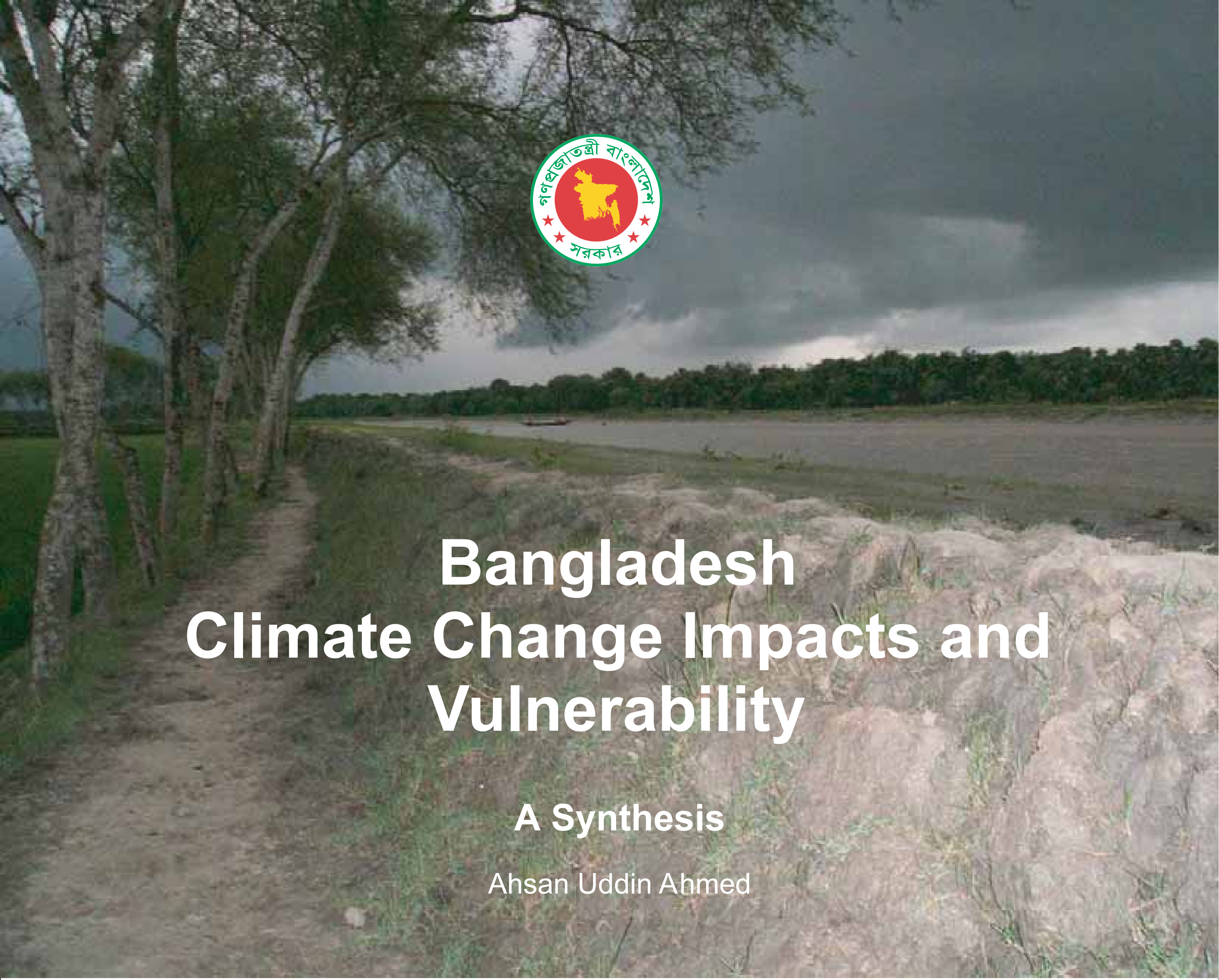

Bangladesh Climate Change Impacts and Vulnerability

A Synthesis

Ahsan Uddin Ahmed

July 2006

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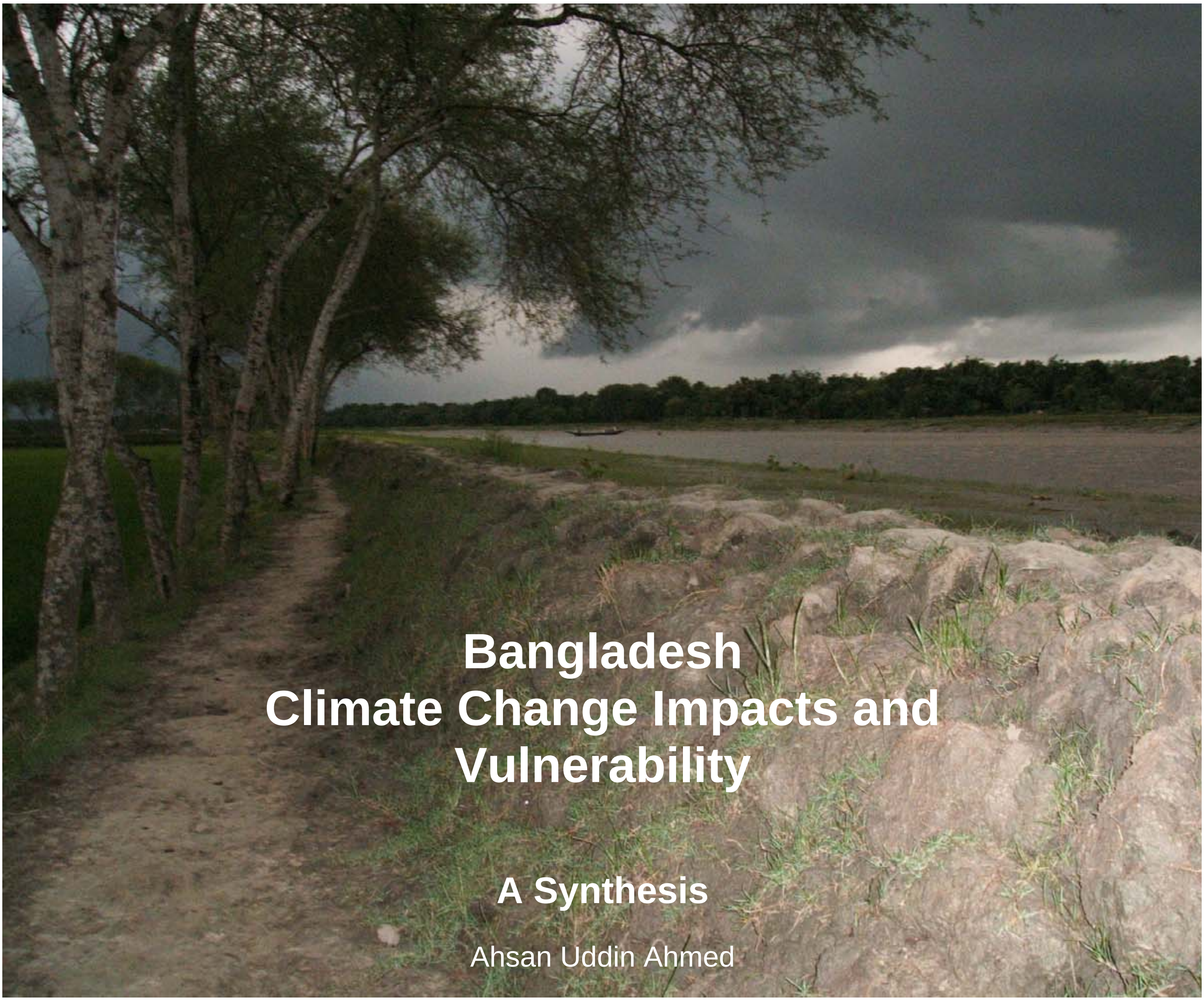

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Preface

Acknowledgement

Table of Contents

LIST OF FIGURES

LIST OF TABLES

BOXES

1. INTRODUCTION

1.1 Background and Objectives

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). 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 hydro-geological and socio-economic factors that include: (a) its geographical location in South Asia; (b) its flat deltaic topography with very low elevation; (c) its extreme climate variability that is governed by monsoon and which results in acute water distribution over space and time; (d) its high population density and poverty incidence; and (e) its majority of population being dependent on crop agriculture which is highly influenced by climate variability and change. Despite the recent strides towards achieving sustainable development, Bangladesh's potential to sustain its development is faced with significant challenges posed by climate change (Ahmed and Haque, 2002). It is therefore of utmost importance to understand its vulnerability in terms of population and sectors at risk and its potential for adaptation to climate change.

To streamline activities of the Government of Bangladesh towards facilitating adaptation to climate change, the Climate Change Cell (CCC) has been established under the aegis of the Ministry of Environment and Forest – one of the focal points on climate change issues. Housed at the Department of Environment, the 'Cell' has initiated its activities with support from the Comprehensive Disaster Management Programme (CDMP), the DfID and the United Nations Development Programme (UNDP). With this document, the CCC made an effort to pull together the available knowledge on climate change impacts and vulnerability in Bangladesh, which is expected to help readers to understand the dynamics of the important concern. The task in hand was to review and synthesize the current knowledge base. An assignment was commissioned based on which the author designed a study to synthesize all the relevant findings available in the currently available literature so it helps in understanding the dynamics of climate change and define courses of action by various actors involved in the national development processes.

The specific objective of the study was to prepare a synthesis for the general readership on climate change issues for Bangladesh. The modality of achieving this objective is to take note of all the important findings in published literature and put it in a form so that the product helps the readership to clearly understand the dynamics of climate change and relate it within the contexts of various relevant sectoral development. It is expected that the publication will help create awareness among the stakeholders and in near future, lead to an 'informed decision making' while considering development decisions in vulnerable areas and/or sectors. The synthesis is, therefore, envisaged as a tool to mainstream adaptation to climate change in Bangladesh, in order to achieve the goals and targets of Bangladesh's Initial National Communication[1] (MOEF, 2002) and the National Adaptation Programme of Action (NAPA[2]) process.

1.2 Approach and Methodology

The general approach for the current synthesis is to highlight the results available in literature on impacts, adaptation and vulnerability to climate change for Bangladesh and present these results in summary form.

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[1] The Government of Bangladesh (GOB), a signatory to the UNFCCC, has developed and submitted the INC in 2002 (MOEF, 2002).

[2] NAPA document has been developed by the GOB in 2005 and submitted to the GEF in a bid to claim LDC funding from GEF-operated LDC Funds for adaptation (GOB, 2005).

In order to achieve the objective of the study the general methodology deals with a number of steps:

a. collecting existing literature on climate change issues for Bangladesh, available both nationally and internationally, to the extent possible;
b. digging into existing literature to find out and collate key findings therein (taking into consideration methodological rigour that had been applied to reach a conclusion);
c. briefly highlighting on the ground adaptation practices as reported in literature; and
d. highlighting gross limitations of the synthesis study.

As appears from the above steps, the outcomes of the study are rather known and this study report will only present a full range of results published earlier. By no means, this study makes an attempt to identify and subsequently fill in the gaps of national level understanding regarding the important issue. No attempt has been made to incorporate aspects such as greenhouse gas (GHG) emissions (or emission inventory) and/or reduction of GHG emissions either through autonomous development or by the use of three financing mechanisms under Kyoto Protocol such as Clean Development Mechanism (CDM). This synthesis limits itself on impacts, adaptation and vulnerability to climate (variability and) change.

2. CLIMATE CHANGE SCENARIOS: EXPERIENCE IN THE USE OF MODELS

Since climate change is a dynamic phenomenon, changes will occur over time, and implications will only be understood in future, it is not possible 'to define a changing climate' that might occur 'within a defined period in future'. In order to appreciate changing climate over a geographic region and/or a country, efforts are made to 'define one or more scenarios of a changing climate' in relation to the area in question. Of course, a set of key assumptions, which would have high sensitivity towards defining the scenario(s), are made prior to defining the scenario(s). Some of the key assumptions are based on 'plausible socio-econo-political pathways' which would shape up the future greenhouse gas emission regime. Each pathway identified in the process may, therefore, be considered to be an element of a scenario. These key assumptions and/or considerations are often stated in the form of verbose statements, bio-geo-physical equations, and complex models which incorporate both the statements and empirical equations. Since scenarios are based on assumptions, approximations, and considerations (social, political, economic, cultural etc.), a scenario 'cannot truly represent' a future climate. Rather it should represent a 'plausible future climate' in view of facilitating assessments of physical, environmental, social, economic and human aspects of the geographic region and/or country in question.

For Bangladesh, efforts have been made to develop climate change scenarios using various generic methods. In early stages of assessing climate change impacts[3], 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. 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).

The following sub-sections highlight the three different set of scenarios which have been developed in Bangladesh at different stages of their development process.

2.1 Speculative Scenario Development

Scenarios based on 'expert judgments' portrayed speculative future climate. Following a sarcastic mode of analysis, scientists have developed these speculative scenarios and posed key questions: 'what would happen' to the bio-geo-physical system 'if' climate parameter(s) change by a given extent. Mahtab (1989) speculated that a general surface warming of 0.3 to 5°C would occur by the year 2050. It is also thought that rainfall would increase by 5 to 20%. For sea level rise, a range of 30 to 150 cm was assumed by the year 2050. However, Mahtab (1989) considered a median value by taking the mean of the two limits and adding 10cm for local subsidence, which provided for 100 cm 'net sea level rise' by the year 2050.

Similarly, the effects of 2°C and 4°C change in average temperature were speculated for defining 'moderate' and 'severe' climate change scenarios, respectively (BCAS-RA-Approtech, 1994). The two scenarios also speculated a rise in peak monsoon rainfall by 18 and 33%, respectively. It was anticipated that the increase in monsoon rainfall would cause an increase in river discharge during peak flow periods by 8 and 15%, respectively, for the two scenarios. The corresponding sea level rise was speculated to be 30 and 100 cms, with a corresponding rise in cyclonic intensity by 10 and 25%, respectively. The same study also considered two other very important 'decision statements' to construct future scenarios: one dealing with water development in international rivers with sharing option (with the upstream neighbour), and the other having 'no sharing option' for the same. Based on these speculative considerations, a set of ten composite scenarios have been considered for the analysis (Huq *et al.*, 1996).

[3] 'Impacts' did not consider 'adaptation' potential.

Ali (1999) considered 2°C and 4°C changes in average temperature as lower and upper bound thresholds for 2010, respectively, in order to analyze impacts of climate change on cyclonic storm surge along the Bay of Bengal. The same study speculated rise in sea level by 30 and 100cm, for the two scenarios, respectively. The base case however considered no change in sea level.

2.2 General Circulation Models: Validation and Outputs

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 0.5C to 2.0C rise in temperature by the year 2030 under 'business as usual' scenario of IPCC. The same modelling effort estimated 10 to 15% rise in average monsoon rainfall by the year 2030. The study could not draw an inference in relation to change in sea level, however it commented that both sedimentation and subsidence were likely to complicate an expected net change in sea level along the Bangladesh coast.

ADB (1994) study also made use of four GCMs: CSIRO9, CCC, GFDLH, and UKMOH. A host of IPCC scenarios available at that point have been considered which provided a number of scenarios. In order to avoid complications, only the IPCC IS92a and its results (modelling outputs) are summarized here. It was reported that, for 2010 the temperature would rise by 0.3C and for 2070, the corresponding rise would be 1.5C. The four models used for developing scenarios all provided different results for monsoon rainfall. The high-estimating GFDL model (GFDLH) projected 59% higher rainfall in South Asian monsoon with a corresponding withdrawal of dry season rainfall by 16%. CCC model, however, projected an increase of monsoon rainfall by 20% and withdrawal of dry season rainfall by 6%. Both considered a doubling of CO_2 concentration in the atmosphere (therefore, time independent). A time-dependent modelling provided a medium scenario for South Asian rainfall: the monsoon rainfall was projected to increase up to 5% by 2010 and between 5 to 30% by the year 2070, while the dry season rainfall was projected to vary between -10 to +10% by the year 2070. No change in dry season rainfall was projected for 2010. For the time dependent medium-scenarios, it was assumed that the concentration of CO_2 would be 400 and 640 ppmv[4] by the year 2010 and 2070, respectively (ADB, 1994).

