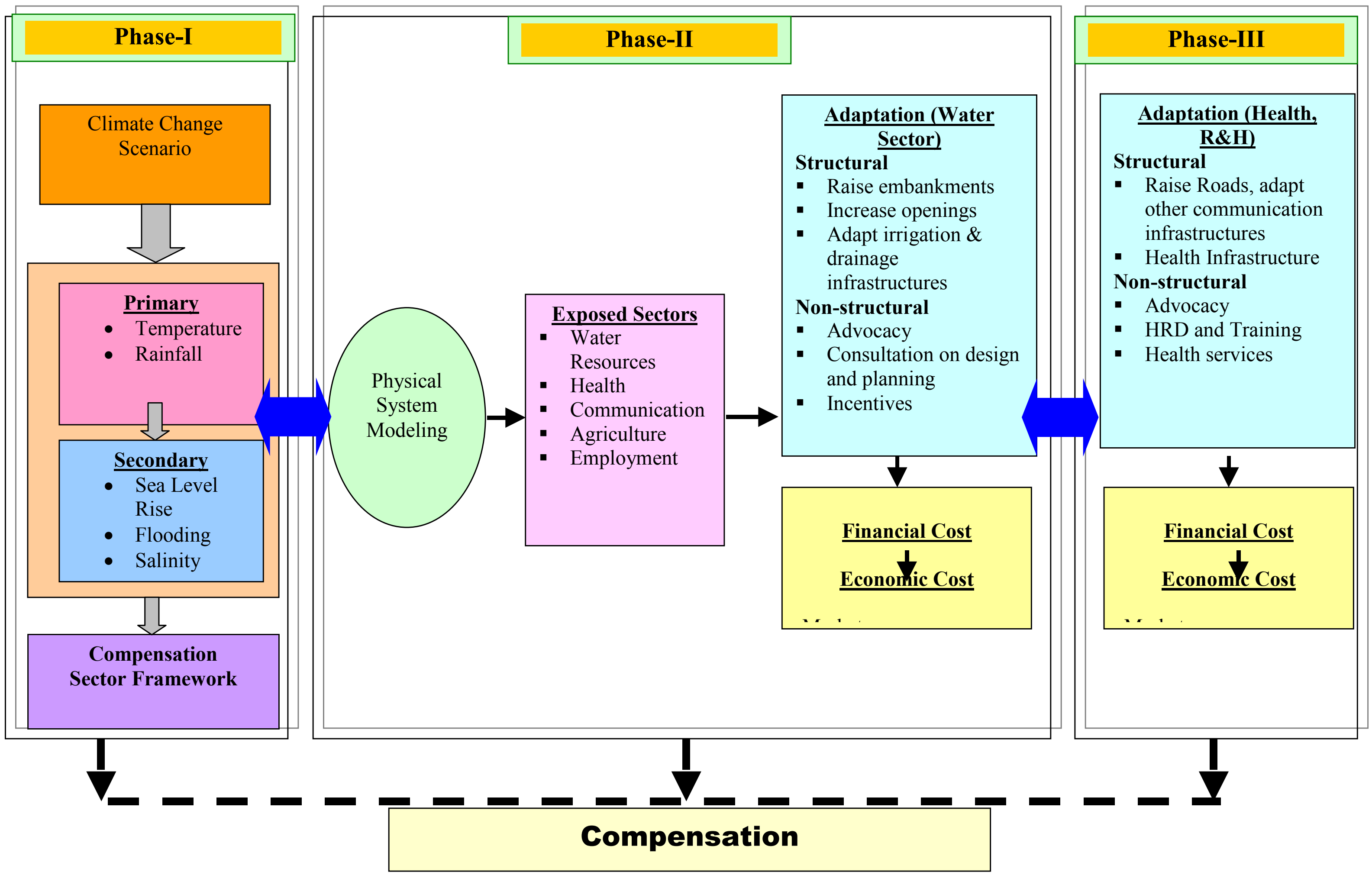


Figure 4.1: Overall study model

The framework for modeling is drawn in the following figure (4.2) in consideration of the above determinants.

The overall cost-benefit modeling exercise has been divided into four major steps as described below:

i. Simulation of climate change risk scenarios
ii. Estimation of expected damage
iii. Physical adaptation cost and probable benefit from adaptation
iv. Modelling the economics of adaptation

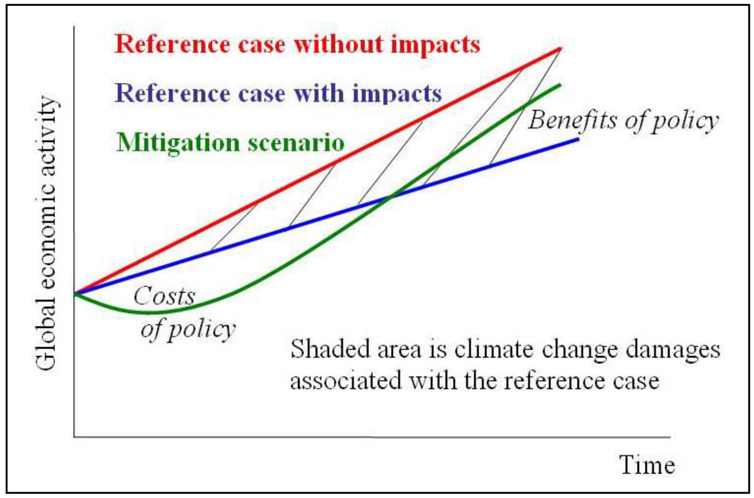


Figure 4.2: Climate change policy framework for benefit cost analysis (the fish diagram)

4.3 Limitations and Feature of the Economic Model

The overall features and limitations of the current modeling frameworks are:

Short-term focus: Climate change impacts can be long term (to 2100 and beyond), but herein this exercise the period of impact assessment has been considered for a 40 years period ranging from 2010 to 2050.

Economic data: Time series data either or loss on economic indices or national economy feedbacks is lacking. Understanding this reality, climate change impact on sectors other than agriculture has been considered here.

Structural adaptation: Both the structural (for transportation sector) and non-structural (health sector) against specific sea level rise has been adopted to comply with variety of uncertainties and complexities of economic modeling exercise. Self and community motivated coping mechanism against natural calamities and immune system developed over time against various diseases caused by changing climate developed has not been considered at this stage. However, some preliminary investigation and rehabilitation need has been assumed to assess the probable damage profile and extent of savings through adaptation.

Discounting Rate: The discounting of future benefit is rational only when the spread of benefit is intra-generational, which is usually the case in project economics. Climate change economics poses theoretical challenge because it compares inter-generational benefits as it has to deal with a very long time frame (more than 100 years). The question is whether to discount benefits accruing to future generations. Possible argument is against discounting benefits of future generation and to use a low (if possible, even zero) discounting rate, which has not been tested here due to available research backup.

5. Development of Economic Model

5.1 Overview of Modelling

This chapter primarily deals with the development of economic model for the water management infrastructures of the coastal zone, which are especially vulnerable to the predicted Sea Level Rise (SLR) due to climate change. Along with that two other separate economic models have been developed for health and transportation sector.

While developing the economic model for water management infrastructures of the coastal zone, raising of existing 138 polders has been considered as key adaptation option and the cost of this option has been compared with expected benefit i.e. saving the expected damage of agricultural crops.

Prior to the development of economic model for the health sector, the relations between the flooding and temperature (those are likely to be increased with sea level rise and climate change) with diseases like diarrhea, malaria, fever etc. has been explored, based on previous studies and other available sources. Besides these, the present and planned activities/programmes have been studied, considering the millennium development goal, to assess the population covered by health service in milestone years (Yr 2050). The additional exposed population and required health services because of the sea level rise have not been estimated to avoid complicacy of estimation.

While developing the economic model for roads and highway sector, existing road network has been classified according to the Roads & Highways and LGED system as practiced in Bangladesh. The design parameters for sections (design elevations including freeboards, crest width, side slopes and materials), alignments and traffic volumes has also been collected from these organizations. Also, the information on flood events those inundated the roads in recent pasts and the damages along with locations and repairing costs has been collected to analyze the scale of vulnerability due to excess flooding because of climate induced sea level rise. The vulnerable road lengths will be classified based on criteria, which will be defined through consultation with experts and degree of required investment for the damage recovery.

Costs of these additional infrastructures and services have been estimated at market prices. Economic costs of these components will again be estimated by using opportunity cost principles and multi-criteria tools (as there will be some non-market components in health sector).

5.2 Economic Modelling for Water Management Infrastructures in the Coastal Zone

5.2.1 Step-1: Simulation of climate change risk scenarios

Risk is the probability of harmful consequences resulting from interactions between threats and vulnerable assets. Here there are two types of threats associated: (i) threat of partial inundation due to sea level rise, and (ii) threat of full inundation due to overtopping of embankments. Agricultural sector has been considered as key vulnerable sector, for which the vulnerability exposure is mainly of two folds: (i) short-term vulnerability due to threat of partial and full inundation, and (ii) long-term vulnerability due to increasing soil salinity.

In the first step, physical adaptation model has been used to simulate two sea level rise (SLR) scenarios; 27 cm SLR at the end of year 2050 and 62cm at the end of year 2080. Against each scenario, depth of flooding has been estimated and results of the net change in the inundated area [ha] for different land types. A combination of two-dimensional and one-dimensional mathematical model of Bay of Bengal and Southwest region of Bangladesh has been applied for defining the base condition and scenarios. MIKE21 and MIKE11 software, developed by DHI, have been used for the modeling exercise, which are well parameterized and validated for the country as well as for the coastal region. Detail methodology of the physical adaptation model is given in Annex-A.

The inundation during monsoon in the coastal zone for base condition has been determined through application of calibration and validated regional models of southwest, southeast, eastern-hill regions resources systems and 2D model of the Meghna Estuary for the year 2005. Inundation has been categorized in depth classes as: flood free, 0-30cm, 30-90 cm, 90-180 cm and greater than 180cm keeping similarities with the widely practiced National Water Plan land classes: F0 (high land), F1 (medium to high land), F2 (medium to low land), F3 (low land) and F4 (very low land). The baseline inundation status in the coastal districts during monsoon is given in Table 5.1. About 50% land is inundated in monsoon for an inundation depth more than 30cm under base condition in 2005. Jhalokhati, Barisal, Barguna, Gopalganj, Patuakhali, Narail are inundated more because these districts are partially empoldered and thus are open to tidal inundation.

Changes in land type due to sea level rise are presented in Table 5.1. These land type classification is mainly based on inundation depth. Due to sea level rise, more flood free land will be inundated and shallower inundated land will experience deeper inundation. The result in Table 5.1 shows that due to sea level rise, F0 and F1 type land will decrease and F2, F3, F4 type of land will increase. For 62cm sea level rise in 2080, about 6% of total land area will be added to F2 land type (inundation 90-180cm) and 6% of total land area will be F3 type.

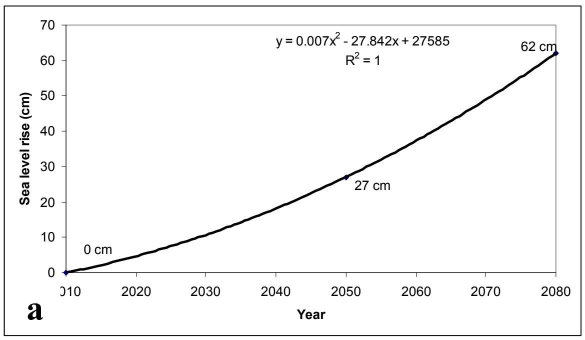
Table 5.1: Inundated area [ha] for different land type

Land Type	Base Condition	2050 (A2, 27cm SLR)	2080 (A2, 62cm SLR)	Change in land type (due to 62cm SLR)
F0 (0-30cm)	358,300	321,100	244,500	-113,800 (-3%)
F1(30cm-90cm)	878,800	843,200	801,000	-77,800 (-2%)
F2(90cm-180cm)	633,400	833,300	967,400	+ 334,000 (10%)
F3(180cm-300cm)	184,700	262,500	376,500	+191,800 (6%)
F4(>300cm)	27,100	34,200	39,000	+11,900 (<1%)

Note: -ve change means decrease of land area and +ve means increase of land area.
Land area in coastal region = 3,455,800 ha

Risk is the probability of harmful consequences resulting from interactions between threats and vulnerable assets. Here there are two types of threats associated: (i) threat of partial inundation due to sea level rise, and (ii) threat of full inundation due to overtopping of embankments. Agricultural sector has been considered as key vulnerable sector, for which the vulnerability exposure is mainly of two folds: (i) short-term vulnerability due to threat of partial and full inundation, and (ii) long-term vulnerability due to increasing soil salinity.

Here it has been assumed that the sea level will be gradually increasing over the period towards 2050 and 2080. In this regard, net annual rise in the sea level has been enumerated from a polynomial regression equation as shown in Figure 5.1 (a). Similarly the depth of partial inundation (only F0 and F1 has been considered) due to sea level rise will also vary at an increasing trend. Yearly depth of inundation due to probable SLR has been estimated through regression analysis as given in figure 5.1 (b). Other than this, the probability of occurrence of intensive cyclonic surges and subsequent overtopping of embankments will rise from 1 in 100 yr to 1 in 60 yrs and 1 in 30 yrs due to net SLR of 27 cm and 62 cm respectively. Here it has been assumed that overtopping of embankment will cause the full inundation of the area inside the polders.



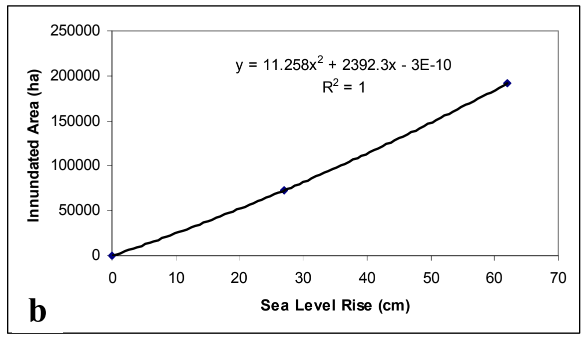


Figure 5.1: a. Yearly increment of sea level over a time horizon of 2010 to 2080
b. Correlation between sea level rise and area of inundation

With the predicted sea level rise, the polders, which will either be subjected to partial inundation or full inundation due to overtopping, has been identified in step-1. The extent of inundation by the spill water is calculated using the existing DEM data from CEGIS. The current crop cultivation practices has been collected from secondary sources and validated through short field visit. Damage to standing crops due to inundation has been calculated by assuming a damage factor and verifying it in the field.

Before assessing the vulnerability, the need for reviewing current research trends in climate change induced agricultural vulnerability has been realized, and hereby the present state of knowledge in this regard is given below:

5.2.2 Step-II: Estimation of expected damage

Coastal plains are mainly used for crop agriculture and for grazing of livestock. Regular or periodic inundation and saline water intrusion has been a problem for agricultural activities in the coastal areas. Since the seventeenth century, construction of small embankments or dikes has been a common practice in this country. The main purpose of these polders/dykes is to protect coastal agricultural land from flooding and intrusion of saline water during high tide, and thereby to increase cultivable areas as well as yields in the coastal region. Land use profile from 123 coastal polders (2nd CERP, 2000) reflected that around 46% of the gross area was engaged by agricultural practice. Present cropping pattern and intensities disaggregated by different land types is given in Annex-A. For vulnerability assessment, only the F0 and F1 land class has been taken into consideration as it has been found that majority (82%) of the agricultural land lies within the F0 and F1 land and cultivable land loss due to inundation will occur only within these two classes. Around 72.8% of the F0 and F1 land is brought under agricultural activity comprises of the grain and non-grain crops and shrimp cultivation. T aman is the main crop that covers 70% of the net cultivable land. The overall copping intensity is 130.7% in the polder-protected areas.

