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Economics of Adaptation to Climate Change

BANGLADESH

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Contents

Tables

Figures

Acronyms

AR4 Fourth Assessment Report
BARI Bangladesh Agricultural Research
BBS Bangladesh Bureau of Statistics
BCAS Bangladesh Center for Advanced Studies
BMD Bangladesh Meteorology Department
BRRI Bangladesh Rice Research Institute
CEGIS Center for Environmental and Geographic Information Services
CGE Computable general equilibrium
CO2 Carbon dioxide
DAE Department of Agriculture Extension
DEM Digital elevation model
DSSAT Decision support system for agro-technology transfer
ENSO El Nino-Southern Oscillation
FAO Food and Agriculture Organization of the United Nations
FCDI Flood control and drainage infrastructure
FFWC Flood Forecast and Warning Center
GBM Ganges-Brahmaputra-Meghna
GCM Global circulation (or climate) model
GDP Gross domestic product
GOB Government of Bangladesh
GTOPO Global topography
HYV High-yielding variety
IFPRI International Food Policy Research Institute
IMD Indian Meteorological Department
IPCC Intergovernmental Panel on Climate Change
IWM Institute of Water Modeling
MJO Madden-Julien Oscillation
MSL Mean sea level
NCA Net cultivable area
NGO Nongovernmental organization
RCM Regional climate model
SRTM Shuttle Radar Topography Mission
TAR Third Assessment Report
TRMM Tropical Rainfall Measurement Mission
USGS United States Geologic Survey

UNITS OF MEASURE

ac acres
ha hectares
kg kilograms
MT metric tons

CURRENCY EQUIVALENTS

US $1.00 = Tk 70.00
(unless otherwise noted, all dollars are U.S. dollars)

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Executive Summary

Climate Hazards: A Risk to Achieving Development Objectives

Bangladesh is one of the most vulnerable countries in the world to climate risks. Two-thirds of the nation is less than 5 meters above sea level and is susceptible to river and rainwater flooding, particularly during the monsoon. Due to its location at the tail end of the delta formed by the Ganges, Brahmaputra, and Meghna (GBM) rivers, the timing, location, and extent of flooding depends on the precipitation in the entire GBM basin, not just on the 7 percent of the basin that lies within the country. Nearly 80 percent of the country's annual precipitation occurs during the summer monsoon season, when these rivers have a combined peak flow of 180,000 m^3/sec, the second highest in the world. Once every three to five years, up to two-thirds of Bangladesh is inundated by floods that cause substantial damage to infrastructure, housing, agriculture, and livelihoods. Low-lying coastal areas are also at risk from tidal floods and severe cyclones. On average once every three years, a severe cyclone makes landfall on the Bangladesh coastline, either before or after the monsoon, creating storm surges that are sometimes in excess of 10 meters. Crops and the livelihoods of the rural poor in low-lying coastal areas are also devastated by saline water intrusion into aquifers and groundwater and land submergence. In addition, seasonal droughts occasionally hit the northwestern region.

Investments during the past 50 years have increased the resilience of Bangladesh to climate-related hazards. Since the sixties, the government of Bangladesh has invested $10 billion on structural (polders, cyclone shelters, cyclone-resistant housing) and non-structural (early warning and awareness raising systems) disaster reduction measures and enhanced its disaster preparedness systems. These investments have significantly reduced damages and losses from extreme climatic events over time, especially in terms of deaths and injuries. In addition, rural households have adapted their farming systems to the "normal floods" that typically inundate about a quarter of the country by switching from low-yielding deepwater rice to high-yielding rice crops. As a result, agricultural production has actually risen over the past few decades. Rising incomes have also enabled an increasing proportion of households to live in homes that are more resilient to cyclones, storm surges, and floods.

Despite the increased resilience, climate-related disasters continue to result in

large economic losses — reducing economic growth and slowing progress in reducing poverty. The 1998 monsoon flood inundated over two- thirds of Bangladesh and resulted in damages and losses of over $2 billion, or 4.8 percent of GDP. The losses were evenly split among agriculture, infrastructure, and industry/commerce. Similarly, Cyclone Sidr resulted in damages and losses of $1.7 billion, or 2.6 percent of GDP in 2007. About half the losses were in the housing sector, followed by agriculture and infrastructure. When averaged over the past decade, the direct annual costs from natural disasters to the national economy—in terms of damages to infrastructure and livelihoods and losses from forgone production—have been estimated at 0.5 percent to 1 percent of GDP. These statistics do not include the significant loss of life that has also occurred during these events. These damages and losses are geographically concentrated in areas that also have higher concentrations of the poor, affecting them disproportionately. They live in thatch or tin houses that are more susceptible to direct damages from cyclones, storm surges, and floods. Additionally, most rural households depend on weather-sensitive sectors—agriculture, fisheries, and other natural resources—for their livelihood. Destruction of their assets and livelihoods leaves the poor with a limited capacity to recover.

A warmer and wetter future climate that goes beyond historical variations will exacerbate the existing climatic risks and increase vulnerability by increasing the extent and depth of inundation from flooding and storm surges and by reducing arable land due to sea level rise and salinity intrusion. The median predictions from the general circulation models (GCMs) are for Bangladesh to be 1.5°C warmer and 4 percent wetter by the 2050s. The median temperature predictions exceed the 90th percentile of historical variability across GCMs for July, August, and September by the 2030s. Severe cyclones originating in the Bay of Bengal are also expected to occur more frequently as a result of warmer ocean surface temperatures. Cyclone-induced storm surges are further exacerbated by a potential rise in sea level of over 27 cm by 2050. Most GCMs predict precipitation increases of up to 20 percent during July, August, and September for the GBM basin. As a result, median discharges in the three rivers during the summer months are expected to increase between 6 and 18 percent by the 2050s. Unlike temperature changes, the predicted changes in precipitation (and discharges) through 2050 are not distinct from the historically observed variability for all months and seasons, reflecting the large variability in precipitation levels historically and even larger uncertainty in future precipitation predictions.

Adaptation Essential for Development

The Bangladesh Climate Change Strategy and Action Plan, adopted by the government of Bangladesh in 2009, seeks to guide activities and programs related to climate change in Bangladesh. Until the past few years, climatic risks have been poorly reflected in national policies and programs Bangladesh. The country launched the National Adaptation Program of Action (NAPA) in 2005, which identified 15 priority activities that were subsequently updated to 45 programs in 2009. The first sectoral policy to explicitly include climate change impacts and actions—the Coastal Zone Policy—was adopted in 2005. Climate change has been a key concern in the redrafting of the National Water Management Plan (NWMP). Recognizing that a wide range of policies have the potential to address climate-related hazards and vulnerability, the government developed and adopted through a consultative process the Bangladesh Climate Change Strategy and Action Plan 2009 to guide economywide efforts to adapt to climate change and to mitigate greenhouse gases. It identifies three climate hazards—tropical cyclones/storm surges, inland flooding, and droughts. The strategy contains 44 programs formulated around six themes—food security/social protection/health, comprehensive disaster management, infrastructure, research/knowledge management, mitigation/low carbon development, and capacity building/institutional strengthening (see Table ES.1). Thirty-four programs listed under five themes are wholly or partially focused on adaptation. The BCCSAP includes an implementation timeframe for the 44 identified programs and is estimated to require $500 million in the first two years and about $5 billion in the first five years for full implementation. The government allocated $100 million of its own resources in FY 2009–10 and has budgeted $100 million in FY2010–11 toward actions contained in the strategy; it is actively seeking additional resources to implement the full strategy.

In a fiscally constrained environment, sequencing of adaptation actions is a necessity, particularly given the large uncertainties about the magnitude and timing of the added risks from climate change. The fundamental problem of policy making in the face of climate change is one of uncertainty with regard to climate outcomes. Shifting resources toward more productive uses and away from less productive ones in the context of uncertainty is already a principal aim of development for a fiscally constrained government. Climate change makes this task more complex. Uncertainty has important effects in any assessment of the impacts of climate change and on the selection and ranking of adaptation actions. These include prioritizing adaptation actions with more certain outcomes with the greatest near-term benefits, while also investing to develop the information base that can reduce the uncertainties and guide the evolution of adaptation actions over time.

Objectives and Scope of Study

The objective of this study is to help decision makers in Bangladesh to better understand and assess the risks posed by climate change and to better design strategies to adapt to climate change. The study takes as its starting point the BCCSAP. It builds upon and strengthens the analytical models and quantitative assessment tools already in use in Bangladesh in support of the research and knowledge management theme of BCCSAP. These tools are used to (a) examine the potential physical impacts of climate change; (b) assess the associated damages and losses in key economic sectors, on vulnerable populations, and in the overall economy; (c) estimate spatially disaggregated costs of adaptation options that can reduce these impacts; and (d) sequence the adaptation actions over time.

The scope of this study is more limited than the BCCSAP, so the reported costs represent a lower bound on the total adaptation costs in Bangladesh. As highlighted in Table ES.1, this study encompasses about 21 of the identified adaptation actions, of which 11 are examined quantitatively as well. Some important and likely expensive adaptation activities that have not been included in this study are urban drainage, river training works, dredging and desiltation, and protection of ecosystems.

The study was developed in four discrete and somewhat independent components with varying degrees of analytical depth and quantification. When feasible, common assumptions and similar methodologies were used to increase comparability and cohesion among the components. The first two components of the study focus on two of the hazards identified in the BCCSAP—tropical cyclones/storm surges and inland flooding. They assess the added risk

TABLE ES.1 SCOPE OF STUDY IN THE CONTEXT OF PROGRAMS AND ACTIVITIES INCLUDED IN THE BANGLADESH CLIMATE CHANGE STRATEGY AND ACTION PLAN*

Theme	*Immediate*	*Short Term*	*Medium to Long Term*
Food, security, social protection and health		Water and sanitation program in climate vulnerable areas Livelihood protection in ecologically fragile areas Livelihood protection of vulnerable socioeconomic groups (including women)	Institutional capacity and research towards climate-resilient cultivars and their dissemination **Development of climate-resilient cropping systems** **Adaptation against drought,** salinity submergence and heat Adaptation in fisheries sector Adaptation in livestock sector Adaptation in health sector
Comprehensive disaster management	Improvement of floods forecasting and early warning system **Improvement of cyclone and storm-surge warning** **Awareness raising and public education towards climate resilience**		Risk management against loss of income and property
Infrastructure	**Repair and maintenance of existing flood embankments** **Repair and maintenance of existing cyclone shelter**	Planning, design, and implementation of resuscitation of networks of rivers and khals through dredging and de-siltation work	**Repair and maintenance of existing coastal polders** Improvement of urban drainage **Adaptation against floods** **Adaptation against future cyclones and storm-surges** Planning, design, and construction of river training works
Research, and knowledge management	Establishment of a center for research, knowledge management, and training climate change **Climate change modeling at national and sub-national levels**	Preparatory studies for adaptation against sea level rise (SLR) and its impacts	Monitoring of ecosystem and biodiversity changes and their impacts **Macroeconomic and sectoral economic impacts of CC** Monitoring of internal and external migration of adversely impacted population and providing support to them through capacity building for their rehabilitation in new environment Monitoring of impact on various issues related to management of tourism in Bangladesh and implementation of priority action plan
Mitigation and low carbon development	Renewable energy development Management of urban waste Afforestation and reforestation programme	Rapid expansion of energy saving devices e.g. (CFL) Improving in energy consumption pattern in transport sector and options for mitigation	Improved energy efficiency in production and consumption of energy Gas exploration and reservoir management Development of coal mines and coal-fired power station(s) Lower emissions from agricultural land Energy and water efficiency in built environment
Capacity building and institutional strengthening	Revision of sectoral policies for climate resilience Mainstreaming climate change in national, sectoral and spatial development programs Strengthening institutional capacity for climate change management Mainstreaming climate change in the media	Strengthening human resource capacity Strengthening gender consideration in climate change management	

* **Quantitative and Quantitative Analysis,** Qualitative Analysis only, Not covered

of these hazards due to climate change relative to the existing risks, identify specific assets and activities that are at risk, and estimate the cost of adaptation actions to protect against these risks. Sequencing of these actions is facilitated by detailed spatially disaggregated identification of adaptation options and associated cost estimates. In addition, the future economic damages from a single super cyclonic event are also estimated, both with current risks and with the added risks from climate change to provide a point of reference for comparing the cost of adapting to this risk. The third component of the study focuses on both the direct and economy-wide impacts of climate change on agriculture and food security from a full range of climate risks, including droughts (the third hazard identified in the BCCSAP), floods, sea level rise, warmer temperatures, and increased CO_2 concentrations. While a full set of adaptation options and the public sector costs to address these impacts are not quantitatively analyzed, the relative desirability of transferring existing coping strategies to newly affected areas is examined. The final component provides local perspectives on adaptation as seen by the poor and most vulnerable population. It examines the determinants of the adaptive capacity of the vulnerable populations and solicits from local, regional and national stakeholders—through the use of participatory scenarios—the types of public support that would best enable the vulnerable population to cope with potential climate change impacts.

Results

The impacts of climate change and adaptation options analyzed and the cost of these options from each study component are summarized below.

(1) Tropical cyclones and storm surges

Impacts. The risk from cyclones and the storm surges they induce spans the entire Bangladesh coastline. Most of it is currently protected by 123 polders constructed since the 1960s. Analyses of all 19 severe cyclones that have made landfall in Bangladesh during the past 50 years indicate that they would overtop 43 of the existing polders. Further, super-cyclonic storms (with winds greater than 220 km/hr) have a return period of around 10 years; currently, a single such storm would result in damages and losses averaging 2.4 percent of GDP. Climate change is expected to increase the severity of cyclones and the surges they induce by 2050. When combined with an expected rise in sea level, cyclone-induced storm surges are projected to inundate an additional 15 percent of the coastal area. The depth of inundation is also expected to increase. While economic expansion is expected to expose additional assets to inundation risk by 2050, expected structural shifts in the economy away from climate-sensitive sectors, increases in urbanization, and greater affordability of cyclone-resilient housing is expected to limit the damages and losses from a single severe storm in 2050 to around $9.2 billion, or 0.6 percent of GDP. About half of these damages and losses would occur even without the added risks from climate change, so the incremental damages from the added risk from a changing climate are around $4.6 billion.

Adaptation. Existing investments, which have reduced the impacts of cyclone-induced storm surges, provide a solid foundation upon which to undertake additional measures to reduce potential damages now and in the future. However, these investments are not sufficient to address the existing risks, much less the future risk from climate change. By 2050, total investments of $5,516 million and $112 million in annual recurrent costs will be needed to protect against storm surge risk, including that from climate change (Table ES.2).

Of this, strengthening 43 polders against existing risks requires investments of $2,462 million and annual recurrent costs of $49 million. Even if the numerous cyclone shelter construction programs provide sufficient capacity to protect all current coastal area residents in at-risk areas, an additional 2,930 shelters will need to be constructed by 2050

TABLE ES.2 COST OF ADAPTING TO TROPICAL CYCLONES AND STORM SURGES BY 2050 ($ MILLIONS)

	Baseline Scenario (existing risks)		(additional risk due to CC)		CC Scenario (total risk= existing + CC)	
Adaptation Option	*IC*	*ARC*	*IC*	*ARC*	*IC*	*ARC*
Polders	2,462	49	893	18	3,355	67
Afforestation			75		75	
Cyclone shelters	628	13	1,219	24	1,847	37
Resistant housing			200		200	
Early warning system			39	8	39	8
Total	3,090	62	2,426	50	5,516	112

CC = climate change; IC = investment cost; ARC = annual recurrent cost

at an estimated cost of $628 million to accommodate the expected population growth in coastal areas even under existing risk. Design innovations and targeted subsidies can reduce the private cost of cyclone-resistant housing and hence the need for an even larger number of shelters.

Protecting against the added risks from climate change will require further strengthening of 59 polders; afforesting sea-facing polders to reduce the hydraulic load of storm surges; constructing 5,702 additional cyclone shelters; providing incentives to increase affordability of cyclone resistant housing; improving the spatial and temporal resolution of forecasting and early warning systems; and expanding disaster preparedness programs in 19 additional districts. These additional measures are expected to require an additional $2,426 million in investments and $50 million in annual recurrent costs.

Recognizing the uncertainties in the timing and magnitude of the added risks from climate change, a prudent strategy would begin by addressing the existing risks that current coastal residents face through (a) continued support for the construction of an adequate number of multipurpose shelters to protect the current populations from the existing risks, (b) upgrading and strengthening 43 existing polders that are at risk of being overtopped even under current risks, and (c) upgrading the spatial and temporal resolution of forecasting and early warning systems. These actions should be accompanied by research to improve knowledge about the timing and spatial distribution of added risks from climate change, which can guide the pace of additional adaptation efforts.

(2) Inland monsoon flooding

Impacts. Bangladesh has been incurring significant damages in terms of crop losses, destruction of roads and other infrastructure, disruption to industry and commerce, and injuries and losses in human lives from severe inland monsoon floods once every three to five years. The 1998 flood inundated over two-thirds of Bangladesh and resulted in damages and losses of over $2 billion, or 4.8 percent of GDP. Increased monsoon precipitation, higher transboundary water flows, and rising sea levels resulting from climate change are expected to increase the depth and extent of inundation. The impacts of climate change are measured by comparing the inundation levels predicted by simulations using the MIROC 3.2 Global Circulation Model predictions under the A2 emission scenario (this simulation predicts the largest increase in runoff) with the inundation levels in the 1998 floods. Climate change places an additional 4 percent of land area at risk of inundation. Further, inundation depth increases in most areas currently at risk, with increases greater than 15 cm in about 544 km^2, or 0.4 percent of the country. These are underestimates of the actual increased risk from climate change, as they do not account for the frequent river course changes. The total inundation risks in 2050 are actually substantial, considering the increased risks are measured relative to the 1998 flood. Despite the higher risks, the rural population exposed to flooding, however, is expected to decline from current levels due to the rural-to-urban migration that is projected to occur by 2050.

Adaptation. Rural households have adapted their farming systems to the "normal floods" that typically inundate about a quarter of the country every year by switching to high-yielding rice crops instead of low-yielding deepwater rice. As a result, agricultural production has actually risen over the past few decades. High-magnitude, low-frequency floods such as the 1998 floods, however, do result in significant damages. The cost of protecting against the existing risks of severe monsoon flooding was not estimated largely because of data limitations. The additional cost to protect (a) road networks and railways, (b) river embankments to protect highly productive agricultural lands, (c) drainage systems, and (d) erosion control measures for high-value assets such as towns against the higher inundation depths due to climate change are estimated at $2,671 million in investment costs and $54 million in annual recurrent costs (Table ES.3). The full cost of protection in 2050 will also require addressing the existing risks of flooding, which are likely to be of the same of order of magnitude. Recognizing the uncertainties in the timing and magnitude of the added risks from climate change, a prudent strategy would begin by addressing the existing risks of monsoon flooding together with research on improving the temporal and spatial resolution of flood predictions, which can guide additional actions.