It is important to note here that the two above modelling experiments haven't tried validation of the GCM outputs for Bangladesh. This is why the area-averaged results for the South Asian domain were used in a bid to develop climate change scenarios for Bangladesh. Recognizing the fact that, the extent of monsoon rainfall diminishes as the front advances towards northwestern parts of the sub-continent, technically one may argue that South Asian domain might not have represented the country-specific rainfall conditions.

The other major attempt to generate a model-driven climate change scenario was made under the 'Climate Change Country Studies Programme' (Ahmed *et al*., 1996; Asaduzzaman *et al*., 1997 and Huq *et al*., 1998). A number of GCMs have been used including Canadian Climate Centre Model (CCCM), Geophysical Fluid Dynamics Laboratory equilibrium model (GFDL), and 1% transient model of GFDL (i.e., GF01). Observed climate data were supplied by the CLIM database, as provided by National Center for Atmospheric Research (NCAR), USA. 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[5], 1988). The downscaling of climate data for Bangladesh down from GCM scale was possible by comparing different GCM outputs. The GFDL 1% transient model represented the long-term climate normal the best and was considered for the development of time-bound climate change scenarios (Ahmed *et al.*, 1996).

[4] Parts per million by volume (ppmv) is a unit to express atmospheric concentration of constituent gases.

[5] The FAO-UNDP report (1988) analysed climate data made available primarily by the Bangladesh Meteorological Department and collected from international sources.

Applying the same methodology, Ahmed and Alam (1998) reproduced the climate change scenarios, which were largely used for a number of subsequent national assessments. It was reported that the average increase in temperature would be 1.3°C and 2.6°C for the two projection years, 2030 and 2075, respectively. It was found that there would be a seasonal variation in changed temperature: 1.4°C change in the winter and 0.7 °C in the monsoon months in 2030. For 2070 the variation would be 2.1°C and 1.7 °C for winter and monsoon, respectively. It was reported that the winter rainfall would decrease at a negligible rate in 2030, while in 2075 there would not be any appreciable rainfall in winter. On the other hand, monsoon precipitation would increase at a rate of 12 per cent and 27 per cent for the two projection years, respectively. The following table summarizes the climate change scenarios developed by Ahmed and Alam (1998).

Table-1: Outputs of GCM exercise using GFD 01 transient model

Year	Average Temperature			Temperature increase			Average Precipitation			Precipitation Increase		
	W	M	Ave	W	M	Ave	W	M	Ave	W	M	Ave
	(°C)			(°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

Note: W stands for winter (i.e., December, January and February: DJF) and M stands for monsoon (i.e., June, July and August: JJA)
Source: Ahmed, A.U. and Alam, M., 1998

Mirza (1997) used a number of GCMs and developed climate change scenarios based on ensemble technique. The results have been used for the World Bank Study (WB, 2000). By the year 2030, the projected rise in monsoon temperature was 0.7°C with a corresponding rise in winter temperature of 1.3°C. WB (2000) results showed similarities with respect to result of Ahmed and Alam (1998). The corresponding rise in rainfall was projected at 11% for monsoon, while a decrease in rainfall by 3% was also projected for winter by the year 2030. For the year 2050, the study projected increase in temperature by 1.1 and 1.8°C for monsoon and winter, respectively. For the same year, the projected changes for rainfall were 28% in monsoon and -37% in winter. These results have been adopted for the First Initial National Communication for Bangladesh (MOEF-2002). Moreover, a linear rise in sea level by 1mm/year was considered, which resulted in 30 and 50cm rise in sea level by the year 2030 and 2050, respectively.

Mirza (2002) considered an ensemble of GCMs, instead of validating outputs of any specific model for observed values of Bangladesh, and projected an ensemble scenario. In another modelling exercise, Mirza (2005) considered three ‘temperature change scenarios’ with 2°C, 4°C, and 6°C changes in average temperature and then computed its response in relation to changes in rainfall over the South Asian subcontinent, particularly over Bangladesh. There have been 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 for the same for the Brahmaputra basin for a 2°C temperature change scenario. There would be increasing mean annual rainfall in both the basins with increasing global warming, as reported by Mirza (2005). The UKTR model suggested as high as 63.3% increase in mean annual rainfall over the Ganges basin associated with a change in surface average temperature of 6°C. The corresponding change in Brahmaputra basin would be much less (Mirza, 2005).

Agrawala *et al*. (2003) have used another ensemble of a dozen GCMs, which were driven by MAGICC model using SCENGEN database. A total of 17 GCMs have been run initially for model validation for Bangladesh’ observed data sets. An analyses of the results thus obtained revealed that only 11 of 17 models could best simulate current climate over Bangladesh. Consequently, the most suited ones have been selected for the study. It is important to note that the models have been run with the IPCC B2 SRES scenario[6] (IPCC, 2001). An ensemble of results has been considered to provide an estimate of the degree of agreement across various models. Table-2 provides the results of validated ensemble model runs applicable for Bangladesh (Agrawala *et al*., 2003).

Table 2: GCM projections for changes in temperature and precipitation for Bangladesh

Year	Temperature change (°C) mean (standard deviation)			Rainfall change (%) mean (standard deviation)		
	Annual	DJF	JJA	Annual	DJF	JJA
Baseline average 2030	1.0 (0.11)	1.1 (0.18)	0.8 (0.16)	3.8 (2.30)	-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.

Source: Agrawala *et al.*, 2003.

The results were compared with previous results (in table-1) as provided by Ahmed and Alam (1998). The core findings appear to be consistent with the analysis presented above. Both the studies agreed that winter warming would be greater than summer warming. The two studies also estimated little change in winter precipitation and an increase in precipitation during the monsoon. The slightly higher monsoon precipitation projected by Ahmed and Alam (1998) compared to that by Agrawala *et al.* (2003) may be attributed to lower climate sensitivity in more recent climate models. In the former case, however, the climate forcing did not follow IPCC B2 SRES Scenario.

The National Adaptation Programme for Action (NAPA) for Bangladesh has been the latest attempt to develop a climate change scenario for the country. Instead of developing one or more scenarios the NAPA Core Team (GOB, 2005) adopted the results obtained by Agrawala *et al*. (2003) for changes in temperature, and modified the results of Agrawala *et al.* regarding changes in precipitation. The modification, however, was based on judgment of the NAPA Core Team and was not based on reflection of any GCM modelling exercise. The scenario provided by the NAPA document is given in Table-3 for comparison.

Table 3: Scenarios provided in NAPA document

Year	Temperature change (°C) mean			Rainfall change (%) mean			Sea Level Rise (cm)
	Annual	DJF	JJA	Annual	DJF	JJA	
2030	1.0	1.1	0.8	5	- 2	6	14
2050	1.4	1.6	1.1	6	- 5	8	32
2100	2.4	2.7	1.9	10	- 10	12	88

Source: Adopted from the Bangladesh NAPA Document (GOB, 2005).

Note: Despite the claim, the values in the shaded cells are not directly adopted from Agrawala et al. (2003). No explanation has been provided in relation to the deviations from the model-resolved ensemble data. Standard deviations were not shown.

The NAPA document has also provided a sea-level rise scenario for Bangladesh. Again, no explanation has been provided in support of the data. Apparently, the upper values of the IPCC SLR

[6] The IPCC SRES (Special Report on Emission Scenarios) B2 scenario assumes a world of moderate population growth and intermediate level of economic development and technological change (IPCC, 2001). SCENGEN estimates a global mean temperature increase of 0.8 °C by 2030, 1.2 °C by 2050, and 2 °C by 2100 for the B2 scenario.

Scenario (WGI, TAR: IPCC, 2001) was adopted for developing the scenarios for 2050 and 2100, while the curve was extrapolated for developing the 2030 SLR scenario.

2.3 The Use of Regional Climate Models

Efforts are now being made to analyze the climate models specifically for Bangladesh. The challenge lies in resolving the physical equations (heat budget and laws of physics) for a finer grid, at higher resolutions (i.e., smaller grid sizes: at 50 Km X 50 Km grid size instead of 500 Km X 500 Km grid size). While one-way GCM nesting has been made possible due to advancement of model itself, robust computers are now available to resolve the equations more efficiently.

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[7] of Bangladesh. A Regional Climate Model, the Hadley Centre Regional (Climate) Model version 2 (i.e., HadCM2) was run with a 50Km X 50Km grids. For the Brahmaputra basin, slightly increased rainfall was obtained for the monsoon and post-monsoon periods (Choudhury *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. It was perhaps due to especial downscaling technique, which considered area-averaged values for each parameter for the entire domain. For temperature, warming appeared to be inevitable and increasing over time. The post-monsoon and winter seasons showed higher values compared to values for the pre-monsoon and monsoon seasons. Overall, the changes in rainfall and temperature for 2020 were 9.1% and 1.4°C, with a corresponding increase by 22.7% and 2.8°C, respectively, by the year 2050.

In Bangladesh, two different Regional Climate Models, RegCM and PRECIS are now being attempted. Initial validations are in progress. Both the models are capable of resolving climatology at 50Km X 50Km scale, with a possibility of going further down up to 30Km X 30Km resolution. It is found that both the RCMs show cold bias towards resolving temperature over the country. The interesting common feature of RCM modelling is that, both the models could reasonably estimate total annual rainfall. However, large scale discrepancies have been observed in resolving winter, pre-monsoon and monsoon seasonal precipitations. Following parameterization of both the models to suit to generate local climatology, it is expected that the models will generate climate change data for any given time in future.

3. CLIMATE CHANGE IMPACTS

3.1 Hydro-geomorphic Contexts of Climate Related Impacts in Bangladesh

Bangladesh is located between $20^{o}34^{/}$ to $26^{o}38^{/}$ North latitude and $88^{o}01^{/}$ to $92^{o}42^{/}$ East longitude. It is bordered on the west, north and east by India, on the south-east by Myanmar and on the south by the Bay of Bengal. The country occupies an area of 147,570 sq. km (BBS, 2005). Geologically it is a part of the Bengal Basin which has been filled by sediments washed down from the highlands on three sides of it, especially from the Himalayas. A network of rivers originated in the Himalayas flow over the country, that carry sediments − the building blocks of the landmass of the delta. The major river systems of the eastern Himalaya − the Ganges, the Brahmaputra, and the Meghna (GBM) − their tributaries and distributaries crisscross the floodplains (Figure-1).

[7] The Brahmaputra basin represented a Selected Hydrological Unit (SHU) within Bangladesh for analytical purposes. The study was part of a regional study that looked into water-related issues of climate change, with special focus on observed coping at the grassroots levels. For details, please see Choudhury *et al*., 2005.

Figure-1: The River Systems of Bangladesh

Source: WARPO-Halcrow et al., 2004

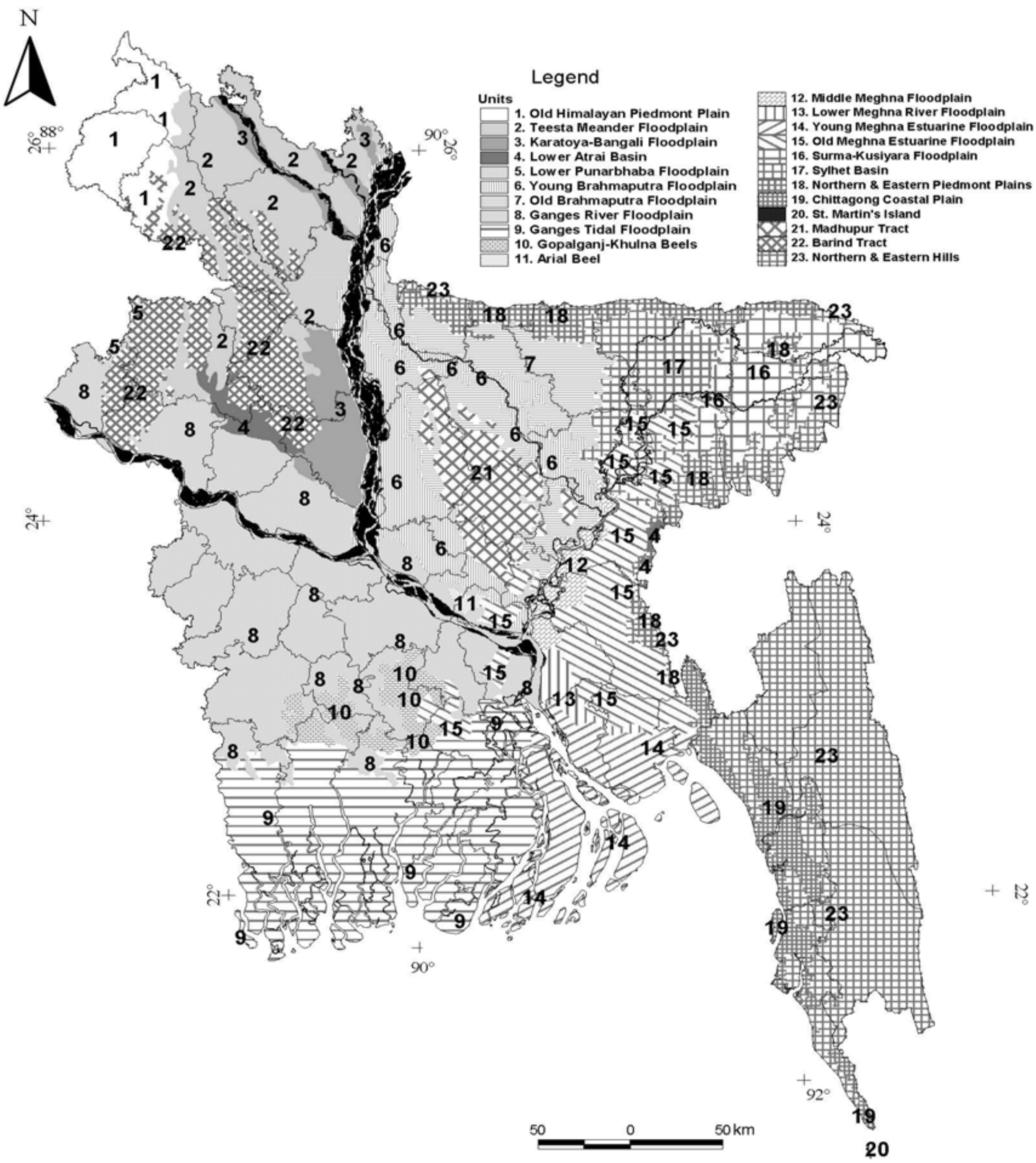

Figure-2: Physiography of Bangladesh

Source: WARPO-Halcrow et al., 2004

The country consists of low and flat land formed mainly by the sediments carried by the Ganges and the Brahmaputra River systems except for the hilly regions in the north-eastern and south-eastern parts. From physiographic point of view, about 80 per cent of the land is floodplains with very low mean elevation above the sea level with the rest made up of hills and elevated lands. Topography of the country is characterised by very low differences in the elevation between adjoining ridge tops and depression centres, which range from less than 1 meter on tidal floodplains, 1 to 3 meters on the main river and estuarine floodplains, and up to 5 to 6 meters in the Sylhet Basin in the north-east (Rashid, 1991). Only in the extreme north-west land elevations exceed 30 meters above the mean sea level. There are two uplifted land blocks, known as the Madhupur and the Barind tracts, which generally have higher elevation: within 1 and 5 meters above the adjoining floodplains. In some places, however, they reach up to 25 meters higher than the adjoining floodplains. Hills are located along the northern and eastern borders of the country. These tertiary hills have higher elevation, some reaching over 1000 meters above MSL. These generally consist of very steep slope, but there are some areas with moderate or gentle slopes. The physiography of the country is exhibited in Figure-2.

The country enjoys a humid, warm, tropical climate. Its climate is influenced primarily by monsoon and partly by pre-monsoon and post-monsoon circulations. The south-west monsoon originates over the Indian Ocean and carries warm, moist, and unstable air. The monsoon has its onset during the first week of June and withdraws in the first week of October, however, the onset and withdrawal dates vary from year to year. The main rainy period begins with the onset of the moisture-laden south-west trades which are drawn to the Indian sub-continent by the intense heat and consequent low pressure over Punjab (in Pakistan and India) and the Upper Ganges Valley and the filling up of the equatorial lows by air masses from these hot areas.