T Aman will be mostly affected by the change climate parameters and it is largely exposed to both short and long term vulnerability. Boro rice and other rabi crops will be partially affected due to long term vulnerability from increasing soil salinity. Other than this, kharif-I crops will be affected by increasing soil salinity and also by the increasing incidence of thunder strom and cyclonic surges. In this regard, it has been assumed that T Aman and Kharif-I crops are 100% vulnerable to immediate or direct or short-term climate change threats, whereas Boro rice and other rabi crops are 50% vulnerable to indirect or long-term climate change threats. Thus, the damage factor has been taken as 1.0 for 100% vulnerability and 0.5 for 50% vulnerability.

Assessment for 27cm SLR scenario

It has already been estimated in the physical modeling part that due to a net rise of 27cm of sea level rise a total of 72,800 ha will be inundated. In this regard, it can be estimated that 53,004 ha of agricultural land (as currently 72.8% of the total land is engaged by agricultural practice) land will be damaged due to estimated SLR of 27 cm. Other than this, due to the stated SLR occurrence, the water levels in front of embankment will rise by 26.5 cm, which will increase the risk of total inundation from 1:100 to 1:60. It aggravate the total situation further, i.e., each year upto 2050, the probability of total inundation is 1.67%. In other words, upto year 2050, an additional cultivated area (within F0+F1) of 15,011 ha per year will be totally damaged due to overtopping of saline water into the coastal polders.

Recent practice of shrimp culture inside the embankments, despite its adverse environmental and ecological effects and serious social problems, has been boosting the national economy. Major shrimp culture activities are centered in Satkhira, Khulna and Bagerhat districts in the western zone and Chokoria, Cox's Bazar and Moheskhali upazilas under the Cox's Bazar district. Salt producing pans and relevant industries are located primarily in the Cox's Bazar district. Damage will be occurred almost in the same frequencies as mentioned above. It has been found from the coastal resources database (CEGIS, 2006) that in the coastal polders a total of 80,489 ha of F0 and F1 lands are engaged with the shrimp culture activity which is around 9% of the net agricultural area. In this regard, it can be estimated that 4,736 ha of shrimp pond may be destroyed due to SLR of 27cm. Other than this, an additional annual damage of 1,341 ha of shrimp pond area loss can be estimated upto year 2050 due to increasing probability of damage due to overtopping.

Assessment for 62cm SLR scenario

A net rise of 62cm of sea level will result in inundation of 191,600 ha. So, it can be estimated that 139,498 ha of agricultural land will be damaged (same assumption made above) due to estimated SLR of 62 cm. Moreover, due to the stated SLR occurrence, water levels in front of embankment will rise by 62 cm, which will increase the risk of total inundation from 1:100 to 1:30. So, each year after 2050 and upto year 2080, the probability of total inundation is 3.33%. In other words, an additional cultivated area (within F0+F1) of 30,023 ha per year will be totally damaged due to overtopping of saline water into the coastal polders.

It is estimated that 12,465 ha of shrimp pond may be destroyed due to SLR of 62cm and an additional annual damage of 2,682 ha of shrimp pond area loss can be estimated after 2050 upto year 2080 due to increasing probability of damage due to overtopping.

Damage worth computation

Before driving to the computation of the net worth of expected damage it is very much essential to establish a reference case considering the "without impact" scenario. In Bangladesh, the overall GDP contribution from agriculture rises at a rate of 3.5% per annum over the last decade (BBS, 2001 and 2004). In this regard, it can fairly be assumed that the overall agricultural contributions from the coastal area will not deviate from this and upto 2080 the growth will be continued due to technological advancement and fair market price availability.

Farm budget analysis has been carried out for a cluster of sample coastal areas named as Char Nangulia, Noler Char and Caring Char to determine the net return per ha of agricultural land. These figures stating the net return per ha for different dominant crops are given in table below; which can also be replicated to other coastal polder cases as the return figures have been validated through field verification in other areas. In has been found through statistical analysis that on an average the farmers in the coastal regions earn around Tk 35,104 per ha per year from the agricultural land through multiple crop culture (including shrimp culture).

Crop	Net return (Tk. per ha)
T. Aman	24,488
B. Aman	12,250
Boro	24,500
B. Aus	5,850
Rabi crops	3,000
Shrimp	84,758

It has already been stated (Table 2 in Annex-A) that a total of 967,833 ha of net area has been brought under cultivation. Assuming that this area will not be changed in future and the only advancement in this sector will be due to the net change in productivity and other types of technological advancements, net worth from the above stated amount of agricultural land during the base year would be Tk. 31,619 million. This worth, in turn, would exponentially rise at the rate of 3.5% per year upto Tk. 351,374 million at the end of year 2080. Net annual total return can be obtained from the regression equation given in figure 5.2 (a).

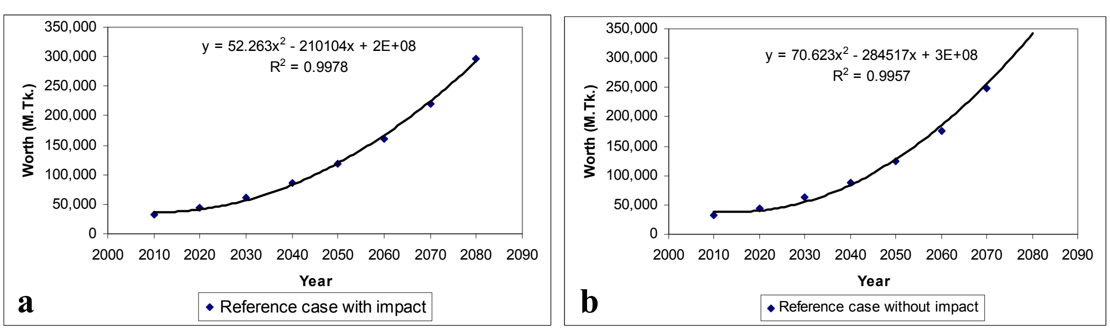


Figure 5.2: Net annual worth of agricultural return for the "reference case"
a. with impact, b. without impact

Using the same net worth of agricultural return per ha, probable damage from 53,004 ha and 139,498 ha of agricultural land due to a net SLR of 27cm and 62cm respectively, which will be worth of Tk. 1,860 million and Tk. 4897 million respectively with respect to the base price. But damage value in year 2050 will also exponentially rise along with the agricultural development trend. So the percent of net damage has been computed with respect to the net agricultural contribution in each year. Percentage of damage worth has been computed as 0% at the year of 2010 to 5.89% at the year of 2050 and 15.49% at the year of 2080. "Reference case with impact" has been derived from subtracting the damage worth from the "reference case without impact" and the development trend has been shown in figure 5.2 (a) and (b).

5.2.3 Step-III: Physical adaptation cost and probable benefit from adaptation

The cost of raising the polders against different levels of sea level rise has been calculated by estimating the length of polder to be raised and knowing the unit cost of raising (source: 2nd CERP, 2000). The adaptation cost will be compared with expected damage.

Mainly two types of costs have been considered for raising the embankments:

- Cost of additional earth filling for adjusted new height over specified length
- Cost of turfing over the embankment

Cost of additional earth filling for adjusted new height over specified length of marginal, interior and sea facing dike can be simply calculated using the following formula:

$$\textbf{Earth Volume, } EV = \left[h\left\{ B + (S + S_1)(H + \frac{h}{2}) \right\} \right] \times L$$

Where, B=Top width of the existing embankment, 1:S and 1:S1 are the slope in both sides of the embankments, h= incremental height that need to be raised and L= Length of the embankment. Different parameters are shown in the schematic embankment x-section below:

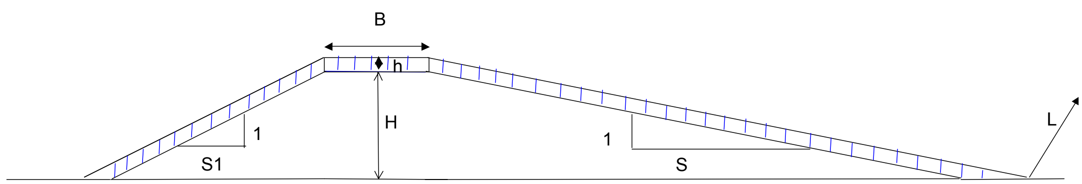


Figure 5.3: Typical embankment cross-section showing different dimensional parameters

Similarly area of new turfing can be calculated using the simple mathmetical relationships:

$$\textbf{Turfing area, } TA = \left[B + \sqrt{(H+h)^2 + \{S(H+h)\}^2} + \sqrt{(H+h)^2 + \{S_1(H+h)\}^2} \right] \times L$$

It has been found from the discussion with BWDB design officials that they use the following unit rate for earth filling and turfing:

- Cost of embankment raising
  - Earth filling — Tk. 125/m^3
  - Compaction — Tk. 60/m^3
- Clearing with grabbing and turfing — Tk. 25/m^2

In this regard, for unit rate earth filling including mechanical compaction becomes Tk. 185/m^3 and for turfing it becomes Tk. 25/m^2. Using the prescribed unit rate cost of rasing different types of embankment along with turfing has been enumerated, which is summarized in the following table:

Table 5.2: Summary of cost profile for embankment raising

Type	Sea level rise scenario	Total Length	Earth filling	Turfing	Total cost	Unit costing
		km	M.Tk	M.Tk.	M.Tk.	M.Tk./km
Interior Dyke	27cmSLR	932	866	911	1,777	1.906
	62cmSLR	1,730	2,099	954	3,054	1.765
Mirginal Dyke	27cmSLR	389	389	347	736	1.892
	62cmSLR	818	969	369	1,337	1.635
Sea Dyke	27cmSLR	1,187	1,187	1,089	2,276	1.918
	62cmSLR	1,007	3,117	1,145	4,262	4.233
Total	27cmSLR	2,441	2,347	2,347	**4,788**	**1.922**
	62cmSLR	3,555	6,184	2,468	**8,653**	**2.434**

In this regard, the total cost associated for raising the existing embankments for 27cm of SLR and 62 cm of SLR becomes Tk. 4,788 and Tk. 8,653 million respectively.

5.2.4 Step-IV: Modelling the economics of adaptation

All costs and benefits are valued in constant 2005 prices. Opportunity cost of capital @ 12% has been assumed for discounting and subsequent computation of net present value (NPV), internal rate of return (IRR), benefit cost ratio (B/C ratio) etc. Different components of the net cash flow stream is elaborated below:

Investment Cost

As derived earlier, net investment cost for raising the embankment for the probable SLR of 27cm (year 2050) and 62 cm (year 2080) will be around Tk. 4,788 million and Tk. 8,653 million respectively. In this regard, it has been assumed that the investment cost for adaptation will occurr progressively against the risk of probable SLR. At year 2010, the first series of investment will be made for 10 years for a cumulative sum of Tk. 4,788 million for safeguarding against the scenario of 27cm SLR. But the cost stream will neither be spent at a constant proportion nor at a lump sump basis. So it has been assumed that for the first three year the investment cost will be increasingly spent at a rate of 10%, 20% and 30% respectively and from the fourth year it will start decreasing to 10% again following at 5% for the next 6 years. Considering the design life of the earthen embankment as 20 years the next stream of investment will recur again at the year of 2030 as a continuation for safeguarding against the scenario of 27cm SLR. But the scenario will be changed after 2050 towards the probable change of SLR of 62 cm. But to remain in the safe side, protection against this SLR scenario should be started at least from 2045 with cumulative worth of Tk. 8,653 million till 2054. Following the same disaggregation cost allotment adopted for 27cm SLR scenario in different years, the investment cost will recur at the year of 2065 with the same amount of investment.

In addition to this, O&M cost has been assumed as 2.5% of the net investment cost for a complete cycle of each 20-year design life cycle. The methodology for deriving the total cost streaming is just similar to that suggested in FAP and other water sector studies.

Benefit from adaptation

Benefit will be derived from the savings from the expected damage due to probable sea level rise. But this savings will neither be realized at the end of year 2050 or year 2080 nor it will be received each year at the same amount with full extent, as the probability of occurrence of SLR will not instantly start occurring to the full extent from right now. In this regard, the gradual trend of net worth of damage has been derived from the net difference of "reference case without impact" and "reference case with impact" and these values are projected for each year through regression analysis as shown in figure 5.4. The savings from the same amount of damage will be the principal component of benefit stream. Another benefit component will be derived from the damage associated with the risk of overtopping of the embankment. Annual benefit amount associated in this regard will be Tk 574 million/year upto 2050 and Tk. 1,148 million onwards upto 2080.

Derivation of economic indices

Economic internal rates of return, net present value and benefit cost ratio has been derived from the net cash flows for different years, which is the difference between the benefits and total investment cost of respective years. Economic benefits and costs have been derived from the above financial values using Standard Conversion Factor (SCF) of 0.9, which is normally used for agricultural projects in Bangladesh. As most of the items of costs (earthwork, turfing etc.) will be incurred in Taka and those of benefits in terms of agricultural products (cereals and vegetables) are locally produced and consumed (non-traded), SCF can take care of the conversion as such to avoid complications.

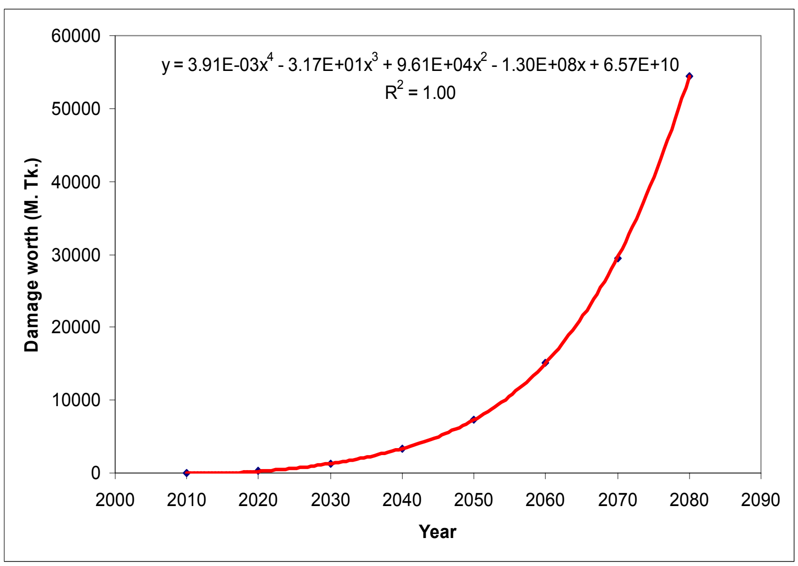


Figure 5.4: Trend of damage worth over the stipulated time period

Cash flow tables showing the net present value of benefits and costs along with other economic indices is shown in Table 1 in Annex-C.

The measures of project worth as derived above, demonstrate economic viability of investing in adaptation and mitigation components. In other words, without adaptation measures, the region is going to suffer an annual average loss of Taka 10,849 million over the stipulated horizon of 70 years (809,443/70). Moreover, the contribution of coastal region to national GDP will also similarly reduce rendering slower economic growth of the nation.

The adaptation of raising of embankments against sea level rise and overtopping is not the full story of potential loss due to climate change. There are other conspicuous factors which have enormous threat to the coastal economy. Following factors have to be addressed (which are not addressed here) while computing the damage impacts due to climate change:

(a) Damage due to drainage congestions and subsequent additional cost of drainage provisions
(b) Yield reduction due to residual soil salinity
(c) Yield loss due to carbon concentration

Costs of adaptation will be much higher than what is estimated in this model if all the above points are taken into consideration.