3) Agriculture and food security

Impacts. The combined effects of rising temperatures, higher precipitation, CO2 fertilization, severe flooding, occasional seasonal droughts, and loss of arable land in coastal areas resulting from climate change are expected to result in declines in rice production of 3.9 percent each year, or a cumulative total of 80 million tons over 2005–50. Overall, climate change is expected to decrease agricultural GDP by 3.1 percent each year—a cumulative $36 billion in lost value-added—during 2005–50. The economic losses increase by threefold—to a cumulative $129 billion—when the indirect impacts on complementary industries and the dynamic effects on asset formation and productivity growth are included. This is equivalent to an average of $2.9 billion per year—and as high as $5.1 billion per year under more pessimistic climate scenarios—with economic losses rising in later years. Around 80 percent of total losses fall directly on household consumption and

TABLE ES.3 TOTAL ADAPTION COST TO ADDRESS INCREASED RISK OF INLAND FLOODING FROM CLIMATE CHANGE BY 2050 ($ MILLIONS)

Adaptation Option	Investment Cost	Annual Recurrent Cost
Transport – Road height enhancement	2,122	42
Transport – Road cross-drainage	5	-
Transport – Railway height enhancement	27	1
Embankment – height enhancement	96	2
Coastal Polders – cross drainage	421	8
Erosion Control Program		1
Total Costs	2,671	54

hence have severe household welfare implications; the southern coastal regions and the northwestern regions are expected to experience the largest income declines.

Adaptation. While the public sector cost of adaptation in the agriculture sector was not quantitatively estimated, the relative merits of a number of short-term adaptation measures—namely the extension of currently available options into new areas—are examined from the farmer's perspective. These measures primarily examine the merits of promoting existing crops from one area to another as the climate regime shifts. They provide low-cost options for adapting to small changes in the climatic regime and may be suitable for some areas in the near term. Part of the medium-term adaptation strategy will be to control the damages from inland floods; the study's inland floods component included some partial cost estimates. In addition, longer term adaptation has to also include development of alternatives, particularly to the *boro* crop in the southern region.

(4) Poverty and local-level perspectives

Impacts. The risks from tropical cyclones, storm surges, floods, and other climatic hazards are geographically concentrated in specific regions of the country, which also have higher concentrations of the poor. The poor and the socially most vulnerable are disproportionately affected, as they have the lowest capacity to cope with these losses. The most vulnerable population includes those with few assets, subsistence farmers, the rural landless, the urban poor, fishing communities, women, children, and the elderly. They do not have sufficient resources to invest in preventive and protective measures such as disaster-resilient housing,

making them more vulnerable to the full effects of these hazards. Their access to public services, which might buffer them from some of the impacts, is also limited. In addition, their ability to better prepare themselves in the longer term is also often limited by the destruction of their asset base. These effects are further compounded if vulnerable households suffer from multiple extreme-event shocks one after the other, without sufficient time for recovery in between the shocks. To the extent that it increases the frequency of these events, climate change will only exacerbate these impacts.

Adaptation. The adaptive capacity of households is generally low, with poor urban dwellers the most disadvantaged due to the limited opportunities for livelihood diversification and low social capital. The most common forms of private adaptation activities among surveyed households are temporary migration of adult men for day labor, construction of platforms to protect livestock, and storage of food and drinking water prior to extreme events. The preferred public adaptation activities from a local perspective—as identified by participants in local and national participatory scenario development workshops—include (a) environmental management (mangrove preservation, afforestation, coastal greenbelts, waste management); (b) water resource management (drainage, rainwater harvesting, drinking water provision, and flood control); (c) infrastructure (roads, cyclone shelters); (d) livelihood diversification and social protection for fishers during the cyclone season; (e) education; (e) agriculture, including development of salt-tolerant and high-yield varieties and crop insurance; (f) fisheries, including storm-resistant boats and conflict resolution between shrimp and rice farmers; (g) governance, especially access to social services for urban poor; (h) gender-responsive disaster management, including separate rooms for women in cyclone shelters, mini-shelters closer to villages, and the use of female voices in early warning announcements; and (i) mobile medical teams in Char areas. While they are similar to adaptation options identified in the BCCSAP, they do provide a greater emphasis on softer approaches (governance), include more general options (education), and are more directly targeted to the community level (use of mobile medical teams).

Some caution is advisable in reviewing these study results.

The mathematical tools and models used in this study impose intellectual discipline; allow for the estimation of impacts, costs, and benefits of adaptation actions; and facilitate prioritization of actions. These strengths can also be limiting if the most important questions depend on institutional, political, or cultural factors that are not amenable to such tools; for example, how to locate residents and economic activity away from high-risk or increasingly unproductive areas, how to improve the allocation of water and land, or how to improve the quality of education. Within the limitations imposed by the modeling frameworks, important limitations of this study derive from three sources of uncertainty: climate, economic growth, and technology. The climate scenarios used in the analysis are predicated on future global economic growth and global efforts to mitigate greenhouse gases (GHGs). Whereas predicted changes in climate through 2050 largely depend on current and past emissions, future global mitigation efforts will increasingly determine the extent of warming toward the latter half of this century. While it is unlikely that technological breakthroughs can greatly reduce the costs of adaptation, dramatic reductions in the cost of mitigation are possible over the next few decades. A higher return on investment in mitigation would in turn reduce the amount of adaptation that would be required in the longer term. Nevertheless, it is essential to invest in adaptation to at least meet the unavoidable warming.

Lessons and Recommendations

Despite significant investments over the past 50 years, climate-related disasters continue to have significant damages. Without additional actions, these damages will certainly persist into the foreseeable future. While there is great uncertainty about the magnitude and the timing of the added risk from climate change, the risks and hence the potential damages are expected to increase. In a fiscally constrained environment with competing priorities, climate adaptation actions have to be prioritized and sequenced, particularly given the large costs required to prevent and protect against these risks. The BCCSAP provides a starting point for doing so. This study examines the key drivers—the degree of certainty, the timing of the benefits, and the cost of action—to enable further substantiation and refinement of the sequencing envisioned in the BCCSAP. A good near-term strategy would be to protect populations and assets against current climate risks while investing to reduce the uncertainties about the magnitude and timing of future risks. The future risks can then be addressed in the medium to long term as the risks and the potential damages become more certain.

NEAR TERM

(1) Addressing current climate-related risks: a current priority

Rehabilitating polders currently at risk of being overtopped during a typical severe cyclone not only protects against the increased future risks from climate change but also provides immediate benefits by reducing the damages from current storms. This study assessed the risk that polders might be overtopped during cyclone-induced storm surges currently and with the added risk of climate change. The polder-specific costs to prevent overtopping under these two conditions were determined from detailed engineering analysis of each polder. A typical severe storm is expected to currently overtop 43 existing polders. The expected damages from a single severe cyclone currently is of the same order of magnitude as the total cost of strengthening all 43 polders that would currently be overtopped. Future damages are expected to be higher for two reasons: (a) higher risks as sea level rise and storms become more intense due to climate change; and (b)an increase in the value of assets that would be located in at-risk areas as incomes rise. Steps taken to strengthen these 43 polders would not only protect against future risks, but also provide immediate benefits by preventing damages from current risks, and hence are a near-term priority.[1]

During cyclonic events, existing multipurpose shelters have also effectively protected the coastal population. The ongoing development benefits of these shelters—as clinics, schools, or community centers—easily offset (fully or partially) the construction cost of these facilities. Numerous programs are already under way to construct additional multipurpose shelters. A near-term priority is to assess the adequacy of the current construction programs to provide sufficient shelter capacity to accommodate the current population living in areas currently at risk of cyclones and storm surges, and to develop a plan for constructing additional shelters as necessary.

Detailed analyses were not carried out to examine the costs of addressing current risks for other climate hazards such as inland monsoon flooding or droughts. Nevertheless, the large damages associated with current climate variability makes it prudent to start by addressing the known current risks in the near term before beginning to address the less certain future risks. Shoring up river embankments, elevating roads, or adding culverts to accommodate drainage requirements

1 If needed, these polders can be further prioritized through further analyses that compare the assets and activities that would be protected by each polder with the costs of strengthening that polder.

for severe monsoon floods that exist today would not only provide immediate benefits, but also protect against increased future flood risks that are expected with climate change.

Similarly, given the large impacts of current climate variability on the agriculture sector, a prudent near-term strategy would be to promote activities and policies that help households and the government build resilience to existing climate shocks affecting crop yields, particularly because of the lead time needed to strengthen research systems and to transfer and adapt findings from the lab to the field. This effort better prepares the country and households for whichever future climate materializes.

(2) Research and Knowledge Building: key to improved targeting of future actions

Given the high cost of infrastructure investments, and the expected gradual increase in climate risk over decades, it is prudent to adapt infrastructure incrementally in response to the added risk of climate change. This is especially true because of the large uncertainties regarding the magnitude and timing of the added risk from climate change. In this regard, research and knowledge focused on improving the spatial and temporal precision of current climate-related risk forecasts and associated early warning systems would enable better targeting of future adaptation actions. These actions not only provide immediate benefits, but also improve the capacity to address climate risks in the future. Supplemental research activities focused on reducing the large uncertainties about future climate risks can also guide the extent of adaptation that will be needed and its prioritization.

MEDIUM TO LONG TERM

A good medium- to long-term strategy has to begin with effective development. Other elements of a longer term strategy include investments in programs and the creation or strengthening of institutions that (a) gradually integrate new knowledge about climate risks into new infrastructure investments; (b) reduce perverse incentives that are often associated with these investments; (c) develop new, more resilient varieties of crops; (d) improve governance and local stakeholder participation to increase effectiveness of the hard investments; and (e) facilitate regional cooperation for the equitable sharing of commonly shared water resources.

(3) Sound development policies: the foundation for an adaptation agenda

Sound development policies provide the foundation for adaptation action in the medium to long term. Adaptation takes place in the context of development, which defines both the opportunities to adapt and generates the means for adapting to climate change. Expected structural changes in the economy—away from climate-sensitive sectors such as agriculture toward industry and services—reduce exposure to climate risks, while urbanization concentrates risks but also provides new opportunities to manage them better. Investments to expand the road system and increase the share of paved roads lowers transport costs, enhances the ability of farmers to respond to market changes and expand markets, while lessening the impacts of floods. Poverty exacerbates vulnerability to weather variability as well as climate change, so reducing poverty is central to both development and adaptation. Rising incomes enable households to autonomously adapt and better cope with climate-related disasters—for instance, by increasing the affordability of climate-resilient housing, which can dramatically reduce the number of shelters that are necessary to protect coastal residents. The effectiveness of adaptation programs can be also be improved through the targeting of adaptation actions that directly assist the poor, such as early warning and evacuation services, basic education (particularly for women), and subsidized insurance programs.

(4) Adjustment of design standards for infrastructure: essential for future resilience

Infrastructure investments are long-lived and expensive and yield large benefits when designed appropriately. It is essential to institutionalize the development of appropriate standards commensurate with the likely climate risks over the expected lives of the assets and to update them over time based on new research results that become available. For example, the prospect of more intense precipitation has implications for unpaved roads, especially in rural areas, which are vulnerable to being washed away by floods and heavy rainfall. Single-lane sealed roads have a higher capital cost, but they provide a more reliable all-weather network with lower maintenance costs. As research makes the risk of flooding in a location more apparent, the design standards for roads in these areas need to be increased accordingly. Similarly, polders need to be strengthened beyond their current protective capacity as the added risk from storm surges becomes more certain. Applying the standards to infrastructure investments as they are replaced not only provides a flexible way to integrate the most updated research outcomes but also provides a natural way to modulate adaptation efforts, scaling up adaptation efforts if the risks are increasing or limiting efforts if the risks are stable or declining.

(5) Reducing perverse incentives: a necessity to increase effectiveness of infrastructure investments

As a general rule, investments—such as flood embankments or polders—designed to protect vulnerable assets should be subjected to careful consideration. Strengthening an embankment is followed, almost by definition, by an accumulation of physical capital in the shadow of the embankment because it is considered “safe.” However, as the tragedy of New Orleans dramatically illustrated, a sufficiently extreme event will breach a polder. The combination of the increasing severity of extreme events, the high costs of providing physical protection, and the accumulation of capital behind such barriers can mean that the expected value of losses, including human suffering, may not be reduced—either at all, or by as much as expected by investments in protection.

The long-term challenge is to move people and economic activity into less climate-sensitive areas and to seek a strategic balance between protecting existing populations and encouraging the mobility of future populations. In 2050, the number of people living in cities will triple, while the rural population will fall by 30 percent. Current policies will determine where this urban population settles and how prepared it is to adapt to a changed climate. Many households have moved further inland, partly due to higher perceived risk, but strengthened embankments may change these perceptions, leading to increased exposure. Good policy needs to encourage future populations to move away from naturally high risk areas, avoiding perverse incentives to remain in high-risk areas and adopting positive incentives to promote settlements and urban growth in low-risk areas. Strengthened education in rural areas is critical for rural migrants to be prepared for productive lives in new urban areas.

Similar concerns apply to efforts to maintain the welfare of populations in areas where climate change alters the comparative advantage of agriculture and other resource-intensive activities. Short-term measures to prevent suffering must be complemented by long-term measures such as education, job training, and migration designed to reduce reliance on resources and assets whose value may be eroded by climate change. Adaptation should not attempt to resist the impact of climate change, but rather it should offer a path by which accommodation to its effects is less disruptive and does not fall disproportionately on the poor and the vulnerable.

(6) Development of climate-resilient cultivars and cropping: an option for long-term food security

Additional research will also be necessary for the development of climate-resilient cultivars and cropping patterns that are more suited to the future climatic conditions, particularly in the southern coastal regions, which are expected to be affected the most by climate change. Bangladesh already has an active network of agricultural research institutes that develop and test new crop varieties to increase national production and resilience against climate risks. The magnitude of the additional effort and the direction it takes will depend on the specific future climate that materializes.

(7) Improved governance and stakeholder participation: a complement to hard investments

The effectiveness of hard investments depends on both the ability of targeted populations to access them and on their uptake. Improved governance and local stakeholder participation are often key determinants of access and uptake. Reaching women requires gender-sensitive designs of interventions such as the provision of separate facilities for women in cyclone shelters. Pro-poor adaptation investments include social protection, livelihoods diversification, and investments in human and social capital (including training, education, and community-based disaster risk management) in order to strengthen local resilience to climate change.

(8) Strengthened regional cooperation: an essential option in the long term

Climate change may greatly increase the need for regional cooperation. Cooperation on the sharing of water resources with neighboring countries in the GBM basin is not a new issue for Bangladesh, but it is one whose importance may be greatly increased by climate change. Recognizing its importance, Bangladesh has been meeting since 2006 with six other neighboring countries—including India, Nepal, and China—as part of the Abu Dhabi Dialogue. These dialogues have resulted in a consensus vision of a "cooperative and knowledge-based partnership of states fairly managing and developing the Himalayan river systems," as well as agreements on specific actions to advance the water cooperation agenda. As the stakes rise, effective steps taken now to promote and strengthen the cooperative programs such as the Abu Dhabi Dialogue can not only provide immediate benefits to all parties, but can also prevent the need for expensive and possibly disruptive solutions in the future.

ONE

Introduction

Motivation and Context for the EACC Study

The Economics of Adaptation to Climate Change (EACC) study has two specific objectives. The first is to develop a "global" estimate of adaptation costs to inform the international community's efforts to help those developing countries most vulnerable to climate change to meet adaptation costs. The second objective is to help decision makers in developing countries to better understand and assess the risks posed by climate change and to better design strategies to adapt to climate change. The study comprises a global track to meet the first study objective and a country case study track to meet the second objective. The country track comprises seven country case studies: Bangladesh, Bolivia, Ethiopia, Ghana, Mozambique, Samoa, and Vietnam.

Using data sets with global coverage at the country level, the global track estimated adaptation costs for all developing countries by major economic sectors, including agriculture, forestry, fisheries, infrastructure, water resources, coastal zones, and health. Adaptation for ecosystem services is also discussed qualitatively. The study also considered the cost implications of changes in the frequency of extreme weather events, including the implications for social protection programs. The global track's initial findings were that developing countries will need \$70 to \$100 billion per year between 2010 and 2050 to adapt to a world that is approximately 2^0C warmer in 2050 (World Bank 2010).

Each country case study under the country track consists of a series of studies that examine the impacts of climate change and the costs of adapting to them for select major economic sectors. Most case studies also included vulnerability assessments and a participatory scenario workshop to highlight the differential impact of climate change on vulnerable groups and to identify the types of adaptation strategies that can benefit those that are most vulnerable. Finally, the sectoral analyses were integrated into analytical tools—such as a computable general equilibrium model—to identify cross-sectoral constraints and effects such as relative price changes. The findings from each of the seven countries—as well as a final synthesis report covering both the global and the country tracks—will be available in 2010.

Context for the Bangladesh Case Study

Bangladesh is one of the most vulnerable countries in the world to climate risks. Two-thirds of the nation is less than 5 meters above sea level and is susceptible to river and rainwater flooding, particularly during the monsoon. Due to its location at the tail end of the delta formed by the Ganges, Brahmaputra, and Meghna (GBM) rivers, the timing, location, and extent of flooding depends on the precipitation in the entire GBM basin, not just on the 7 percent of the basin that lies within the country. Nearly 80 percent of the country's annual precipitation occurs during the summer monsoon season, when these rivers have a combined peak flow of 180,000 m^3/sec, the second highest in the world. Once every three to five years, up to two-thirds of Bangladesh is inundated by floods that cause substantial damage to infrastructure, housing, agriculture, and livelihoods. The performance of the agriculture sector is in turn heavily dependent on the characteristics of the annual floods. Low-lying coastal areas are also at risk from tidal floods and severe cyclones. Bangladesh is one of the most vulnerable countries to climate risks, and is the most vulnerable to tropical cyclones. Between 1877 and 1995, Bangladesh was hit by 154 cyclones—including 43 severe cyclonic storms and 68 tropical depressions— or one severe cyclone every three years, either before or after the monsoon, creating storm surges that are sometimes in excess of 10 meters. The largest damages from a cyclone result from the induced-storm surges, and Bangladesh is on the receiving end of about 40 percent of the impact of total storm surges in the world. Crops and the livelihoods of the rural poor in low-lying coastal areas are also devastated by saline water intrusion into aquifers and groundwater and land submergence. In addition, seasonal droughts occasionally hit the northwestern region.