Besides monsoon, the easterly trade winds are also active, providing warm and relatively drier circulation. In Bangladesh there are four prominent seasons[8], namely, winter (December to February), Pre-monsoon (March to May), Monsoon (June to early-October), Post-monsoon (late-October to November). The general characteristics of the seasons are as follows:

- Winter is relatively cooler and drier, with the average temperature ranging from a minimum of 7.2 to 12.8˚C to a maximum of 23.9 to 31.1˚C. The minimum occasionally falls below 5°C in the north though frost is extremely rare. There is a south to north thermal gradient in winter mean temperature, generally the southern districts are 5°C warmer than the northern districts.
- Pre-monsoon is rather hot with an average maximum of 36.7˚C, predominantly in the west for up to 10 days, very high rate of evaporation, and erratic but occasional heavy rainfall from March to June. In some places the temperature occasionally rises up to 40.6˚C or more. The peak of the maximum temperatures are observed in April, the beginning of pre-monsoon season. In pre-monsoon season the mean temperature gradient is oriented in southwest to northeast direction with the warmer zone in the southwest and the cooler zone in the northeast.
- Monsoon is both hot and humid, brings heavy torrential rainfall throughout the season. About four-fifths of the mean annual rainfall occurring during monsoon. The mean monsoon temperatures are higher in the western districts compared to that for the eastern districts. Warm conditions generally prevail throughout the season, although cooler days are also observed during and following heavy downpours.
- Post-monsoon is a short-living season characterised by withdrawal of rainfall and gradual lowering of night-time minimum temperature.

The mean annual rainfall is about 2300mm, but there exists a wide spatial and temporal distribution. Annual rainfall ranges from 1200mm in the extreme west to over 5000mm in the east and north-east (MPO, 1991). Generally, the eastern parts of the country enjoy higher rainfall than the western parts. Spatial distribution of rainfall is shown in Figure-3.

The country is endowed with both surface and ground water resources and on a per capita basis it has one of the highest quantum available in the world. Its surface water system is dominated mainly by the GBM rivers, covering about 7 per cent 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 (Rahman *et al.,* 1990). It is estimated that in an average year availability of surface water flows is 1350 billion cubic meters (BCM), of which only 1160 BCM is available for use in Bangladesh or flows to the Bay of Bengal (Ahmad, 2000). It is to be noted here that, in-country availability of about 80 percent of surface water is concentrated during the monsoon months.

[8] From cultural point of view, most Bangladeshis perceive six distinct seasons. However, from technical (meteorological) point of view, only four seasons can distinctly be identified.

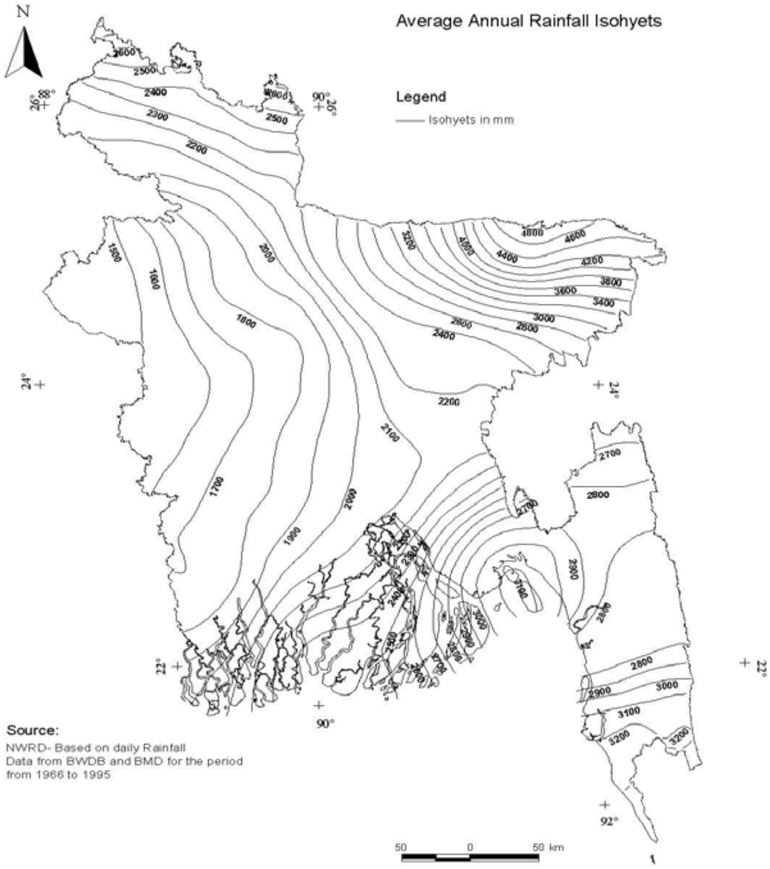

Figure-3: Spatial variability of rainfall

The country lies at the bottom of the catchment of the GBM rivers systems, as may be shown in Figure-4. As a result, its surface water system including hydrology is dependent on timing and distribution of availability of water in the upper catchments of the three major river systems. Since the majority of surface runoff in the GBM systems is influenced by monsoon, surface water inflow into Bangladesh' territory from upstream is characterised by high temporal fluctuations. About two-thirds of the inflow occurs during the months of July, August, and September; and the volume of water in August is nearly thirty times as much as that in March.

Due to inter-annual variability sometimes the timing of onset of monsoon trough over the plains of the Indian sub-continent exhibit anomalies for a few days to weeks. Peak flows inside Bangladesh occurs depending on the timing of onset of monsoon over the vast GBM basins. In general, peak flows occur in July to August; the Brahmaputra exhibits its peak flows in July, while it occurs in the Ganges in August. Average monthly discharge of the major rivers at selected points is presented in Table-4. It is evident that the surface flows of the major rivers start to lower significantly following the withdrawal of monsoon in October. The rivers attain their lowest flows during January and March. Since over nine-tenths of the surface flow is received from outside Bangladesh, the rise and fall of the water level in rivers is governed predominantly by the amount of rainfall beyond (upstream) the country's political boundaries (Ahmad *et al*., 1994).

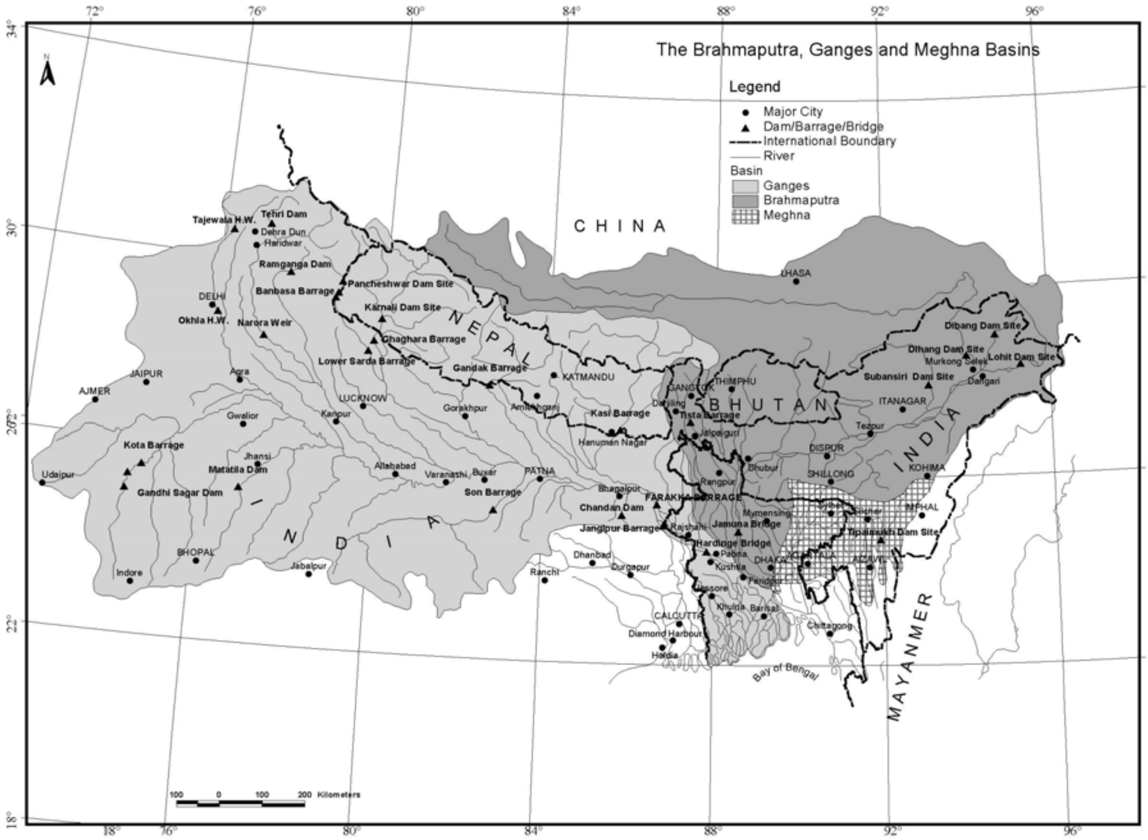

Figure-4: Map showing GBM catchment areas and the lowest riparian Bangladesh

Source: WARPO-Halcrow et al., 2004

Beneath the alluvial plains there is a fairly extensive aquifer at a very shallow depth of 20-40 feet. In many parts of the country a deeper aquifer at about 200-400 feet depth has also been identified. Although groundwater resources have extensively been utilised primarily for agricultural as well as for domestic and other purposes, excepting in a few identified urban areas natural recharge of groundwater aquifers due to rainfall and runoff has been satisfactory. The available recharge of groundwater is estimated to be as high as 21 BCM. The recently undertaken National Water Management Plan (NWMP) used relatively less conservative assumptions for recharge than the previous estimates and inferred that information on groundwater is still inadequate to make reliable projections beyond the next 10-15 years (WARPO-Halcrow *et al.*, 2004).

Table-4: Average monthly discharge of a few major rivers

River	Discharge (m^3/sec)											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Ganges	2744	2336	1984	1781	1971	4136	18324	38466	36699	17439	6682	3819
Brahmaputra	4944	4209	4786	7752	15280	30225	46242	42962	38418	24335	11137	6980
Meghna	370	264	362	1106	2778	6348	10691	11785	10722	8008	3240	919
Padma	7243	6242	6756	10220	15867	29337	56466	66980	62889	36716	16078	10104

Note: The data represent values for the stations Hardinge Bridge, Bahadurabad, Bhairab Bazar and Bhagyakul for the Ganges, Brahmaputra, Meghna, and Padma rivers, respectively.

Source: Hofer, 1998.

3.2 Water Resources: Current Status and Availability as Against Climate Variability

In terms of per capita water availability the country fares well compared to many other countries. However, due to high seasonal variability in terms of water availability, ecosystem and human activities suffer considerably because of reduced availability of water in the dry season. It is anticipated that the current sufferings due to lower water availability in the dry season will be accentuated not only by climate change, but also by increase in demand exerted by increased population.

Generally, the country is highly prone to natural hazards – a few of which take disastrous proportions. In most cases, however, disasters are manifested as hydrological events caused by climatic extremes (Khan, 2000). The country's geographical location, high dependence on the overall 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). In order to appreciate the future vulnerabilities to climate change, it is necessary to understand the interrelationship between climatic regime and associated risks in the form of water-related disasters.

A combination of upstream inflows and runoff generated from rainfall within the country feed all the rivers, canals, creeks, *beels*, natural and man-made seasonal and/or perennial reservoirs (i.e., *haors*, *baors*, *dighees* and ponds), and all other forms of water bodies which constitute the natural surface water resources in Bangladesh. The major water bodies provide a dense network of river systems. According to preliminary estimates, the cross-border annual flows into the country amount to around 1010 billion cubic meters (BCM), and an additional amount of 340 BCM is generated from local rainfall, considering an average of about 2300 mm per annum (Halcrow and Associates, 2001a). Of this total quantum of available water (1350 BCM), about 190 BCM of water is lost in the atmosphere through evaporation and evapo-transpiration, while the balance of 1160 BCM is available for use or flows into the Bay of Bengal. Over eighty per cent of this huge flow of water is concentrated in the five-month monsoon period of June to October. The minimum dry season water availability is 3,710 million cubic meters in March, and the maximum availability in August is 111,250 million cubic meters (MPO, 1991).

Variability in climate system affects six sectors which are found to be the major users of water in Bangladesh. These include agriculture (for irrigation), domestic or municipal, fisheries, navigation, industry, and environment (in-stream flow including salinity control). Other than in the low-flow season, available water resources are found to be sufficient to meet the present demand. Over the next 25 years, however, with the increase in the absolute size of the population the per capita water availability in Bangladesh will progressively be reduced (Ahmad *et al*., 2001). Under general climate variability, the annual per capita water availability in 2025 will become 7,670 cubic meters as against 12,162 cubic metres in 1991. However, such reduction in water availability will only affect the country's huge population during the dry season, where the current availability is already very low. Moreover, per capita water demand might also be increasing gradually due to a number of factors. According to government statistics, about 3 million hectares of net cropped area are yet to be brought under irrigation, mostly in the dry season. Keeping in view the poor water availability in the dry season, the per capita available supply will be much less, while demand for irrigation and other purposes (i.e., industrial process water, domestic & municipal water supply etc.) will continue to rise.

It is an undeniable fact that management of the hydrological cycle of the country that signifies abundance of water in monsoon and scarcity in the dry season and consequently, the water-related extremes ─ flooding, drought, riverbank erosion, sedimentation/siltation, and salinity ingress ─ are the most critical physical/natural problems, second perhaps only to arsenic mitigation. A large proportion of a total of over 130 million population lives in highly vulnerable physical environment. Sometimes a water-related hazardous event assumes disastrous proportions and seriously disrupts the functioning of the economy and society causing human, material, and environmental losses to such an extent that far exceeds the ability of the affected people to cope with, using their own resources (Ahmad, 2000).

Such disastrous events visited the land from time to time over the centuries and wrecked havoc on the well-being and socio-economic prospects of the people. Impacts and shocks caused by natural disasters have contributed significantly to the pauperization processes in Bangladesh. Researchers often argue that, frequent devastation by natural disasters have been one of the major causes for the country being so poverty stricken (Ahmad and Ahmed, 2002; Mirza *et al*., 2003). It is believed that managing disasters is a vital prerequisite for the country's stride towards any long-term development goals. The Government of Bangladesh has attached high importance to disaster management in pursuit to achieve and sustain its development efforts (MOP, 2005; MOFDM, 2005).

Since time immemorial, flood has been a recurring phenomenon for the country. Another very common hazardous phenomenon is riverbank erosion, triggered primarily by high velocity stream flows, but very little has so far been effectively done to minimize losses caused by riverbank erosion. Although sedimentation is the root cause for the formation of landmass in deltaic Bangladesh, sustained sedimentation along the river beds has caused problems with respect to reducing drainage capacity of the rivers, the latter being responsible for aggravation of floods. In terms of availability of water there is a high seasonal variation that leads to water stress in some areas and aggravates salinity ingress in the surface water systems. A few water-related problems are highlighted below.

Floods

The most common water-related natural hazard in a deltaic floodplain such as Bangladesh is flood. Flooding in Bangladesh is the result of a complex series of factors. These include a huge inflow of water from upstream catchment areas coinciding with heavy monsoon rainfall in the country, a low floodplain gradient, congested drainage channels, the major rivers converging inside Bangladesh, tides and storm surges in coastal areas, and polders that increase the intensity of floodwater outside protected areas. Different combinations of these various factors give rise to different types of flooding (Ahmed and Mirza, 2000).