Sensitivity Analysis

Any project implies a number of risks of uncertainties. Following risks are generally experienced:

(a) Cost may increase during project construction. Here the risk of cost increase has been taken as 20%
(b) Total stipulated benefits may be achieved or decreased due to many physical or natural reasons. Benefit can be assumed to reduce by 20%.
(c) Benefits may take more time to reach its target, i.e., gestation gap may be longer by 2 years.
(d) All the above 3 risks may occur simultaneously.

The sensitivity analysis has been carried out for the project on the basis of the said for envisaged risks. Table below (5.3) summarizes the impacts on the economic indices of aforesaid changes:

Table 5.3: Summary of impact on economic indices by the sensitivity cases

Economic Indices	Base Case	Cost increase by 20%	Benefit decreased by 20%	Lag in benefit recognition by 2 yrs	Costs+20%, Benefits-20%, Lag by 2yrs
ENPV of net cash flow (Million Taka)	4,444	3,683	2,794	3,571	1,335
EIRR	28%	21%	20%	19%	14%
E B/C ratio	1:2.17	1:1.81	1:1.73	1:1.94	1:1.29

5.3 Economic Model for the Transportation Sector

Development steps for the economic model as described earlier in the methodology section are elaborated below:

5.3.1 Step 1: Simulation of climate change risk scenarios

Climate change is a result of the externality associated with greenhouse-gas emissions – it entails impacts mostly on those who are not the principal creators of the emissions. It has been observed that the vulnerability of the country to climate change is the result of a complex interrelationship among biophysical, social, economic and technological characteristics of the country. It is revealed that many anticipated adverse impacts of climate change including sea level rise, higher temperatures, enhanced monsoon precipitation and run-off, potentially reduced dry season precipitation, and an increase in cyclone intensity would in fact aggravate many of the existing stresses that have already posed a serious impediment to the process of economic development of Bangladesh (MoEF, 2005). The projected increase in rainfall during monsoon would be reflected in the flow regimes of the rivers of Bangladesh. Increased flooding and drainage congestion, therefore, are the expected consequences of increased rainfall from a warmer and wetter condition. An increase in monsoon rainfall, therefore, will complicate drainage problem further resulting in increasing duration of floods (Ahmed *et al.*, 1998a). The 'best-estimate' scenario for the year 2030 is that monsoon rainfall could increase by 10 to 15 per cent. For the scenario year 2075 the average rainfall in monsoon will increase by about 27% with respect to the base year (Ahmed, 2006). Tanner et. al. (2007) also showed that the frequency and severity of flooding of the Ganges-Brahmaputra-Meghna River basis is correlated with the amount and timing of precipitation, the condition of the basin and the upstream controls.

The standard approach for estimating natural disaster risk and potential impacts is to

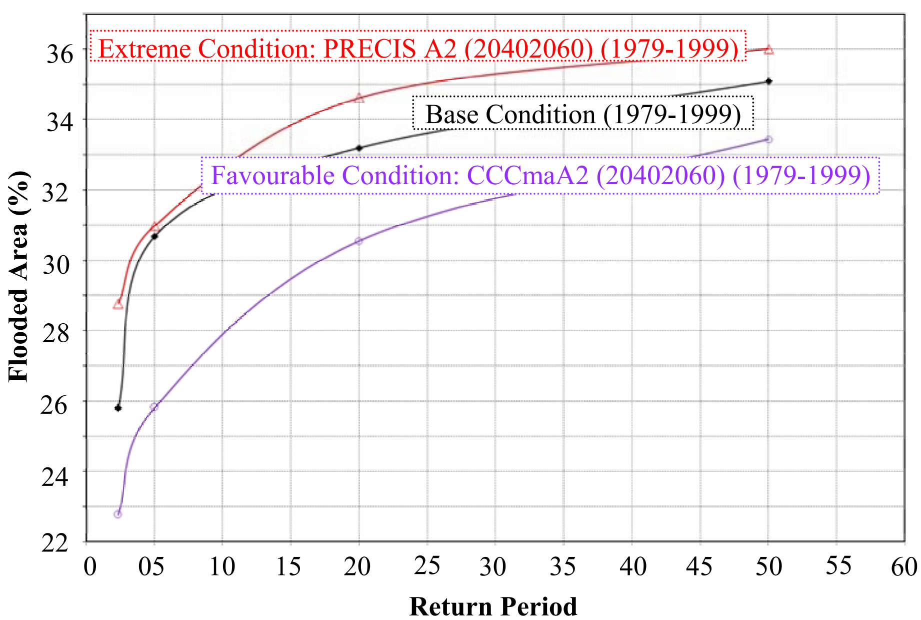


Figure 5.5: Projected change in frequency of severe instances with areas flooded (Source: Tanner et. al. (2007)

understand natural disaster risk as a function of hazard and vulnerability (Kohler, Jülich, & Bloemertz, 2004). Hazard analysis involves determining the type of hazards affecting a certain area with specific intensity and recurrence. Prior to the assessment of vulnerability, the relevant elements (population, assets) exposed to hazard(s) in a given area need to be identified. It has already been evident from various literatures (Ahmed, 2006; Tanner et. al., 2007; Nizamuddin *et al*., 2001; Siddiqi, 1997; Siddique and Chowdhury, 2000) that Floods, especially the high intensity and more frequent, often devastate physical infrastructures such as road networks, educational centres, market places, administrative buildings etc.

Specifically, flood loss potentials to road infrastructures have been huge. In 1998 and 2004 flood, for example, the direct damage to roads sector is estimated as TK 15,272 and TK 10,031 Million, accounting for 15 and 9 per cent of the total damage respectively (Siddiqui and Hossain, 2006). The situation is expected to be deteriorating in the days to come, with the increased extent and intensity of flooding due to potential climate change and sea level rise in future. Tanner et. al. (2007) showed that for the most extreme scenario (PRECISA2 scenario) the frequency of flooding will be doubled in the long run. As shown in Figure 5.5, it can be revealed that the return period of a 1 in 30 year return period flood in base condition will be reduced to 1 in 15 year return period for the PRECISA2 scenario. Thus the increasing probability of more intensified and frequent flooding has been considered as key hazard risk exposed to the transportation sector.

Before moving to the assessment of economic risk, previous information on impacts in terms of asset losses has been set in relation to GDP in the year of the event. Disaster statistics for major flood events has been shown in Table 5.4, which listed the direct economic losses in terms of impacts on physical structures such as roads, buildings and other assets.

Islam and Mechler (2007) showed that people and societies are continuously bracing themselves for natural hazards and aiming at reducing vulnerability; these vulnerability-reducing efforts can readily be discerned in the statistics: As evident from Table 5.5, the 1998 flood event, considered the largest event so far with an estimated return period of 90 years, incurred relative asset losses of 4.8% of GDP, whereas those losses were much higher in the 9 year floods of 1974. Similarly, fatalities were reduced strongly in the 1998 event (ca. 900dead) with a much stronger hazard intensity compared to the 1974 disaster (ca. 29,000 dead).Thus, adjustments need to be undertaken in order to arrive at a first-order representation of risk for today’s (2007) conditions.

Table 5.4: Physical and economic impacts for historical flood events in Bangladesh

Year	Asset losses (million US$)	Fatalities	Affected (million)	Affected area (‘000 km^2)	Houses damaged (‘000s)	GDP current (million US$)	Asset losses as % GDP	Estimated return period (years)
1998	2128	918	31	100	2647	44092	4.80%	90
1988	1424	2379	47	90	2880	26034	5.50%	55
1987	1167	1657	30	57	989	23969	4.90%	13
2004	1860	285	33	56	895	55900	3.30%	12
1974	936	28700	30	53	Na	12459	7.50%	9
1984	378	1200	30	Na	Na	19258	2.00%	2

Source: Islam and Mechler, 2007

Islam and Mechler (2007) has proposed some standard approach for the adjustment incorporating the dynamism of exposure due to higher asset concentration, population growth or migration, or/and fragility. In their study, risk has been proposed to be normalized to current conditions by dividing relative losses per GDP by the “relative GDP losses per area affected” indicator. Herein this study, the same indicator has been considered as proxy of fragility and the losses has been adjusted for vulnerability-reducing efforts by dividing this proxy value in the year of the event by the value of the last year in the dataset (=2004). Table

5.5 shows how the value of this proxy (Relative GDP Loss per area affected) decreases over time for the major floods over the last 33 years. For example, for the 1974 floods, the value of the current risk indicator (GDP loss per area affected) has been derived (1.42) by dividing the current risk value (actual GDP loss=7.51%) with the affected area (53 km^2). Later the value of the proxy has been normalized (2.32) to current situation by dividing the value of year 1974 (1.42) with the value of the year 2004 (0.59). This could roughly be interpreted as the potential degree of damage (fragility) in 1974 being 232% of that in 2004.

Table 5.5: Historical flood loss and risk profile in terms of actual and normalized GDP

Year	Affected area ('000 km^2)	GDP Loss (% of current GDP)	Current Risk: GDP loss (%) / area affected	Relative GDP Loss per area affected	Normalized risk: (to year 2004)	Actual return period (estimated in years)	Projected return period (years)**
1998	100	4.83%	0.48	0.81	5.9%	90.0	45.0
1988	90	5.47%	0.61	1.02	5.3%	55.0	27.5
1987	57	4.87%	0.85	1.44	3.4%	13.0	6.5
2004	56	3.33%	0.59	1.00	3.3%	12.0	6.0
1974	53	7.51%	1.42	2.39	3.1%	9.0	4.5

***Flood recurrence will be doubled as referred by Tanner et. al., 2007*

In the next step, the annualized economic risk has been estimated from the annual average difference between *with* and *without adaptation to climate change scenario*. Total value of economic risk due to flood has been estimated from the area under the curve between the base and future without adaptation scenario derived from the definite integral of trend equations over the return period of o to 100 yr. Annualized risk has been estimated by dividing the difference between total value of risk for two different scenarios by overall

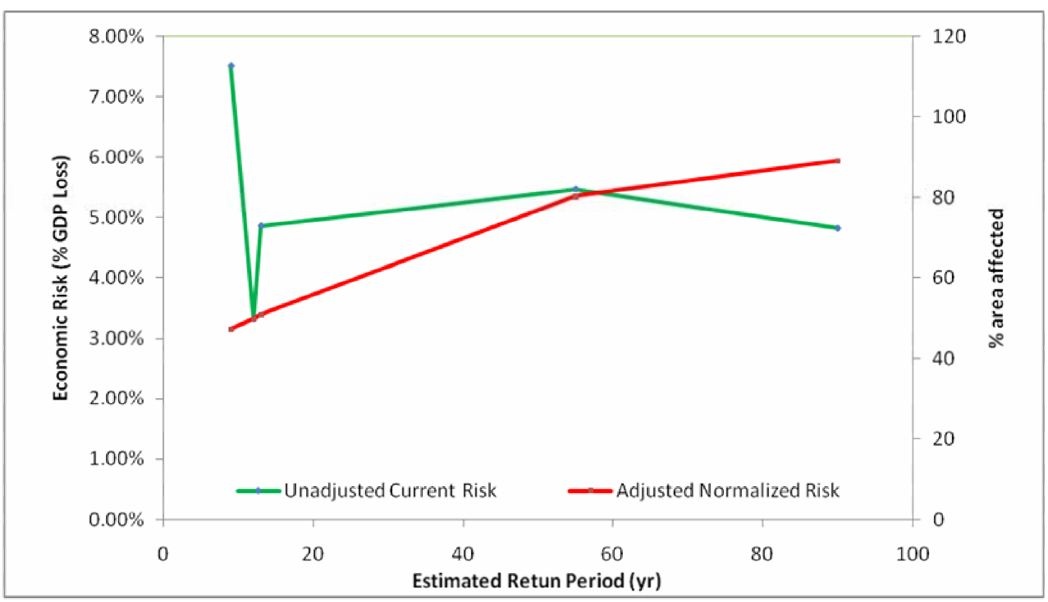


Figure 5.6: Actual and normalized economic risk due to probable flood recurrences

period of 100 yr.

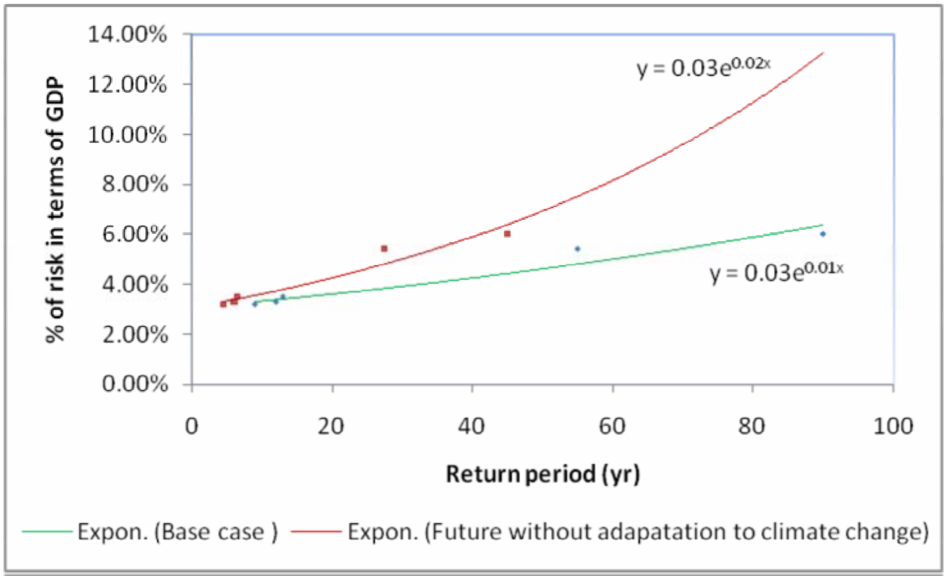


Figure 5.7: GDP at risk in terms of with and without climate change scenario

Table 5.6: Estimation of estimated average annual economic risk

Scenario	Trend equation	Total value of risk derived from the definite integral over the return period from 0 to 100	Difference between total value risk over 100 yr period	Estimated annual average economic risk
Base case	$y = 0.03e^{0.01x}$	4.76	2.96	2.96%
Future without adaptation to climate change	$y = 0.03e^{0.02x}$	7.72		

Thus, if no adaptation is assumed (standards set out in such assessments, e.g. Stern, 2007), annual average losses could increase to 3% of GDP due to the increased frequency of flood over the next 100 year. This figure is close to the figure estimated by Islam and Mechler (2007), where they have stated that annual increase in risk from adding the climate change scenarios to the hazard burden is estimated to amount to 2.6% per year.

5.3.2 Step-II: Estimation of expected damage

Benefits of the option would be the avoided GDP loss from the transportation sector due to floods. From the risk analysis it has been reveled that per year annual GDP loss is around 3% over the projected period (2010 to 2050) due to increased frequency of flood.

If we adopt the backward looking approach for future GDP projection, over the last 17 years average annual GDP growth for the transportation sector has been found as 8.4%. If we assume that this growth will gradually decrease to 5% in 2050, as the foreign investment component of GDP is expected to decrease over the next 40 years (up to 2050) considering no climate change impact, then the net GDP worth from the transportation sector will rise from Tk. 409,324 million to Tk. 4,737,763 million from year 2010 to 2050. Considering the climate change scenario, net risk to GDP per year can be estimated from the area under the curve. Thus, the annual amount of damage is estimated as Tk. 52,725 Million from the GDP loss due to climate induced flood damage.