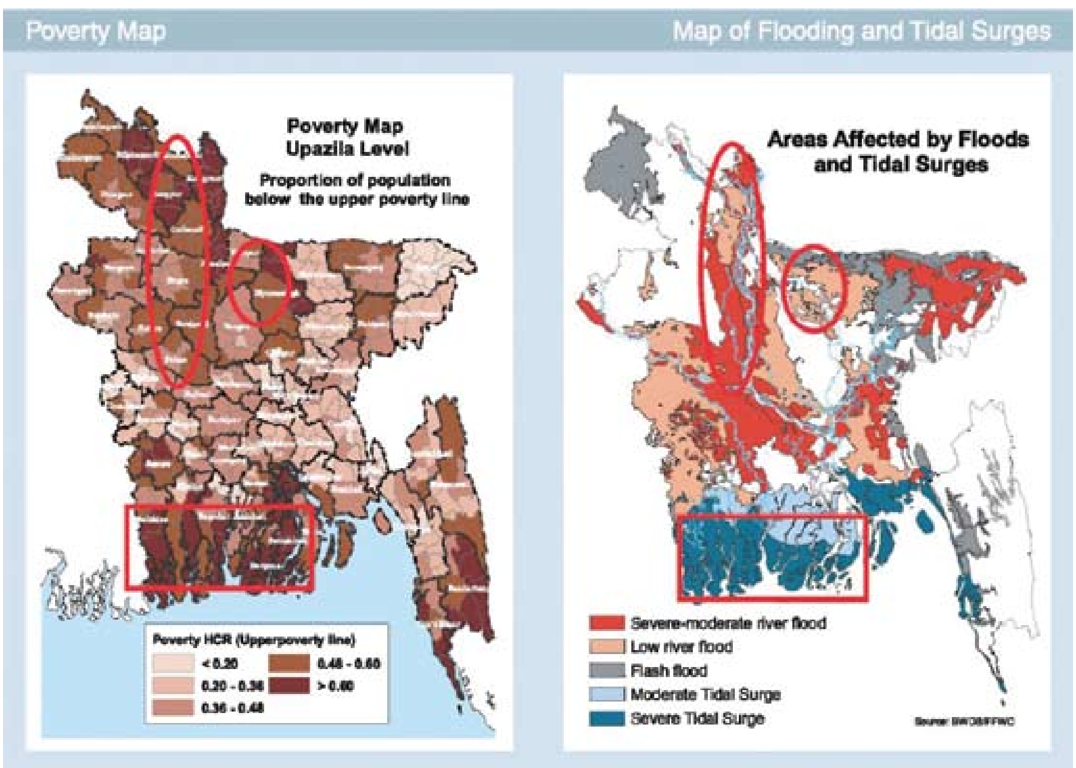
Addressing the impacts of climate and non-climate natural disasters has been an integral part of the nation's development plans. Investments made over the past 50 years have made Bangladesh more resilient to climate-related hazards, but additional steps are necessary to reduce potential damages from both existing and future climate-related hazards. Agricultural production has actually risen over the past few decades as rural households have adapted their farming systems to the "normal floods" that typically inundate about a quarter of the country by switching from low-yielding deepwater rice to high-yielding rice crops. Higher incomes have also enabled an increasing proportion of households to live in homes that are more resilient to cyclones, storm surges, and floods. In addition, the government of Bangladesh has invested $10 billion since the sixties on disaster reduction measures—both structural (polders, cyclone shelters, cyclone-resistant housing) and non-structural (early warning and awareness raising systems) measures—and enhanced its disaster preparedness systems. These investments have significantly reduced damages and losses from extreme climatic events over time, especially in terms of deaths and injuries.

Large damages and losses, reduced economic growth and slowed progress in reducing poverty following recent climate-related disasters, however, indicate that these measures are insufficient to protect the exposed population and assets against existing risks. The 1998 monsoon flood inundated over two- thirds of Bangladesh and resulted in damages and losses of over $2 billion, or 4.8 percent of GDP. The losses were evenly split among agriculture, infrastructure, and industry/commerce. Cyclone Sidr resulted in damages and losses of $1.7 billion, or 2.6 percent of GDP in 2007. About half the losses were in the housing sector, followed by agriculture and infrastructure. When averaged over the past decade, the direct annual costs from natural disasters to the national economy—in terms of damages to infrastructure and livelihoods and losses from forgone production—have been estimated at 0.5 percent to 1 percent of GDP. These statistics do not include the significant loss of life that has also occurred during these events.

These damages and losses are geographically concentrated in areas that also have higher concentrations of the poor, affecting them disproportionately (Figure 1.1). They live in thatch or tin houses that are more susceptible to direct damages from cyclones, storm surges, and floods. Additionally, most rural households depend on weather-sensitive sectors—agriculture, fisheries, and other natural resources—for their livelihood. Destruction of their assets and livelihoods leaves the poor with a limited capacity to recover. The importance of adapting to these climate risks to maintain economic growth and reduce poverty is thus very clear.

In a fiscally constrained environment, with competing priorities, efforts to address climate related risks can easily be set-aside. Recognizing these complexities, the government of Bangladesh adopted the Bangladesh Climate Change Strategy and Action Plan in 2009 to guide its actions in all areas related to climate change. Until the past few years, climatic risks have been poorly reflected in major national policies and programs in Bangladesh. The country launched the National Adaptation Program of Action (NAPA) in 2005, which identified 15 priority activities that were subsequently updated to 45 programs in 2009. The first sectoral policy to explicitly include climate change impacts and actions—the Coastal Zone Policy—was adopted in 2005. Climate change has been a key concern in the redrafting of the National Water Management Plan (NWMP). Recognizing that a wide range of policies have the potential to address climate-related hazards and vulnerability, the government developed and adopted through a consultative process the Bangladesh Climate Change Strategy and Action Plan 2009 to guide

FIGURE 1.1 **POVERTY AND CLIMATE HAZARDS**



Source: BBS, World Bank, and WFP 2009

economy-wide efforts to adapt to climate change and to mitigate greenhouse gases. It identifies three climate hazards—tropical cyclones/storm surges, inland flooding, and droughts. The strategy contains 44 programs formulated around six themes—food security/social protection/health, comprehensive disaster management, infrastructure, research/knowledge management, mitigation/low carbon development, and capacity building/institutional strengthening (see Table ES.1). Thirty-four programs listed under five themes are wholly or partially focused on adaptation. The strategy includes an implementation timeframe for each program and is estimated to require \$500 million in the first two years and about \$5 billion in the first five years for full implementation. The government allocated \$100 million from its own resources in FY 09-10 and has budgeted \$100 million in FY10–11 toward actions contained in the strategy. It is actively seeking additional resources to implement the full strategy.

Climate Change and Bangladesh

A warmer and wetter future climate that goes beyond historical variations will exacerbate existing climatic risks and increase vulnerability by increasing the extent and depth of inundation from flooding and storm surges and by reducing arable land due to sea level rise and salinity intrusion. The median predictions from the general circulation models (GCMs) are for Bangladesh to be 1.5°C warmer and 4 percent wetter by the 2050s. Severe cyclones originating in the Bay of Bengal are also expected to occur more frequently as a result of warmer ocean surface temperatures. Cyclone-induced storm surges are further exacerbated by a potential rise in sea level of over 27 cm by 2050. Most GCMs predict precipitation increases of up to 20 percent during July, August, and September for the GBM basin. As a result, median discharges in the three rivers during the summer months are expected to increase between 6 and 18 percent by the 2050s. These climatic changes are expected to exacerbate existing climate hazards — such as cyclones/storm surges, different floods, droughts, salinity, waterlogging, and drainage congestion — increasing their severity and frequency.

Scope of This Report

This report synthesizes the series of studies that constitute the EACC Bangladesh case study. The study is intended to assist the government of Bangladesh in its efforts to understand how climate change may alter the physical and economic impacts of existing climate-related hazards, as well as the effectiveness and costs of available adaptation options. The study takes as its starting point the BCCSAP. It builds upon and strengthens the analytical models and quantitative assessment tools already in use in Bangladesh in support of the research and knowledge management theme of BCCSAP. This study uses these tools to (a) examine the potential physical impacts of climate change; (b) assess the associated damages and losses in key economic sectors, vulnerable populations, and in the overall economy; (c) estimate spatially disaggregated costs of adaptation options that can reduce these impacts; and (d) sequence the adaptation actions over time. The study is not a substitute for the BCCSAP, instead it is designed to provide more precise cost estimates actions in the BCCSAP and approaches to sequencing these actions in a fiscally constrained environment.

The scope of the study is more limited, encompassing about 21 of the adaptation actions identified in BCCSAP (as highlighted in Table ES.1). Some important and likely expensive adaptation activities—such as urban drainage, river training works, dredging and desiltation, and protection of ecosystem services—are not included in the study, so the reported costs represent a lower bound of the total adaptation costs in Bangladesh.

The study was developed in four discrete and somewhat independent components with varying degrees of analytical depth and quantification. When feasible, common assumptions and similar methodologies were used to increase comparability and cohesion among the components. The first two components of the study focus on two of the hazards identified in the BCCSAP—**tropical cyclones/storm surges and inland flooding.** They assess the added risk of these hazards due to climate change in the context of the existing risks, identify specific assets and activities that are at risk, and estimate the cost of adaptation actions to protect against these risks. Sequencing of these actions is facilitated by detailed spatially disaggregated identification of adaptation options and associated cost estimates. In addition, the future economic damages from a single super cyclonic event are also estimated to provide a point of reference for comparing the cost of adapting to this risk. The third component of the study focuses on both the direct and economy-wide impacts of climate on **agriculture and food security** from a full range of climate risks, including droughts (the third hazard identified in the BCCSAP), floods, sea level rise, warmer temperatures, and increased CO2 concentrations. While a full set of adaptation options and their public sector costs to address these impacts are not analyzed, the relative desirability of transferring existing coping strategies to newly affected areas is examined. The final component provides **local perspectives on adaptation** as seen by the poor and most vulnerable population. It examines the determinants of the adaptive capacity of the vulnerable populations and solicits from local, regional and national stakeholders—through the use of participatory scenarios—the types of public support that would best enable the vulnerable population to cope with potential climate change impacts.

TWO

Existing Climate Variability and Climate Change

Most of Bangladesh consists of extremely low land. Dhaka, the capital city with a population of over 12 million, is about 225 km from the coast but within 8 meters above mean sea level (MSL). Land elevation increases toward the northwest and reaches an elevation of about 90 meters above MSL. The highest areas are the hill tracts in the eastern and Chittagong regions. The lowest parts of the country are in the coastal areas, which are vulnerable to tidal and cyclone-induced storm surges and sea level rise.

Bangladesh is situated at the confluence of three great rivers—the Ganges, the Brahmaputra, and the Meghna. Over 90 percent of the Ganges-Brahmaputra-Meghna (GBM) basin lies outside the boundaries of the country. The country is intersected by more than 200 rivers, of which 54 rivers enter Bangladesh from India. Like the rest of the GBM basin, Bangladesh has a humid subtropical climate. The year can be divided into four seasons: the relatively dry and cool winter from December to February, the hot and humid summer from March through May, the southwest summer monsoon from June through September, and the retreating monsoon from October to November. The southwest summer monsoon is the dominating hydrologic driver in the GBM basin. More than 80 percent of annual precipitation occurs during this period. Some areas of the South Asia subcontinent can receive up to 10,000 mm of rain. The hydrometeorological characteristics of the three river basins make the country vulnerable to a range of climate risks, including severe flooding and periodic droughts.

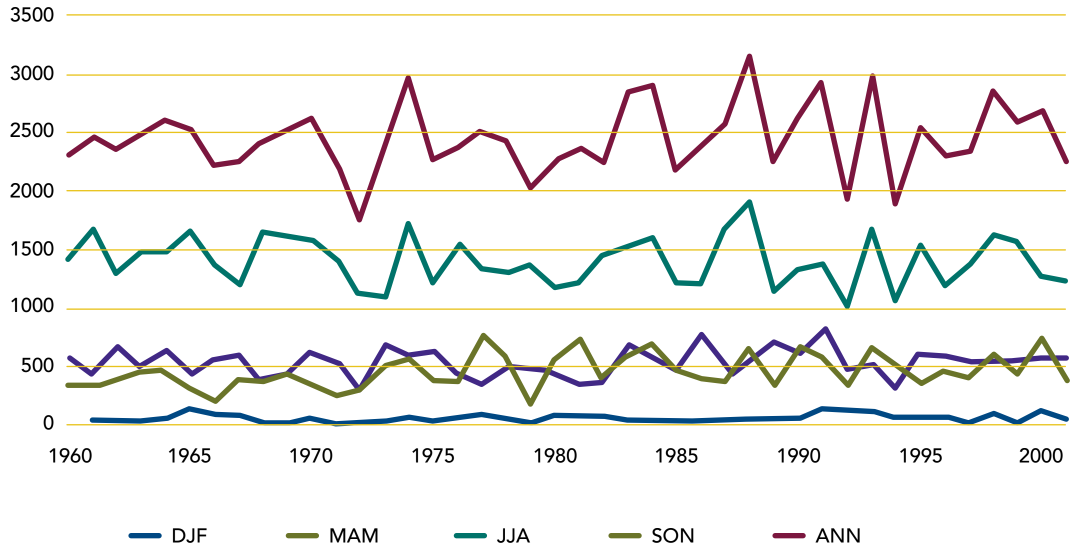
This chapter characterizes the risks that Bangladesh is currently facing due to variability in the current climate and how these are expected to change based on projections of the future climate through 2050. It is largely based on a complementary World Bank study focused on climate change and food security that has recently been completed (Yu et al. 2010).

Existing Climate Variability

Historical precipitation levels

Figure 2.1 shows trends in the annual and seasonal precipitation levels averaged across 32 rainfall stations (both BMD and BWDB stations) in Bangladesh between 1960 and 2001. The national mean annual rainfall during this period was 2,447 mm, with a maximum of 4,050 mm (in Sylhet) and minimum of 1450 mm (in Rajshahi). The maximum rainfall occurs during the June, July, and August monsoon months (JJA). Neither the annual nor seasonal precipitation time series show any statistically significant changes over this time period.

FIGURE 2.1 ANNUAL AND SEASONAL (MM) PRECIPITATION AVERAGED ACROSS METEOROLOGICAL STATIONS BY YEAR



Note: DJF = December, January, February; MAM = March, April, May; JJA = June, July, August; SON = September, October, November.
Source: Yu, W.H., et al. (2010)

TABLE 2.1 PEAK DISCHARGE AND TIMING DURING EXTREME FLOOD YEARS

Extreme Years	Brahmaputra		Ganges		Meghna		Return period (area)	Return period (vol)
	Date	m3/s	Date	m3/s	Date	m3/s		
1974	7-Aug	91,100	3-Sep	50,700	-	21,100	7	7
1980	20-Aug	61,200	22-Aug	57,800	7-Aug	12,400	2	2
1984	20-Sep	76,800	17-Sep	56,500	17-Sep	15,400	2	4
1987	16-Aug	73,000	20-Sep	75,800	4-Aug	15,600	9	10
1988	31-Aug	98,300	4-Sep	71,800	18-Sep	21,000	79	34
1998	9-Sep	103,100	11-Sep	74,280	-	18,600	100	52
2004	12-Jul	83,900	19-Jul	77,430	-	16,300	10	20
Average		**67,490**		**51,130**		**13,370**		
Min		**40,900**		**31,500**		**7,940**		

Source: BWDB

TABLE 2.2 WATER LEVEL TRENDS AT DIFFERENT STATIONS ALONG THE COASTLINE

Station Name	Station Location	Duration	No. of years	Trend (mm/yr)
Hiron Point	Passur	1977 – 2002	26	5.6*
Khepupara	Nilakhi	1959 – 1986	22	2.9
Galachipa	Lohalia	1968 – 1988	21	3.3
Dasmunia	Tentulia	1968 – 1986	19	1.3
Kyoyaghat	Tentulia	1990 – 2002	12	3.6
Daulatkhan	Lower Meghna	1959 – 2003	31	4.3
Nilkamal	Lower Meghna	1968 – 2003	33	2.3
Chadpur	Lower Meghna	1947 – 2002	50	0.0
Companyganj	Little Feni Dakatia	1968 – 2002	32	3.9
Chittagong	Karnafuli	1968 – 1988	16	3.1
Dohazari	Sangu	1969 - 2003	32	2.0
Lemsikhali	Kutubdia Channel	1969 - 2003	27	2.1
Cox's Bazar	Bogkhali	1968 - 1991	22	1.4

* statistically significant to $p < 0.05$

Source: BWDB

Historical discharges

The observed peak discharges during severe flood events with the corresponding dates in the three rivers are summarized in Table 2.1. The peak discharges are almost 50 percent larger than the corresponding average discharge levels, highlighting the extreme inter-annual variability. The timing of the peak discharges on the three rivers on average does not coincide, with the Brahmaputra peaking in July and August and the Ganges in August and September. The Brahmaputra starts rising in March due to snow melt in the Himalayas, while the Ganges starts rising in early June with the onset of the monsoon. Monsoon rainfall occurs in the Brahmaputra and Meghna basins earlier than the Ganges basin due to the pattern of progression of the monsoon air mass. In addition, due to its location at the tail end of three major rivers, current and future water levels in these rivers invariably depend on the hydroclimatic, demographic, and socioeconomic features that characterize the patterns of water utilization in the neighboring countries.

The 1987 flood was primarily from the Ganges. In 1988, all three rivers had peaks within one week of each other. The 1998 flood discharge in the Ganges and Brahmaputra rivers was even higher. This particularly devastating flood was a result of a simultaneous peak in both the Brahmaputra and the Ganges rivers (Mirza 2003). In 2004, the Ganges and Brahmaputra peaked early. The 1998 event is the 1-in-100-year event from the total area impacted perspective, and the 1-in-50-year event from the discharge perspective.[2]

Historical rise in sea level

Long-term reliable data are not available to assess the historical rise in sea levels along the Bangladesh coast. Trends in daily mean water levels in the coastal zone may provide some insight on historical rise in sea levels. Observations from 13 stations over 12 to 42 years are summarized in Table 2.2. The annual changes range from 5.6 mm/yr at Hiron point station to no change at the Chadpur

2 Return periods are estimated in terms of the total area affected and the total volume discharged in the Ganges and Brahmaputra using a Gumbel Type I distribution.

station. The water level increased at a rate of 1.4 mm/yr at Cox's Bazar in the southeast and 3.9 mm/year at Companyganj in the middle of the south coastal zone. Though trends are positive at all stations, only the observations at Hiron Point are statistically significant. While the considerable sedimentation occurring at this location may partially explain the upward trend, these observations may also result from land subsidence.

Climate Change

Future temperature and precipitation changes

Yu et al. (2010) summarize the changes in temperature and precipitation changes predicted by 16 global circulation models for three emission scenarios for the fourth assessment report of the

FIGURE 2.2 MONTHLY, ANNUAL, AND SEASONAL TEMPERATURE CHANGES

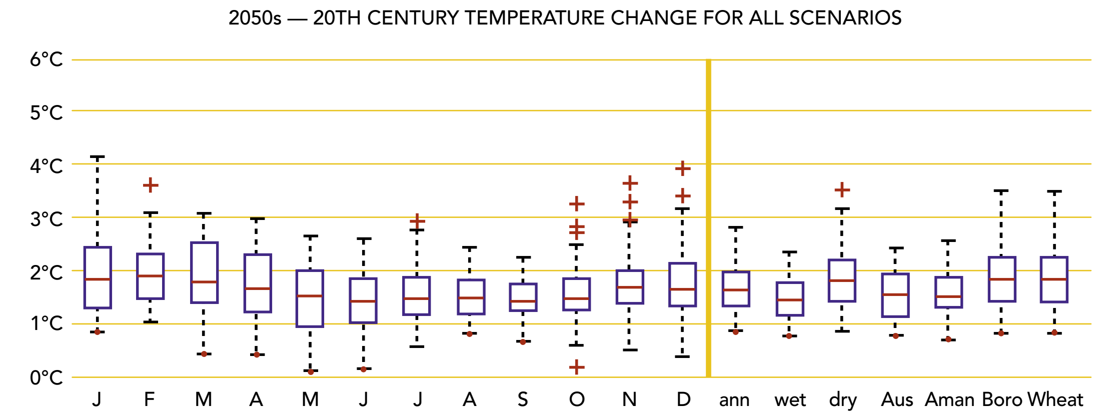
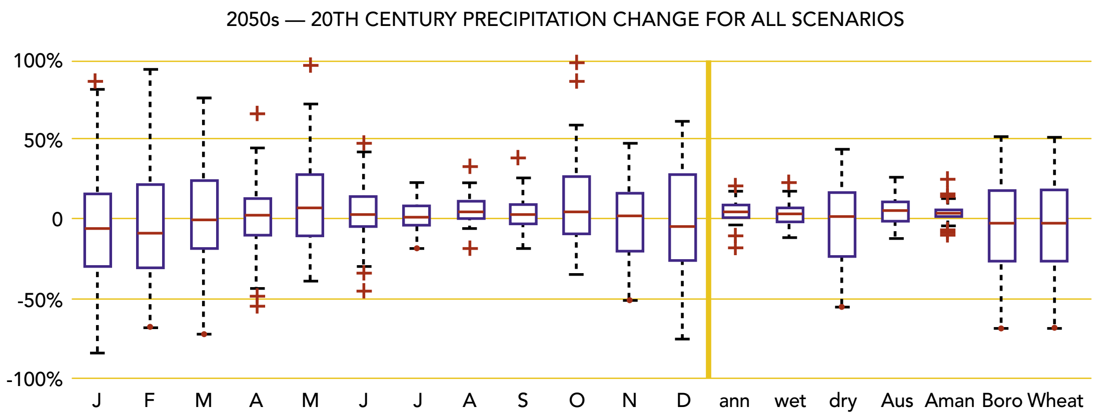


FIGURE 2.3 MONTHLY, ANNUAL, AND SEASONAL PRECIPITATION CHANGES



Note: The box and whiskers diagrams in Figure 2.2 and Figure 2.3 consist of a red line representing the median value, a box enclosing the inter-quartile range, dashed whiskers extending the to the furthest model that lies within 1.5x the inter-quartile range from the edges of the box, and red plus symbols for additional models that are perceived as outliers. *Source:* Yu, W.H., et al. (2010)

IPCC.[3] Figure 2.2 shows the projected monthly, annual, and seasonal temperature changes in the 2050s relative to the corresponding data for 1980–99.[4] Temperature rises during all months and seasons, but does not show any obvious seasonal structure except a wider distribution during the dry winter months. The median warming predictions for Bangladesh across the models by the 2050s is 1.55^{0}C.