Statistically, about a quarter of the country is flooded in an average hydrological year (Hofer, 1998). The average flooded area takes into account floods of all kind and intensities, including the severe flood events. But in reality, medium-sized floods that inundate areas ranging 10,000 to 25,000 hectares are very seldom observed since the mid-1970s, which had been frequently observed prior to that time. A historical account of flooded areas suggests that only the minor and very high intensity floods have been occurring during the past three decades (Agrawala *et al*., 2003). There is high distribution in inter-annual variability of flooded areas. Depending on rainfall variability within the country and in the GBM catchment area, the location and timing of flooding vary from one part of the country to another. Areas affected by various types of floods are shown in Figure-5. During catastrophic floods about two-thirds of the country may be affected (Ahmad *et al*., 2000).

Four main types of natural floods occur in Bangladesh: flash floods, river floods, rainwater floods, and coastal floods induced by storm surges (Ahmad *et al*., 1994; Ahmad *et al*., 2000). Flooding usually begins in flashy rivers in the hilly areas during the pre-monsoon months of April and May. These flash floods take place suddenly and last for a few hours to a couple of days. Run-off during exceptionally heavy rainfall occurring in neighboring upland areas is responsible for flash floods. Such floods occur as waters from the hilly upstream rush to the plains with high velocity, mauling standing crops and destroying physical infrastructure. They occur most frequently - sometimes several times a year - at the foot of the northern and eastern hills of Bangladesh (Huq *et al*., 1996).

Flash floods cause extensive damages to crops and property, particularly in the *haor* areas. For crops, it is their timing which is usually most important. Early floods (in April-May) generally cause severe damages: damages to *boro* rice are reported in some part or other of the eastern foothill regions virtually every year. Damages to property - especially road and railway embankments and bridges, and buildings alongside river channels - occur during exceptionally high flash floods. Flood embankments along some eastern rivers, especially the Khowai, are breached by floods almost every year. Cultivated land and land adjoining foothill streams sometimes get buried under sand.

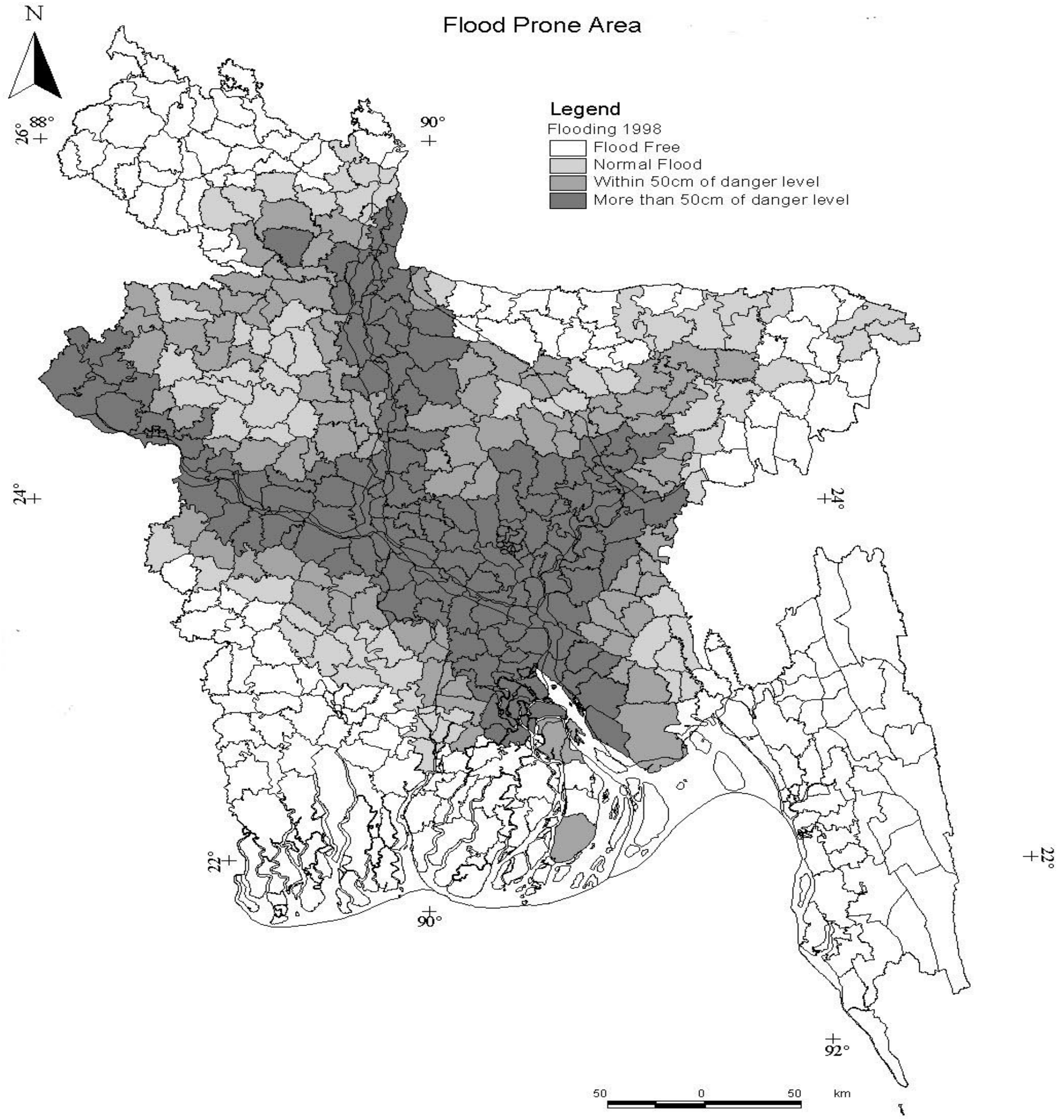

Figure-5: Areas in Bangladesh having susceptibility to various types of floods

Source: WARPO-Halcrow et al., 2004

Rainwater floods are caused by heavy rainfall occurring over floodplain and terrace areas within Bangladesh. Heavy pre-monsoon rainfall (April-May) causes local run-off to accumulate in floodplain depressions and in the lower parts of valleys within the Madhupur Tract. Later (June-August), local rainwater is increasingly accumulated on the land by the rising water levels in adjoining rivers. Thus, the extent and depth of rainwater flooding vary within the rainy season and from year to year, depending on the amount and intensity of local rainfall and on contemporary water levels in the major rivers which control drainage from the land. Rainwater flooding is characteristic of meander floodplains, major floodplain basins, and old piedmont and estuarine floodplains. The interior parts of tidal and young estuarine floodplains are also flooded mainly by rainwater. The severe 1987 flood in north western parts of Bangladesh was mainly caused by excessive rainfall occurring over the north of the area almost throughout the monsoon; but it was aggravated at times by flash floods passing down the Teesta and other rivers entering Bangladesh from the northwest, and by high levels in the Jamuna and the Ganges rivers. The severe late flood of 2004 in the southern and centrals parts of Bangladesh[9] was due to excessive rainfall.

[9] A cyclone had landfall in Bangladesh on 13 September, 2004 and caused severe flooding following a extremely high intensity rainfall event. Not only the country side was flooded, most parts of the capital city Dhaka was also inundated.

Normal river floods generally occur during monsoon. River floods result from snow-melt in the high Himalayas and heavy monsoon rainfall over the Himalayas, the Assam Hills, the Tripura Hills and the upper Brahmaputra and Ganges floodplains outside Bangladesh. They particularly affect active river floodplains. The large catchment of the GBM systems receives a huge amount of rainfall in each monsoon, about nine-tenths of which flows through the major rivers in Bangladesh. These rivers sometimes cannot drain all the waters coming from the combined GBM catchments. Consequently, bank spillage occurs which inundate the adjoining lands. River floods extend beyond the active floodplains and damage crops in parts of the adjoining meander floodplains, mainly alongside distributary channels. The timing of the flood (whether early or late) and sometimes the duration of flooding are as important determinants of crop damage as is the absolute height reached by a particular flood. Sediments deposited in channels reduce the drainage capacity of minor rivers, road and railway bridges and culverts, as well as irrigation and drainage canals.

Floods of high intensity occur when huge rate of discharge of the Bangladeshi rivers is grossly fall behind the rate of accumulation of water. Discharge is often impeded because of low river gradients, unplanned infrastructure and strong backwater effect at the confluences of large rivers, the latter being induced by high oceanic stages. The confluences between the Brahmaputra and the Ganges, and between the Meghna and the combined flow of the earlier two rivers (known as the *Padma*) become two huge water pools during the peak seasons and cause high intensity flooding, particularly in the central part of the country. A synchronization of peak flows of the major rivers, often caused by variability in timing of occurrence of monsoon over the GBM catchments, induces an unusual situation where the entire drainage system in the floodplain fails to drain all the incoming waters and suffer catastrophic floods of very high intensity (Ahmed and Mirza, 2000). The floods of 1987, 1988, 1998 and the 2004 are the four most devastating floods in recent history, among which the one occurring in 1998 was the worst on record.

An examination of annual mean peak discharges of the major rivers as against observed maximum peak discharges, representing high intensity floods in Bangladesh, provides an understanding of catastrophic floods of the past. Table-5 gives such a comparative analysis of peak annual discharges of major rivers at a few selected representative stations. Water levels also can characterize a high intensity flood. The catastrophic floods of 1987, 1988 and 1998 are characterized by comparing the peak water levels of the major rivers at those representative points as against their respective flood danger levels and recorded maximum water levels (FFWC, 1998). The comparative analysis of peak water levels is presented in Table-6.

Table-5: Mean and peak discharge of major rivers

River (Station)	Basin Area	Annual peak Discharge	
		Mean	Observed maximum
	(Million hectare)	(m^3s^{-1})	(m^3s^{-1})
Ganges (Hardinge Bridge)	109.50	54,000	80,230
Brahmaputra (Bahadurabad)	57.90	67,000	98,600
Meghna (Bhairab Bazar)	8.02	14,000	19,900

After Mirza et al. (2002)

Table-6: Water level at four important points along the major rivers

River (Station)	Recorded maximum	Danger Level	Peaks of the Year			Days above Danger Level		
			1987	1988	1998	1987	1988	1998
	m	m	m	m	m	day	day	day
Brahmaputra (Bahadurabad)	20.62	19.50	19.68	20.62	20.37	13	27	66
Ganges (Hardinge Bridge)	15.04	14.25	14.80	14.87	15.19	55	23	27

Padma (Bhagyakul)	7.58	6.00	6.99	7.43	7.5	56	47	72
Meghna (Bhairab Bazar)	7.66	6.25	6.91	7.66	7.33	30	68	68

Source: FFWC, 1998

Depending on the terrain and topography about 6 million hectares of cultivable land are susceptible to flooding. The floodplains of the country may be categorized in five classes based on their flooding characteristics, as presented in Table-7.

Table-7: Land types based on flood depth

Land type	Description	Flood depth	Nature of flooding
FO	Highland	Not flooded	Intermittent or flooded up to 30 cm
F1	Medium	30 to 90 cm highland	Seasonal
F2	Medium	90 to 180 cm lowland	Seasonal
F3	Lowland	Over 180 cm	Seasonal (<9 months)
F4	Lowland/ very lowland	Over 180 cm	Seasonal (>9 months) or perennial

Source: MPO, 1991

There exists a strong relationship between (flooding) land-type and cultivars used during monsoon (*Kharif*-II) season. Susceptibility to yield reduction of a particular variety is higher if the land in question has higher susceptibility of flooding. Land type F0 is not flooded, whereas land type F4 is flooded for more than nine months of the year with a maximum flood depth of more than 1.8 meters. About 3.3 million hectares are subjected to flood depth of 30 to 90 centimeters. An area of about 0.076 million hectares has a flood depth of more than 1.8 meters, which remains under water for more than nine months in a year.

Severe floods, which cause extensive damages to crops and some damage to property, especially roads, occur at intervals of about 7-10 years. Catastrophic floods, occurring at intervals of 20-50 years or more, almost totally destroy crops in adjoining floodplains, and also cause considerable damages to houses, roads and other infrastructure. The 1988 and 1998 floods are rated as 50-100 year events. Coverage of inundation and damage caused by major floods during the period 1954 to 1998 is presented in Table-8. Figure-6 presents spatial extent of flood 1998.

Table-8: Inundation area and damage caused by various floods during 1954-1998

Year	Area inundated	Proportion of total area	Cost of damage (approximate)	Population affected	Deaths
	Square kilometers	%	Million Taka	Million persons	Number of persons
1954	36,920	25	1,200	N/A	112
1955	50,700	34	1,290	N/A	129
1956	35,620	24	900	N/A	N/A
1962	37,440	25	560	N/A	117
1963	43,180	29	580	N/A	N/A
1968	37,300	25	1,160	N/A	126
1970	42,640	28	1,100	N/A	87
1971	36,475	24	N/A	N/A	120
1974	52,720	35	28,490	30	1,987

1984	28,314	19	4,500	20	553
1987	57,491	38	35,000	30	1,657
1988	89,970	62	> 100,000	47	2,379
1998	> 100,000	74	> 120,000	>55	1,050
2004	> 58,000	~ 40	> 200,000	>36	~ 750

Sources: Modified from Choudhury *et al*., 2003.

Note: N/A means data not available in common sources. Please note that the available flood damage information is not always complete and consistent. The high intensity floods, in terms of extent of flood, are shaded.

The south-western coastal areas are sometimes inundated by high tidal surges. There are a large number of pockets in the southern coastal areas which are deliberately made free from 'normal tidal' flooding. Marginal areas outside the embankments are prone to tidal inundation. Sometimes excessive rainwater accumulates inside an embankment which does not have adequate drainage facilities, particularly the low-lying pockets of such an embankment suffer from flood caused by drainage congestion. Head difference of water levels inside and outside the embankments, the latter remaining at a higher stage, can often lead to drainage congestion. Flood damage in embanked areas also occurs occasionally when high spring tides overtop coastal embankments.

Storm surges refer to onrush of water of high amplitudes, caused by a combination of low barometric pressure and strong onshore winds associated with tropical cyclones. They cause sudden, but temporary, flooding of coastal areas with sea-water or brackish estuarine water up to a few kilometers inland during the passage of cyclones. Storm surges are responsible for most of the casualties in the past caused by cyclones (Haider *et al*., 1991). Exceptionally, as in May 1965, storm surges extend along the Meghna estuary as far inland as the south of the Sylhet Basin, flooding adjoining land with non-saline river water. Surges of high amplitude during the November 1970 cyclone wrought widespread devastation in the coastal zones, causing loss of more than 300,000 lives.