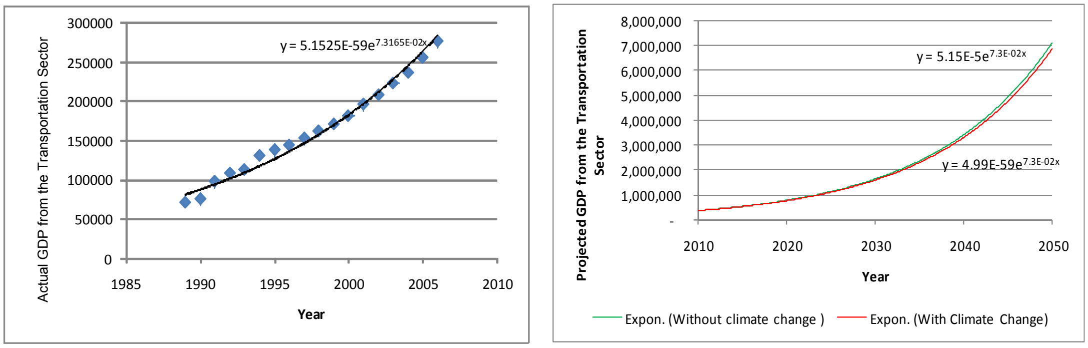


Figure 5.8: Actual and projected GDP from the transportation sector for damage estimation

5.3.3 Step-III: Physical adaptation cost and benefit

Bangladesh is covered by the road network of The Roads and Highways Department (RHD) and Local Government Engineering Department, of which the major proportion crosses the flood plain. Only the RHD authority is responsible for protecting and maintaining about 20,782 kilometers of roads and around 15,000 bridges and culverts with an estimated asset value of TK 370,000 Million, which is of vital importance to the national economy. Thus, the key option studied here is in line with the flood-proofing of the Bangladesh roads and highways, relevant to the DFID-supported programme "Roads and Highways Policy Management, budgetary and TA Support" (RHD). This option has investigated the Flood-proofing of roads and highways by raising road height to the highest recorded flood and provision of adequate cross-drainage facilities.

All national and regional roads were previously planned and designed for the construction above the highest flood level (HFL) with a return period of 50 years and the feeder roads were constructed above the normal flood level (NFL) (Siddiqui and Hossain, 2006). But the catastrophic 1987, 1988, 1998 and 2004 flood just swapped away the confidence of safety by this previously practiced design estimations. In the 1998 and 2004 flood, for example, the direct damage to roads sector is estimated as TK 15,272 and TK 10,031 Million, accounting for 15 and 9 per cent of the total damage respectively (Islam and Mechler, 2007).

From, 1954 to 2007, a total of 33 floods occurred in Bangladesh in a span of 53 years. Eleven of these floods were severe (1956, 1962, 1970, 1971, 1973, 1975, 1976, 1980, 1983, 1984, 1995) and eight were catastrophic (1954,1955,1974,1987,1988, 1998, 2004 and 2007)[1]. So on an average, in every alternative year there exists huge risk of recurrence of either a severe, catastrophic or normal flood event. But this situation is not static and is expected to be deteriorating in the days to come, with the increased extent and intensity of flooding due to potential climate change and sea level rise in future (Tanner et. al., 2007; Islam, 2007; Ahmed, 2006). Hence, it is important to develop flood proofing systems as a response to natural disasters, in designated flood risk zones, to protect life, property and vital infrastructure such as roads.

The National Water Management Plan- NWMP (2001) put focus on the regional distribution of roads according to high and low flood risk levels, assuming that from the year 2000 all

[1] Compiled and updated from Siddiqui and Hossain, 2006

new roads have been constructed keeping in view of the highest flood level of the 1998 flood. It was intended that all national and regional roads not above flood level at present, and one-fifth of the district (feeder) roads in high risk areas only, will be raised by the end of 25 year period. Estimated total amount of road length was estimated as 811 km with around equally distributed among the high and low risky road types.

The figure presented in the Table 5.7 is also amenable to recently issued 'The Roads Master Plan' (Government of Bangladesh, 2007), which reiterated the maintenance of 1 to 1.2 meter freeboard above a 50 year flood with the entire scope of provide appropriate flood proofing to nearly 800 Km of roads through roads raising across the country.

Table 5.7: Estimated regional distribution of roads to be raised

Road Type	**Risk level**	**Length of road to be raised, by type and region (Km)**						
		SW	**SC**	**NW**	**NC**	**NE**	**SE**	***Total***
National Highways	High	6.7	15.8	19.4	39.6	0.4	7.3	***89.2***
National Highways	Low	10.3	0.6	12.8	12.5	1.4	9.6	***47.2***
Regional Roads	High	19.9	7.4	16.1	18.6	2.9	14.6	***79.5***
Regional Roads	Low	7.7	4	41.1	8.9	5.4	9.9	***77***
District Road Type A	High	17.8	34.8	48.3	94.5	4.2	41.2	***240.7***
District Road Type A	Low	31.9	38.8	62.8	108.8	8.4	26.7	***277.5***
Overall	**High**	**44.4**	**58**	**83.8**	**152.7**	**7.5**	**63.1**	***409.4***
	Low	**49.9**	**43.4**	**116.7**	**130.2**	**15.2**	**46.2**	***401.7***
	Total	**94.3**	**101.4**	**200.5**	**282.9**	**22.7**	**109.3**	***811.1***

Source: NWMP, 2001; adopted and modified from Islam and Mechler, 2007

Table 5.8: Cost estimates by category of roads by risk level

Roads type		**Length of roads to be raised (Km)**	**% of total in each category**	**Rate Tk/Km (2007 prices)***	**Total (TK-Million)**
High flood risk areas	National Highway	89.2	2.5	13.8	1,228
	Regional Highway	79.5	1.9	13.2	1,053
	District (Feeder) Roads- Type A	240.7	3.7	9.9	2,388
	District(Feeder)Roads – Type B	277.5	4.2	8.8	2,455
	Subtotal	686.9	12.3	45.7	7,124
Low flood risk areas	National Highway	47.2	1.3	13.8	650
	Regional Highway	77.0	1.9	13.2	1,020
	Sub-total	124.2	0.6		1,670
Grand Total		811.1			8,794

Source: Islam and Mechler, 2007

As per the option proposed above, Islam and Mechler (2007) has estimated the total cost of raising some 170 Km of national and regional roads and some 518 Km of district (feeder) roads in high risk areas for raising by 1 meter. Under the same option, about 124 km of national and regional roads in low risk area has been proposed to be raised by 0.5m. Table 5.8 presents cost estimates for road raising and related drainage improvements by roads category of high and low risk areas. In total, about TK 8,794 Million has been estimated to be required for the implementation of the option. The cost estimates have considered an average of two culverts per Km (for cross-drainage facilities) for each category of roads, instead of currently practiced 0.71 culverts per Km. An average culvert costs 1 million Taka. The road maintenance cost assumed to be at the rate 4% (Tk. 352 Million/year) will have to be incorporated while estimating NPV.

The expected value of the benefits is considered to equal the area under the curve considering avoided GDP loss from the transportation sector due to floods, assuming that roads and highways are flood-proofed to the highest ever-recorded flood and floods can thus be avoided, although in reality full protection against extreme events is normally not possible and cost-efficient (Islam and Mechler, 2007). Thus the amount of benefit is equal to the annual amount of probable damage to GDP from the transportation sector; i.e. from the savings of Tk. 52,725 Million GDP loss due to climate induced flood damage.

5.3.4 Step-IV: Modelling the economics of adaptation

Based on the estimates of costs and benefits, the economic efficiency of this option has been estimated. Table 2 in Annex-C outlines the process of estimating the BC ratio, NPV and IRR. For each given year over the time horizon of 40 years, costs and benefits and net benefits are displayed both in discounted and non-discounted format in constant 2007 values for a (high) discount rate of 12%, the rate most commonly assumed in similar exercises. Dividing benefits by costs leads to the B-C ratio, subtracting costs from benefits to the net present value (NPV), and the IRR is calculated as the rate that discounts the NPV to zero.

Although NWMP has assumed that flood proofing measures for the road sector will be done over a period of 25 years, but experiencing three catastrophic flood within past ten years has been repeatdely reminding us regarding the need of adaptation measures against flood. So in this study, period of investment has been considered as 10 years and it has been assumed that 75% of the total investment will be made within the first five years at a rate of 7.5% for the first year, 18.75% for the next three year and 11.25% for the fifth year followed by remaining 25% of the total investment equally distributed over the next five years. Following the traditional design life of the earthen embankment or road base as 20 years the next stream of investment will recur again at the year of 2030 as a continuation for safeguarding against the increased flooding.

Cash flow tables showing the net present value of benefits and costs along with other economic indices is shown below. Here total cost of investment over the 40 year period (2010-2050) is around Tk. 29,300 Million (US$420 Million) including 40% of the regular O&M cost. Net present value of the investment is positive with a net worth of Tk. 172,618 Million. B/C Ratio is 20:1 with an outstanding IRR of 70%.

Any project implies a number of risks of uncertainties. Following risks are generally experienced:

(a) Cost may increase during project construction. Here the risk of cost increase has been taken as 20%
(b) Total stipulated benefits may be achieved or decreased due to many physical or

natural reasons. Benefit can be assumed to reduce by 20%.

(c) Benefits may take more time to reach its target, i.e., gestation gap may be longer by 2 years.

(d) All the above 3 risks may occur simultaneously.

The sensitivity analysis has been carried out for the project on the basis of the said for envisaged risks. Table below (5.9) summarizes the impacts on the economic indices of aforesaid changes and it has been revealed that the project is individually and jointly resilient to the above-mentioned probable risky scenarios. For different scenarios, B/C ratio varies in between 16:1 to 7:1 with a variance in IRR from 63% to 39%.

Table 5.9: Sensitivity analysis for economic efficiency indicators

Economic Indices	Base Case	Cost increase by 20%	Benefit decreased by 20%	Lag in benefit recognition by 2 yrs	Costs+20%, Benefits-20%, Lag by 2yrs
NPV of net cash flow	130,416	128,642	102,558	90,864	69,143
EIRR	63%	58%	57%	45%	39%
E B/C ratio	16:1	13:1	13:1	11:1	7:1

5.4 Economic Model for Health Sector

Recently published IPCC fourth assessment report clearly correlated between the climate change phenomenon to the global burden of disease and premature deaths with a very high confidence. Now it is evident that human beings are exposed to climate change through changing weather patterns (temperature, precipitation, sea-level rise and more frequent extreme events) and indirectly through changes in water, air and food quality and changes in ecosystems, agriculture, industry and settlements and the economy. Zooming into the Asian countries, McMichael et al., 2004 elaborated that this changing phenomenon poses substantial risks to human health by climate-change attributable diarrhoea and malnutrition, which are already the largest in South-East Asian countries including Bangladesh. He also concluded that the relative risk for these conditions for 2030 is expected to be also the largest. IPCC fourth assessment report also agreed to the same fact that: *adverse health impacts will be the greatest in low-income countries*. It also warned that at this early stage the effects are small but are projected to progressively increase in all countries and regions. It is obvious that economic development is an important component of adaptation, but in terms of financial resource Bangladesh is poor and it is very difficult for the policy makers to go for any sort of adaptation means without any prior assessment of the economic and financial need. In this regard, a systematic approach has been adopted here to enumerate the economic cost of possible adaptation measures and its benefit in monitory terms. Overall approach and methodological steps are similar to that of the transportation sector.

5.4.1 Step 1: Simulation of climate change risk scenarios

Here the simulation of climate induce health risk assessment follows the more rigorous risk-based framework (forward-looking, risk-based) combining data on hazard and vulnerability to an estimate of risk and risk reduced. But there exists limited information on Bangladesh perspective towards understanding current and future impacts of climate change on human health. In this regard, current risk assessment exercise will systematically focus on:

- developing the existing knowledge/literature base to draw the base of climate induced health research and
- explore and using various projection statistics pertinent to Bangladesh scenario on tentative risk of climate change attributable diseases.

Following sub-sections has been dedicated in this regard:

Evidence of heath hazard from existing knowledge base:

Rahman (2008) stated that climate change affects human health both directly and indirectly. People are exposed directly to changing weather patterns (temperature, precipitation, sea-level rise and more frequent extreme events) and indirectly through changes in the quality of water, air and food, and changes in ecosystems, agriculture, industry, human settlements and the economy. IPCC-IV illustrated the relationship between climate change and human health as multidimensional, as presented schematically in the diagram (Figure 5.9).

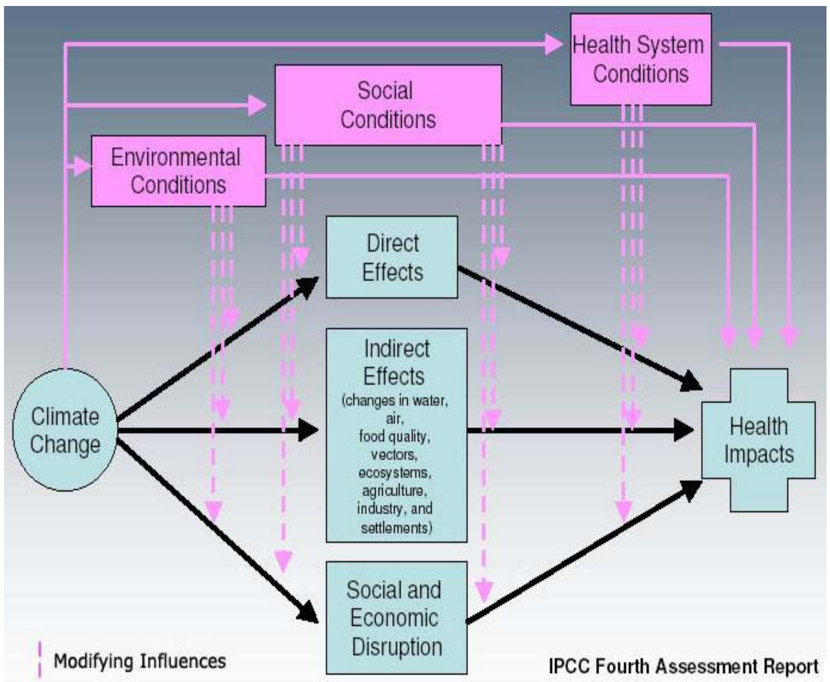


Figure 5.9: Schematic diagram of pathways by which climate change affects health, and concurrent direct-acting and modifying (conditioning) influences of various conditions.

Few years ago, there exists limited information towards understanding impacts of climate change on human health. But now IPCC-IV clearly classified the emerging evidence of climate change effects on human health (IPCC 2007) into the following categories:

- altered the distribution of some infectious disease vectors;
- altered the seasonal distribution of some allergenic pollen species; and
- increased heat wave-related deaths.

Other than this, a comparative risk assessment study at regional and global levels was carried out by WHO to quantify the amount of premature morbidity and mortality due to a range of risk factors, including climate change, and to estimate the benefit of interventions to remove or reduce these risk factors. The study found that in 2000, climate change was estimated to have caused the loss of over 160,000 lives worldwide annually (Campbell-Lendrum et al., 2003; Ezzati et al., 2004; McMichael, 2004). The assessment included the following health outcomes:

- episodes of diarrhoeal disease;
- cases of Plasmodium falciparum malaria,
- fatal accidental injuries caused by coastal floods and inland floods/landslides; and
- nonavailability of the recommended daily calorie intake (as an indicator for the prevalence of malnutrition).

The study also indicated that the adverse health impacts would be the greatest in low income countries. Those at greater risk include, in all countries, the urban poor, the elderly and children, traditional societies, subsistence farmers and coastal populations. Stern Review on the Economics of Climate Change (2006) reported that the total cost of 'business as usual' (BAU) climate change over the next two centuries equates to an average welfare loss equivalent to at least 5% to11% of the value of global per-capita consumption, now and forever. The Bangladesh NAPA, however, considered that the implications of climate change on human health was rather uncertain, though it echoed with Agrawala *et al.* (2003) towards commenting that the health risk on the poor would be disproportionate given the government's spending on health sector.