Figure 2.3 shows the projected monthly, annual, and seasonal precipitation changes for the 2050s relative to the corresponding data for 1980–99. Deviations for each time period are displayed as the percentage change from their baseline average. Annual and wet season precipitation increases, though some models do continue to show decreases in precipitation.[5] Only simulations for the post-monsoonal rabi dry season do not suggest a rise in precipitation. The median prediction for Bangladesh across the models is for precipitation increases of 4 percent by the 2050s.

Comparison to historical variability

A trend toward a warmer and wetter future climate will impact the agriculture sector in Bangladesh, particularly if the climate state goes beyond the variations found in the historical record. Warming is projected to generally accelerate over the 21st century, although the model-based probability distribution widens. By the 2030s, the median temperatures in July, August, and September of the future model distribution surpasses the 90th percentile of the historical temperature variability.

Precipitation is subject to large existing variation in the historical record. Differences in the monsoon structure and the influences of large-scale circulation patterns like the Madden-Julien Oscillation (MJO) and the El Niño-Southern Oscillation (ENSO) contribute to this background variability. Despite the consistently noted enhancement of the monsoonal circulation pattern that leads to a drying trend during the winter months and increased rainfall during the monsoons in the climate scenarios of the 2050s, precipitation does not separate itself from the historical variability for any month or season due to the larger uncertainty in future predictions and the substantial existing variability.

Future flood hydrology

Due to its location at the tail end of the GBM basin, the flood hydrology of Bangladesh (including the location, timing, and extent of future floods) depends not just on the 7 percent of the basin that lies within Bangladesh, but on the entire GBM basin. The super or national flood model is used to estimate hydrologic changes within the country from changes in temperature and precipitation in Bangladesh and changes in water flows into the country. The later is determined from changes in precipitation and temperature predicted by GCMs using the Ganges-Brahmaputra-Meghna (GBM) river basin model.[6] Future flood estimates are modeled for five GCMs and 2 emission scenarios (A2 and B1) due to resource limitations.[7] The chosen models are skillful in replicating the dynamics of the monsoon in the GBM basin, provide sufficient spatial resolution

3 The 16 models are BCCR_bcm2.0, ccma_cgcm3.1(T63), cnrm_cm3, csiro_mk3.0, gfdl_cm2.0, gfdl_cm2.1,giss_model_er, inmcm3.0, ipsl_cm4, miroc3.2(medres0,miub-echio_g, mri_cgcm2.3.1a, mpi_echam5, ncar_pcm1, ncar_ccsm3.0, ukmo_hadcm3.

4 The resolution of the models varies with about 5 grid boxes typically covering Bangladesh. The national values are weighted averages, with the weights equal to the percentage of each grid that is within Bangladesh.

5 Despite only small changes in actual magnitude, rainfall deviations in the dry months of the year appear as very large percentage changes due to the low baseline average. These dry season totals would not have any noticeable impact on the annual rainfall totals, but could still have significant ramifications for the severity of droughts. Conversely, simulated rainfall deviations in the wet season have to be very large to produce high percentage changes.

6 These models are described in detail in Annex 15. Models used for flood hydrology

7 The five GCMs are University Corporation for Atmospheric Research – CCSM, Max Planck Institute for Meteorology – ECHAM5, Hadley Center for Climate Prediction – UKMO, Center for Climate System Research – MIROC, and Geophysical Fluid Dynamics Laboratory – GFDL. The A1B scenario predictions are similar to the A2 scenario through 2050.

TABLE 2.3 ESTIMATED AVERAGE CHANGE (%) IN DISCHARGE*

	2030s			2050s		
	Brahmaputra	Ganges	Meghna	Brahmaputra	Ganges	Meghna
May	7.5	9.3	0.0	17.4	11.8	12.3
June	5.4	11.9	3.1	10.9	16.7	7.7
July	3.4	13.5	0.0	6.9	15.0	3.6
August	5.5	8.8	3.7	9.5	12.0	7.8
September	3.7	7.3	-2.0	9.7	12.5	5.9

* 5 GCM x 2 SRES = 10 model experiments Source: Yu, W.H., et al. (2010)

for hydrologic modeling, and capture the range of changes and climate sensitivity across GCMs.

Future temperature and precipitation changes over GBM basin

Across the five models and two emission scenarios, a clear consensus exists on a warming trend in the GBM basin with increases of 1° to 3° C by 2050, with greater warming during the dry winter months. Models differ widely regarding changes in precipitation in the GBM basin.[8] Rainfall increases during the monsoon season (both in the 2030s and the 2050s)—up to 20 percent more from July to September in most GCMs. Large changes at the onset of the monsoon (during May and June months), particularly in the Ganges, may reflect an earlier arrival of the monsoon season. During the dry season, some models show increased precipitation, while others show decreased precipitation. The temperature and precipitation changes predicted by each model are applied to the baseline historical climate data for use in generating flood scenarios.[9]

Future estimated discharges

Simulations of the future transboundary inflows of the three major rivers (Ganges, Brahmaputra, and Meghna) indicate increased basin precipitation will result in increased inflows into Bangladesh over the monsoon period (Table 2.3).[10] The magnitude of change from the baseline depends on the month, with larger changes on average on the Ganges and in the 2050s. There is not much difference between the A2 and B1 scenarios. Larger changes are anticipated by the 2050s compared to the 2030s.

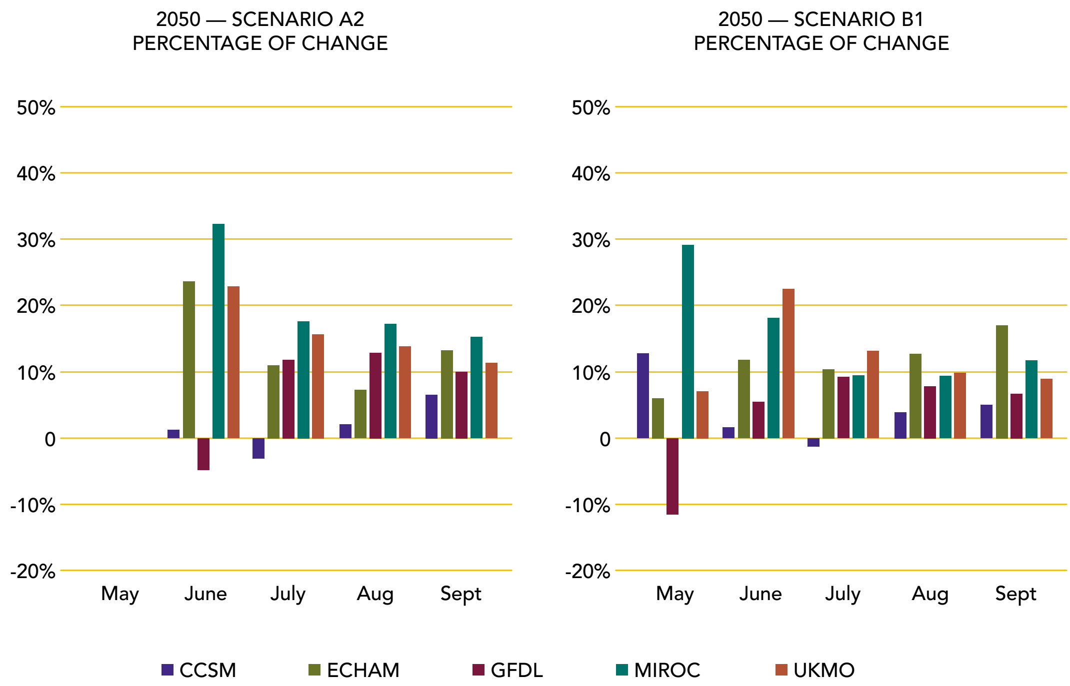
8 There is not even agreement on the direction of rainfall change between emissions scenarios for individual models (e.g. in January, ECHAM A2 estimates decreases, ECHAM B1 estimates increases).

9 This is a standard ("delta") approach used to overcome the following shortcomings of directly using predictions of GCMs to generate future flood scenarios: (1) GCM outputs may contain significant biases both in the baseline period and in the future period; (2) daily output is required while the GCM output is typically monthly; (3) the GCM spatial resolution reduces extreme events and misses sub-grid scale geographic variability; and (4) year-to-year variability at a particular location in the GCM output tends to be underestimated due to simplified greenhouse forcing scenarios and coarse spatial resolution. In this approach, the starting point for all scenarios is the actual historical observed 30-year precipitation and temperature data, which captures differences between subregions and day-to-day and year-to-year variability. For each GCM/emission scenario, a monthly rainfall and temperature series, averaged over each 30-year time period, is determined for the historical period, the 2030s and 2050s. By comparing the baseline and future monthly averages, a "delta" value for both rainfall and temperature is calculated (i.e. percentage change is used for precipitation and absolute change in degrees Celsius is used for temperature). The delta value is applied to the baseline historical climate data to estimate temperature and precipitation predictions from each GCM/emission scenario. The baseline climate period (1979–99) differs slightly from the baseline hydrologic period (1978–2008), which introduces slightly higher baseline conditions for the delta method. However, changes between 1999 and 2008 are the smallest of the 20th century.

10 Not all models predict increases in discharge. The model range is largest for the Meghna (55 percent increase to 32 percent decrease) in the GFDL scenario. This partly reflects the smaller baseline discharge at the onset of the monsoon.

FIGURE 2.4 **TOTAL CHANGE IN NATIONAL FLOODED AREA FOR 2050 IN THE A2 AND B1 SCENARIOS**

THE B1 SCENARIOS SHOW SMALLER CHANGES THAN THE A2 SCENARIOS, THOUGH IN THE SAME DIRECTION.



Source: Yu, W.H., et al. (2010)

Changes in spatial extent of land flooding

Given that most climate models indicate an increasing trend of monsoon rainfall and greater inflows into Bangladesh, all else being equal, the extent of flooding is likely to increase. Monthly water levels are estimated for each grid point in flood-relevant regions of Bangladesh for the historical period, the 2030s and 2050s. Accounting for the existing flood protection infrastructure (e.g. roads, embankments, polders), the proportion of area flooded (greater than 0.3m) is highest during July through September, peaking in August, when the peak levels coincide in the three major rivers. The percentage change in flooded area by month and model is summarized in Figure 2.4 for 2050 for the A2 and B1 scenarios. The B1 scenarios show smaller changes than the A2 scenarios, though in the same direction.

The flooded area is estimated to increase for most of the flood season for most models.[11] For the A2 scenario, the average increase of flooded area is 3 percent in 2030 and 13 percent in 2050. However, the changes in flood areas in many subregions fall within one standard deviation of the historical variability for these areas. The most significant changes occur later in the flood season, primarily in August and September at the height of the monsoon, and

11 Some models indicate a decrease in flooding during the month of May, June, and July. The GFDL model, for instance, shows the largest decrease of 17 percent in flooded area in the month of May for the A2 scenario in the 2050s.

in the south and central parts of the country. The maximum observed increase in flooding occurs during May (about 50 percent) for the MIROC model under the A2 scenario in the 2050s.

Changes in temporal flood characteristics

For each climate model/emission scenario, the future and baseline hydrographs are compared at 36 locations across the country to determine the changes in the temporal flood characteristics—annual peak values, onset, and recession dates of the flood. By the 2050s, many of the northern subregions show statistically significant increases in the annual peak, while many in the southwest show decreases.[12] Across the subregions, most GCMs show earlier onset of the monsoon and a delay in the recession of flood waters, driven in large part by increased flows and flooding.[13] While the shifts are as large as 1–2 weeks across the models, year-to-year variations in the annual hydrograph are larger than the predicted changes in a number of cases, making them inseparable from the historical variability.

Future sea level rise

Rising sea levels rise are one of the most critical climate change issues for coastal areas. The Intergovernmental Panel on Climate Change (IPCC 2007a) projected that an average rise of 9 to 88 cm could be expected by the end of the century. Recent projections suggest even more substantial rises (Allison et al 2009). Increasing temperatures result in sea level rise by the thermal expansion of water and through the addition of water to the oceans from the melting of continental ice sheets. A 1 meter sea level rise is estimated to impact 13 million people in Bangladesh, with 6 percent of national rice production lost (Nicholls and Leatherman 1995). Sea level rise may also influence the extent of the tides—currently the lower third of the country experiences tidal effects—and alter the salinity quality of both surface and groundwater. Currently, because of the low topography in these coastal areas about 50 percent typically becomes inundated during the annual monsoons.

Estimating the changes in area that will be inundated due to sea level rise is complicated by the active river morphology. With over a billion tons of sediment being deposited in the alluvial fan of Bangladesh (Goodbred and Kuehl 2000), a combination of accretion and erosion processes will work to both increase and decrease the land area available in the coastal areas. For instance, satellite images from the coastal zone reveal that some land areas have gained, while others have eroded over the last several decades. In the Meghna Estuary specifically, about 86,000 ha of land were lost between 1973 and 2000 (MES 2001). The relative contribution of these competing processes is largely unknown and an area for future research.

Changes in the total flood land type area based on previous coastal zone modeling effort—using the MIKE21 two-dimensional estuary model for the 15 cm, 27 cm, and 62 cm sea level rise scenarios—is shown in Table 2.4 (DEFRA 2007). Of a total 33,000 km^2 in these coastal areas, over half is annually flooded. The total flooded area increases by 6, 10, and 20 percent for the three sea level rise scenarios respectively. The southernmost regions are expected to face the largest increases in flooded area.

12 Any observed change in average yearly peak levels must be considered in relation to this background variability. The baseline inter-annual variation is itself almost 0.5 m (average value of 11.6 m).

13 The baseline onset and recession dates are May 15 and September 15. The onset (recession) date for a future scenario occurs when the water level reaches the same level as on the baseline onset (recession) date of May 15 (September 15). These are determined separately for each of the 16 locations for each of the climate models.

TABLE 2.4 SEA LEVEL RISE IMPACTS ON FLOOD LAND TYPES [14]

	F0 (0-30 cm)	F1 (30-60 cm)	F2 (60-90 cm)	F3 (90-180 cm)	F4 (180 + cm)	Flooded Area (F1+F2+F3+F4)	% of total
Base	15,920	4,753	4,517	5,899	1,759	16,928	52
15 cm	14,841	4,522	4,705	6,765	2,015	18,007	55
27 cm	14,189	4,345	4,488	7,456	2,370	18,659	57
62 cm	12,492	3,967	3,818	8,977	3,594	20,356	62

14 Note that the flood land type classes used in DEFRA (2007) are slightly different than the MPO definitions.

THREE

Tropical Cyclones and Storm Surges

Bangladesh has been identified as the most vulnerable country in the world to tropical cyclones (UNDP 2004), with a severe cyclone striking Bangladesh every three years on average (GoB 2009). Cyclone Sidr alone resulted in damages and losses of $1.7 billion, or 2.6 percent of GDP in 2007, primarily in the coastal region. The largest damages from cyclones result from the storm surges they induce. Storm surge heights are typically less than 10m, but Bangladesh has experienced surges in excess of 10m in some areas on occasion. A surge can be even more devastating if it makes landfall during high tide.

Faced with significant cyclone and storm surge risk, Bangladesh has invested over $10 billion during the past 35 years on disaster risk mitigation measures—both structural (polders, cyclone shelters, cyclone resistant housing) and non-structural (early warning dissemination and awareness raising)—and enhanced its disaster preparedness system to address unavoidable risks (GoB 2009). These measures have significantly reduced the loss of life and livelihoods and property damage from these extreme events.

Nevertheless, given the significant large damages from Cyclone Sidr, examining the adequacy of existing measures and the cost effectiveness of taking additional risk mitigation measures is timely. The urgency of doing so is only hastened by the significant additional future risks that are expected due to climate change. The Fourth Assessment Report of the IPCC projects that climate change is likely to increase the severity of tropical cyclones and storm surges over the 21st century (IPCC 2007b). For the Bay of Bengal, Unnikrishnan et al. (2006) report increases in the frequency of the highest storm surges, despite no significant change in the frequency of cyclones.[15]

In the absence of additional preventive measures, future storm damage risk in Bangladesh is likely to be larger because of expansion of the vulnerable zone further inland, increase in the areal extent of inundation, and increased inundation depths during each cyclonic event. Actual future damages are also expected to increase in line with the projected increase in the assets and activities that are located in the inundated areas, and with how well they are protected from these risks.

This chapter starts with a brief review of the past experience of cyclones and storm surges in Bangladesh, followed by a review of the major adaption measures that are currently in place to reduce the risk. The third section provides an

15 These results are based on dynamic models driven by climate projections from regional climate models.

overview of the five-step methodology used to assess the potential damages from storm surges and the adaptation costs that would need to be incurred to prevent these damages. The first step is to define the inundation risk exposure zones for the baseline and climate change scenarios in 2050. The next three steps are to characterize the assets and activities that are exposed to inundation risk, potentially affected during a single cyclonic event and to estimate the potential damages and losses that would be incurred. The last step is to estimate the adaptation cost that would have to be incurred to prevent these damages. The final section of the chapter discusses the implications of the analysis for prioritizing adaptation actions in the context of Bangladesh's development and climate change strategy.

Historical Vulnerability to Tropical Cyclones and Storm Surges

UNDP has identified Bangladesh as the most vulnerable country in the world to tropical cyclones (UNDP 2004). Cyclones hit the coastal regions of Bangladesh almost every year, in early summer (April–May) or late rainy season (October–November). A severe cyclone strikes Bangladesh every three years on average (GoB 2009). Between 1877 and 1995, Bangladesh was hit by 154 cyclones, including 43 severe cyclonic storms, 43 cyclonic storms, and 68 tropical depressions.[16] Since 1995, five severe cyclones hit the Bangladesh coast in May 1997, September 1997, May 1998, November 2007, and May 2009.