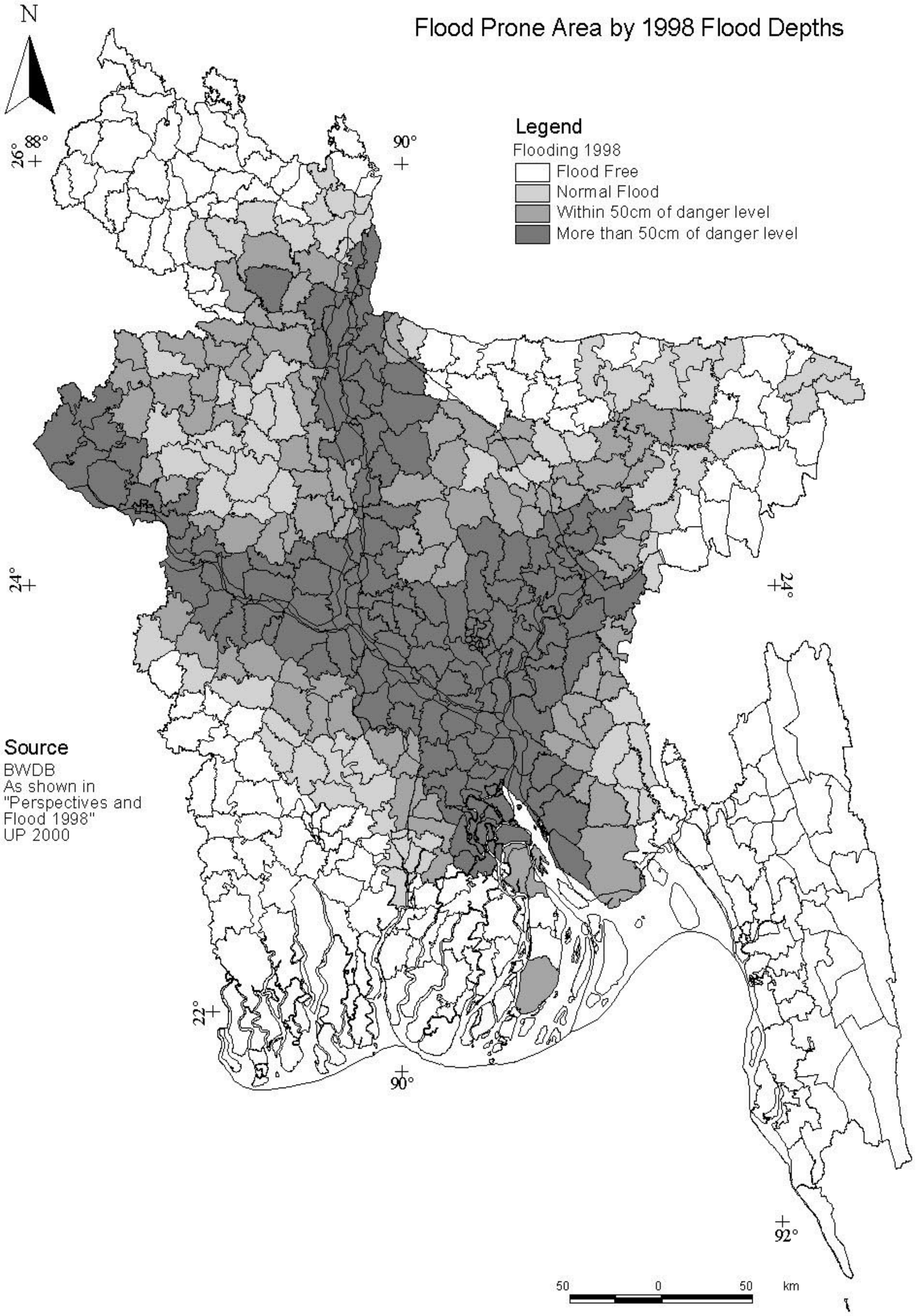

Figure-6: Map of Bangladesh showing areas which have been affected during the flood of 1998

Source: WARPO-Halcrow et al., 2004

Riverbank Erosion

Most of the rivers of Bangladesh flow through unconsolidated sediments of the Ganges-Brahmaputra-Meghna floodplain and delta. The riverbanks are susceptible to erosion by river current and wave action. River erosion includes channel shifting, the creation of new channels during floods, bank slumping due to undercutting, and local scour from turbulence caused by obstruction. The Brahmaputra, the Ganges, the Meghna, the Teesta, and the Surma-Kushiyara rivers flow within well-defined meander belts on extensive floodplains where erosion is heavy. Sudden changes are common during floods that cause rapid bank erosion. In lower deltaic areas, river bank erosion is caused by tidal currents and storm surges from the sea.

The Brahmaputra-Jamuna has changed course completely after 1762. This is a highly braided river, has steadily migrated westward in recent years, eroding the old floodplain and creating new sections of floodplain on its east bank. The Ganges, with larger areas of resistant clay on its older floodplain, is more stable than the Brahmaputra. The Bangladesh Water Development Board (BWDB) estimated that about 1,200 kilometers of riverbank has been actively eroded and more than 500 kilometers has been facing severe problems related to erosion. Satellite-image studies of the Ganges-Brahmaputra-Middle-Meghna rivers show that an area of 106,300 hectares has been lost due to erosion between 1982 and 1992, while the accretion amounted to only 19,300 hectares. The net erosion rate was therefore estimated at 8,700 hectares per annum. Erosion of border riverbanks is serious because it can cause loss of land to neighbouring countries (Halcrow *et al.*, 2001a).

Sedimentation

Bangladesh is the outlet of all the major upstream rivers 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[10]. All rivers in Bangladesh are alluvial and highly unstable. Alluvial channels consist primarily of deposited sediment that originated upstream. Constant interactions occur within the suspended sediment load of the channel, leading to significant changes in channel geometry. A part of the sediment load is deposited on the floodplain, gradually changing its topography and often severely reducing the water conveyance capacity and navigability of the drainage channels.

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 floodability of the alluvial plain.

Droughts

Drought is primarily an agricultural phenomenon that refers to conditions where plants are responsive to certain levels of moisture stress that affect both the vegetative growth and yield of crops. It occurs when supply of moisture stored in the soil is insufficient to meet the optimum need of a particular type of crop. As a consequence of usual hydro-meteorological variability, drought occurs in pre-monsoon season when the potential evapo-transpiration (PET) is higher than the available moisture due to uncertainty in rainfall while in post-monsoon season it is due to prolonged dry periods without appreciable rainfall (Karim *et al.*, 1990a). In both the seasons, due to sudden increases in temperature coupled with non-availability of rainfall causes a sharp rise in PET. One may relate to occurrence of drought with certain physical observations: (i) development of continually broken cracks on the dried up topsoil, (ii) burnt-out yellowish foliage in the vegetation cover (top yellow syndrome), particularly observed in betel nut trees and bamboo groves, and (iii) loosening of soil structure, ending up in the topsoil transforming into a dusty layer.

Pre-monsoon drought is called *Rabi* and Pre-*Kharif* drought since it affects both *Rabi* and Pre-*Kharif* crops. The commonly affected major crops include HYV *Boro*, *Aus*, wheat, pulses, sugarcane, and potatoes. Significant damages can occur where irrigation possibilities are limited. Post-monsoon

[10] There is a host of literature which provides different sets of rates of sedimentation along the three major river systems. Due to large uncertainties, no specific figure has been provided in this report.

drought is also known as *Kharif* drought as it affects *Kharif* crops. *Aman* is the most common *Kharif* crop that is affected by post-monsoon drought as its reproductive stage is severely constrained by shortage of available moisture. Table-9 presents drought prone areas by cropping seasons.

Table-9: Drought affected areas by cropping season

Crop season	Area under various drought severity class (in million ha)					
	Very severe	Severe	Moderate	Slight	Unaffected	Non-T. *Aman*
Pre-*Kharif*	0.403	1.15	4.76	4.09	2.09	-
Kharif (T. *Aman* only)	0.344	0.74	3.17	2.90	0.68	4.71
Rabi	0.446	1.71	2.95	4.21	3.17	-

Source: Iqbal and Ali, 2001.

In terms of magnitude drought exhibit a pronounced spatial distribution. The western parts of the country receive less rainfall averaging some 1400 mm as against the national average of about 2150 mm. As a consequence, susceptibility and severity of drought in the western districts are much higher than elsewhere. Availability of moisture on the top soils also determines severity of drought: the higher the capacity of the top soil to hold moisture, the lower the severity of drought. In terms of moisture retention capacities the soils of Bangladesh vary considerably. Based on the characteristics of moisture retention capacity, infiltration etc. high prevalence of drought is observed in the western districts of Rajshahi, Bogra, Pabna, Dinajpur, Rangpur and Kustia. The areas affected by *Rabi* drought is graphically presented in Figure-7.

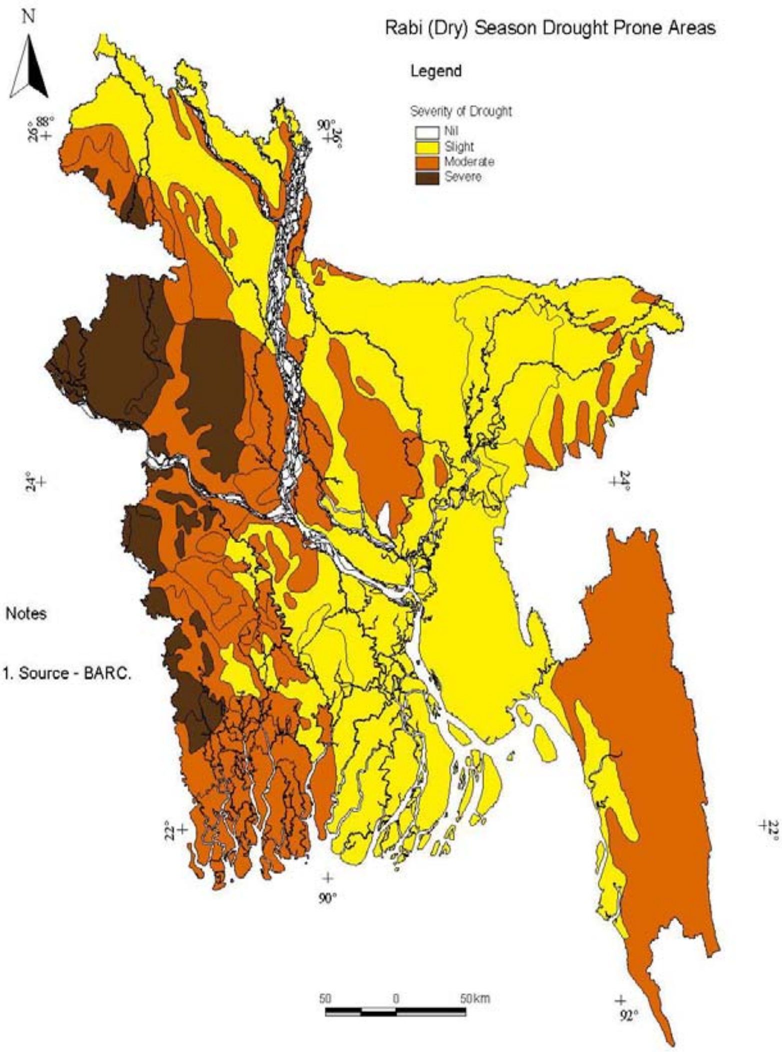

Figure-7: Map showing areas susceptible to Rabi drought

Irrigation is a widely used method to reduce drought risks. In absence of rainfall, irrigation from surface and groundwater sources prevent drought-related crop damage. Low-flow in rivers during the pre-monsoon months put constrain on surface water irrigation. In the southwestern parts of the country, due to reduced flow regime in the Ganges Dependent Areas surface irrigation becomes extremely difficult. Unfortunately, in the extreme south groundwater irrigation is also constrained due to salinity ingress.

Mirza and Paul (1992) reported that drought occurred 19 times between 1960 and 1991. Very severe droughts hit the country in 1951, 1961, 1975, 1979, 1981, 1982, 1984, 1989, and 1995. It is claimed that as high as 47% area of the country is drought vulnerable where 53% of current population live. The drought that occurred during 1978-79 took a huge toll. In 1995 drought occurred during the late *Kharif* period and caused a net reduction of 377,000 tonnes of *Aman* production.

Salinity Ingress

Ingress of salinity is a major problem in Bangladesh. The coastal zone directly affected by salinity is extensive (Karim *et al*., 1990b) and is inhabited by a large population. The zone includes major urban centres of Chittagong and Khulna.

All the rivers of Bangladesh, except for those in Chittagong in the extreme southeast, combine to form a single, broad, and complex estuary ─ popularly known as the Meghna estuary. The greatly diminished flow in the dry season allows salinity to penetrate far inland through this estuarine river system. Salinity limits opportunities for supplemental irrigation of *Aus* crops in freshwater areas and damages the same crops by flooding during very high tides. The upland progression of saline water during the dry season eliminated surface water potentials for significant land areas in the southwest, south-central and southeast regions.

Fresh groundwater for human and industrial consumption is also affected by salinity. The shallow coastal aquifers in fact have high salinity. Therefore, water supply wells must penetrate 250 meters or more to find water of acceptable quality. The recharge zones of these deep coastal aquifers are located away from coastal zones in Jessore, Kushtia, Faridpur and Comilla areas and perhaps further north. Activities which decrease recharge in these upland areas, such as flood prevention, will affect the dynamic balance within these aquifers between the salt water interface, withdrawals, and recharge.

Environmental degradation caused by salinity intrusion is a major problem in southwestern Bangladesh. The reduced flow of the Ganges in the dry season has exacerbated the process of northward movement of the salinity front, thereby threatening the environmental health of the region.

3.3 Impacts of Climate Change on Bio-geophysical Systems and Implications

Global warming and the resultant climate change could have profound effects on the water resources of Bangladesh (both surface and ground water). Translating the GCM projections of climate parameters provided in section 2, it may be concluded that the country will be highly susceptible to: (a) increased flooding, both in terms of extent and frequency; (b) increased moisture stress during dry periods leading to increased drought susceptibility in terms of both intensity and frequency; and (c) increased salinity intrusion during the low flow conditions. These changes in the physical system of the country will directly affect a number of major productive systems that include (a) crop agriculture, (b) livestock production, (c) aquaculture and fish production, (d) coastal shrimp production, and (e) forest and vegetation. Due to changes in temperature and humidity, human health will also be affected. The high susceptibility to water-based natural hazards will affect settlement of the population and also physical immobile infrastructure. Based on secondary sources, the following sub-sections provide brief understanding on anticipated impacts of climate change on bio-physical aspects of the country.

No research has so far been attempted to analyze susceptibility of riverbank erosion in reference to increased flood vulnerability under global warming. Similarly, no serious attempt has so far been made to examine how sedimentation would be affected due to increased flood vulnerability under climate scenarios. One may, however, take note that rate of sediment deposit along the river bed and adjacent floodplains might increase if duration of high intensity floods increase as a consequence of sea-level induced stronger backwater effect on receding flood water. This requires further hydro-morphological analysis.

3.3.1 Flood and Water-logging

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. The increased run-off would also aggravate the existing drainage problems and create new ones. Bangladeshi rivers, especially the major ones, have lost gradient during the past several decades. Consequently, their conveyance capacity is diminished significantly. 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.

In the coastal areas there will be stronger-than-usual backwater effect due to sea level rise induced high oceanic stage, resulting into retardation of discharge flow, particularly along the confluence points of the major rivers. As a consequence, the risk of riverine and rainfall-induced high intensity floods with prolonged duration, as in the case of flood 1998, will increase significantly. 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). Polders at risk of submergence in three southwestern Districts are shown in Figure-8. Breach of existing coastal embankments will also inundate land with saline waters.

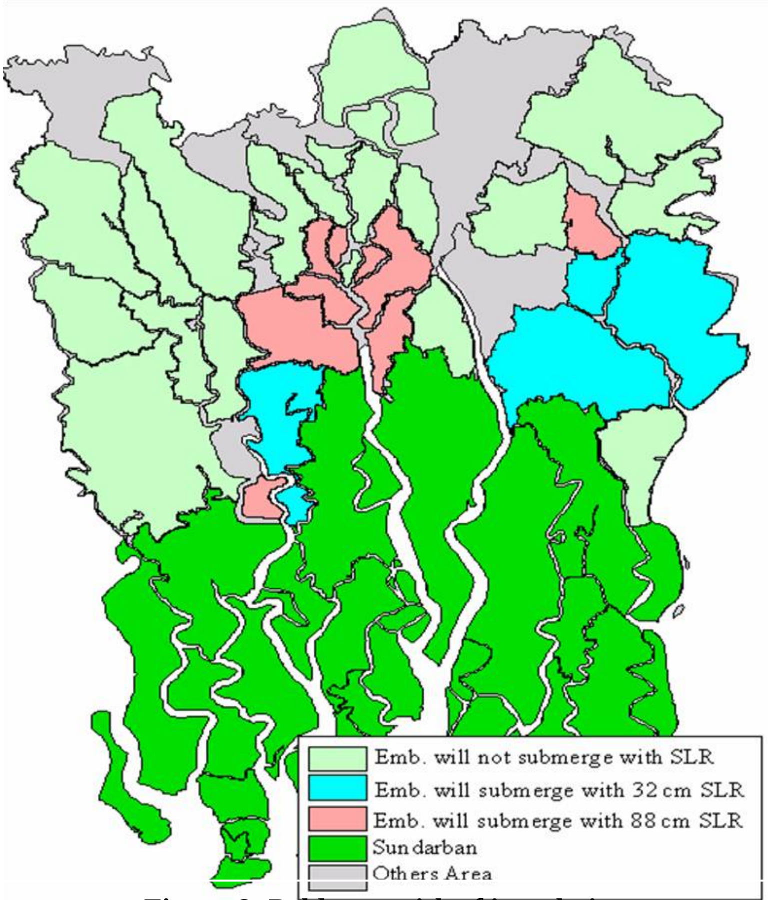

Figure-8: Polders at risk of inundation

Source: CEGIS, 2006

The current literature could not provide information whether the timing of the peak flood will be shifted and if so, in which direction. With increased rainfall, both the height and timing of peak flood levels might change (ADB, 1994; BUP-CEARS-CRU, 1994; Warrick and Ahmad, 1996). Alam *et al.* (1998) examined flood susceptibility of Bangladesh under climate change scenario. Based on their findings it may be concluded that, increased flooding would alter the relative proportions of the different land types based on flood depths, viz., FO, F1, F2, F3 and F4. The implication is that the proportion of FO (highland) would decrease, while the other land types (F1 to F4) would increase through a cascading effect of re-categorization of land types of different flood depths. Under climate change scenario about 18 per cent of current lowly flooded areas will be susceptible to higher levels of flooding while about 12 to 16 per cent new areas will be at risk of varied degrees of inundation. On an average hydrological year, flood prone areas will increase from about 25 per cent to 39 per cent.