WHO (2000) reported that climate change is projected to increase the burden of diarrhoeal diseases in low-income regions by approximately 2% to 5% in 2020. Various researchers confirmed that climate variability is strongly linked with activity of pathogens (WB, 2000; Koelle et al., 2005). Bangladesh is vulnerable to outbreaks of infectious, waterborne and other types of diseases (World Bank, 2000). Flood related increases in diarrhoeal disease have been reported in Bangladesh (Kunii et al., 2002; Schwartz et al., 2006). Rodó et al. (2002) found increases in cholera cases in Bangladesh with increases in intensity of El Niño events and there are other significant evidence that the bimodal seasonal pattern of cholera in Bangladesh is correlated with sea-surface temperatures in the Bay of Bengal and with seasonal plankton abundance (a possible environmental reservoir of the cholera pathogen, Vibrio cholerae (Colwell, 1996; Bouma and Pascual, 2001). Recently, ICDDR,B (2007) conducted an unique research to enumerate the impact of climate change on the transmission dynamics of cholera and to develop a climate based prediction model of cholera epidemic. They have found temperature has been detectable as the 'agent of change' for transmission dynamics of cholera out of changing climatic parameters. Significant association of cholera incidence with other local climatic variables (rainfall and tide) and biological factors (Phytoplankton) has been observed and their model can explain up to 68% variability of the monthly cholera incidence.

Estimation shows that 2400 millions of tropics and subtropics are at risk of malaria (IPCC, 2001; Githeko and Woodward, 2003). Other sources estimate that climate change causes 2 percent of all cases of malaria (WHO, 2006). Records show that the incidence of malaria increased from 1556 cases in 1971 to 15,375 in 1981, and from 30,282 cases in 1991 to 42,012 in 2004 (WHO, 2006). Other diseases such as diarrhoea and dysentery, etc. are also on the rise especially during the summer months. It has been predicted that the combination of higher temperatures and potential increase in summer precipitation may cause the spread of many infectious diseases [Ministry of Environment and Forests (MoEF), Bangladesh].

Dengue is the world's most important vector-borne viral disease, which also hit Bangladesh during the recent years. Several studies have reported an association between spatial, temporal or spatiotemporal patterns of dengue and climate (Hales et al., 1999; Corwin et al., 2001; Gagnon et al., 2001; Cazelles et al., 2005).

Deaths from unsafe or unhealthy conditions following the extreme event are also a health consequence, but such information is rarely included in disaster statistics (Combs et al., 1998; Jonkman and Kelman, 2005). Drowning by storm surge is the major killer in coastal storms where there are large numbers of deaths. An assessment of surges in the past 100 years found that major events were confined to a limited number of regions, with many events occurring in the Bay of Bengal, particularly Bangladesh (Nicholls, 2003). From published sources (Nelson, 2003), it is found that, in a major storm event, the total daily-adjusted life year (DALY) loss might reach 290 per thousand people, including both deaths and injuries, compared to a current all cause rate of about 280 per 1000 people in the region . However, the study restricted to DALY index only, which limits its application towards understanding the total health sector implications of climate change.

Malnutrition increases the risk both of acquiring and of dying from an infectious disease. A study in Bangladesh found that drought and lack of food were associated with an increased risk of mortality from a diarrhoeal illness (Aziz et al., 1990). Acclimatization in tropical environments does not eliminate the risk, as evidenced by the occurrence of heatstroke in metal workers in Bangladesh (Ahasan et al., 1999) and rickshaw pullers in South Asia (OCHA, 2003). Other than this, national and international agencies (BCAS and NIPSOM ,2007 and WHO, 2004) are indicating that the climatic factors including temperature, rainfall (annual and seasonal) and salinity have positive correlation with another climate attributable disease skin infection/disease in their selected study areas of Bangladesh. Actually, skin disease spreads out mostly just during the recession of flood or after flood. But it is very tough and no literature evidence has yet been found for differentiating those cases which are climate induced and which are not.

5.4.2 Step-II: Estimation of expected damages

From the above-mentioned literature evidences, a list of vector and water borne diseases has been identified. These are climate sensitive and may pose huge threat over human health.

A recent study carried out jointly by the BCAS and the National Institute of Preventive and Social Medicine (NIPSOM) in 2007 indicated that the annual incidence of diarrhoea was 2,8 42,273 cases during the period 1988– 2005 and that of skin diseases was 2,623,092 cases during 1988–1996. Climate change is projected to increase the burden of diarrhoeal diseases in low-income regions by approximately 2 to 5% in 2020. *Remaining in the most conservative side, assuming no adaptation scenarios, this would create an additional burden of 7% diarrhoea patients in Bangladesh at 2050 due to change in climate.*

The following table shows the incidence of some of the major climate-sensitive diseases and their trend during the last few decades:

Table 5.10: Historical profile of climate induced vector and water borne diseases

Diseases	Total cases per period	Period	Average annual cases
Diarrhoea	48,302,636	1988– 2005	2,842,273
Malaria	1,018,671	1974– 2004	33,956

Dengue	19,830	1999– 2005	3,305
Skin diseases	23,697,833	1988– 1996	2,623,092

(Source: BCAS and NIPSOM, 2007)

The IPCC report also stated that approximately one third of the world's population lives in regions where the climate is suitable for dengue transmission. An empirical model based on vapour pressure projected increases in latitudinal distribution. It was estimated that, in the 2080s, 5-6 billion people would be at risk of dengue as a result of climate change and population increase, compared with 3.5 billion people if the climate remained unchanged (Hales et al., 2002). *Remaining in the most conservative side, assuming no adaptation scenarios, here it has been assumed that an additional burden of 1% total population will suffer from dengu in Bangladesh at 2050 due to change in climate.*

India (Ministry of Environment and Forest and Government of India, 2004) projected that due to climate change there would be increase in communicable diseases and malaria has been projected to move to higher latitudes and altitudes in India. Another research finding correlated between Southern Oscillation (ENSO) and malaria. It concluded that the impact of El Niño on the risk of malaria epidemics has been well established in parts of Southern Asia and South America (Kovats et al., 2003). Evidence of the predictability of unusually high or low malaria anomalies from both sea-surface temperature (Thomson et al., 2005) and multi-model ensemble seasonal climate forecasts in Botswana (Thomson et al., 2006) supports the practical and routine use of seasonal forecasts for malaria control in southern Africa (DaSilva et al., 2004). Other than this, drought related factors may result in a short-term increase in the risk for outbreaks of malaria due to stagnation and contamination of drainage canals and small rivers. Actually, malaria is a complex disease to model and all published models have limited parameterization of some of the key factors that influence the geographical change and intensity of malaria transmission. More difficulty arises while generalizing this critical health outcome from one setting to another, when it has important local transmission dynamics that cannot easily be represented in simple relationships. Large changes are projected in the risk of Plasmodium falciparum malaria in countries at the edge of the current distribution, with relative changes being much smaller in areas that are currently highly endemic for malaria (McMichael et al., 2004; Haines et al., 2006). Lieshout et. al. (2004) modelled the regional distribution of malaria epidemic and stated that the vulnerability to malaria varies between regions. The MIASMA model developed by them estimates the population at risk of malaria under the current climate to be 3.1 billion (60% of total current population), whereas the largest current population at risk is in Asia. The model estimated that the 40% of the world's population would be at risk for living in the medium and high risk regions groups; where India is included but Bangladesh is not[2]. But this model result is not depicting the original picture of Bangladesh, as records are showing that the incidence of malaria increased in Bangladesh from 1,556 cases in 1971 to 15,375 in 1981, and from 30,282 cases in 1991 to 42,012 in 2004 (WHO, 2006). If this continues in the long run assuming without adaptation scenario, then at the year 2050 the additional burden of malaria

[2] They assumed that Bangladesh fall within the countries where malaria transmission is high and there are effective and well-funded control programmes in place. There is likely to be a relatively strong health care system where malaria control is a priority. In countries where the health care system is weaker large amounts of foreign aid will allow for effective malaria control.

patients will be around 6.5% of the total population. So, if we assume that some sort of adaptation measures will be taken against the outbreak of malaria, at least some additional burden of 3.5% of the total population would be under the risk of malaria.

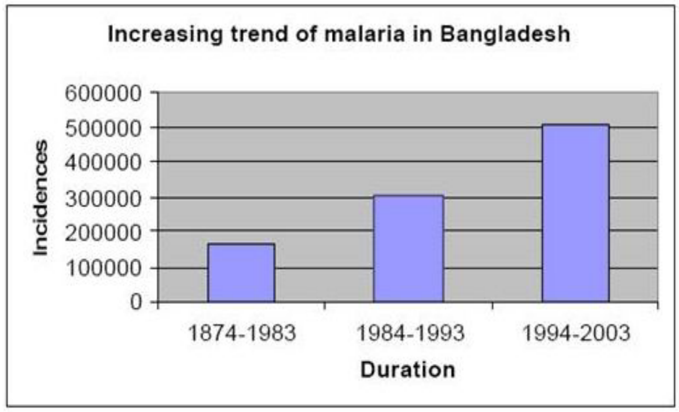


Figure 5.10: Increasing trend of malaria in Bangladesh

Skin disease in Bangladesh is one of the major products of riverine floods. It has been shown earlier that flood recurrence risk will be doubled in the coming years and for the sake of simplicity it can also be assumed that the present risk of skin disease cases will also be doubled at the year 2050. Other than this, it has also been assumed that temperature induced heat strokes will also be doubled in long run (2050).

Before estimating the number of climate attributable disease affected population in the long run, the projection of population is the first and foremost task. Website of the "World Population Prospect" (supported by the United Nations) projected the future population extent and growth both for the World and most other countries including Bangladesh. Their projection shows that at the year 2050, world population may rise to 9,191 million and Bangladeshi population will grow from 167 million to 254 million within 40 years. Considering this reality, Table 5.11 has been constructed to have an idea of the total possible affected population in 2050 by climate attributable diseases. It is reflecting that, around 15% of the Bangladeshi population will be under the threat of climate induced diseases at the year 2050.

Table 5.11: Current and future risk of climate induced diseases

Diseases	Total cases per period	Period	Average annual cases	Current Disease burden	Future disease burden
Diarrhoea	48,302,636	1988 - 2005	2,842,273	1.85%	17,785,880 (7%)
Skin diseases	23,697,833	1988 - 1996	2,623,092	1.71%	8,696,260 (3%)
Malaria	1,018,671	1974 - 2004	33,956	0.02%	8,892,940 (3.5%)
Mental disorders	201,881	1988 - 1996	22,431	0.01%	74,365 (0.02%)
Dengue	19,830	1999 - 2005	3,305	0.00%	2,769,862 (1.1%)
Total			**5,525,057**	**3%**	**38,219,306 (15%)**

5.4.3 Step-III: Physical adaptation cost and benefit

Adaptation is needed now in order to reduce current vulnerability to the climate change that has already occurred and additional adaptation is needed in order to address the health risks projected to occur over the coming decades. Weak public-health systems and limited access to primary health care contribute to high levels of vulnerability and low adaptive capacity for hundreds of millions of people (IPCC, 2007). But Rahman (2008) urged that the planning horizon of public health decision-makers is short, as compared to the projected impacts of climate change. Therefore, the current risk-management approaches that focus only on short-term risks will need to be modified. Some other researchers focused that the degree to which programmes will need to be augmented will depend on factors such as the current burden of climate-sensitive health outcomes, the effectiveness of current interventions, projections of where, when and how the burden could change with changes in climate and climate variability, access to the human and financial resources needed to implement activities, stressors that could increase or decrease resilience to impacts, and the social, economic and political context within which interventions are implemented (Yohe and Ebi, 2005; Ebi et al., 2006a). Thus it is quite evident that, in the health sector the scope and extent of adaptation measures and subsequent economic cost will not be the same as other sectors like water management infrastructure and transportation sector. Here the scope and extent of adaptation will not be developed by some isolated designed health care programme. The process would be continuous and step-by-step and carefully year-to-year joint initiative among and by the stakeholders. In this regard, Rahman (2008) has proposed for a two-tiered approach may be needed, with modifications to incorporate current climate change concerns into ongoing programmes and measures, along with regular evaluations to determine a programme's likely effectiveness to cope with projected climate risks.

BBS health statistics are showing that, in Bangladesh total health expenditure is 3.5% of the total GDP, out of which 69% is private and 31% is public financed. In this regard, if we can project the per capita GDP within the time horizon of 2010-2050 and multiplying this figure by the additional population burden under the threat of climate induced risky diseases, then we can estimate the amount of pressure on overall economy for health care financing. In this regard, we have projected the per capita GDP up to 2050 from using the best fitted available national statistics. From the per capita GDP we have also projected the per capita health expenditure disaggregated by private and public expenditure, assuming the same proportion of financing source that currently exists for the health care systems. It has also been found discussing with different health service experts of Bangladesh that the proportion of spending for the above-mentioned five climate-induced diseases is only around 10%-20% per capita per year. But, in future additional health investment expenditure would be totally met from public finance in terms of different adaptation measures taken. In this regard, a matrix has been prepared in line with the above findings and assumptions as shown in Table 5.12.

If the outbreak of this climate induced diseases can be avoided by taking appropriate adaptation health care measures, then benefit will be derived in two folds: private expenditure savings from medical treatment cost and wage savings from non-absence in employment. In this case, average wage of Tk. 100 for a period of five days per person has been considered as benefit against appropriate adaptation means. Table 5.13 elaborated the total amount of benefit realized from the full implementation of adaptation means.

Table 5.12: Cost of adaptation for health care

Year	Per capita GDP	Total GDP (in Billion Tk./yr)	HE/capita (Tk./yr)	Private HE/capita (Tk./yr)	Public HE/capita (Tk./yr)	Additional Health Investment (Million Tk./yr)
2010	23,026	3,837	81	25	56	655
2015	26,582	4,788	93	29	64	1,030
2020	30,139	5,827	105	33	73	1,513
2025	33,695	6,942	118	37	81	2,111
2030	37,251	8,118	130	40	90	2,830
2035	40,808	9,338	143	44	99	3,670

2040	44,364	10,585	155	48	107	4,631
2045	47,920	11,840	168	52	116	5,707
2050	51,476	13,079	180	56	124	6886

Using the approach of the area under the curve, each year the cost of adaptation has been estimated as Tk. 1,264 Million (Figure 5.11).