The largest adverse impacts of a cyclone occur from the inundation resulting from the storm surges that cyclones induce in coastal regions. The Meghna estuarine region is the area where most of the surge amplifications occur. Bangladesh is on the receiving end of about 40 percent of the impact of total storm surges in the world (Murty and El Sabh 1992). The reasons for this disproportionately large impact of storm surges on the coast of Bangladesh were reported (Ali 1999) to be the following: (a) recurvature of tropical cyclones in the Bay of Bengal; (b) a shallow continental shelf, especially in the eastern part of Bangladesh;[17] (c) high tidal range;[18] (d) the triangular shape at the head of the Bay of Bengal;[19] (e)almost sea-level geography of the Bangladesh coastal land; and (f) the high density of population and coastal protection system.

Table 3.1 presents surge inundation characteristics for cyclones of varying strength in Bangladesh as documented by the MCSP (1993). While historical (time series) records of storm surge height are scarce in Bangladesh, the existing literature suggests typical storm surge height during severe cyclones is between 1.5 and 9.0 meters. Storm surge heights in excess of 10 m are less common, but occasional references are in the literature.[20] A surge can be even more devastating if it makes a landfall during high tide. In general, it has been observed that the frequency of a wave (surge plus tide) along the Bangladesh coast with a height of about 10 meters is approximately once in 20 years, and the frequency of a

16 The Indian Meteorological Department (IMD) is responsible for tracking tropical storms and cyclones in South Asia, including the Bay of Bengal. The IMD classifies tropical storms based on the observed maximum sustained surface wind measured at a height of 10m and averaged over 3 minutes as follows: Super Cyclonic Storm (greater than 220 km/hour), very severe cyclonic storm (119–220 km /hour), severe cyclonic storms (90–119 km/hour), cyclonic storms (60–90 km/hour), Deep depression (51–59 km/hour), Depression (32–50 km/hour) (IMD 2010).

17 A wide continental shelf, especially off the eastern part of Bangladesh, characterizes the coastline of Bangladesh. This wide shelf amplifies the storm surges as the tangential sea-level wind-stress field associated with the tropical cyclone pushes the seawater from the deepwater side onto the shelf. Being pushed from the south by wind stress, the water has no place to go but upwards, which is the storm surge.

18 Records from the Sandwip Channel indicate high tides of 7–8 m.

19 The triangular shape at the head of the Bay of Bengal helps to funnel the seawater pushed by the wind toward the coast and causes further amplification of the surge.

20 The 1876 Bakerganj cyclone had the highest reported surge height of 13.6 meters. More recently, the 1970 cyclone had a reported height of 10 meters (SMRC 2000).

TABLE 3.1 TYPICAL STORM SURGE CHARACTERISTICS FOR CYCLONES IN BANGLADESH

Wind Velocity (km/hr)	*Storm Surge Height (m)*	*Limit to inundation from the coast (km)*
85	1.5	1.0
115	2.5	1.0
135	3.0	1.5
165	3.5	2.0
195	4.8	4.0
225	6.0	4.5
235	6.5	5.0
260	7.8	5.5

Source: MCSP, 1993

wave with a height of about 7 meters is approximately once in 5 years (MCSP 1993). In addition to these exceptional surges, waves caused by wind also occur; the dimensions depend on wind speed and direction, water depth, and duration of wind blowing over the bay. It has been observed that wind-induced waves of up to 3.0 m in height may occur under unfavorable conditions in the coastal regions (MCSP 1993).

Adaptation Measures Currently in Place

Faced with a significant chronic risk from storm surges induced by cyclones, the government of Bangladesh—with the support of its development partners—has put in place both a set of risk mitigation measures as well as a disaster preparedness program. These include structural risk mitigation measures, such as the construction of polders, cyclone shelters, and cyclone-resistant infrastructure; and non-structural measures, such as an early warning dissemination system, education, and raising awareness among residents and stakeholders. Toward better preparation for the unavoidable disasters, the government has also developed community-based disaster preparedness plans, including training of relevant community workers. Residents have also complemented these public measures with private actions that reduce their own personal risks through the construction of cyclone-resistant housing and migrating further inland away from more vulnerable low-lying and coastal areas, when feasible.[21] The rest of this section contains a brief summary of the current status of these adaptation measures.

Embankments: Bangladesh started a program to create polders through the construction of embankments around 1960. Currently there are 123 polders formed by 5,017 km of embankments, of which 957 km enclose 49 sea-facing polders, and the remaining 4,060 embankments enclose 74 interior polders. These embankments protect around 1.5 million ha of land, of which 0.8 million ha is cultivable land. Drainage is facilitated by 1,347 regulators and 5,932 km of drainage channels. Figure 3.1 shows the location of the existing polders. They have protected the densely populated coastal areas of Bangladesh. No polders are currently in place in areas that are less populated and where there is limited economic activity, including the Sundarbans and the numerous small islands. The Bangladesh Water Development Board (BWDB) maintains an extensive

21 Unlike most other countries, the population growth rate in coastal areas of Bangladesh is smaller than the national average, indicating slower net migration to these areas.

FIGURE 3.1 LOCATION OF COASTAL POLDERS IN BANGLADESH

Source: CDMP

database of coastal polders, which includes information on the length, location, construction year, and cost of each polder. [22]

While embankments have effectively protected polders against storm surges during most cyclones, some of the embankments have been breached, particularly during the more severe cyclones. For instance, a large section of the Patenga embankment was washed away during the 1991 cyclone, and some inland embankments breached during Cyclone Sidr in 2007. Some embankments even breached during the mid-size Cyclone Aila in 2009.

22 In addition, information on riverbank and shoreline protection and re-sectioning of embankment works has been extracted from the Coastal Embankment Rehabilitation Project (CERP) and South-Eastern Zone-Chittagong, South-Western Zone-Faridpur, and Southern zone-Barishal maintained by the BWDB. It includes information on the ongoing projects, construction period, and cost.

Experts at BWDB, IWM, and CEGIS indicated four reasons for breached embankments during past cyclones:

a) *Overtopping* is the most important factor for embankment collapse. Rapid and deep scours form on the country side slope of the embankment after it has been overtopped. The process rapidly weakens the structure and leads to its collapse.

b) *Toe erosion* is another major reason for weakening of an embankment. Regular tidal wave action and occasional cyclone-related water surge exerts tremendous hydrological load on the embankments, causing damage to the structure, thus weakening them and making them prone to collapse.

c) *Slope Erosion* from natural causes such as precipitation, piping action, poor design (e.g. insufficient setback), substandard construction, inadequate compaction, and activities of rats and earthworms has been another factor resulting in damaged embankments.[23]

d) *Inadequate O&M* has also been responsible for the collapse of some embankments. Shortage of resources has restricted even routine O&M of existing embankments, making them weaker and susceptible to collapse.

Foreshore Afforestation: Foreshore afforestation has proven to be a cost effective method to dissipate wave energy and reduce the hydraulic load on embankments during storm surges. This was evident during the 1991, 2007(Sidr), and 2009 (Aila) cyclones. The virtual absence of mangrove forests in Chokoria and surrounding areas resulted in large damages to property and loss of lives in 1991 (BCAS 1992). In contrast, even scattered and unplanned forestation on the foreshore of embankments affected by the 2007 Cyclone Sidr substantially broke the storm surge velocity, reducing damages and losses (GoB 2008).

Officials from the Department of Forests, GoB, and experts from the Institute of Water Modeling (IWM) have recommended planting mangrove forests with a minimum width of 500 meters as a cost-effective method to protect embankments in front of sea-facing polders. Currently, approximately 60 km of the total 957 km of embankments along sea facing polders are protected by mangrove forests. These include some forest belts that are degraded.

Early Warning and Evacuation System: Bangladesh has put in place an effective early warning and evacuation system that has saved thousands of lives during recent cyclones. The system is a partnership between civil society organizations, the private sector, and multiple levels of government. The Bangladesh Meteorological Department tracks tropical storms in close collaboration with other regional organizations and issues alerts of impending cyclone and storm surges for different geographic areas. Newspapers, television channels, and radio stations broadcast the warnings, and the local government administration and the local Cyclone Preparedness Program (CPP) volunteers run by the Red Crescent Society lead the evacuation.

The Current Cyclone Preparedness Program covers 32 of 51 upazilas/thanas that are exposed to cyclones and storm surges. This subset of upazillas faces a combination of cyclone risk, salinity, and tidal water movement above critical levels (Islam et al 2006) Recently these efforts have been decentralized, including the establishment of a forward operation center with a government-appointed commander in chief to oversee relief and early recovery operations. Coordination of relief operations at the local, regional, and national levels has been greatly enhanced through (a) the use of high frequency (HF) transceiver radios for long-distance communication between Dhaka headquarters and field stations; (b) very high frequency (VHF) transceiver radios for short-distance communication between field stations and substations located at union/isolated islands; and (c) cell phones as an emergency communications system. By locating the coordination of these operations closer to the affected population, the decentralization of relief operations has improved their timeliness and effectiveness, as evidenced during Cyclone Sidr.

Pre-positioning of emergency relief materials and life-saving drugs and medical supplies played an increasingly important role in quickly initiating relief and rehabilitation activities during Sidr. For example, detailed and written instruction exists

23 Sometimes, local people have cut the embankments to let saline water in for their shrimp farms located behind the embankments. Even after repair, the section remains weak and vulnerable to breaching. Prevention entails improved institutions and governance that are compatible with local needs.

regarding what relief materials and medical supplies to preposition in and around possible storm-surge-impacted areas. Before the landfall of Sidr, national and international NGOs pre-positioned staff and relief materials closer to the forecasted impact areas. This action had a strong positive impact, as access to hard-hit places became quite difficult and pre-positioned staff along with relief materials were already on the field to start relief operations shortly after the cyclone was over.

While the effectiveness of the EWES has improved over the years, consultations with experts indicate scope for improvement in three areas: (1) geographic precision of warnings, (2) communication of warnings in local dialects to increase reach, and (3) greater awareness about the importance of timely evacuation. BMD alerts for impending cyclones currently cover a large section of the coastal zone, due to the limited geographic precision with which storm forecasts can be made. Repeated evacuations in areas that ultimately do not experience a storm lead to a gradual erosion of faith in the early warning system. Improved precision in forecasting, especially in the landfall location and location-specific inundation depth, is currently feasible and can enhance the effectiveness of the EWES. Additionally, Red Crescent Society officials, CPP volunteers, and residents of major cyclone-affected areas indicated the importance of broadcasting warnings in resident-friendly local dialects to ensure timely evacuations. Finally, the CPP volunteers and residents of cyclone-affected areas noted higher fatality rates among residents that ignored/resisted/delayed evacuation and stressed the importance of raising awareness about the importance of timely evacuation.

Cyclone Shelters: Cyclone shelters have protected human lives and livestock in the coastal region of Bangladesh during past cyclones, including Cyclone Sidr, when 15 percent of the affected population took refuge in shelters (GoB 2008). There are currently 2,591 usable shelters with the capacity to serve 2.8 million people, or 7.3 percent of the coastal population.[24] These are essentially brick buildings on concrete stilts. An additional 924 schools constructed under Primary Education Development Programme, Phase II (PEDP-II) with open ground floor structures have also been used as shelters, even though they are not suitable as shelters.[25]

Figure 3.2 shows the location of existing cyclone shelters. The shelter construction program has been reactive, with construction following the occurrence of major disasters.[26] The east coast (Noakhali, Chittagong, Cox's Bazar, and Feni) has a greater concentration of shelters than the west coast.

The government has an active program to construct additional cyclone shelters. While reliable estimates of the number of shelters under construction or being planned are not available because of the multitude of government agencies and NGOs undertaking this effort, they are likely to be in the thousands eventually.[27] The consensus among experts in these institutions and the relevant government agencies is that an additional 2,000–2,500 cyclone shelters need to be built. The attractiveness of investing in multi-purpose cyclone shelters is partly due to the immediate and ongoing benefits that they provide as a primary school or office. The newer designs are starting to accommodate user concerns with the inclusion of

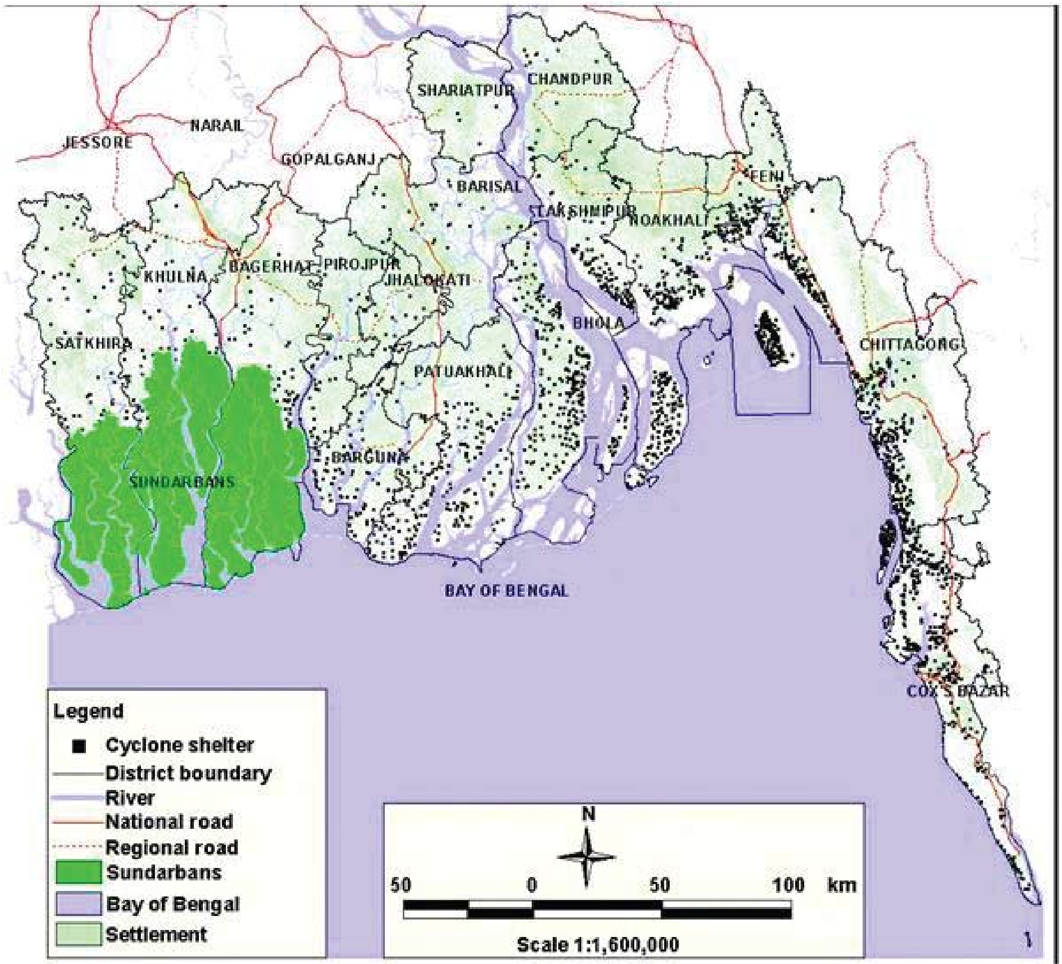
24 Cyclone shelters built in the early 1970s were designed to shelter people from cyclones but were later also used for other purposes such as primary schools. An additional 262 shelters are not usable and 88 have been washed away, destroyed, or dismantled.

25 Data and information on existing cyclone shelters are from the IWM and CEGIS, compiled from the Public Works Department (PWD), LGED, Education Engineering Department, Red Crescent Society, donor agencies, NGOs, and local experts.

26 Cyclone shelters were built in Bhola and Potuakhali after the 1970 cyclone; in Anwara, Banshkhali, and Cox's Bazar after the 1991 cyclone; and in the southwest region after the 2007 cyclone.

27 ADB, with support from other development partners, is building 398 cyclone shelters for completion by June 2011. The World Bank is currently constructing 50 shelters, along with 30 killas. The Islamic Development Bank is reviewing proposals to construct another 800 cyclone shelters.

FIGURE 3.2 LOCATION OF CYCLONE SHELTERS IN COASTAL AREAS



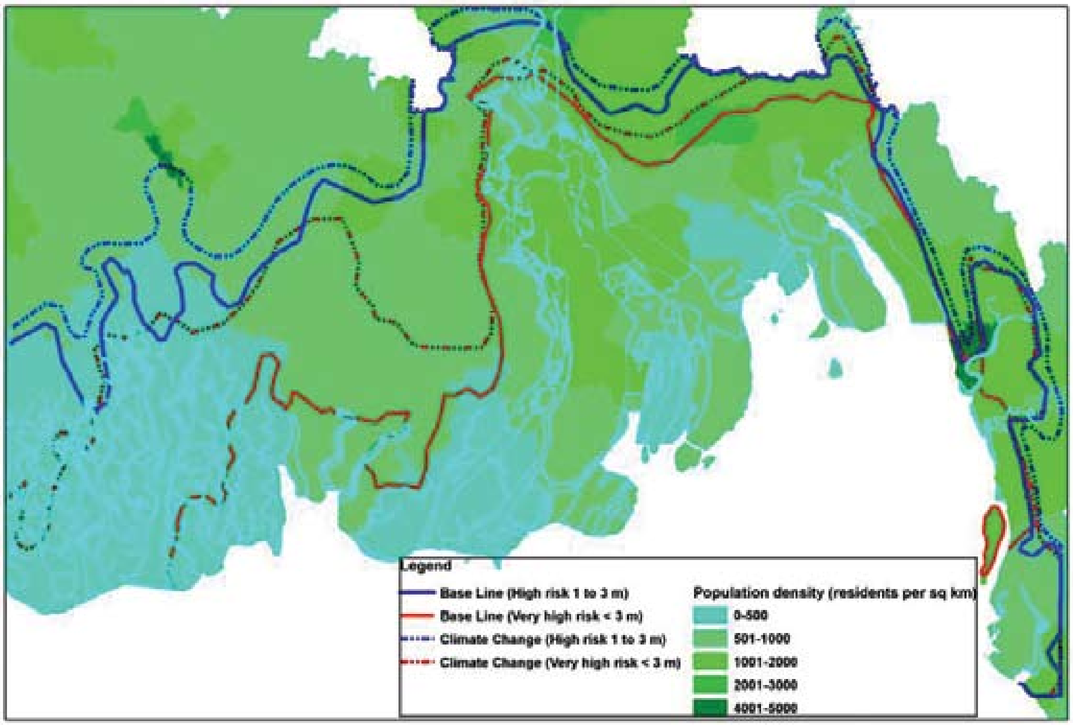
Source: CDMP

elevated space for livestock and overhead water storage, making them potentially more effective. The cost of constructing a multipurpose shelter varies with its capacity and its non-emergency purpose and usage. For instance, multipurpose shelters under construction in a World Bank project in the aftermath of Cyclone Sidr have a capacity to accommodate 1,600 people and are expected to cost $214,000, or about $134/person accommodated.

CEGIS (2004) examined the effectiveness of cyclone shelters in saving lives. Focus group interviews with residents of cyclone-affected areas revealed that willingness to use shelters during an emergency would increase if shelters (a) were easier to access, (b) were located closer to residents' homes, (c) were less crowded, (d) had separate facilities for women, (e) had facilities for people with disabilities, (f) had sanitation facilities above the ground floor, and (g) had facilities to protect livestock.[28]

28 Shelters with separate facilities for women (35 percent); facilities for people with disabilities (less than 5 percent); sanitation facilities (5 percent), facilities to protect livestock (20 percent), facilities with only ground floor toilets (1,000).