In absence of any 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.

3.3.2 Drought

It is prognosticated that, under climate change scenario evapo-transpiration will increase significantly, especially during the post-monsoon and pre-monsoon seasons, in the backdrop of diminishing rainfall in winter and already erratic rainfall variability over time and space (Karim *et al.*, 1998). As a consequence, severity of moisture stress, particularly in the north-western districts mentioned in earlier sections, will increase leading to drought conditions. An earlier estimate suggests that the area severely affected by drought in Rabi season could increase from 4000 km^2 to 12000 km^2 under severe climate change scenario (Huq *et al.*, 1996).

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 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.*, 2001b).

3.3.3 Low Flow and Salinity Ingress

In a normal hydrological cycle, rivers suffer from low flow conditions when there is no appreciable rainfall runoff. 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 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). Bangladesh NAPA document has also highlighted the concerns regarding salinity ingress,

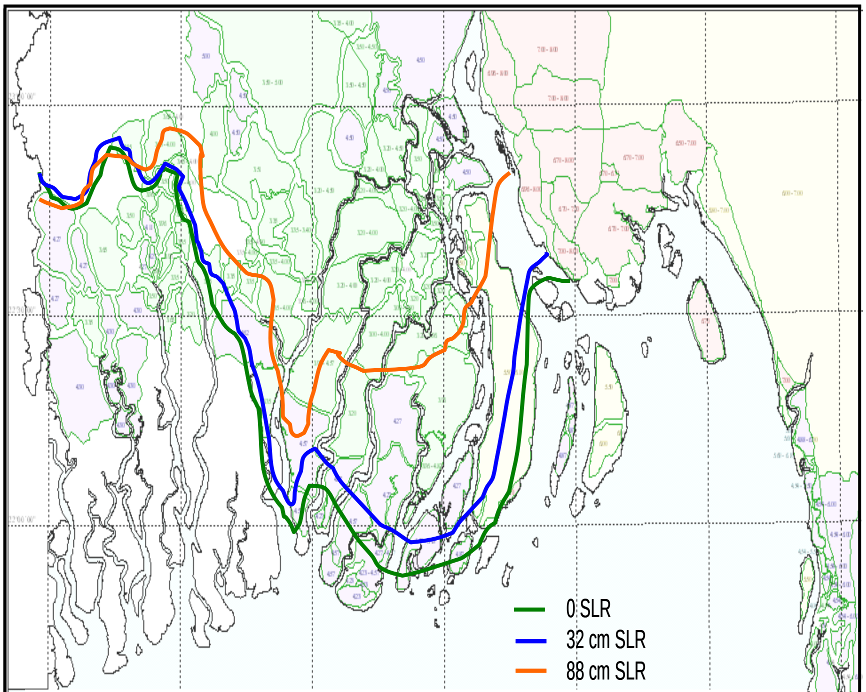

Figure-9: Line of equal salinity (5 ppm) for different sea level rise during the dry season. ***Source: CEGIS, 2006***

especially for the southwestern region (GOB, 2005). The isohaline lines on surface water systems[11], as a response to rising sea level of 32 and 88 cms, are shown in Figure-9 (drawn from CEGIS, 2006).

3.3.4 Cyclone and Storm Surge

The current level of understanding in relation to adverse impacts of cyclone and subsequent storm surge under climate change is rather tentative. In earlier writings speculations (qualitative statements) have been made that the coastal zones of the country will be increasingly vulnerable to climate change driven cyclonic storm surge (BCAS-RA-Approtech, 1994). In the published literature, no quantified estimation has been quoted to justify such claims. Ali (1999) however provided rationale that not only the frequency of occurrence of cyclones along the Bay of Bengal would increase as a response to rising Sea Surface Temperature (SST), cyclonic intensity would also increase, with a corresponding increase in surge height in newly inundated shoreline. It is, however, also argued that the surge height along the continental shelf would somewhat decrease as a consequence of sea level rise (Ali, 1999).

The latest IPCC findings reveal that, current climate models do not perform a good job of resolving the influence of climate change on cyclones owing to their relatively small spatial extent. Further, the historical record has large decadal variability, which makes any trend analysis based upon only a limited time-series data difficult to interpret conclusively (IPCC, 2001). Based on emerging insights from some climate model experiments as well as the empirical record IPCC states, "*… there is some evidence that regional frequencies of tropical cyclones may change but none that their locations will change. There is also evidence that the peak intensity may increase by 5% to 10% and precipitation rates may increase by 20% to 30%"* (IPCC 2001b).

Despite the fact that the IPCC assessment on cyclone is tentative, Ahmed (2005a) argues that the results have several major implications for Bangladesh. First, projection on no-change in cyclone tracks under climate change means that Bangladesh is likely to remain vulnerable to cyclonic hazards with perhaps a higher possibility[12] of formation of cyclones in a warmer world. This is in agreement with the results provided by Ali (1999). Moreover, the fact that peak intensities may increase by 5-10% has serious implications for a country already very vulnerable to storm surges. Finally, an increase in 20-30% in the associated precipitation could only make the concerns even more serious, particularly in the coastal embanked areas where heavy rainfall can instantaneously inundate otherwise protected agricultural lands (Ahmed, 2005a). Indeed, the recently disclosed results of CEGIS suggested that, due to sea-level rise driven backwater effect and resulting head difference along the southern reaches of a few identified coastal embankments, the embankments will face increasing water-logging (CEGIS, 2006), which will be accentuated by intense rainfall events under climate change.

3.3.5 Crop Production

Rice is by far the most important crop in Bangladesh. 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 due to constraints in irrigation), the total area suitable for rice production may in the future stagnate or possibly decrease (WB, 2000). CEGIS (2006) has shown that due to sea level rise along the southwestern region of Bangladesh Aman[13] suitable areas would decrease significantly.

Floods affect agriculture production considerably. Karim *et al*. (1996) reported that the 1988 flood caused reduction of agricultural production by some 45 per cent. In the case of the most devastating flood of recorded history, in 1998, *Aman* production potential of some 2 to 2.3 Mha could not be realized. The prolonged flood of 1998 did not allow the farmers to transplant seedlings in appropriate

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[11] The coastal polders should not face similar salinity regime. The imaginary lines are only for surface water systems.
[12] An extensive modelling exercise (using RegCM) can verify such a statement. However, results are not yet available.
[13] Referring to HYV Aman varieties.

time rendering a loss of about 3.5 Mmt. With the possibility of increasing frequency of such high intensity floods, it may be argued that *Aman* production is likely to suffer heavy damages under climate change.

A GCM-coupled crop modeling exercise was carried out by Karim *et al*. (1998). The model took into consideration a variety of soil, edaphic and agronomic parameters and examined their sensitivity to climate regime under different scenarios. It is reported that, Aus production would suffer by 27 per cent while wheat production would decline by 61 per cent under a moderate climate change scenario. Under a severe climate change scenario which is associated with 60 per cent moisture stress, yield of Boro might reduce by 55 to 62 per cent. Table-10 summarizes the output of modeling study[14]. It is interesting to note that, CO_2 fertilization would be able to prevent croploss to a certain degree, but with increasing temperature the potential yield loss could not be completely offset by increase in CO_2 concentration in the atmosphere. The Bangladesh NAPA (GOB, 2005) is found to be in full agreement with the earlier results.

Table-10: Rice and wheat production under different climate change scenarios

Simulation	HYV *Aus*		HYV *Aman*		HYV *Boro*		Wheat	
	('000' tonnes)	Percent change	('000' tonnes)	Percent change	('000' tonnes)	Percent change	('000' tonnes)	Percent change
Baseline (1994-95)	702	0	4,484	0	6,200	0	890	0
CCCM	512	-27	4,170	-7	6,014	-3	712	-20
GFDL	512	-27	3,901	-13	5,766	-7	347	-61
330 ppmv CO_2 +2°C	569	-19	3,901	-13	5,952	-4	561	-37
330 ppmv CO_2 +4°C	435	-38	3,363	-25	5,766	-7	285	-68
580 ppmv CO_2 +0°C	920	31	5,605	25	7,626	23	1,228	38
580 ppmv CO_2 +2°C	793	13	4,977	11	7,440	20	881	-1
580 ppmv CO_2 +4°C	660	-6	4,529	1	7,192	16	534	-40
660 ppmv CO_2 +0°C	983	40	5,964	33	8,060	30	1,317	48
660 ppmv CO_2 +2°C	856	22	5,336	19	7,874	27	970	9
660 ppmv CO_2 +4°C	730	4	4,888	9	7,626	23	614	-31

Source: Karim et al., 1998

Under normal hydrological regime salinity ingress along the coastal rivers not only cause reduction of about 0.2 Mmt of rice production, it also forces farmers to forfeit the potential of the most benefiting crop. With the possibility of increasing soil salinity under climate change scenarios, it is highly likely that foodgrain 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 suffer over two-fold yield reduction (Habibullah *et al*., 1998).

3.3.6 Aquaculture

In recent years, aquaculture has shown great prospects, especially in areas that are now virtually flood free due to presence of embankments. A large proportion of pond/water tanks inside embankments are now utilized for fish culture (pisciculture). Fish culture, in most areas, is a year-round activity. If there is any breach in embankment, the culture ponds may get washed off and fish are released in open water. This may also happen during a high intensity flood, when water from outside easily overtops embankments. Although the fish thrive in openwater, it inflicts losses to the fish-farmers. It is already known that climate change would increase the extent of monsoon flooding. Therefore, the potential threat to culture fisheries would also increase under climate change (GOB, 2005).

[14] The limitation of the study was that, it did not take time-dependent climate variables into consideration. As a result, there are uncertainties in assigning any time frame to such a drought condition.

3.3.7 Coastal Shrimp Culture

Stronger surge and tidal bores would increase potential for saline water to overtop coastal embankments. Shrimp farms outside embankments create earthen mini-polders, locally known as *ghers*, to produce shrimp in captivity. It is now a days a big business in the coastal districts of Cox's Bazaar, Satkhira, Khulna and Bagerhat. High tides would certainly threaten these *ghers* both inside and outside embankments (WB, 2000). On the other hand, salinity ingress in new areas to the north of current shrimp growing zones would facilitate shrimp business (CEGIS, 2006).

General rise in surface water temperature would also put shrimps into heat related stress. It is found that, if the temperature crosses a threshold of 32˚C, the small shrimp fries would show very high rates of mortality. In April the temperature is already quite high. Simultaneously, warmer water might appear conducive for algal bloom – the latter having detrimental effects on growth of shrimps. Climate change can, therefore, put this profitable business into uncertainty.

3.3.8 Livestock

In addition to affecting human beings, natural disasters cause tremendous sufferings for the livestock population of Bangladesh. Livestock suffer large-scale death in cyclonic storm surge (Haider *et al.*, 1991). Prolonged flood can also cause death of livestock through a number of direct and indirect mechanisms (Ahmad *et al*., 2000; Choudhury *et al.*, 2003). During droughts, livestock in Bangladesh do not suffer death, but lack of water increases their vulnerability to diseases. Since climate change would increase susceptibility to natural disasters, as mentioned in earlier sections, the anticipated toll on livestock sector would be quite high (Ahmed, 2005a; GOB, 2005).

The sufferings of livestock in the coastal zone are much higher than in other parts of the country. Field observations clearly suggest that, livestock density is relatively low in the coastal areas, particularly in the southwestern parts of the country. The local elderly informed that, gradual increase in salinity also increased competition for freshwater resources, the livestock suffered the brunt of such a calamity (RVCC, 2003). Animals use to have least access to freshwater sources during the dry season. Due to drinking of poor quality water these animals fell victim to diseases, which reduce their economic efficiency (draught power, milk production etc.). Ultimately, these poor animals are sold out. Lack of grazing land and proliferation of shrimp areas (*ghers*) are also identified as potential reasons for decreasing population of livestock in coastal areas. Under climate change, these factors are likely to be affected further. It may, therefore, be concluded that the livestock sector would also be vulnerable to adverse impacts of climate change.

3.3.9 Forest and Vegetation

The Sundarbans forest, the home of many endemic species including the Royal Bengal Tiger (*Panthera tigris*), will be severely affected under climate change. The mangrove forest depends largely on the freshwater supply along the Ganges system. Under climate change induced aggravated low-flow conditions, the Gorai system might not be able to supply adequate quantum of freshwater. The problem is likely to be compounded by withdrawal of surface flows in the upstream areas to offset increasing moisture stress. In such a scenario, salinity is likely to penetrate inland and the salinity regime, on which the succession process of the vegetation of the forest depends, will be disturbed, leading to a gradual decline in the forest vegetation. It is inferred that poor quality shrubs will dominate with increasing salinity and high-value timber species will gradually disappear (Ahmed *et al*., 1998b). The recent research findings suggest that vegetation health index for Sundri species (*H. fomes*) would deteriorate significantly, as graphically presented in Figure-10 (drawn from CEGIS, 2006).