Table 5.13: Realized benefit from adaptation scenario

Year	Benefit (M.Tk.) realized from adaptations		
	Private health expenditure	Wage savings	Total
2010	312	4,062	4,374
2015	521	5,535	6,056
2020	797	7,170	7,967
2025	1,149	8,950	10,099
2030	1,580	10,852	12,431
2035	2,091	12,849	14,940
2040	2,683	14,913	17,596
2045	3,353	17,012	20,366
2050	4,095	19,110	23,204

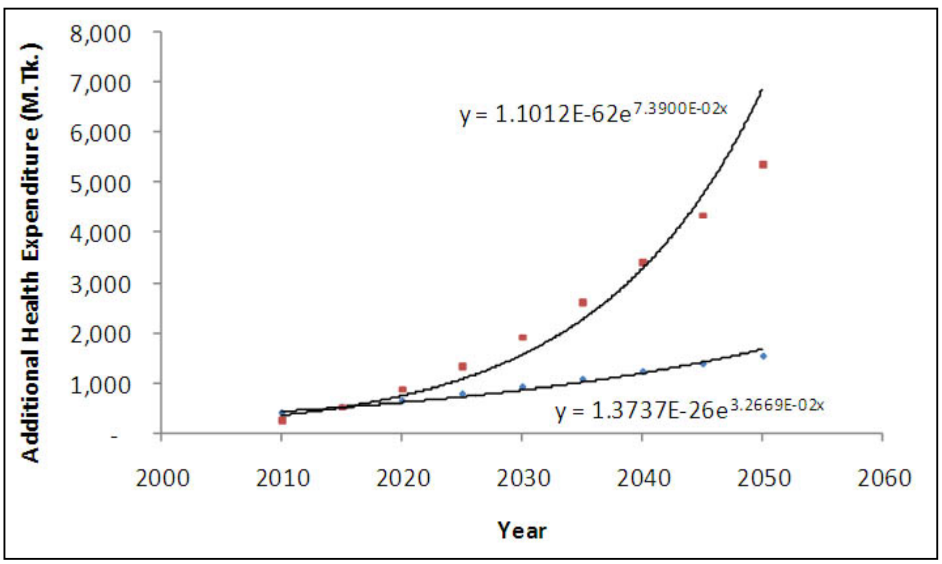


Figure 5.11: Development steps of benefit calculation from adaptation scenario

5.4.4 Step-IV: Modelling the economics of adaptation

Economic efficiency of the probable healthcare related adaptation options, benefit-cost efficiency has been estimated in Table 3 in Annex-C in terms of BC ratio, NPV and IRR. For each given year over the time horizon of 40 years, costs and benefits and net benefits are displayed both in discounted and non-discounted format in constant 2007 values for a (high) discount rate of 12%, the rate most commonly assumed in similar exercises. Dividing benefits by costs leads to the B-C ratio, subtracting costs from benefits to the net present value (NPV), and the IRR is calculated as the rate that discounts the NPV to zero.

In this section, continuous investment has been considered over the fourty year period and it has been assumed that benefit of investment will be realized from 5 years after the starting of investment.

Cash flow tables showing the net present value of benefits and costs along with other economic indices is shown below. Here total cost of investment over the 40 year period (2010-2050) is around Tk. 51,800 Million (US$740 Million). Net present value of the investment is positive with a net worth of Tk. 36,679 Million. B/C Ratio is 4.14:1 with an IRR of 41%.

Any project implies a number of risks of uncertainties. Following risks are generally experienced:

a) Cost may increase during project implementation. Here the risk of cost increase has been taken as 20%
b) Total stipulated benefits may be achieved or decreased due to many physical or natural reasons. Benefit can be assumed to reduce by 20%.
c) Benefits may take more time to reach its target, i.e., gestation gap may be longer by 2 years.
d) All the above 3 risks may occur simultaneously.

The sensitivity analysis has been carried out for the project on the basis of the said for envisaged risks. Table below (5.14) summarizes the impacts on the economic indices of aforesaid changes and it has been revealed that the project is individually and jointly resilient to the above-mentioned probable risky scenarios. For different scenarios, B/C ratio varies between 4.14:1 to 2.75:1 with a variance in IRR from 41% to 31%.

Table 5.14: Sensitivity analysis

Economic Indices	Base Case	Cost increase by 20%	Benefit decreased by 20%	Lag in benefit recognition by 2 yrs	Costs+20%, Benefits-20%, Lag by 2yrs
NPV of net cash flow	36,679	34,342	26,825	29,633	24,488
EIRR	41%	37%	36%	30%	31%
E B/C ratio	4.14:1	3.45:1	3.30:1	3.54:1	2.75:1

6. Conclusions

6.1 Conclusions

Global climate risks have now started to take concrete shapes and it is widely predicted that Bangladesh is one of the countries most vulnerable to climate change. Adaptation to climate change risk will put additional strain on development efforts of a country like Bangladesh. The economic cost is expected to be significant not to mention the social and environmental cost. Developed countries have made commitments to share adaptation costs with developing countries.

This study has been carried out in three phases. In the first phase, it has been seen that climate change risk to Bangladesh and adaptation requirements are sufficiently known. Rigorous analysis of economic costs of adaptation requires development of physical as well as economic model for different sectors. It has been observed during this study that there are number of such models available in water, road and health sector. What is lacking is the integration of these two types of models, which has been attempted in next phases of this study.

In the second phase, economic modelling exercise has been initiated considering the raising options for the 138 polders in the coastal region. The sea dykes of these polders were designed so that the risk of inundation will be once in 100 year. But due to SLR this risk will increase. It has been found that in case of Hatiya, the risk of inundation will increase once in 60 years for 27 cm SLR and once in 30 years for 62 cm SLR. The modeling results show that the rise of water levels outside the embankments varies from 1.1-27 cm and 2.6-62 cm due to SLR 27cm and SLR 62 cm respectively. The water levels will increase by more than 10 cm in front of the embankments of 110 polders and 123 polders due to SLR 27cm and SLR 62 cm respectively. Net investment cost for raising the embankment for the probable SLR of 27cm (year 2050) and 62 cm (year 2080) will be around Tk. 34,828 million (US$ 500 million approximately). In this regard, it has been assumed that the investment cost for adaptation will occur progressively against the risk of probable SLR.

By raising the embankment, benefit will be derived from the savings from the expected damage due to probable sea level rise. Annual benefit associated in this regard will be Tk 574 million/year upto 2050 and Tk. 1,148 million/year onwards up to 2080. The incremental B/C ratio of raising embankment will be 2.17 and IRR will be 28%.

In the third phase, separate economic models have been developed both for the transportation and health sector. The damage to the road sector during flood occurs due to damage to infrastructure and due to disruption of traffic. It has been seen that the loss incurred by road sector during historic floods is very high. The situation is expected to be deteriorating in the days to come, with the increased intensity of flooding due to potential climate change and sea level rise in future. In order to avoid such loss against PRECISA2 climate change scenario, total cost of adaptation over the next 40 year period (2010-2050) has been estimated to be around Tk. 29,300 Million (US$420 Million) including 40% of the regular O&M cost. Such investment for adaptation will be highly beneficial as the net present value of the investment is Tk. 130,416 Million with an IRR of 63%.

Total cost of adaptation in health sector for climate change induced diseases such as diarrahea, dengue and malaria has been calacuated. The cost over the 40 year period (2010-2050) is around Tk. 51,800 Million (US$740 Million). Net present value of the investment is Tk. 36,679 Million with an IRR of 41%.

6.2 Future Research Need

The study has opened a window to dive deeper into the issues of climate change with respect to land, water and environment. More integrated approach towards assessing impacts of climate change may be a welcome attempt for the government as the challenge has marked strokes on the economy through erratic extremes of disasters in Bangladesh.

Definite needs for future research in this respect may be identified as:

Integrated 1st order physical modeling of climate change: This modeling will establish linkage between magnitudes of difference in elements of climate change and levels of impacts on biotic and abiotic components of environment for medium and long term considerations

Integrated 2nd order physical modeling of climate change: This modeling will link the results of 1st order modeling with macro-economic implications of such results under medium and long term.

Policy formulation phase will require further research on (i) change in climate change adaptation needs, (ii) reforms in land and water use profiles, (iii) reconstitution of terms of international trade with respect to abatement and adaptation costs and benefits.

A wider forum for brainstorming on these issues is urgent because the climate change factors are incipient and impacts are undercutting our economic strength in terms of drawing more and more resources to repair the severe dents.

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ANNEXTURE

Annex-A: Coastal Zone of Bangladesh

Bangladesh has a vast area meeting the sea, with 710 km long coastline. Nineteen (19) districts are situated in the coastal zone, the definition of which is mainly constituted by three basic natural processes and events: tidal fluctuations, salinity, cyclone and storm surge risk. These factors govern opportunities and vulnerabilities of the coastal zone.

The region is characterized by an ever dynamic network of rivers and estuary system with interaction between freshwater and saline waterfront. This salinity is penetrating inland from the sea due to gradually depleting freshwater flows from upstream.

Area and Population

Bangladesh is one of the most densely populated countries in the world. About 28% of its population lives in the coastal area, who are victims to frequent natural calamities like tropical cyclones, tornados, floods, storm surges and droughts. Its low lying topography and funnel-shaped coast offer its human and other resources on this huge chunk of landmass a virulent exposure to cyclone, tidal surges, seasonal flooding and salinity intrusion. The zone has at least 185 identified islands and chars (ICRD, WARPO, 2005) with increasing population and social overhead capital. As a consequence, repeated damage to human and material capital due to natural extremity emerging from the sea give rise to widespread poverty, constrained institutional development, loss of bio-diversity, vegetated land and agricultural production.

The total population in the coastal zone (19 districts) was around 35.4 million during the last census (2001) while it has been expected to rise to around 41 million in 2010. Projected at a rate of 1.14 (it was 1.54 in 2001 census), its population will arrive at around 64 million in 2050 (ICRD, WARPO, 2005). The rural-urban distribution of littoral population in 19 districts is given in Table A1.

Economic significance of Coastal zone and advocacy for its protection

In line with increase in population, their education, water and sanitation and above all region's economic resources like agriculture, forest, fisheries, industries and services will continue to contribute to the national GDP at an increasing rate. A quick estimate is presented below to depict graduated situations up to a foreseeable time horizon of 2025:

Year/GDP Scenario	2005	2010	2015	2020	2025
GDP as usual	21.9	27.2	32.6	37.9	43.3
GDP at high growth	25.1	31.3	37.5	43.6	49.8
GDP at low growth	20.8	25.9	30.9	36.0	41.1

Source: ICRD, ICZMPP, Future Scenarios Development, 2005, WARPO

Mentionable with the said statistics, the area's salt farming and tourism potentials comprise the most important components contributing to the growth of potentials, including foreign exchange earnings through ports. Present cropping pattern in the coastal polders is given in Table A2.

Table A1: Coastal zone population statistics disaggregated by urban and rural areas

District	Area (km^2)	Urban				Rural				Total (Both)
		1991	2001	2005	2010	1991	2001	2005	2010	2010
BAGERHAT	3649	189,415	206,554	211,236	214,020	1,241,917	1,342,477	1,376,689	1,405,929	1,619,949
BARGUNA	1325	67,146	87,582	97,190	106,329	708,547	760,972	777,935	792,040	898,370
BARISAL	2287	330,975	394,567	420,669	443,566	1,876,451	1,961,400	1,978,906	1,988,846	2,432,412
BHOLA	2006	189,574	234,302	253,907	271,823	1,286,754	1,468,815	1,545,624	1,618,171	1,889,994
CHANDPUR	1695	188,476	314,102	384,858	458,597	1,843,973	1,957,127	1,989,343	2,014,082	2,472,678
CHITTAGONG	4080	2,407,117	3,381,723	3,872,992	4,357,816	2,889,010	3,230,417	3,366,568	3,492,108	7,849,924
COX'S BAZAR	2066	192,814	272,395	312,689	352,545	1,226,446	1,501,314	1,631,240	1,759,792	2,112,336
FENI	911	95,878	170,200	213,438	259,188	1,000,867	1,070,184	1,091,709	1,109,186	1,368,374
GOPALGANJ	1544	74,174	113,133	133,964	155,136	986,617	1,052,140	1,071,920	1,087,705	1,242,841
JESSORE	2537	282,480	400,851	460,996	520,594	1,824,516	2,070,703	2,173,125	2,269,297	2,789,891
JHALOKATI	715	85,527	104,070	111,991	119,116	580,612	590,161	587,285	582,180	701,296
KHULNA	3569	1,007,255	1,284,208	1,410,977	1,529,768	1,003,388	1,094,763	1,127,676	1,156,632	2,686,400
LAKSHMIPUR	1200	185,446	1,264,475	2,161,913	3,264,658	1,126,891	225,426	74,184	-709	3,263,949
NARAIL	964	66,769	85,809	94,610	102,902	588,951	612,638	616,642	618,282	721,184
NOAKHALI	2633	228,709	353,342	420,525	489,083	1,987,976	2,223,902	2,318,123	2,405,055	2,894,138
PATUAKHALI	2458	132,472	175,284	195,722	215,324	1,141,400	1,285,497	1,344,224	1,398,887	1,614,211
PIROJPUR	1110	129,658	166,970	184,258	200,570	933,527	944,098	937,144	926,654	1,127,224
SATKHIRA	3444	131,984	171,614	190,182	207,808	1,465,194	1,693,090	1,791,801	1,886,060	2,093,869
SHARIATPUR	1243	68,975	114,776	140,551	167,403	884,046	967,524	998,078	1,025,166	1,192,569
Total Population (Million)	**39437**	**6.1**	**9.3**	**11.3**	**13.4**	**24.6**	**26.1**	**26.8**	**27.5**	41.0

Source: BBS

Table A2: Cropping pattern and intensities disaggregated by land class in the coastal polders

Land Type	Cropping Pattern	Cultivated Area (ha)	Agri. Area Covered
F0 (0-30 cm)	Fallow-Fallow-T.aman	29,631	30.68%
	Rabi crop-B.aus-T.aman	17,559	18.18%
	Boro-Fallow-T.aman	10,632	11.01%
	Mixed Thickets & Forest	8,869	9.18%
	Fallow-Shrimp-T.aman	6,933	7.18%
	Orchard	5,794	6.00%
	Rabi crop-B.aus-Fallow	4,325	4.48%
	Fallow-Shrimp/Salt bed-Fallow	4,024	4.17%
	Mixed Evergreen & Deciduous Forest	2,709	2.81%
	Fallow-T.aus-T.aman	2,567	2.66%
	Fallow-B.aman	1,855	1.92%
	Fallow-B.aus-T.aman	790	0.82%
	Fallow (Waterlogged)	538	0.56%
	Fallow-Mixed B.aus & aman	339	0.35%
	Sub-Total	**96,565**	
F1 (30 cm-90 cm)	Fallow-Fallow-T.aman	589,802	54.45%
	Rabi crop-Di.aus-T.aman	164,760	15.21%
	Fallow-Shrimp-T.aman	116,849	10.79%
	Fallow-T.aus-T.aman	96,753	8.93%
	Boro-Fallow-T.aman	33,227	3.07%
	Fallow-B.aus-T.aman	22,853	2.11%
	Rabi crop-B.aus-T.aman	14,759	1.36%
	Fallow-Shrimp/Salt bed-Fallow	14,194	1.31%
	Planted Mangrove Forest	12,701	1.17%
	Natural Mangrove Forest	7,402	0.68%
	Mud Flat	3,014	0.28%
	Mixed Thickets & Forest	2,885	0.27%
	Fallow-B.aman	1,769	0.16%
	Orchard	1,047	0.10%
	Beach	1,014	0.09%
	Mixed Evergreen & Deciduous Forest	99	0.01%
	Boro-Fallow-Fallow	24	0.00%
	Sub-Total	**1,083,151**	
F2 (90 cm-180 cm)	Fallow-B.aman	22,193	26.14%
	Boro-Fallow-T.aman	11,472	13.51%
	Fallow-Fallow-T.aman	11,276	13.28%
	Rabi crop-mixed B.aus & aman	7,412	8.73%
	Fallow-Mixed B.aus & aman	7,301	8.60%
	Rabi crop-B.aus-Fallow	6,119	7.21%
	Boro-Fallow-Fallow	5,983	7.05%
	Rabi crop-Di.aus-T.aman	5,584	6.58%
	Fallow-T.aus-T.aman	4,230	4.98%
	Mud Flat	2,232	2.63%

Land Type	Cropping Pattern	Cultivated Area (ha)	Agri. Area Covered
	Fallow (Waterlogged)	397	0.47%
	Fallow-Shrimp/Salt bed-Fallow	380	0.45%
	Orchard	261	0.31%
	Beach	60	0.07%
	Sub-Total	**84,900**	
R (River)	Fallow-Fallow-T.aman	574	99.84%
	Fallow-Shrimp-T.aman	1	0.16%
	Sub-Total	**575**	
	Total Cultivated Area	***1,265,192***	
	Net Cultivated Area	***967,833***	
	Cropping Intensity	***130.72%***	

Source: CEGIS, Coastal Resources Database

Bangladesh economy, therefore, owes a great deal to the available contributions and future potentials of its coastal zone. Its rich ecosystems and brave littoral population constitute the cortex part of the country's backbone. Its land, water, fisheries, agriculture, livestock, forest and the last but not the least important energy potential along with people's coping capacity to withstand nature's hostilities constitutes the zone's strength to support economic progress of Bangladesh.