FIGURE 3.3 **POPULATION DENSITY IN COASTAL AREAS IN RELATION TO AREAS OF INUNDATION RISK**



Source: CEGIS

The number of cyclone shelters needed in an area depends on the population and housing characteristics of the area. While *pucca houses* (brick and concrete) can structurally withstand most of the wind damages from the average severe cyclone, they provide no remedy for inundation from storm surges. *Pucca houses* can effectively substitute for cyclone shelters in areas with inundation depth of less than 1 meter. In contrast, cyclone shelters are necessary to protect inhabitants living in single story dwellings that can potentially be exposed to inundation depths in excess of 3 meters.

Cyclone Resistant Housing: During past severe cyclones, thatched and *kachha* houses have often been completely damaged. In contrast, *pucca* houses have remained structurally intact, primarily incurring damages to the plaster on the exterior walls and the contents within. Coastal residents prefer to reside in *pucca* houses partly to reduce their own risk. A review of Census data from coastal areas indicates that nearly all families with an annual income level of $470 live in *pucca* houses. Significant increases in income levels expected over the next few decades should result in an increasing proportion of residents living in *pucca* houses and decreasing the need for cyclone shelters. Nevertheless, the need for shelters will remain for residents residing in single-story houses in areas with projected inundation depth that exceeds 3 meters.

Inland Migration: Finally, unlike most other countries, households and economic activity have accounted for the increased perceived risk from storm surges by locating themselves further inland as evidenced by the slower rate of growth in the coastal population compared to the rest

TABLE 3.2 ECONOMIC INDICATORS BANGLADESH: CURRENT AND 2050

	Current Indicators			Indicators in 2050	
Indicator	*Value*	*Year*	*Source/comments*	*Value*	*Source/comments*
Population (million)	130	2001	BBS	228	BBS
Population average annual growth rate	1.58	1991-01	State of the Coast, 2006	1.15%	BBS & State of the Coast, 2006 (replacement fertility in 2021)
Coastal population (million)	35	2003	State of the Coast, 2006	58	BBS & State of the Coast, 2006
Coastal population average annual growth rate	1.36%	1991-01	State of the Coast, 2006	1.05%	BBS & State of the Coast, 2006
GDP (billions of constant 2009 USD)	$75	2007	WDI 2009	$1,614	Projected with growth rates in the following row.
GDP avg. annual growth rate	5.9%	2001-09	Ministry of Finance	7.5%	Various government announcements
Per capita GDP (constant 2009 USD)	$470	2007	WDI 2009	$6,395	Implied
Road length (km)	272,487	2007	BBS	340,609	Assumed 25% expansion
Share of paved roads	30%	2007	BBS	100%	Assumed
Primary school net enrollment rate	91%	2007	Ministry of Education	100%	WDI 2009, average level in comparator countries *
Secondary school gross enrollment rate	43%	2007	Ministry of Education	70%	WDI 2009, average level in comparator countries *
Per capita electricity consumption (KWh)	150	2007	BBS	3000	WDI 2009, average level in comparator countries *
Share of pucca houses in rural areas	2.23%	2001	BBS	98%	current housing characteristics in Bangladesh by income level
Rice production (million metric tons)	27	2006	BBS	75	Yu et al, 2010, existing climate variability scenario

Notes: Current per capita GDP in comparator countries: Brazil($5,860), Malaysia($6,420), Lebanon($5,800), and Uruguay($6,390).
Source : World Development Indicators, World Bank

of the country. It can also be observed from the population density maps, which shows increasing density further inland (Figure 3.3). [29]

Estimating Potential Damage and Adaptation Cost

The additional potential damage from storm surges and the cost of adaptation in 2050 are determined by comparing the damages and costs under climate change against the counterfactual baseline scenario that does not include climate change. The analysis is based on simulating average severe cyclones with a ten-year return period, which enables a more precise definition of the baseline scenario. This choice also results in a more conservative estimate of damages and costs as it ignores the more intense but less frequent storms that may occur during this period. The potential damages and the cost of adaptation are determined separately for each scenario in the following 5-steps: (1) demarcate inundation risk exposure zones from storm surges; (2) identify assets and activities exposed to inundation risk; (3) determine assets and activities affected in a single cyclone; (4) estimate potential damage and loss from a single

29 The inundation zones computed in the next sections for the baseline and climate change scenario are also shown.

cyclone; and (5) estimate adaptation measures and costs necessary to mitigate inundation risk.

Economic Development Baseline: Both assessments are completed under a common projected development baseline that builds on recent economic trends and extends them to 2050 based on normal economic development patterns. Table 3.2 summarizes the key changes in the Bangladesh economy between now and 2050, which includes 53 percent more people, more than a twenty-fold increase in GDP, and decreased dependence on agriculture. The people of Bangladesh are expected to be nearly ten times richer, consuming twenty times more electricity per person, living in *pucca* houses, and enrolling all primary-aged children in schools.

Inundation risk exposure zones

Inundation risk exposure in an area is characterized by the maximum potential inundation depth that may occur for any of the simulated storms under a scenario. Two scenarios are developed: (1) a climate change scenario, and (2) a baseline scenario that is used as a counterfactual to determine additional risk exposure due to climate change.

Baseline Risk Scenario: The 19 cyclones that made landfall in Bangladesh between 1960 and 2009 collectively define the current cyclone-related risks in Bangladesh. Detailed information about each of these historical cyclone tracks is available in Annex 1. These storms on average have a return period of 10 years and span the entire coastal region of Bangladesh. The baseline inundation risk exposure is developed from simulations combining these 19 historical cyclones with their corresponding observed wind and pressure fields with the Bay of Bengal hydrodynamic model. This scenario is the counterfactual against which future climate change risk is measured, but is also useful to assess the current inundation risk that Bangladesh faces.

Climate Change Risk Scenario: Storm-surge-related risk is expected to increase from these historical levels due to climate change. Future storms tracks cannot be predicted with any degree of precision. Cyclone-related risks under the climate change scenario are developed collectively by simulating a set of five storms that span the entire Bangladesh coastline (see Annex 2). Simulations of the 1974, 1988, 1991, and 2007 cyclones indicated that these cyclones adequately cover the Sunderban coast, southwestern coat (Sunderban to Patuakhali), the Bhola and Noakhali coast in the Meghna Estuary, and the eastern coast (Shitakunda to Bashkhali). In addition, a fifth hypothetical track was simulated to cover the remaining Sandwip coast and the part of the Noakhali and Chittagong coasts at the central region of the Meghna Estuary. The inundation risk exposure for the climate change scenario is developed from simulations combining these five cyclones with the Bay of Bengal hydrodynamic model. Each of the simulations is based on the following three assumptions about the increasing intensity of an average 10-year return period cyclone brought about by climate change by 2050.

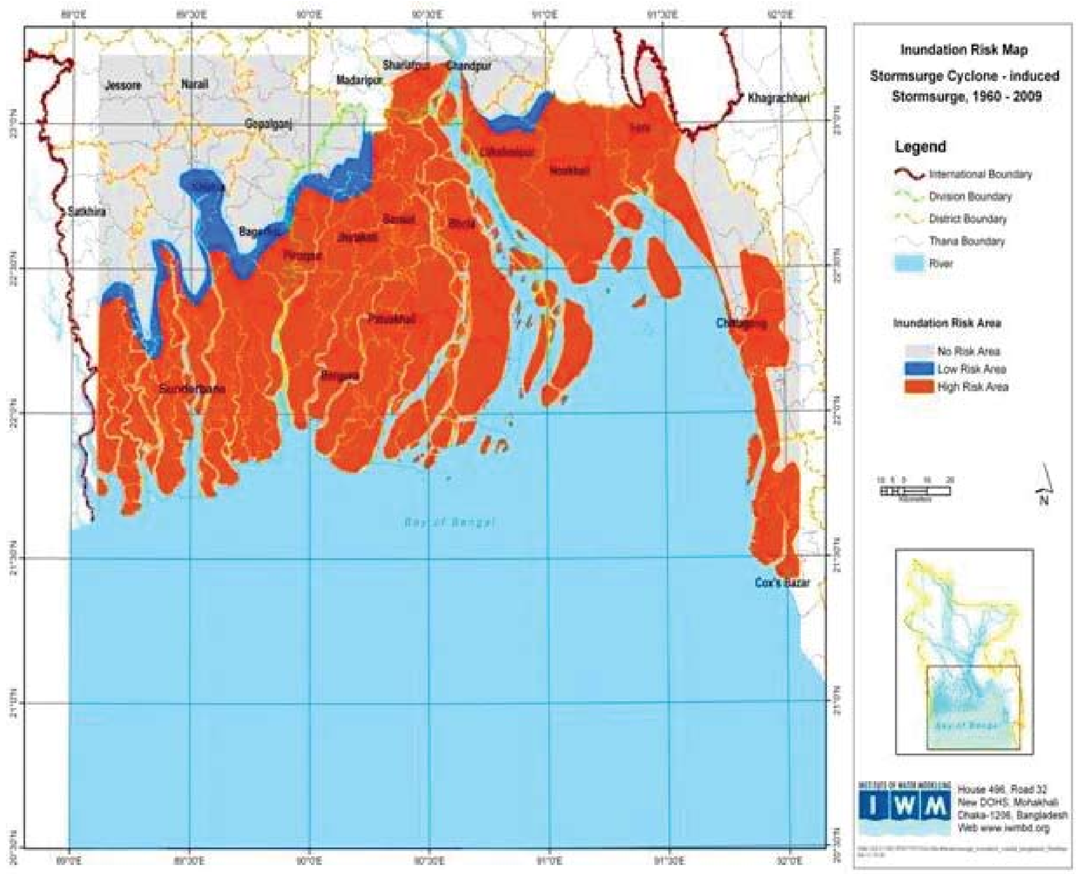
- A rise in sea level of 27cm (UK DEFRA 2007).
- An increase in wind speed by 10 percent relative to Cyclone SIDR.
- Landfall occurs during high tide.[30]

Inundation risk exposure for each scenario is determined in three steps. First, the extent and depth of inundation associated with each cyclone (nineteen for the baseline and eight for the climate change scenario) is determined based on simulations using the cyclone model and the two-dimensional Bay of Bengal model.[31] (A detailed description of the model is provided in Annex

30 Since scientific evidence to date points toward an increase in the frequency of intense cyclones in the Bay of Bengal, the probability of a potential landfall during high tide will also increase.

31 The Bay of Bengal model is a hydrodynamic model based on the Mike 21 hydrodynamic modeling system. Its domain covers the coastal region of Bangladesh up to Chandpur and the Bay of Bengal up to 16° latitude. It was recently updated and upgraded under the Comprehensive Disaster Management Program (CDMP) of Bangladesh (UK DEFRA 2007).

FIGURE 3.4 INUNDATION RISK EXPOSURE MAP—BASELINE SCENARIO

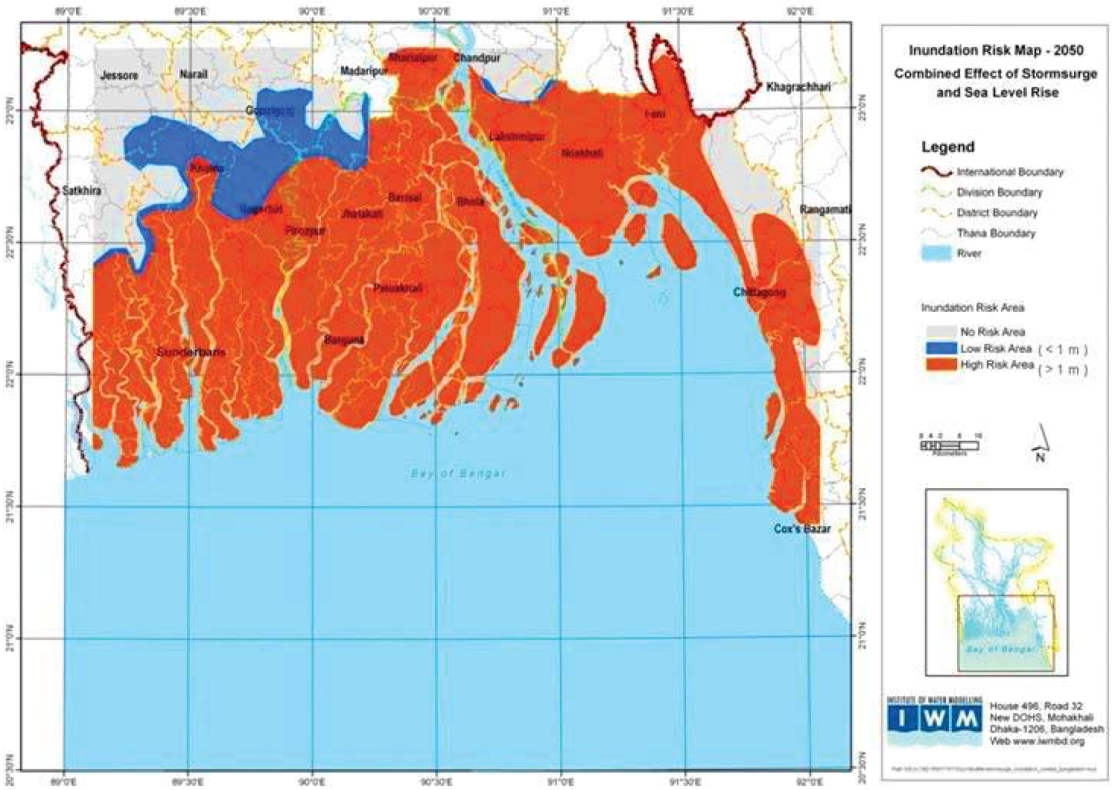


1.) Second, for each grid point, the inundation depth results from each of the cyclone simulations for the scenario are combined together to determine the highest inundation depth for all simulated cyclones under that scenario. All of the simulations are based on the existing set of coastal protection infrastructures (embankments, and polders). Finally, for the subsequent economic analysis, risk exposure zones are formed by grouping grid points into one of three inundation levels (0–1 m, 1–3 m, and more then 3m).

Figure 3.4and Figure 3.5 show the inundation risk exposure map of Bangladesh, as measured by the potential maximum inundation depths from the simulations, under the baseline and the climate change scenarios respectively. They do not show inundation levels for a single cyclone, rather they indicate the largest inundation risks from any of the simulated cyclones. So, the baseline scenario map shown in Figure 3.4 reflects the largest inundation risk that a specific location has faced since 1960.

The inundation risk exposures under the two scenarios are summarized in Table 3.3. Under the baseline scenario, inundation depth is greater than 1 meter under at least one of the cyclone tracks for 20,876 square kilometers of land, and is greater than 3 meters for 10,163 square kilometers. Under the climate change scenario, the inundation depth increases for areas already inundated in the baseline scenario. In addition,

FIGURE 3.5 INUNDATION RISK EXPOSURE MAP—CLIMATE CHANGE SCENARIO



areas further inland become inundated. The net result is an increase of 14 percent in the areas inundated by more than 1 meter and an increase of 69 percent in the areas inundated by more than 3 meters.

Assets and activities exposed to inundation risk

The current spatial distribution of assets and activities provides the starting point for identifying assets and activities that are exposed to inundation risk in 2050. Expected changes in the Bangladesh economy—including growth in population and income and structural shifts in the economy—are applied uniformly to project the expected assets and activities in 2050 (see Table 3.2). The inundation exposure risk zones for the baseline and climate change scenarios are overlaid on the asset and activities map using geographic information system (GIS) software to determine the assets and activities that are exposed to inundation risk under each scenario.

The assets and activities considered for the analysis include housing (by building material type), education institutions, growth centers, mills/ factories (large scale), national highways, regional highways, feeder roads (type A), feeder roads (type B), bridges, power plants, power transmission lines, deep tubewells, mosques, temples, historical places and tourist destinations, land by crop suitability, and population by socioeconomic status.

The best available spatially disaggregated maps and data for these activities are available from

TABLE 3.3 POTENTIAL INUNDATION RISK EXPOSURE AREA (SQ KM)

Inundation Risk Exposure (Depth)	Baseline Scenario	Climate Change Scenario	Percent Change
More than 1 m	20,876	23,764	+ 14%
More than 3 m	10,163	17,193	+ 69%

TABLE 3.4 POPULATION EXPOSED TO INUNDATION RISK (MILLION)

Inundation Risk Exposure (Depth)	Baseline Scenario 2007 (a)	Baseline Scenario 2050 (b)	Percent Change between (a) and (b)	Climate Change Scenario 2050 (c)	Percent Change between (b) and (c)
More than 1 m	18.5	28.3	+ 53%	35.3	+25%
More than 3 m	8.9	13.5	+53%	22.6	+67%

TABLE 3.5 ROAD EXPOSED TO INUNDATION RISK (KM)

Inundation Risk Exposure (Depth)	Baseline Scenario 2007 (a)	Baseline Scenario 2050 (b)	Percent Change between (a) and (b)	Climate Change Scenario 2050 (c)	Percent Change between (b) and (c)
0 -1 m	3,198	3,988	+ 25%	10,466	+162%
More than 1 m	7,177	8,972	+25%	10,553	+18%
All inundated	10,375	12,969	+25%	21,019	+62%

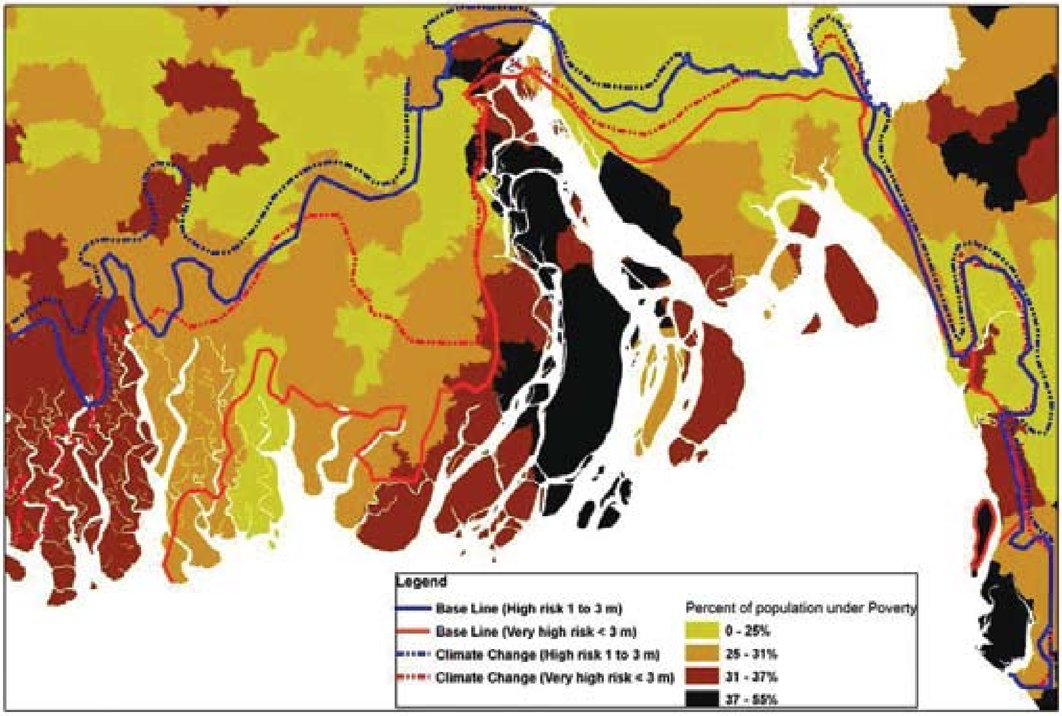
various public sources, including Bangladesh Railways, the Bangladesh Water Development Board, the Local Government Engineering Department (LGED), the Center for Environmental and Geographic Information Services (CEGIS), the Public Works Department, the Roads and Highways Department, the Water Resources Planning Organization, and the World Bank.