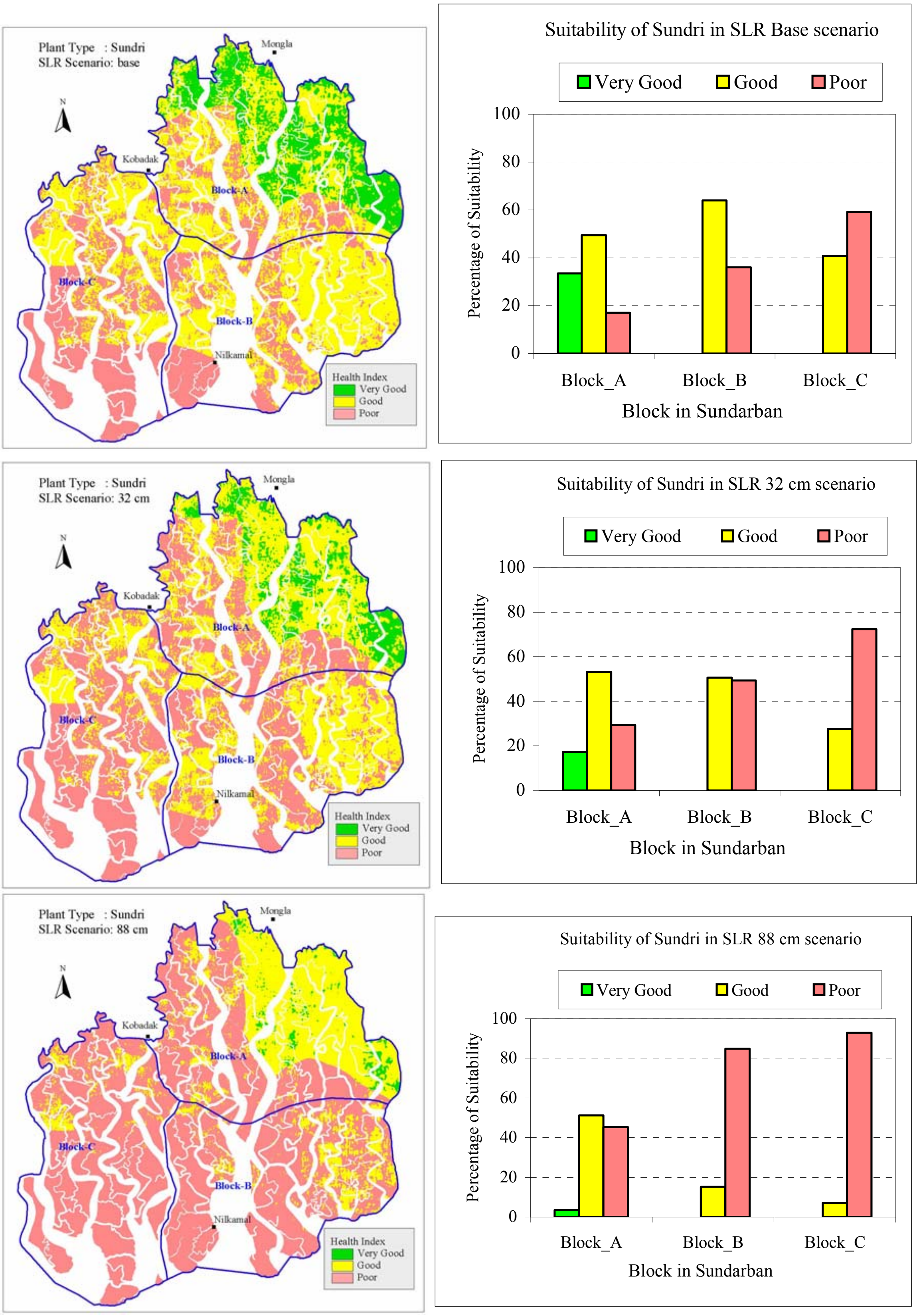

Figure 10: Plant Type – Sundari – health Index under different SLR scenarios

Source: CEGIS, 2006

3.3.10 Human Health

There exists limited information towards understanding impacts of climate change on human health. Climate variability is strongly linked with activity of pathogens (WB, 2000; Koelle *et al.*, 2005). Rodó *et al.* (2002) found increases in cholera cases in Bangladesh with increases in intensity of El Niño events. Incidences of pathogen-induced diseases would likely to be increased under climate change. Incidence of malaria and dengue fever are common in Bangladesh. Increase in surface temperature would practically help parasites such as mosquitoes. One may therefore infer that deadly diseases such as malaria, dengue etc. would put human health into higher risks under climate change (Agrawala *et al.*, 2003). 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.

From internationally published sources, 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 (Nelson, 2003). However, the study restricted to DALY index only, which limits its application towards understanding the total health sector implications of climate change.

3.3.11 Settlements and Infrastructure

About half the population of Bangladesh falls below poverty line. Under the prevailing socio-economic circumstances, it is easily understandable that the poor do not have good quality houses. Moreover, natural disasters often take huge toll on poorly built houses and sanitation infrastructure (Ahmad *et al.*, 2000). Human settlements are, therefore, highly vulnerable to climate change induced floods and cyclonic storm surges.

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). Even flood protecting embankments are threatened to be breached during high intensity floods. The 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 (Haider *et al.*, 1991; Haider, 1992). 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.

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 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).

3.3.12 Peoples' Livelihoods

Since climate change will have significant influence on water-related hazards and disasters, peoples' livelihoods will also be severely affected (RVCC, 2003; Ahmed and Schaerer, 2004; Asaduzzaman *et al.*, 2005). Not only subsistence agriculture will be affected adversely, food security of the poor people will be at risk, they will face adverse health effects due to outbreaks of pathogen-driven and water borne diseases, their settlements will also be deteriorated, and their overall quality of life will be diminished. Drawing from Asaduzzaman *et al.* (2005), the Bangladesh NAPA also commented that the anticipated adverse impacts of climate change on peoples' livelihoods will be disproportionate on the poor (GOB, 2005). Ahmad and Ahmed (2002) reported that frequent disasters might trigger out-migrations from impacted rural areas and create ecological refugees within Bangladesh.

4. ADAPTATION TO CLIMATE CHANGE

4.1 Adaptation Possibilities: A brief Overview of Options

The word adaptation has been evolved from the term 'adapt', which means "making things/conditions/situations more suitable by altering". According to Smit *et al.* (2000), 'adaptation' refers to both the process of adapting and the condition of being adapted. The most commonly available definitions of adaptation, in relation to climate change, are provided in BOX-1.

BOX-1: Definitions of Adaptation to Climate Change

Adaptation to climate is the process through which people reduce the adverse effects of climate on their health and well-being, and take advantage of the opportunities that their climatic environment provides (Burton, 1992; Burton, 1997);

Adaptation involves adjustments to enhance the viability of social and economic activities and to reduce their vulnerability to climate, including its current variability and extreme events as well as longer term climate change (Smit, 1993);

The term adaptation means any adjustment, whether passive, reactive or anticipatory, that is proposed as a means for ameliorating the anticipated adverse consequences associated with climate change (Stakhiv, 1993);

Adaptation to climate change includes all adjustments in behaviour or economic structure that reduce the vulnerability of society to changes in the climate system (Smith *et al.*, 1996);

Adaptability refers to the degree to which adjustments are possible in practices, processes, or structures of systems to projected or actual changes of climate. Adaptation can be spontaneous or planned, and can be carried out in response to or in anticipation of change in conditions (Watson *et al.*, 1996).

A careful analysis of the above definitions suggests that, all these refer to adjustments in a system in response to climatic perturbation and/or stimuli, but they also indicate differences in scope, application and interpretation of the term adaptation (Smit *et al.*, 2000). Adaptation can refer to climate change, to change and variability, or just to climate. Adaptation can be in response to adverse and/or favourable effects of climate variability and change, which refer to past, actual or anticipated conditions, changes or opportunities.

In general, adaptations are mere reflections of 'needs of adjustments' felt by the impacted individual, household, and community. However, 'needs of adjustments' are largely characterized by extent of adverse impacts. In Bangladesh, water-related impacts of climate change warrant the highest attention for adaptation due to the severity of such impacts and their socio-economic implications, as elaborated in Chapter-3.

The implications of high intensity floods cannot be overemphasized in Bangladesh. Management of flood in future will remain a major challenge, especially in view of further densification in increasingly flood vulnerable lands (Ahmed *et al.*, 1998a, Faruque and Ali, 2005). Creation of flood defense along the major rivers has been recommended by several authors (Alam *et al.*, 1998; Mahtab, 1989, Faruque and Ali, 2005). Community efforts to cope with floods can tremendously benefit from issuance of early warning. Improvement of current flood warning system and dissemination in people-friendly manner are thought to be highly potential adaptation option for future (Ahmed, 2005a). To enable this, one may contemplate further improvements in terms of modelling of monsoon rainfall throughout the GBM region and effective regional cooperation for on-time transfer of data from upstream areas along the GBM river systems as necessary pre-conditions for adaptation (Mirza and Ahmed, 2003).

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.*, 1998a, Ahmed, 2005a; Faruque and Ali, 2005). Pumping out water to remove water logging, especially in polder areas, has already been practiced, which will likely to be considered as an adaptation option for future (Faisal *et al.*, 2003). 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). Similar to that of Multi-purpose Cyclone Shelters, flood shelters should be built in FVAs (Choudhury *et al.*, 2003; GOB, 2005). In recent years, community-based flood management practices had shown high potential, which could also be considered as an important modality to adapt to climate change induced floods (Ahmad *et al.*, 2004). A large number of small steps have been considered to advance community-based flood management, each of which deserves due consideration.

For drought management, making water available to offset moisture deficit appears to be the major adaptation modality (Karim, 1996). However, creation and recreation of water storage systems (ponds, *khals*, reservoirs etc.) – operated and maintained by vulnerable communities – needs to be given due emphasis (WB, 2000). Choice of low-water-consuming crops instead of paddy will reduce immense pressure on dwindling ground water aquifers (Ahmed, 2005b). Such an adaptation will not only help diversify crop agriculture, it will also counteract gradual lowering of piezoelectric surface of groundwater aquifer system (Ahmed, 2005a). Capacity building for advanced irrigation techniques could also be considered as an important adaptation option in order to conserve available water resources. Conjunctive use of water for irrigation, as highlighted in National Water Policy, might also be considered as an important adaptation option (Ahmed, 2004a). Resuscitation of surface water bodies including silted-up rivers and rivulets should be given due priority in order to maintain water bodies even during the dry season for irrigation purposes (Ahmed *et al.*, 1998a). The proposed Ganges barrage is thought to offer huge potential for adaptation, especially for the entire Southwestern region (BUP, 2001; CEGIS, 2006). Regional cooperation towards ensuring augmentation of dry seasonal flows in international rivers has also been considered as an adaptation option (Ahmed, 2004a; Ahmed, 2005a).

Maintaining a sustained flow regime in coastal rivers throughout the dry season and flushing of brackish water zones with increased volumes of freshwater will help adaptation to increasing salinity ingress under climate change. Ahmed (2004a and 2005a) argued that, investing on a barrage on the Ganges River would profusely benefit the southwestern region of the country by pushing salinity front towards the bay. Indeed, CEGIS (2006) found this measure as highly beneficial against ingress of salinity under climate change. It is also found that the option of having a barrage with proposed link canals to maintain a good flow regime along Betna-Bhairab, Gorai, and Madhumati systems would provide high dividend in terms of salinity control under climate change.

Deaths arising from cyclones and associated tidal bores (both human and livestock) could be minimized by maintaining the Cyclone Preparedness Programme, and further strengthening the programme by means of building new MCSs, killas and other facilities along the coastal zone (Mahtab, 1989; Ali, 1999). The dilapidated structures need to be replaced by new ones, whereas those requiring occasional repairs should be repaired to enhance capacity to save lives when needed. The polders which might be at risk of inundation due to rising sea levels and/or by invigorated tidal waves should be identified and rationalized, in order to enhance their efficiency towards safeguarding lives, crops, and properties (Ahmed, 2005a). NAPA for Bangladesh proposed community focused coastal afforestation as a priority adaptation measure to reduce climate hazards (GOB, 2005).

According to Ahmed (2004a), there exist a good number of policy elements in the current policy regime which offer good adaptation potentials. Efforts need to be made to analyse these options further and through institutional coordination, a few of these adaptation measures – as outlined earlier in this section – be implemented on a priority basis. The NAPA has forwarded a few prioritized programmes in water sector (GOB, 2005), which could be given high priority. This itself has been regarded as an institutional adaptation, which may be advanced further as well as mainstreamed by the development of a proposed 'climate change adaptation policy' (Ahmed, 2004a).

In addition to adaptation in water-resources sector, one must consider adaptation in agricultural sector. The gravity of the issue and its importance on people's livelihoods deserve special treatment, which is why the potential adaptation options in agriculture are discussed separately in the following section.

According to WB, the risk associated to human health in tropical developing countries is one of the salient risks of climate change (WB, 2000). Bangladesh's current vulnerability to outbreaks of cholera and other waterborne and diarrheal diseases such as dengue or dysentery needs to be given due importance in view of increasing risk potentials caused by climate change induced drainage congestion and standing water. Treating pathogen-laden water with a mixture of lime, bleaching powder and alum, as provided in Ahmad *et al*. (2004), should be given due importance to avoid large-scale outbreak of water borne diseases. Inadequate provisions for drinking water in saline affected regions adds to people's vulnerability, which needs to be given high priority towards designing national adaptation programmes (Ahmed, 2005a). Providing saline free drinking water should be considered as an immediate adaptation in view of current as well as future health risks (Ahmed, 2004b). The pressure on the availability and access to safe water, in particular during the dry period, and the increasing reliance on groundwater are an additional threat. RVCC project considered designation of community ponds to establish PDFs as an adaptation (RVCC, 2003). Moreover, sinking deep hand tubewells, subject to availability of groundwater sources, and building community/household based rainwater harvesting units in water scarce regions should be considered as adaptation measures, as promoted through the RVCC project (Ahmed and Schaerer, 2004).

Awareness needs to be increased among illiterate and poor people, especially along the drier western parts of the country, to combat heat-stress related health disorders. Improved cyclone as well as flood shelters, with increasing capacity and coverage, are likely to reduce overall death tolls in case of climate change induced high intensity disastrous events. Similarly, building relatively stronger houses by low-cost retrofitting along the cyclone-affected coastal regions could save lives as well as assets (RVCC, 2003). Safe use of carbolic acid would reduce susceptibility to snake bites in flooded regions. Use of oral rehydration saline for treating diarrheal patients will continue to save lives. Other major adaptation proposed for human health involves improving the health care system, which is needed anyway to address the current human health situation. These improvements could significantly reduce the risks to human health from climate change (WB, 2000). Thus, the benefits of improving health care are likely to be even greater when avoided health impacts of climate change are accounted for.

Very little research has so far been undertaken to fully appreciate implications of climate change on ecosystems and biodiversity. However, it is suggested that ecosystems and biodiversity may be at greatest risk of all sectors sensitive to climate change (WB, 2000). Since the management of ecosystems is still relatively weak in its institutional realization and the institutions that are involved lack the capacity, adaptation to climate change for ecosystems and biodiversity warrant special institutional arrangements. Maintaining a sustained freshwater flow along the distributaries of the Ganges River, particularly in the dry season, has been recommended as a viable adaptation option

(Ahmed, 2004a). CEGIS (2006) considered two adaptation options[15]: the 'Ganges barrage option' and the option for 'augmentation of lean flow of River Gorai'. Modelling results provide ample evidence that both the options will be useful for adapting to increasing salinity along the Sundarbans.

4.2 Adaptation in Agriculture: Identifying Potential and Limitations

Crop agriculture in Bangladesh is highly susceptible to variations in the climate system. It is anticipated that crop production would be extremely vulnerable under climate change scenarios, and as a result, food security of the country will be at risk. Despite being highly vulnerable, very little efforts have so far been made to understand potential of agricultural adaptation in Bangladesh. Ahmed (2000) made an early attempt to analyse the adaptation potential of the country's crop agriculture in a warmer world. Faisal and Parveen (2004) examined food security aspect and implications of climate change, however adaptation potentials were not discussed. A brief account of adaptation types, based on IPCC typology of adaptation (UNEP, 1996), and limitations of a few adaptation options in agriculture are provided below.

Bear Crop Losses When potential loss of a standing crop is totally accepted by the growers, bearing crop losses is an adaptation option. It is however criticised that the option is rather theoritical, with limited applicability in Bangladesh (Ahmed, 2000). In practice, it is argued that, it is possible only when the cost of adaptation appears to be higher compared to the net crop loss. Such responses are often strategic and situation-specific.

Share Losses The anticipated crop losses may be shared among the stakeholders. Compensating the farmers for trying out agricultural activities under high threats of crop loss can be a potential mechanism for sharing loss. Provision of insurance against crop loss has worked well in advanced economies. Provision of government subsidies and remission of taxes for the farmers operating in susceptible croplands could be other possible options where some of the losses might be shared among the different stakeholders. Loss sharing strategies necessitate strong political will, adequate financial resources and careful planning. Loss sharing mechanisms can be a very local affair, and sometimes can even be extended to the worldwide family of humanity.

Modify the Threats to Crop Production This appears to be the mostly practiced option in Bangladesh. Vulnerability analysis may provide important lessons concerning the nature and extent of the threats to crop production under a given climate regime. In such cases, adequate precautionary measures might possibly modify the threats. Although most of the precautionary measures are anticipatory in nature, there might be some spontaneous measures as well. Modifications may be approached either on an individual or a collective basis. Many such measures are technology-oriented and may require early investment for research and extension.

Development of drought and/or salinity tolerant varieties, switching to alternative cropping patterns with respect to altered agro-ecological zones etc. could modify the threat to a significant extent. Good extension programmes would help achieve awareness up to a desired level so that the farmers may respond to the threatening environmental factors. Adequate policy framework and market instruments (technology availability at subsidized rates, credit, etc.) coupled with social engineering processes could facilitate implementation of such measures.

Prevent Adverse Effects Some measures might consider preventing the losses in agricultural production. Preventive measures are anticipatory and might require large-scale investments. Building of large embankments to protect prime agricultural lands from excessive flooding may be cited as an example of preventive measure. Preventive measures often involve financial and institutional support of the government for planning and implementation.