These economic resources have to be protected from calamities, particularly from those caused by human interventions like sea-level rise owing to climate change. It was envisaged in late 1990s that global climatic change could exacerbate some of the physical consequences of natural hazards (Warrick and Ahmad, 1996). According to the Third Assessment Report of IPCC, South Asia is the most vulnerable region of the world to climate change impacts (McCarthy et al., 2001).

Another review of Bangladesh disaster and public finance (Benson and Clay, 2002) remarked that the effects of rising sea-level on low-lying coastal areas, where there is elevation in progress and interacting with high flood levels, were clearly complex and uncertain.

The international community also recognizes that Bangladesh ranks high in the list of most vulnerable countries on earth. Bangladesh's high vulnerability to climate change is due to a number of hydrological, geological and socio-economic factors. Geographical location in South Asia, flat deltaic topography with very low elevation, extreme climate variability which is governed by monsoon resulting in acute temporal and spatial distribution of water, high population density, high poverty incidence, climate-dependent crop agriculture etc. make up the utterly volatile regime of vulnerability. It is, therefore, most important to understand its vulnerability in terms of population and sectors at risk. Climate change phenomena like temperature rise; sea-level rise, erosion, precipitation, drought etc. impact the primary variables like physical, biological and human systems. These, in turn, impact the secondary variables like aquatic, terrestrial and marine environments. Its final incidence falls upon the various economic sectors like agriculture, livestock, poultry, wildlife, livelihood and health, affecting GDP of the economy.

Description of coastal polder system in Bangladesh

Bangladesh has a coast of approximately 710 km long along the Bay of Bengal between Indian and Myanmar (Burma) borders. The landward distance of the delineated coastal zone from the shore is between 30 and 195 km whereas the exposed coast is between 37 and 57 km. The coastal zone is low-lying area with 62% of the land having an elevation less than 3 meters and 86% less than 5 meters.

Objective of the polders

The coastal polders were built to protect the embanked areas from tidal and monsoon flooding, saline water intrusion and to increase the crop production.

Infrastructures of the polders and their functions

The main polder infrastructures are:

(i) Embankment,

(ii) Sluices, and

(iii) Drainage canals/khals.

Embankments: Embankments in coastal polders are of three types depending on location and threats from waves and water level fluctuations. Those are named as (a) Sea dyke, (b) Interior dyke, (c) and Marginal dyke.

Sea dyke: All sea dykes and major river embankments were designed to protect from 1 in 100 year FSL with more stable section parameters considering wave action and stabilities. Usually the sea facing slopes of sea dykes were given 1:7 or 1:5; whereas the country side slopes were 1:2 in design condition. The design top width was fixed to 14 feet.

Interior dyke: The design top width is 14 feet, river side slope is 1:3 and country side slope is 1:2.

Marginal dyke: The design top width is 8 feet and river side and country side slopes are 1:2.

All three types of embankments have to be surfaced by the grass turfing. The standard design sections for the coastal embankments of Bangladesh developed by Leedshill Deleuw in 1968

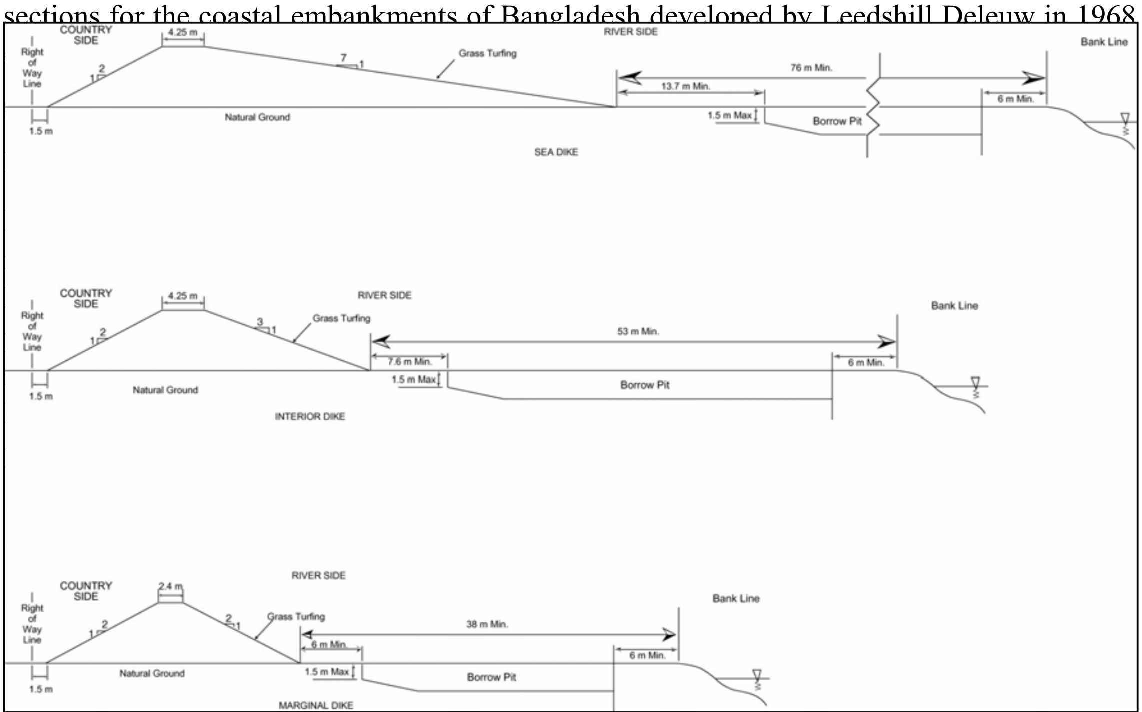


Figure B2: Locations of coastal polders

Present condition of the polders

Under 2nd CERP a survey was conducted for all the coastal polders in 1999-2000. The embankment long profiles and sluice information was gathered in a GIS database. The surveyed elevations of the embankment crest show that due to lack of proper and timely maintenance, the sections had deteriorated from the design section except the 11 polders rehabilitated under CERP-II. It has been observed that, the major regular cause of embankment damage is the *Toe Erosion*. Other causes are breach, major erosion, rain-cuts and subsidence.

The embankments have not been designed to protect from cyclone surges, but it still gives a degree of protection. In case of recent SIDR about 25 polders were affected, such as polder 37, 38, 35/1, 35/2, 39/1, 39/2, 40/1, 40/2, 41, 42, 41/6, 41/7, 41/2, 43/1, 44, 54, 55/1, 55/2, 55/3, 55/4, 52/53, 50/51, 46, 47, 48 and 45 (Source: IWM). The affected polders are shown in Figure below (B3):

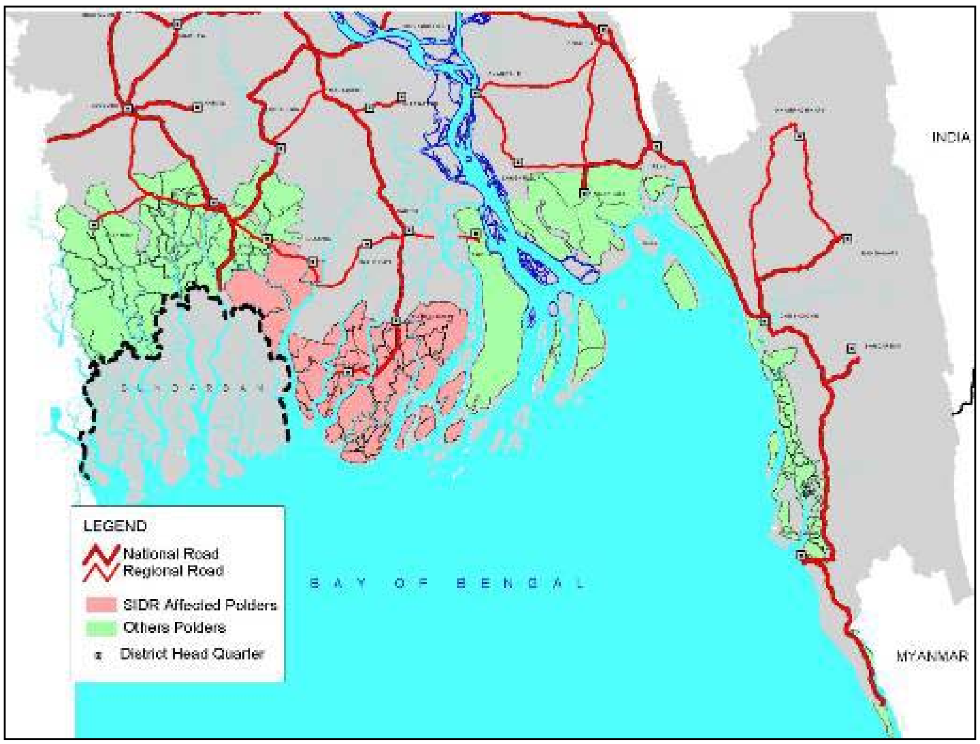


Figure B3: SIDR 2007 affected polders

Modeling of Sea Level Rise (SLR)

Under this study, there was no provision for hydrodynamic modeling of river system considering Sea Level Rises. Hence, the study used model results from a project titled "Investigating the Impact of SLR on Coastal Communities and their Livelihoods in Bangladesh" conducted by IWM and CEGIS during 2006-07 assigned by the UK Department for Environment Food and Rural Affairs (DEFRA). The modeling were done by IWM using Mike 11, Bay of Bengal Model, TD model etc.

Description of the model simulation

This section has been extracted from reports titled "Impact of Sea Level Rise on Landuse Suitability and Adaptation Options" and "Investigating the Impact of SLR on Coastal Communities and their Livelihoods in Bangladesh". The modelling parts of the studies were conducted by IWM. Year 2005 was selected as base year considering the average year upstream flows. The Sea Level Rises (SLRs) were assumed 27 cm and 62 cm in years 2050 and 2080 respectively according to the IPCC results.

Model Setup: A combination of two-dimensional and one-dimensional mathematical model of Bay of Bengal and Southwest region of Bangladesh has been applied for defining the base condition and scenarios. MIKE21 and MIKE11 software, developed by DHI, have been used for the modeling exercise, which are well parameterized and validated for the country as well as for the coastal region. Latest available hydrological data have been used for simulating the hydrodynamic conditions for different sea level rise scenarios. The two-dimensional model of the Bay of Bengal describes the flow, water level and sediment transport processes in the Bay. The results of two-dimensional Bay of Bengal model have been used for developing as the downstream boundary condition for the one-dimensional Southwest regional model.

The regional hydrodynamic models have been used to simulate the water levels, discharge, and velocities at predefined locations along the rivers in the study area. The existing polders with drainage structures have been incorporated to represent the best plausible hydrology/hydraulics. Po lders have been incorporated in the model by extracting data from the updated DEM of the area. Each of the existing water control structures in the polders have been replaced by an equivalent single vent lumped structure and incorporated in the model accordingly.

In the model set up, a complex network of tidal and non-tidal river branches have been included. Catchments were also included in the model. Schematization of the river system were done by using Dx = 2000 to 10000 m depending upon the length of the river reach and availability of the cross-section data.

Projected future sea level rise for 2020, 2050, 2080: Taking the greenhouse gas-emission scenarios from 3rd IPCC, it is estimated that the global rise in sea level from 1990 to 2100 would be between 9 and 88 cm. Global sea level rise for the projected year 2020, 2050 and 2080 has been selected from Third Assessment Report (TAR) of IPCC 2001 for high and low emission scenarios of SRES (Special Report on Emission Scenarios). SRES scenarios in 3rd IPCC have four families, A1, A2, B1, B2 and six emission scenarios. The global SLRs for different SRES scenarios are presented in Figure B4.

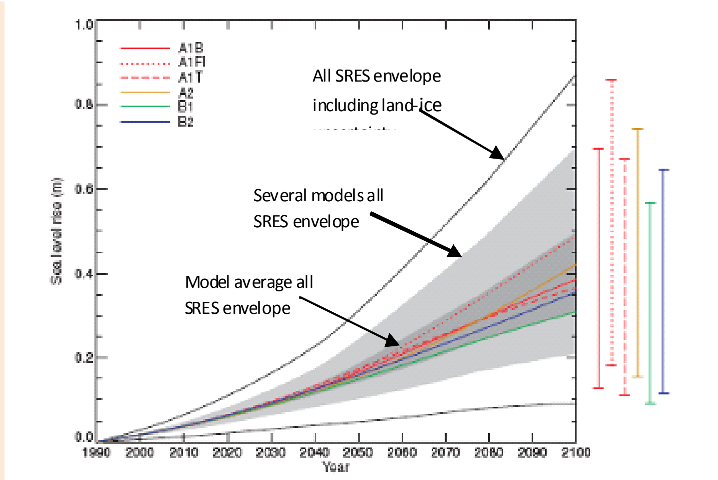


Figure B4: Global SLRs for the SRES scenarios (IPCC 2001)

The models were run using A2 and B1 scenarios with predicted SLRs as shown in Table B1.

Table B1: Predicted Sea Level Rise under different emission scenarios

SLR in Year	A2 (High Emission Scenario)		B1 (High Emission Scenario)	
	High	Low	High	Low
2020	6 cm	-	5 cm	-
2050	27 cm	5 cm	23 cm	8 cm
2080	62 cm	9 cm	48 cm	15 cm

Under this study, model results of Base condition (Year 2005 hydrologic situation), SLR 27 cm and SLR 62 cm were used to estimate the required increase of embankment crest elevations.

Model Boundary Condition: The description of the boundary condition of the model is described below which has been extracted from the Report "Impact of Sea Level Rise on Landuse Suitability and Adaptation Options", of which this section was written by IWM.

Water Levels: Water level time series data along the Southwest Rivers have been generated for base condition using the 2D Model. Then different sea level rise scenarios have been added to this water level to get the downstream boundary for the one dimensional (1D) model. The upstream boundary has taken from observed time series data. The downstream boundaries have been taken from 2D Bay of Bengal model. The south boundary of the 2D Model is located in the deep sea and has been generated from the predicted tide at Baruva in India and Shearle Point in Myanmar. Same approach had been applied in Southwest Coastal Hydraulics study (ICRD, 2005).

Physical Impact on Polders

The modeling results show that the rise of water levels outside the embankments varies from 1.1-27 cm and 2.6-62 cm. The water levels will increase by more than 10 cm in front of the embankments of 110 polders and 123 polders due to SLR 27 cm and SLR 62 cm respectively. The water level changes for both SLR 27 cm and SLR 62 cm is presented in Figure B5.

These increases of water levels will have several consequences as follows:

1. ***The risk of overtopping the embankment will increase from its designed condition.*** The sea dykes were designed for 100 year return period—means it has a risk of inundation once in a 100 year, i.e. 1/100. But due to SLR this risk will increase, other way the degree of safety will decrease.