The assets and activities exposed in each inundation risk zone are determined using one of three methods. For most assets, such as schools, the exposure estimate is a count of the number of assets located in that risk zone. For assets with a large spatial extent, the exposure estimate is measured by the spatial extent (land surface and agriculture extent in square kilometers, roads and railways in kilometers). Finally, the exposed population count is estimated at the thana level, which is the lowest administrative unit, using the population density and the total area that falls into each risk zone. The total exposed population count is the sum of the exposed population across thanas.

Under the baseline scenario, of the 35 million coastal residents in 2007, nearly half are exposed to inundation risk depth of more than 1 meter and about a quarter are exposed to inundation risk of over 3 meters (Table 3.4). Expected population growth between 2007 and 2050 increases the number of exposed people by 53 percent within each risk zone. With the additional risk of inundation under the climate change scenario, about 35 million coastal residents are exposed to inundation of more than 1 meter; nearly two-thirds of them are exposed to inundation of more than 3 meters. In the absence of added protective measures, the combined effects of population growth and climate change nearly doubles the population exposed to inundation risk of more than 1 meter, and increases those at risk of inundation of more than 3 meters by two-and-a half times by 2050.

Similarly, under the baseline scenario, of over 272,487 kilometers of roads in Bangladesh in 2007, about 4 percent are exposed to inundation risk, of which about 70 percent are exposed to inundation risk of more than 1 meter (Table 3.5) Bangladesh

FIGURE 3.6 POPULATION UNDER POVERY IN RELATION TO INUNDATION RISK



Source: CEGIS

already has one of the highest road densities in the world and there is limited room for expansion of the road network. The road network is assumed to expand by 25 percent between now and 2050 or about 0.5 percent per year, with most of the effort expended on strengthening the existing roads by paving and or raising them. With the additional risk of inundation under the climate change scenario, over 21,000 km of roads are exposed to inundation, of which about half are exposed to inundation of more than 1 meter. In the absence of added protective measures, the combined effects of expansion in the road network and climate change nearly doubles the roads exposed to inundation risk by 2050. The largest inundation risks also occurs in areas which have the largest share of the poor under both scenarios (Figure 3.6)

The other assets and activities exposed to inundation risk are determined in a similar manner, and are discussed separately in detail in the next section as part of the damage estimation. While the method remains the same, there are significant differences in the growth rate of assets and activities between 2007 and 2050. Additionally, in cases when detailed spatial data was not available for a specific asset, the additional risk due to climate change is based on changes in the exposed population (housing, power consumption) or changes in the inundation risk area (power infrastructure).

Assets and activities potentially affected during a single storm

Without additional risk mitigation measures, affected assets and activities can be damaged if they are in the path of a storm. The assets and activities affected in a single storm depend on the areal extent of the storm. The average severe cyclone with a 10-year period under the baseline

TABLE 3.6 AREA AFFECTED IN A SINGLE CYCLONE WITH A 10-YEAR RETURN PERIOD (SQ KM)

Inundation Risk Exposure (Depth)	Baseline Scenario	Climate Change Scenario	Percent Change
More than 1 m	5,428	10,219	+ 88%
More than 3 m	2,642	7,393	+ 180%

TABLE 3.7 POPULATION AFFECTED IN A SINGLE CYCLONE WITH A 10-YEAR RETURN PERIOD (MILLIONS)

Inundation Risk Exposure (Depth)	Baseline Scenario 2007 (a)	Baseline Scenario 2050 (b)	Percent Change between (a) and (b)	Climate Change Scenario 2050 (c)	Percent Change between (b) and (c)
More than 1 m	4.8	7.4	+ 53%	15.2	+107%
More than 3 m	2.3	3.5	+53%	9.7	+177%

TABLE 3.8 ROADS AFFECTED IN A SINGLE CYCLONE WITH A 10-YEAR RETURN PERIOD (KM)

Inundation Risk Exposure (Depth)	Sidr 2007* (a)	Baseline Scenario 2050 (b)	Percent Change between (a) and (b)	Climate Change Scenario 2050 (c)	Percent Change between (b) and (c)
0 -1 m*	6,361	1,039	n/a	4,500	+333%
More than 1 m*	1,714	2,333	n/a	4,538	+ 95%
All inundated	8,075	3,372	n/a	9,038	+168%

* The affected roads for Sidr and the baseline scenario are not directly comparable. For Sidr 2007, the affected roads categories reported are partially damaged and fully damaged roads instead of inundation depth.

scenario affects 26 percent of the exposed area.[32] In contrast, 43 percent of the exposed area is affected by the more intense cyclones under the climate change scenario. The combined effects of the larger inundation risk exposed area and the increased aeral extent during a single storm increases the areas inundated more than 1 meter by 88 percent and areas inundated more than 3 meters by 180 percent (Table 3.6).

Similarly, the potential affected population living in these respective areas increases by 107 percent and 177 percent respectively (Table 3.7). The other assets and activities affected in a single storm also depend on the areal extent of the storm. However, the mix of assets and activities within each sector that are exposed and affected can be significantly different than the mix of roads that are damaged. For instance, in the case of roads, unpaved roads accounted for nearly 78 percent of the total kilometers of damaged roads during Cyclone Sidr. They can be damaged by even low levels of inundation (Table 3.8).

Potential damage and loss during a single cyclone

Potential damages and losses in each of the major economic sectors resulting from induced storm surges from a single-cyclonic event are computed for the baseline and the climate change scenarios. They are determined by applying sector-specific damage and loss functions to the affected assets and activities in the sector.

32 The extent of inundation includes areas with inundation depth of 1 m or more.

TABLE 3.9 DAMAGES AND LOSSES DURING A SINGLE SUPER CYCLONIC STORM BY ECONOMIC SECTOR

Economic Sector	Damages and Losses (Cyclone Sidr)			Damages & Loss (Average Severe Cyclone)
	(Current Million USD)	(Constant 2009 Million USD)	Share of total (%)	(Constant 2009 Million USD)
Housing	839	978	50	900
Agriculture	438	510	26	469
Transport	141	164	8	151
Water Resource Control	71	83	4	83
Education Infrastructure	69	80	4	73
Industry/ Commerce/ Tourism	52	61	3	56
Urban and municipal	25	29	2	27
Power	14	16	1	15
Other	26	30	2	28
Total Damages and Losses	1,675	1,952	100	1,802
Share of GDP		2.6%		2.4%

The major economic sectors impacted are limited to those that incurred damages and losses during Cyclone Sidr in 2007, the most devastating cyclone in the recent past. Table 3.9 summarizes the damages and losses by sector during Cyclone Sidr. Damages and losses from this single event accounted for 2.6 percent of GDP. Sidr was an above-average cyclone with a 10-year return period. The damages from an average cyclone with the same return period would actually be lower.[33] Scaling the damages down to reflect the smaller areal extent of an average cyclone indicates that if an average cyclone with a 10-year return period were to strike the Bangladesh coast today, the expected damages and losses would be about 2.4 percent of GDP. Nearly half of the damages and losses would occur in housing, followed by agriculture and transport.

Damage and loss functions for each of the above sectors are developed from the damages incurred during Sidr, when available. In addition, fatality and injury rates are also developed from the deaths and injuries resulting from Sidr. Damages include complete or partial destruction inflicted on assets (assets not portable as well as stock). Losses refer to the flows of goods and services that are not produced or rendered due to a disaster. Losses also include disaster-induced cost increases incurred in continuing essential services.

Human Casualty and Injury: Approximately 3.45 million coastal inhabitants of Bangladesh were exposed to storm-surge-related inundation during Sidr in 2007. Post-disaster assessments indicate 3,406 human casualties, or a casualty rate of 1per thousand exposed and 55,282 injuries, or an injury rate of 16 per thousand exposed. Although cyclone shelters saved thousands of lives, focus group interviews with the residents of cyclone-affected areas revealed that a large section of population was reluctant to move to cyclone shelters even during an emergency.[34] Casualty and injury

33 Cyclone Sidr (wind speed of 223 km / hour) has a return period of 10 years based on the 21 major cyclone events from 1960 to 2009 in Bangladesh. Its areal extent was 8.7 percent larger than the average cyclone with a 10-year return period.

34 Distance from the homestead, difficult access to shelters, unwillingness to leave livestock behind unprotected, scarcity of sanitation facilities, lack of user friendly facilities for women, overcrowding condition in shelters are the primary reasons behind their reluctance.

rates can be expected to decline as cyclone-resilient *pucca* houses become affordable for an increasing proportion of coastal residents and if user-friendly shelter designs encourage higher usage rates.

The exposed population is expected to rise to 5.34 million in 2050 under the baseline scenario due to the expected growth in the coastal population and further increase to 10.04 million due to the increase in the affected area. If there are no changes in the human casualty and injury rates, **the upper bound estimates are 4,637 additional human casualties and 75,268 additional injuries due to climate change**.[35]

Housing: The housing sector accounted for about half of the damages and losses from Cyclone Sidr. Almost all of the damages occurred in "*Semi-pucca*"[36] houses, "*kacha*"[37] houses, and "*jhupris*"[38]. In contrast, "*pucca*" houses, constructed with brick walls and a concrete roof, remained structurally intact, sustaining minimal damages requiring replastering of walls. Analysis of the 2001 Bangladesh census indicates that households increasingly move to "*pucca*" houses as their incomes rise. The projected increase in per capita incomes by 2050 is expected to alter the mix of housing types in Bangladesh, resulting in a significant reduction in housing damage, but also a substantial increase in household asset damages.

In 2001 only 2.23 percent of rural households with an annual per capita income of $470[39] or more could afford a "*pucca*" house. By 2050, rising income levels will enable approximately 98 percent of households to afford a "*pucca*" house. As a result, most of the housing damage in 2050 is from damages to the contents within the houses. The average "*pucca*" dwelling in Bangladesh in 2050 is assumed to remain at the current size of 400 sq feet in size with 2,000 sq feet of brick wall surface. Household assets in 2050 are estimated to be approximately $2,143 (Tk 150,000). If 50 percent of the walls require replastering at a cost of $0.0714 per sq ft (Tk 10/sq ft) and 50 percent of the household assets are damaged due to inundation, the damages per affected house will be $1,214.

Under the baseline scenario, 28.7 million people are exposed to inundation risk greater than 1 meter in 2050.[40] An additional 7.08 million inhabitants (or 1.45 million houses[41]) are exposed to this same level of risk under the climate change scenario. Accounting for the larger areal extent of a cyclone under the climate change scenario, an additional 1.6 million houses are projected to be damaged due to climate change. **The total additional housing damages in 2050 due to climate change consists of $229 million for re-plastering damaged houses and $1,718 million in content damage, for a total of $1,947 million.**

Education infrastructure: Damaged primary school facilities accounted for over 95 percent of the education sector damages from Cyclone Sidr. With the mandate for universal primary education and gross primary school enrollment rates of 90 percent, there are many more primary schools that are at risk of inundation and damage. As per capita incomes rise, school enrollment rates are expected to increase at all levels of education, resulting in a corresponding increase in the number of educational institutions. By 2050,

35 Estimated human casualties in 2050 under the baseline and climate change scenarios are 5,274 and 9,911 respectively. The corresponding number of injuries are 85,609 and 160,877 respectively.

36 Typical characteristics of semi-pucca housing are: foundation made of earthen plinth or brick and concrete, walls made of bamboo mats, CI sheet and roof made of CI sheet with timber framing.

37 Typical characteristics of kacha housing are: foundation made from earthen plinth with bamboo, walls made of organic materials, and roof thatched made of straw, split bamboo etc.

38 Typical characteristics of jhupris are: ceiling less than four feet, cheap construction materials such as straw, bamboo, grass, leaves, polythene, gunny bags, etc.

39 Monthly income Taka 2,750 per capita.

40 Inundation depth of less than 1m is assumed to have a negligible impact on houses in 2050.

41 The average household size is assumed to be 4.89, unchanged from current levels.

TABLE 3.10 CROPPED AREA EXPOSED TO INUNDATION RISK IN THE BASELINE AND CLIMATE CHANGE SCENARIOS (HA)

Crop	Baseline Scenario 2050 (hectares)	Climate Change Scenario 2050 (hectares)	Percent Change
Aman	1,092,645	1,305,028	+19
Aus	526,040	618,897	+18
Boro	272,768	388,828	+43

secondary school enrollment rates are expected to rise from the current 43 percent to 70 percent by 2050, while primary school enrollment is expected to increase to 100 percent. The combined effects of population growth, a changing age structure, and higher school enrollment rates are expected to increase by over 1 million the number of exposed school students (0.63 million in primary schools and 0.43 million in secondary schools)[42]. Climate change is expected to further increase the number of exposed primary school students by 0.46 million (in 2,283 primary schools) and secondary school students by 0.31 million (in 2,086 primary school equivalents[43]). Accounting for the larger areal extent of a cyclone under the climate change scenario, an additional 4,840 primary school (equivalents) are expected to be damaged due to climate change.

The standard size specification for a primary school in Bangladesh enrolling 200 students is approximately 160 sqm (LGED). By 2050, its average contents are expected to rise to $2,857 (Tk 200,000). If 50 percent of the walls in affected schools are damaged and require replastering and 50 percent of its contents are damaged, average damages per affected school are $1,851. When additional losses to provide interim facilities during reconstruction of 9.6 percent are included, the total damage and loss per school is $2,029. **The total additional education sector damages and losses in 2050 under the climate change scenario consist of $9 million in damages requiring replastering of walls and replacing contents and $1 million in losses for interim facilities.**

Agriculture: Crop losses accounted for nearly 95 percent of agriculture sector damages and losses during Cyclone Sidr. Damage and loss to fisheries and livestock were much smaller. Crop losses from a specific cyclone vary based on the season it strikes. The cropping calendar, planting/harvesting dates, of the major rice crops *Aman*, *Aus*, and *Boro* are different.[44] Bangladesh is twice as likely to be hit by a tropical cyclone during the post-monsoon season as during the pre-monsoon season. The expected crop damage estimates from a cyclone is the probability-weighted crop damages from cyclones that occur during different seasons.

Crop losses resulting from a cyclone are determined in detail for the three main rice crops. Non-cereal crop losses are estimated based on the crop loses for these rice crops.

Table 3.10 shows the cropped area that is exposed to inundation risk under the baseline and climate change scenarios for the three rice crops. The exposed area increases by twice as much for the boro crop than for the aman and aus crops. The larger areal extent of a storm under the climate change scenario implies that the affected areas in a

42 These estimates are based on the following assumptions: (a) Bangladesh will attain 100 percent enrollment in primary schools and 70 percent enrollment in secondary schools by 2050. These are the current school enrollment rates in comparator countries (Brazil, Lebanon, Malaysia, Uruguay) with current per capita incomes similar to that projected for Bangladesh in 2050; (b) ratio of primary school-age and secondary school-age children enrolled in school to total population will be 6.45 percent and 4.42 percent respectively by 2050, (c) the standard capacity of a primary school is 200 students and a similar size school can accommodate up to 150 secondary students in Bangladesh.

43 Cost of constructing a secondary school is estimated from the costs of primary schools. Secondary schools are typically are larger and enroll more students than a primary school. However, the space required per secondary school pupil is about 33 percent larger. A primary school equivalent normalizes for this larger space requirement.

44 Aman grows in the monsoon season, Aus grows in pre-monsoon, and Boro grows in the post-monsoon season.

cyclone for aman, aus, and boro will increase by 98 percent, 94 percent, and 136 percent respectively.

By 2050, the agriculture sector is expected to grow at an annual average growth rate of 2.4 percent, largely through increases in yields (Yu et al. 2010). As a result, by 2050, yields for aman, aus, and boro are expected to rise to 5.5, 4.7 and 9.5 mt/ha respectively. If 50 percent of the affected crops are lost, at a price of $676 per metric ton, the expected crop losses for the three rice crops in the baseline and climate change scenarios are $501 and $1,017 million respectively. Assuming non-cereal crops losses increase in proportion to the rice crops, total crop losses will rise to $767 and $1,556 million in the baseline and climate change scenarios respectively. **The estimated additional crop loss in 2050 due to climate change is $789 million.**

The damage and loss to fisheries and livestock are much smaller. In 2007 Sidr inflicted damages and losses of $19.3 million on livestock and $6.7 million on fisheries. If livestock and fisheries continue to grow at the observed (2001–07) annual growth rates of 3 percent and 6 percent respectively, **the estimated additional damage and loss due to climate change in 2050 is $56 million for livestock and $66 million for fisheries**.[45]

Non- agricultural productive sector: Cyclone Sidr caused total damages of $4 million and losses of $48 million to the non-agricultural productive sectors (industry, commerce, and tourism) in 2007. These sectors accounted for 82 percent of GDP (Yu et al 2010). Urbanization and structural shifts in the economy associated with rising income levels in 2050 are expected to increase the contribution of these sectors to the economy by 2050, accounting for an additional 9 percent of GDP, or a total of 91 percent of GDP.[46] Under the baseline scenario, higher GDP levels combined with increased shares of the non-agricultural productive sectors in the economy in 2050 result in total damages of $96 million and losses of $1,237 million. The increased risk due to climate change and the larger areal extent of **a storm under the climate change scenario will result in additional damages of $88 million and additional losses of $1,084 million**.

Transport: Roads accounts for almost all of the damages in the transport sector. This is likely to remain unchanged in 2050 as well. Roads are highly sensitive to inundation and become partially damaged with inundation of less than 1 meter and are fully damaged when inundation exceeds 1 meter. As a result, national and regional roads in Bangladesh are constructed to lie above the highest flood level (HFL) with a return period of 50 years and feeder roads to lie above normal flood levels (Siddiqui and Hossain 2006). The density of roads in Bangladesh is already one of the highest in the world. By 2050, the road network is expected to expand by 25 percent, much slower than the expansion of the overall economy. However, the road network is expected to be upgraded and built to higher design standards. The share of paved roads is also expected to gradually rise to 100 percent by 2050.

Under the baseline scenario, 12,969 km of roads are exposed to inundation, of which about two-thirds are exposed to inundation greater than 1 meter in 2050. With the additional risk of inundation under the climate change scenario, 21,019 km of roads are exposed to inundation, of which about half are exposed to inundation of more

45 Estimated damage to livestock is $63 million under the baseline scenario and $119 million under the climate change scenario. The corresponding damage and loss for fisheries is $76 million and $142 million. These estimates are relatively crude—based on aggregate growth trends only—and can be higher or lower based on the underlying growth and exposure factors. For instance, improvements in in-situ (individual or community-based) protective measures such as the construction of platforms to protect livestock can reduce damages. On the other hand, technological improvements such as the increased use of diesel boats instead of sail boats can lead to greater exposure and potential damages.

46 Yu et al. 2010; also average non-agricultural share of GDP in comparator countries (Brazil, Lebanon, Malaysia, and Uruguay).

than 1 meter. In the absence of added protective measures, the combined effects of expansion in the road network and climate change nearly doubles the length of roads exposed to inundation risk by 2050.