Change Land Use In case it becomes extremely risky to continue agricultural activities under an altered climate scenario, an alternative land use might be considered as the next available option. If the

[15] According to OGDA Study, commissioned by the GOB, these two options for the betterment of OGDA areas are known as Option No. 8 and 7, respectively (Halcrow *et al*., 2001b).

suitability of Aus[5] paddy in pre-*Kharif* months (March-June) appears to be too low, the farmers should alter the land use and instead grow other suitable crops. However, such alterations should ideally lead to acceptable economic returns, optimizing social goods and services. In *beel* areas, growing *kachu & kachu-mukhee* (a local vegetable) appears to be better land use option than growing paddy with a risk of higher levels of inundation. In water logged areas, attempts have been made under the RVCC project to create floating gardens (i.e., hydroponics) by the use of water hyacinth and grow vegetables. The application of a indigenous practice through capacity building and extension allowed farmers of Jessore District to profitably change their land use and maintain livelihoods (Ahmed and Schaerer, 2004).

Change Location Change of location entails relocation of agricultural activities in areas that are not likely to be adversely affected. For Bangladesh, this appears to be a theoretical approach. Here access to land resources per capita is already high and there is hardly any unproductive land. Relocation, therefore, might not be socially accepted. Opting for relocation may necessitate long-term planning involving the farmers, farming communities and local governments. Planning for relocation has to be done through consultations among those involved. The farming communities that would have to accept such relocation in their areas should be compensated for lost opportunities. On the other hand, change of location may be a spontaneous adaptation (rather coping) measure in the highly vulnerable areas and people may become *climate change refugees* (UNEP, 1996). Table-11 highlights a few agricultural adaptation, according to the IPCC typology of Adaptation (Ahmed, 2000).

Table 11: Adaptation measures and requirements for crop cultivation under climate change

Adaptation Measures	Requirements	Comment
Bear loss (no adaptation) - Loss of production - Loss of assets		Hypothetical, highly unlikely to take place.
Share losses - Crop insurance - Cooperative management - Governmental subsidies	Additional investment in terms of premium. Agreement for sharing the output. State allocation for offering subsidies. Adequate legal and institutional framework.	Provisions to be made. Political motivation is required.
Modify the threats - Preparedness (early warning) - Awareness and training - Investment for structural measures	- Research & extension - Extension, media campaign - Investments (anticipatory) - Crop calendar adjustment - Opting for less susceptible crops	Farmers are already practicing it, based on ancestral behaviour/ knowledge. Manifold opportunities are plausible, barrier removal and implementation could be less costly. High priority option.
Prevent adverse effects - Structural measures	- Large investment - Political motivation - Long-term planning	Investment intensive option. Financial constraints might hinder implementation process.
Change land use - Alternative cropping - Abandon crop agriculture	- Innovation through research, investment - Means of survival, skills for alternative employment	Unless alternative employment opportunities are created, it is not likely to be accepted socially.
Change location - Relocate to less vulnerable places	- Free cultivable land	Heavily constrained due to unavailability of fallow cropland.

Source: Modified from Ahmed, 2000.

The project titled Reducing Vulnerability to Climate Change (RVCC), implemented in six southwestern Districts of Bangladesh during 2002 till 2005, applied a few interesting adaptation measures in a bid to reduce vulnerability of communities to climate change by increasing people's coping capacity (RVCC, 2003; Schaerer and Ahmed, 2004). The agricultural adaptations worth special mention, due primarily to their simplicity and their overall social acceptance. Table-12 highlights the agricultural adaptation measures considered under the project.

Table 12: Strategic Approaches Considered for Agricultural Adaptation for RVCC Project

Strategy	Measure	Brief Description of Measure
Household level strategies in agriculture (crop, fishery, agro-forestry, & livestock)		
Increase food through agriculture	Drought tolerant crops/vegetables	Introduction of drought tolerant crops such as groundnuts, watermelon, etc.
	Floating gardens	Cultivation of vegetables on floating beds of water hyacinth (hydroponics)
	Low-cost irrigation	Demonstration of treadle pump and other simple technologies for irrigation
	Homestead gardening	Cultivation of vegetables and fruits on homestead plots for consumption and market
	Saline tolerant non-rice crops	Introduction of saline tolerant varieties of chili, mustard, maize and potato
Increase income through alternative livelihoods	Embankment cropping	Cultivation of beans, gourds, okra & other vegetables on embankments surrounding prawn *ghers* (ponds)
	Integrated farming systems	Using small area of land, small water body, and surrounding embankments to produce rice, fish and vegetables
	Cage aquaculture	Small-scale fish farming in cages, implemented in household ponds or common water bodies
	Prawn fish poly-culture	Prawn and fish culture in fresh-water *ghers* (ponds)
	Shrimp fish poly-culture	Shrimp and fish culture in salt-water *ghers* (ponds)
	Cattle rearing	Raising cattle for consumption and market
	Poultry rearing	Raising chickens to produce meat and eggs for consumption and market
	Crab fattening	Collection, rearing and feeding of crabs for a period of 15 days to increase their market value
	Duck rearing	Raising ducks to produce meat and eggs for consumption and market
	Goat rearing	Raising goats for consumption and market
	Pig rearing	Raising pigs for consumption and market
	Apiculture & honey processing	Beekeeping and processing of honey for market
	Nursery & homestead afforestation	Establishment of community nurseries and distribution (with handling instructions) of indigenous varieties of tree saplings (mango, coconut, *sofeda, korai*, guava, *mehaguni*, neem, *kewra*, etc.) to beneficiaries for homestead planting
	Saline tolerant tree plantation	Planting of saline tolerant fruit and timber trees for longer term income generation
	Mele (reed) cultivation	Cultivation of reeds that are used to produce mats that are widely used for sitting and sleeping on

Source: Modified from Schaerer and Ahmed, 2004.

Limitations of Agricultural Adaptation

It is reported that the existing institutions had inherent inefficiencies, lack of foresight in planning for the future, poor coordination among relevant institutions, poor information assimilation capacity and lack of trained and motivated personnel (Ahmed, 2000). As a result, those often proved to be ineffective. The central government could not successfully utilize the full potential of the local government and the latter could not assume the full responsibility of implementing local-level planning due to weaknesses in governance system. This made it difficult to implement development activities at the grassroots. All these are possible barriers to successful adaptation, which might have direct implications in agricultural sector.

People's lack of understanding might also be considered as a possible barrier. Lack of understanding on far-reaching implications of certain actions considered by one can jeopardize adaptation options taken by many. Resorting to alternative livelihood options could be of immense help if understood their merits properly and planned early. Capacity building might be a pre-requisite to enhance people's understanding.

Poverty might be identified as another potential barrier. Many people would not be able to take advantage of crop insurance due to acute poverty. It was argued that, in order to overcome the limitations of adaptation the first step should be to strengthen the institutions which would enable and facilitate the farming communities to go for adaptation measures (Ahmed, 2000). Weaknesses in the current legal framework were also considered to be a limitation. Weak institutional coordination, especially among large numbers of institutions dealing with agriculture and support facilities, might also be identified as a limitation. Strengthening of the agricultural extension services was recommended as an institutional adaptation towards safeguarding future agricultural activities.

Financing investments in agriculture may appear a major issue, especially amongst poor farmers (Warrick and Ahmad, 1996). Requirements for cash investment soon after a major flood event limit cultivation of cash crops such as vegetables (brinjal) and spices (chilli), as observed in Jamalpur District. Early investments in relatively highlands for seedbeds could not be possible, even though the benefits of doing so were known to the farmers of the same region (Choudhury *et al*., 2004). Lack of adequate credit facilities is reported as major constraints of coping in agriculture (Ericksen *et al.*, 1996; Asaduzzaman *et al.*, 2005).

4.3 Adaptation Measures as Prioritized in NAPA

By collating available information from literature and through four regional consultations, the NAPA document highlighted a few adaptation measures and prioritized them. The following are the adaptation measures which have received endorsement of the Government of Bangladesh through NAPA exercise. It is important to note that the proposed adaptation measures are primarily based on existing coping mechanisms and practices, as well as 'needs based suggestions' forwarded by national experts in relevant field/sector.

Intervention Type Measures

- Promoting adaptation to coastal crop agriculture to combat salinization through maize production under Wet Bed No-tillage Method and Sorjan systems of cropping in tidally flooded agro-ecosystem.
- Adaptation to agriculture systems in areas prone to enhanced flash flooding – North East and Central Region through no-tillage potato cultivation under water hyacinth mulch in wet sown condition, and Vegetable Cultivation on Floating Bed.
- Promoting adaptation to coastal fisheries through culture of salt tolerant fish especially in coastal areas of Bangladesh.
- Adaptation to fisheries in areas prone to enhanced flooding in North East and Central Region through adaptive and diversified fish culture practices.
- Construction of flood shelter, and information and assistance centre to cope with enhanced recurrent floods in major floodplains.
- Reduction of Climate Change Hazards through Coastal afforestation with community focus.
- Providing drinking water to coastal communities to combat enhanced salinity due to sea level rise.
- Enhancing resilience of urban infrastructure and industries to impacts of climate change including floods and cyclone.

Facilitating Type Measures

- Capacity building for integrating Climate Change in planning, designing of infrastructure, conflict management and landwater zoning for water management institutions.
- Exploring options for insurance and other emergency preparedness measures to cope with enhanced climatic disasters (e. g. flood, cyclones and drought).
- Mainstreaming adaptation to climate change into policies and programmes in different sectors (focusing on disaster management, water, agriculture, health and industry).
- Inclusion of climate change issues in curriculum at secondary and tertiary educational institution.

- Climate change and adaptation information dissemination to vulnerable community to raise awareness.
- Promotion of research on drought, flood and saline tolerant varieties of crops to facilitate adaptation in future.
- Development of eco-specific adaptive knowledge (including indigenous knowledge) on adaptation to climate variability to enhance adaptive capacity for future climate change.

4.4 Recommended Institutional Issues of Adapting to Climate Change

A number of institutional issues have been recommended by various authors in order to advance adaptation to climate change in Bangladesh (Ahmed *et al*., 1998a; Ahmed, 2004a; Ahmed, 2005a; Choudhury *et al*., 2004; Thomalla *et al*., 2005). Mainstreaming adaptation in development thinking and practices has been recommended as a priority (Ahmed and Haque, 2002; Huq *et al*., 2003). Ahmed (2004a) revealed that the basic premise of adaptation to climate change has been grounded in the policy pronouncements; which needed to be formally recognized as another dimension of concern. Another institutional recommendation was to give climate change its due importance in decision-making processes.

It is necessary to understand that most of the climate change induced problems are likely to be exhibited in the form of water-related problems. Since climate change will have severe adverse impacts on agriculture and livelihoods and well being of the poor will most likely be at risk, a holistic policy approach should be considered.

It is recommended that, in order to mainstream adaptation to climate change, specific institutional guidelines need to be developed, which will provide for mechanisms on how inter-ministerial coordination will be achieved, how inter-ministerial policy conflicts will be resolved and who is supposed to mainstream adaptation to climate change, in which direction (Ahmed, 2005a). It is argued that, the current institutional authority revolves around two national institutions[16], leading to a potential impasse in terms of integrated and coordinated approach towards mainstreaming adaptation (Ahmed, 2004a). Removal of such institutional hindrance is therefore recommended. NAPA for Bangladesh is found to be in full conformity with the integrated approach of adaptation (GOB, 2005).

Ahmed (2004a) highlighted a few inter-sectoral policy conflicts, which might be counter productive towards implementing adaptation. It is recommended to establish an appropriate institutional regime, supplemented by the creation of a policy and regulatory regime. It is also recommended that the proposed Climate Change Policy should be housed and implemented under a supra-ministerial institutional platform, in order to facilitate its smooth functioning and to avoid unnecessary confusion. The proposed institution must be adequately empowered so that it can operate in cooperation with other relevant sectoral ministries[17]. To facilitate its functions, it may invite designated ministerial focal points to ensure coordination and cooperation among relevant line ministries. It is recommended that the pronouncement of the Coastal Zone Policy and the applications of generic guidelines provided in the Standing Orders on Disaster on horizontal and vertical integration may be revisited towards developing the proposed Climate Change Policy.

Recognizing that there exists a lack of awareness regarding all aspects of climate change, it is recommended that the government would consider steps towards enhancing awareness at all levels (WB, 2000; GOB, 2005). Building capacity through training appeared a useful mechanism to enhance human ability to adapt to a given climate condition (RVCC, 2003; Ahmed and Schaerer, 2004). Mainstreaming concerns of climate change would not take place without enhancing human capacity to analyze and respond. It is recommended that government officials, especially those dealing with water resources, agriculture, land-use, human health, coastal zone, fisheries and livestock should be

[16] Ministry of Environment and Forest (MOEF), and Bangladesh Meteorology Department (BMD).
[17] The NAPA for Bangladesh, however, duly emphasized on an integrated approach and advocated for coordination.

provided with adequate training on climate change issues (Ahmed, 2004a). Climate change issues should also be an integral part of primary to tertiary level education, as advocated by RVCC (2003) and the NAPA for Bangladesh (GOB, 2005). RVCC has already initiated school-based educational programme on climate change, which should be integrated into national level curricula.

A major cross-cutting adaptation is to fill in the existing gaps in understanding on climate change (WB, 2000). The long-term water sector planning identified climate change as a gap[18] area and therefore no specific adaptation measures have been forwarded as such (WARPO-Halcrow *et al.*, 2004). It is recommended that such lack of understanding be removed on a priority basis during the time of revision of the plan (Ahmed, 2005b). It is recommended that the entire development regime would follow a planned approach, similar to that in water sector, and inter-sectoral coordination be ensured during implementation of programmes. Through the latter approach, it is anticipated that, the concerns of adaptation could be integrated into the plans and a climate resilient future therefore be established. NAPA for Bangladesh fully endorses such an institutional adaptation (GOB, 2005).

Recognizing that the major impacts of climate change will likely to be in water resources sector and national water resources are highly influenced by regional flow patterns, it is argued that efforts must be made to engage in regional cooperation on water (Ahmed, 2005a). Sharing of water in international rivers, especially during the lean flow period, should be a priority. Exchange of data from upstream areas to increase lead time for flood warning is a long-standing concern (BANCID, 1997), which need to be resolved with co-riparian countries. The micro-level planning exercises carried out under the RVCC project at Union levels should be replicated to identify key risks of climate change and to seek solutions that might be useful to reduce vulnerability of that area.

Several studies emphasized on the needs of involving ‘environmental diplomacy’ as an institutional adaptation mechanism (Ahmed, *et al*., 1998a; Huq *et al*., 1996; Asaduzzaman *et al*., 1996; Haque, 1996). Engaging in negotiations to draw adaptation financing have been recommended. In water sector, engaging in regional cooperation with a view to augment lean flows of international rivers has been recommended as an institutional adaptation (Ahmed, 2004a; Faruque and Ali, 2005). Considering legal measures have also been recommended by Freestone *et al*. (1996).

The civil society organizations have so far been proactive to raise public awareness and concerns regarding the country’s special vulnerability to climate change. Bangladeshi researchers have been conducted research on climate change issues and projected the country’s vulnerability at various international forums. The official GOB delegations have also played very important roles for raising concerns through official deliberations at SBSTA and COP. Continued engagement in negotiations and development of scientific background for adaptation should also be recognized as activities which would eventually facilitate institutional adaptation in the long run.

5. LIMITATIONS OF THE STUDY

The study is a synthesis of literature and therefore provides an incomplete picture on impacts, vulnerability and adaptation potential in view of climate change. No attempt has been made to make the report robust with new analyses and understanding. Moreover, no attempt has been made to analyze the gaps of the currently available literature. Again, this study never attempted to include emission inventory of greenhouse gases, emission projections, and ‘mitigation’ issues. Having this limitation, the current report provides a reasonable overview of what have been discussed in published literature on impacts, adaptation and vulnerability to climate change in relation to Bangladesh. Since it is a mere reflection of the literature, no attempt has also been made to provide a conclusion.

[18] However, there exist a few programmes/components which would facilitate adaptation in water resources sector.

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