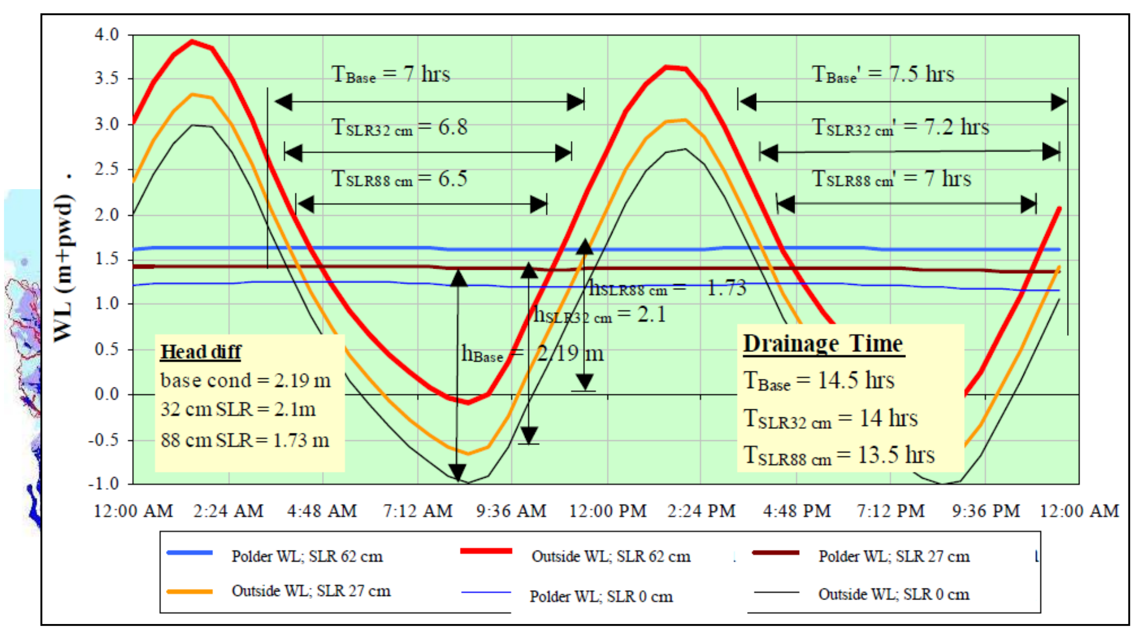
   For example: In Hatiya, the design elevation was fixed to 6.3 m PWD considering the 1:100 year risk coverage. But with SLR 27 cm and SLR 62 cm, the water levels in front of embankment will rise by 26.5 cm and 62 cm. These rises will increase the risk from 1:100 to 1: 60 and 1:30 respectively. Other way, the embankment should be raised 26.5 cm by year 2050 and 62 cm by year 2100 to maintain the design safety level.

2. ***The drainage will be slower through the sluice gates.*** The sluice gates for draining the rainwater were designed based on polder water levels, sea side water levels and drainage periods. The sluices can drain during the period when the polder water levels are higher than the sea water levels. The overall drainage of polder through sluices is function of both time and head difference. The sluice openings are estimated based on these parameters.

   Sluice openings = f (head diff., drainage period)

   The drainage period and head difference varies over the season and tidal periods. Due to sea level rise, both the drainage period and head difference will reduce. As a consequence, the drainage congestion will increase because of elongated drainage periods. Hence, to return to the design condition, the drainage opening (sluices) needs to be increased.

   The slow and elongated drainage will have adverse effect on the settlements and cropping areas and favorable effect on shrimp cultivation. It is to be noted that the polders were originally designed for crop and flood free human and animal habitations, and the sluices



FigFigure B6: An example of impact of SLR on drainage (Polder 15) ar 2005 were designed for faster drainage. An example of this type of slow drainage in polder 15 has been presented in Figure B6.

The drainage time in one complete tide cycle is 14.5 hr in base condition (without SLR), which will reduce to 13.5 hr with 62 cm SLR condition. Moreover, the head difference is 2.19 meter in base situation, and will reduce to 1.73 meter in 62 cm SLR condition. It is to be noted that even if the head difference remains unchanged, the higher elevation in polder water level will cause higher volume of water to be drained. This will ultimately cause elongated drainage period.

3. ***The most useful types of lands (dry – 30 cm inundation) will be inundated for longer period with higher depth.*** As consequence of elongated drainage periods and increased rainfall due to climate change effects (which is assumed 10%+), the F0 (dry-30 cm inundated) lands will reduce. It will cause loss of agriculture and change in hydro-ecology within the polders.

4. ***Tendency of embankment toe erosion will increase.*** In earthen embankment, the toe erosion due to the regular high tide wave actions is one of the major causes of damage where the wave reaches upto the embankment. A considerable amount of money is involved in maintenance of the embankment toe.

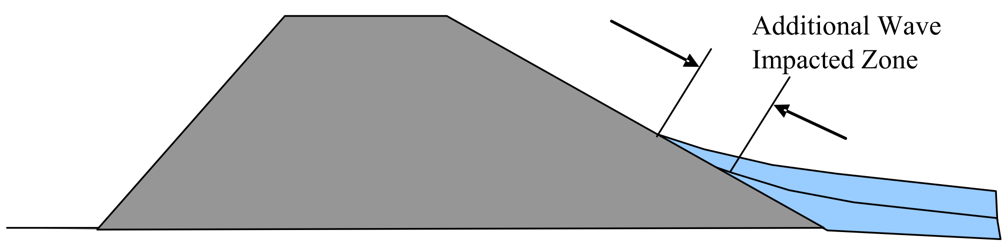


Figure B7: Schematic diagram of the portion of embankment additionally subjected to wave actions due to the SLR

Figure B7 shows the schematic diagram of the portion of embankment additionally subjected to wave actions due to the SLR. The additional wave impacted zone as shown in the figure will make the toe erosion aggravated. This will increase the maintenance cost. In case of block protection, the cost will be much higher.

Annex-C: Economic Indices Calculation

Table C1: Combined enumeration of economic indices for climate change induced impacts

Year	Investment Cost (M. Tk.)	O&M cost (M.Tk.)	Total Cost (M.Tk.)	Agricultural Benefit (M.Tk.)	Net Cash Flow (M.Tk.)
2010	431		431	517	86
2011	862	11	873	517	-356
2012	1,293	32	1,325	517	-808
2013	431	65	496	517	21
2014	215	75	291	517	226
2015	215	81	296	517	220
2016	215	86	302	522	220
2017	215	92	307	557	249
2018	215	97	312	600	288
2019	215	102	318	652	334
2020		108	108	712	604
2021		108	108	780	672
2022		108	108	855	747
2023		108	108	936	829
2024		108	108	1,025	917
2025		108	108	1,120	1,012
2026		108	108	1,222	1,114
2027		108	108	1,330	1,223
2028		108	108	1,446	1,338
2029		108	108	1,568	1,460
2030	431		431	1,698	1,267
2031	862	11	873	1,836	963
2032	1,293	32	1,325	1,982	656
2033	431	65	496	2,136	1,641
2034	215	75	291	2,301	2,010
2035	215	81	296	2,476	2,179
2036	215	86	302	2,661	2,360
2037	215	92	307	2,859	2,552
2038	215	97	312	3,070	2,758
2039	215	102	318	3,295	2,977
2040		102	102	3,536	3,433
2041		102	102	3,792	3,690
2042		102	102	4,067	3,965
2043		102	102	4,361	4,259
2044		102	102	4,676	4,574
2045	779	102	881	5,013	4,132
2046	2,336	19	2,356	5,375	3,019
2047	2,336	78	2,414	5,762	3,347
2048	779	136	915	6,176	5,261
2049	389	156	545	6,621	6,076

Year	Investment Cost (M. Tk.)	O&M cost (M.Tk.)	Total Cost (M.Tk.)	Agricultural Benefit (M.Tk.)	Net Cash Flow (M.Tk.)
2050	389	165	555	7,097	6,542
2051	389	175	565	8,123	7,558
2052	389	185	574	8,668	8,094
2053	389	195	584	9,252	8,668
2054	389	204	594	9,876	9,282
2055		204	204	10,543	10,339
2056		204	204	11,256	11,051
2057		204	204	12,016	11,812
2058		204	204	12,828	12,623
2059		204	204	13,692	13,488
2060		204	204	14,613	14,409
2061		204	204	15,594	15,389
2062		204	204	16,637	16,432
2063		204	204	17,745	17,540
2064		204	204	18,921	18,717
2065	779	204	983	20,170	19,187
2066	2,336	19	2,356	21,494	19,138
2067	2,336	78	2,414	22,897	20,482
2068	779	136	915	24,382	23,466
2069	389	156	545	25,952	25,407
2070	389	165	555	27,612	27,058
2071	389	175	565	29,366	28,801
2072	389	185	574	31,217	30,643
2073	389	195	584	33,169	32,585
2074	389	204	594	35,226	34,632
2075		204	204	37,392	37,188
2076		204	204	39,672	39,468
2077		204	204	42,070	41,866
2078		204	204	44,590	44,386
2079		204	204	47,237	47,033
2080		204	204	50,015	49,810
Total			**34,828**	**809,443**	**774,614**
NPV	**BDT 4,444**				
IRR	**28%**				
B/C ratio	**1: 2.17**				

Table C2: Estimation of economic efficiency through discounted benefit-cash flow analysis

Discount rate =			12.0%					
Year	Cale n-dar Year	Costs	O&M	Benefits	Net benefits: benefits-costs	Discounted costs	Discounted benefits	Discounted net benefits
0	2010	660			-660	660	0	-660
1	2011	1,649	26		-1,675	1,496	0	-1,496
2	2012	1,649	92		-1,741	1,388	0	-1,388
3	2013	1,649	158		-1,807	1,286	0	-1,286
4	2014	989	224		-1,214	771	0	-771
5	2015	440	264	5,273	4,569	399	2,992	2,593
6	2016	440	281	10,545	9,824	365	5,342	4,977
7	2017	440	299	15,818	15,079	334	7,155	6,821
8	2018	440	317	21,090	20,334	305	8,518	8,212
9	2019	440	334	26,363	25,589	279	9,507	9,228
10	2020		352	31,635	31,283	113	10,186	10,072
11	2021		352	36,908	36,556	101	10,610	10,509
12	2022		352	42,180	41,828	90	10,827	10,736
13	2023		352	47,453	47,101	81	10,875	10,794
14	2024		352	52,725	52,373	72	10,789	10,717
15	2025		352	52,725	52,373	64	9,633	9,568
16	2026		352	52,725	52,373	57	8,601	8,543
17	2027		352	52,725	52,373	51	7,679	7,628
18	2028		352	52,725	52,373	46	6,856	6,811
19	2029		352	52,725	52,373	41	6,122	6,081
20	2030	660	352		-1,011	105	0	-105
21	2031	1,649	26		-1,675	155	0	-155
22	2032	1,649	92		-1,741	144	0	-144
23	2033	1,649	158		-1,807	133	0	-133
24	2034	989	224		-1,214	80	0	-80
25	2035	440	264	5,273	4,569	41	310	269
26	2036	440	281	10,545	9,824	38	554	516
27	2037	440	299	15,818	15,079	35	742	707
28	2038	440	317	21,090	20,334	32	883	851
29	2039	440	334	26,363	25,589	29	986	957
30	2040		352	31,635	31,283	12	1,056	1,044
31	2041		352	36,908	36,556	10	1,100	1,089
32	2042		352	42,180	41,828	9	1,122	1,113
33	2043		352	47,453	47,101	8	1,127	1,119
34	2044		352	52,725	52,373	7	1,118	1,111

Discount rate =			12.0%					
Year	**Cale n-dar Year**	**Costs**	**O&M**	**Benefits**	**Net benefits: benefits-costs**	**Discounted costs**	**Discounted benefits**	**Discounted net benefits**
35	2045		352	52,725	52,373	7	999	992
36	2046		352	52,725	52,373	6	892	886
37	2047		352	52,725	52,373	5	796	791
38	2048		352	52,725	52,373	5	711	706
39	2049		352	52,725	52,373	4	635	630
40	2050		352	52,725	52,373	4	567	563
Total		**17,588**	**11,731**	**1,159,950**	**1,130,631**	**8,871**	**139,286**	**130,416**
NPV								**130,416**
B/C Ratio								**16**
IRR								**63%**

Table C3: Economic efficiency estimation through discounted cash flow analysis

Discount rate =			12.0%					
Year	Calen-dar Year	Costs	O&M	Benefits	Net benefits: benefits-costs	Discounted costs	Discounted benefits	Discounted net benefits
0	2010	1,264			-1,264	1,264	0	-1,264
1	2011	1,264	0		-1,264	1,129	0	-1,129
2	2012	1,264	0		-1,264	1,008	0	-1,008
3	2013	1,264	0		-1,264	900	0	-900
4	2014	1,264	0		-1,264	803	0	-803
5	2015	1,264	0	6,433	5,169	717	3,650	2,933
6	2016	1,264	0	6,702	5,438	640	3,395	2,755
7	2017	1,264	0	6,982	5,718	572	3,158	2,587
8	2018	1,264	0	7,274	6,010	511	2,938	2,427
9	2019	1,264	0	7,578	6,314	456	2,733	2,277
10	2020	1,264	0	7,895	6,631	407	2,542	2,135
11	2021	1,264	0	8,225	6,961	363	2,365	2,001
12	2022	1,264	0	8,569	7,305	324	2,200	1,875
13	2023	1,264	0	8,928	7,664	290	2,046	1,756
14	2024	1,264	0	9,301	8,037	259	1,903	1,645
15	2025	1,264	0	9,690	8,426	231	1,770	1,539
16	2026	1,264	0	10,095	8,831	206	1,647	1,441
17	2027	1,264	0	10,517	9,253	184	1,532	1,348
18	2028	1,264	0	10,957	9,693	164	1,425	1,260
19	2029	1,264	0	11,415	10,151	147	1,325	1,179
20	2030	1,264	0	11,893	10,629	131	1,233	1,102
21	2031	1,264	0	12,390	11,126	117	1,147	1,030
22	2032	1,264	0	12,908	11,644	104	1,067	962
23	2033	1,264	0	13,448	12,184	93	992	899
24	2034	1,264	0	14,010	12,746	83	923	840
25	2035	1,264	0	14,596	13,332	74	859	784
26	2036	1,264	0	15,206	13,942	66	799	732
27	2037	1,264	0	15,842	14,578	59	743	684
28	2038	1,264	0	16,504	15,240	53	691	638
29	2039	1,264	0	17,195	15,931	47	643	596
30	2040	1,264	0	17,914	16,650	42	598	556
31	2041	1,264	0	18,663	17,399	38	556	519
32	2042	1,264	0	19,443	18,179	34	517	484
33	2043	1,264	0	20,256	18,992	30	481	451
34	2044	1,264	0	21,103	19,839	27	448	421
35	2045	1,264	0	21,985	20,721	24	416	392

Discount rate =			12.0%					
Year	**Calen-dar Year**	**Costs**	**O&M**	**Benefits**	**Net benefits: benefits-costs**	**Discounted costs**	**Discounted benefits**	**Discounted net benefits**
36	2046	1,264	0	22,905	21,641	21	387	366
37	2047	1,264	0	23,862	22,598	19	360	341
38	2048	1,264	0	24,860	23,596	17	335	318
39	2049	1,264	0	25,900	24,636	15	312	297
40	2050	1,264	0	21,103	19,839	14	227	213
Total		51,824	0	512,549	460,725	11,684	48,363	36,679
NPV								36,679
B/C Ratio								4
IRR								41%

This document is produced by

Climate Change Cell
Department of Environment
Ministry of Environment and Forests

with the assistance of

Ministry of Food and Disaster Management
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