Under the baseline scenario, 3,372 km of roads are affected in a single cyclone, with partial damages to 1,039 km and full damages to 2,333 km. Accounting for the larger areal extent of a cyclone under the climate change scenario, the affected roads increase by over 2.5 times to 9,038 km. Partially damaged roads nearly quadruple to 4,500 km, while fully damaged roads almost double to 4,538 km.

Repair costs after Cyclone Sidr were estimated at $28,571 (Tk 2 million) per km for fully damaged roads and $14,286 (Tk 1 million) per km for partially damaged roads. Repairing damages to bridges and culverts along these roads increased total transport sector damages by 1.13 times. Finally, economic losses due to the closure of roads during the reconstruction of damages were about 22 percent of the total damages to the road infrastructure.

Applying these cost factors, the estimated damages and losses for roads, bridges, and culverts under the baseline scenario total $212 million, including $174 million in damages and $38 million in losses. Under the climate change scenario, total damages increase to $413 million and losses to $90 million. The additional damages and losses due to climate change in the transport sector in 2050 **are $240 million and $53 million respectively.**

Power infrastructure: In 2007, Cyclone Sidr caused $8.2 million in damages to power transmission and distribution infrastructure in coastal Bangladesh. Loss of power also resulted in additional economic losses of $5.1 million. Rising income levels are expected to result in an increase in both power consumption and in the infrastructure to deliver this power. By 2050, per capita power consumption is expected to increase twentyfold, from the current 150 Kwh to 3,000 Kwh.[47] The power grid and infrastructure is expected to expand fivefold to deliver the added electricity demand.[48] The combined effects of population growth and rising per capita consumption are expected to increase damages to power infrastructure to $68 million and economic losses to $171 million in 2050 under the baseline scenario. The increased inundation risk and areal extent under the climate change scenario is expected to increase damages to $129 million and losses to $321 million. **The estimated additional damage due to climate change is $60 million and the additional potential loss is $150 million.**

Coastal protective infrastructure: In the 1960s, 123 polders and supporting infrastructure were constructed to protect low-lying coastal areas against tidal flood and salinity intrusion in Bangladesh. In 2007, Sidr induced damages of $70.3 million to the polders and related water regulators in coastal Bangladesh. Overtopping of embankments is the most important factor responsible for damages to coastal infrastructure during cyclones. Comparison of projected surge heights and heights of existing embankments of polders (as described in the next section) indicate an additional 13 polders are likely to be overtopped by 2050 due to climate change, resulting in **additional potential damage of $17.3 million**.

Potential damage across all sectors: The total potential damages and losses under the baseline and climate change scenarios in 2050 are summarized in Table 3.11. Total damages

47 The consumption of power in Brazil, Lebanon, Malaysia, Uruguay, and South Africa—countries with present per capita income similar to the projected per capita income of Bangladesh—indicates per capita consumption of power is likely to increase 20 times in Bangladesh.

48 Experts at the Asian Development Bank working on the Bangladesh power sector indicated that the power infrastructure has to be expanded at one-fourth the rate of growth in electricity consumption.

TABLE 3.11 DAMAGES AND LOSSES FROM CYCLONE SIDR (2007) BY ECONOMIC SECTOR

Economic Sector	Average Severe Cyclone 2009	Baseline Scenario (a)	Climate Change Scenario (b)	Additional due to Climate Change (b) - (a)
Housing	900	1,825	3,772	1,947
Non-Agriculture Productive Sector	56	1,333	2,505	1,172
Agriculture/Fisheries/Livestock	469	906	1,816	910
Transport	151	212	504	293
Power	15	239	449	210
Water Resource Control	83	83	100	17
Education Infrastructure	73	9	19	10
Other	55	n/a	n/a	n/a
Total Damages and Losses	1,802	4,607	9,166	4,560
Share of GDP	2.4%	0.3%	0.6%	0.3%

TABLE 3.12 ADDITIONAL DAMAGES AND LOSSES DUE TO CLIMATE CHANGE IN 2050

Economic Sector	Damages (Million USD)	Losses (Million USD)	Damages and Losses (Million USD)	Share of Damages & Losses (%)
Housing	1,947	—	1,947	43
Industry/ Commerce/Tourism	88	1,084	1,172	26
Agriculture	75	835	910	20
Transport	240	53	293	6
Power	60	150	210	5
Coastal Protection	17	0	17	0
Education Infrastructure	9	1	10	0
Others	n/a	n/a	n/a	n/a
Total	2,437	2,123	4,560	100

and losses under the baseline scenario are $4,607 million. While housing continues to account for the largest share of total damages and losses, its share declines to 40 percent as households adapt to the risks they face. Structural shifts in the economy also reduce the share of agriculture, while increasing those for non-agricultural productive sectors and power. Even though these damages and losses are more than twice as large as the damages from Cyclone Sidr, their economic impact is expected to be much smaller, accounting for only 0.3 percent of GDP. Climate change is expected to increase damages and losses from an average 10-year return period cyclone in 2050 by $4,560 million, nearly doubling the total damages and losses. The total additional damages and losses account for another 0.3 percent of GDP.

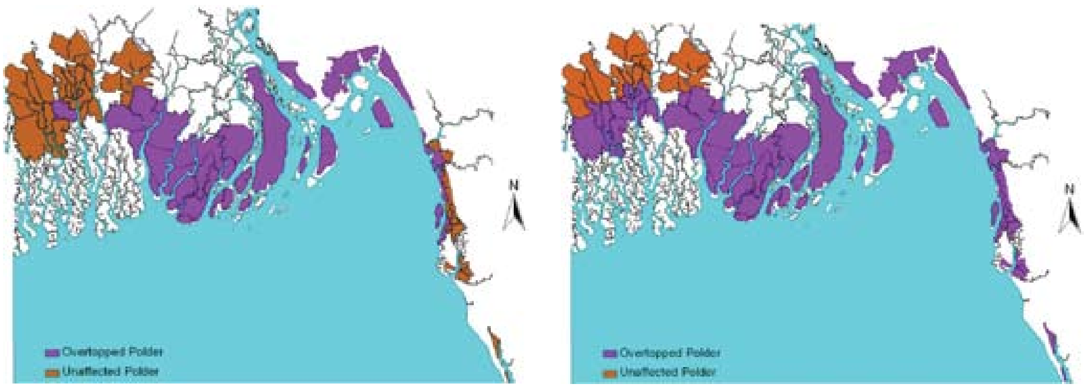
Table 3.12 summarizes the distribution of additional damages and losses by sector. Losses account for nearly half of the additional economic impacts of climate change in 2050. In contrast, losses only accounted for a third of the economic impacts from Sidr.

Adaptation options and cost

Bangladesh has invested over $10 billion (in constant 2007 USD) during the last 35 years in

FIGURE 3.7 LOCATION OF OVERTOPPED POLDERS

BASELINE SCENARIO (LEFT), CLIMATE CHANGE SCENARIO (RIGHT)



measures to make the nation less vulnerable to natural disasters such as cyclones and floods (GoB 2009). The coastal protection measures already in place provide a good foundation to build upon to further mitigate existing current risks and future inundation risks. They reveal what has worked well and what has not worked well with a high degree of geographic detail, and the potential effectiveness of these measures to address the additional risks posed by climate change. This analysis is primarily focused on the upgrading and expanding of existing adaptation measures to prevent the inundation risks identified under the baseline and climate change scenarios. Specifically, adaptation costs are estimated for five measures—embankments (upgrade only), afforestation (expansion only), cyclone shelters (expansion only), cyclone-resistant housing (expansion only), and early warning systems (upgrade and expansion)—under the two climate scenarios. These adaptation measures aim to reduce the area, assets, and activities exposed to inundation risk, and hence diminish the need for additional asset-specific resilience enhancing investments, such as raising the height of roads further inland. However, such resilience enhancing investments are essential to protect assets in areas that are currently not protected by polders (e.g. many small islands). Polders were not constructed in these areas primarily because of the low density of assets and activities in these areas. The cost of increasing the resilience of specific assets in these areas should be relatively small; no attempt was made to estimate this cost.

In each case, the total costs are estimated through a gap analysis, taking into account the existing adaptation investments already in place. The additional set of adaption measures that would be required to prevent damages are computed for both scenarios. The costs under the baseline scenario are the adaptation deficit. The difference in the cost between the two scenarios represents the cost of adaptation due to climate change.

Height enhancement of coastal polders: Geographic information system (GIS) software is used to overlay the best available spatially disaggregated data on polders over the areas exposed to inundation risk under the baseline and climate change scenarios. Polders likely to be overtopped and the extent of overtopping under each scenario are identified by taking the difference between the crest level of the embankments of each polder and the inundation depths projected for them under the respective scenario. Under the baseline scenario, 14 interior polders and 30 sea-facing polders are expected to be overtopped

(Figure 3.7).[49] The extent of overtopping in these polders increases under the climate change scenario for 2050. Further, 12 additional interior polders and 3 additional sea-facing polders are also overtopped under the climate change scenario. Annex 5 lists each of the overtopped polders and the height by which each is overtopped in the two scenarios.

The cost of preventing overtopping in the interior and sea-facing polders under the baseline and climate change scenarios are computed separately for each polder likely to be overtopped based on detailed engineering analysis. Detailed cost estimates for each cost component and polder for each scenario are provided in Annex 6. In each case, costs are estimated separately by polder for earthwork, turfing, toe erosion, plantation, land acquisition, and major protection.

For interior polders, earthwork accounts for over 50 percent of the cost of preventing overtopping, and 40–50 percent for sea-facing polders. The amount of earth needed is derived from detailed engineering designs, as outlined in Annex 7. Raising the height of an existing embankment also entails extending the base that supports it. Earth that is available locally within 1 km from the polder costs Tk 109.96 per cubic meter.[50] The costs rise to Tk 133.44/ m^3 if earth is not available locally and has to be collected from distances greater 1 km.[51]

Compaction and turfing of the soil is used to protect the earth from rapidly washing away with subsequent precipitation events. They account for a small fraction of costs, but effectively extend the deign life of the earthwork. Turfing area is determined using the trapezoidal rule, considering the length and slope of the embankment. The BWDB rates for turfing of Tk 7.07 per sq meter are used determine total turfing costs.[52]

The need to strengthen the slope or base of specific polders and the extent of such strengthening is based on polder-specific field observations by experts at BWDB and IWM. They are not required for the majority of polders that are likely to be overtopped, but for those that do, they can account for up to 70 percent of the cost of prevention. "Major protection" includes slope protection on the sea side or river side, using cement concrete blocks or boulders and filter materials. The base or "toe" of embankments is subject to significant erosion from hydraulic stress. Protecting against toe erosion includes hard protection using cement concrete (CC) blocks with sand filters and geo-textile, the best locally available technology to protect against major erosion. Total toe erosion protection costs are based on BWDB rates of Tk 224,100 per sq meter. Minor erosion can often be prevented through the planting of vetivera grass. However, high soil salinity along the Chittagong belt has reduced its growth and survival rates. Since soil salinity is even higher along the southwestern coast, the effectiveness of vetivera plantations may be limited to a few polders on a case-specific basis. Vetivera planting costs Tk 70,700 per ha (BWDB 2003b).

Enhancing polder heights entails an expansion in the base to maintain the slope of each embankment, as indicated by the shaded area in Annex 7. Requisition of the additional land, if privately owned, requires compensation, and in some cases, their rehabilitation cost. For sea-facing dykes, foreshore land is usually government-owned or *khas* land. For interior and marginal dykes, however, neighboring land is often under private ownership. Land acquisition costs are based on BWDB rates of $17,143 (Tk 1.2 million) per ha from a BWDB project.[53]

49 The overtopping would occur currently as well as in 2050 since the risks under the baseline scenario are the existing risks.

50 Source: Bangladesh Water Development Board.

51 Ibid.

52 Source: Schedule of Rates, Mymenshing O&M Circle, Bangladesh Water Development Board, 2008–09

53 Source: Feasibility Study for Flood Control Embankment and River Bank Protection on the Left Bank of Jamuna and Right Bank of Dhaleshwari at Nagorpur and Chowkhali, Final Report, June 2007, Directorate of Planning-1, Bangladesh Water Development Board, Dhaka.

TABLE 3.13 ESTIMATED COST FOR HEIGHT ENHANCEMENT OF COASTAL POLDERS ($ MILLIONS)

	Baseline Scenario	Climate Change Scenario	Additional Cost due to Climate Change
Interior polders	317	706	389
Sea facing polders	2,145	2,648	503
Total all polders	2,462	3,354	893

The total investment cost for strengthening coastal polders to prevent overtopping is $2,462 million under the baseline scenario and $3,354 million under the climate change scenario (Table 3.13). Sea-facing polders account for 87 percent of costs under the baseline scenario. About half of this ($1,195 million) is for major protection and toe erosion of specific polders. Raising embankments to prevent overtopping under the climate change scenario requires an additional cost of $893 million, almost evenly split between interior and sea-facing polders. Earthwork accounts for over three-fourths of the added cost due to climate change for sea-facing dykes, while the corresponding share for interior dykes is about half. Most of the remaining costs are needed for major protection and toe erosion in the 12 dykes that are overtopped in the climate change scenario, but not in the baseline scenario.

In addition to the direct investment requirements, the operation and maintenance (O&M) cost is assumed to increase by an estimated 2 percent of investment per year, or $49 million in the baseline scenario and an additional $18 million with climate change.

Coastal afforestation: Planting mangrove forests with a minimum width of 0.5 km in front of sea-facing polders is a cost-effective method of protecting them from above-average severe storms. While they may not be essential to protect against the average 10-year return period cyclone under the baseline scenario,[54] they constitute cost-effective protection against the more intense cyclones expected under the climate change scenario. The addition of the requisite 500 meter forest belt may reduce the embankment height enhancement necessary for some sea-facing polders by up to 30 cm (IWM & DHIA 2000).

Maps of the coastline available through Google Earth indicate that only 60 km of embankments currently are protected by the recommended 0.5 km of afforestation, while the remaining 897 km remains unprotected. Fully protecting these embankments requires reafforestation in nearly 448.5 sq km (897km x 0.5 km). Afforestation costs are $168,000 / sq km in the CERP II project.[55] **The cost of afforestation to reduce the hydraulic load on embankments under the climate change scenario is $75 million.**

Multipurpose Cyclone Shelters: Cyclone shelters protect human lives and livestock in coastal Bangladesh. While the construction cost of multipurpose cyclone shelters varies based on the capacity of the shelter and the design adjustments necessary for the other regular usage of the shelter, unit costs of about $134 per person reported for the post-Sidr shelter construction project funded by the World Bank is fairly typical.

The number of cyclone shelters needed to protect the affected population depends on the type of house they live in. Pucca houses can structurally withstand cyclones. While residents may be able to withstand inundation depths of 1 meter with minimal risk to their lives, inundation depths

54 Most existing embankments remained intact under the above-average Cyclone Sidr in 2007.

55 Source: Coastal Embankment Rehabilitation Project, Stage-II, Final Report, Volume I/II, June 2003, Chittagong.

greater than 3 meters for an extended duration certainly requires the evacuation of affected residents.[56] The shelter capacity needed under the two scenarios is estimated based on the population exposed to inundation depth of more than 3 meters.

In coastal Bangladesh, 8.9 million people were exposed to inundation risk of greater than 3 meters in 2007 under the baseline scenario. Population growth increases the exposed population by 4.7 million to 13.6 million by 2050 under the baseline scenario, or nearly a fivefold increase in the cyclone shelter capacity compared to what is currently available.[57] The current deficit will likely be eliminated with the extensive shelter construction efforts that are planned or already under way. These efforts will need to be sustained in the future to keep up with the increasing population and will cost an estimated $628 million (about 2,930 shelters with an average capacity of 1600).

The population exposed to inundation risk rises further by another 9.1 million to 22.6 million under the climate change scenario. This represents a 67 percent increase in the cyclone shelter capacity needed by 2050 compared to the baseline scenario, or an additional 5,702 shelters with an average capacity of 1600. **The construction cost for the additional shelters needed to accommodate people that are exposed to the additional inundation risk from climate change in 2050 is estimated at $1,219 million.**

Cyclone resistant private housing: Cyclone resistant private housing is an effective alternative to cyclone shelters, particularly in areas exposed to low inundation risk. Pucca houses have remained structurally intact during past cyclones such as Sidr. In contrast, thatch, tin and kaccha houses in affected areas have been severely damaged. They can serve as single/multi-family cyclone shelters during storm surges. The census data indicate that people with annual incomes greater than $470 live in pucca houses, while poorer resident live in tin, thatch, or other less permanent structures. Most rural households will have sufficient income by 2050 to afford to live in pucca houses.

The need to construct additional cyclone shelters in areas exposed to low inundation risk can be reduced by (a) instituting suitable building designs and codes to make houses cyclone resistant, and (b) putting in place a revolving fund for subsidizing construction material and extending housing credits. Consultations with local architects and civil engineers indicate that **a $200 million revolving fund would be sufficient to encourage construction of pucca houses in accordance with appropriate building codes.** These steps can be justified as a cost-effective means of protecting the poorest rural households in low inundation risk areas in lieu of constructing additional shelters. As with any subsidy program, its effectiveness and fiscal prudence hinges on the structure and design of the program.

Early warning and evacuation system: The effectiveness of the early warning and evacuation system can be enhanced through improved geographic precision of warnings and the expansion of the cyclone preparedness program to reach the additional inundation risk zones under the climate change scenario. Consultations with experts at the relevant agencies identified specific actions necessary to achieve these objectives and their costs.

The geographic precision of warnings can be improved through improved monitoring of weather systems and finer scale modeling of storm surges and inundation depths. Officials at

56 Multi-story houses may temporarily protect residents from drowning as they move to higher heights. They can be substitutes for an extended duration only if affected residents have adequate supplies of essentials.

57 The deficit is slightly smaller if the PDEP II school facilities currently being used as shelters are also included.

the Meteorology Department identified the need to (a) upgrade and expand its network of observatories, (b) expand the number of radiosonde stations,[58] and (c) modernize the existing workshop, laboratory, and training facilities. In addition, the Institute of Water Modeling indicated the need to acquire finer scale topographic data covering 23,500 sq km of the coastal region, as well as upgrade the mathematical modeling to better utilize the new data. **These improvements require an initial investment of $39 million and annual recurrent costs of $5 million, as itemized in Table 3.14.**

The effectiveness of the early warning system depends critically on the awareness and cooperation of residents, the community, local and central government agencies, and volunteer organizations. Under the climate change scenario, 19 additional coastal districts are exposed to inundation risk. The Red Crescent Society estimates that $3 million per year is required to expand the annual awareness promotion program to these 19 new districts.[59]

Total adaptation cost

Table 3.15 summarizes the investment cost of adapting to climate change that would prevent damages from cyclone-induced storm surges under the two scenarios. Under the baseline scenario, all of the total investment costs of $2,462 million are for upgrading polders. The costs for additional cyclone shelters are not included since an adequate number of these are assumed to be already under construction or have been planned. These investments prevent damages from the average cyclone with a 10-year return period, as has been experienced during the past 50 years. The potential damages from a single such storm currently are $1,802 million and are expected to rise to $4,607 million by 2050. On average, four such storms can be expected over the next 40 years. The potential benefits exceed the investment costs by several times, even when the future benefits and costs are discounted.

Under the climate change scenario, additional investments of $2,426 million, or approximately $60 million per year, and annual recurrent costs of $50 million are required to counter the additional risks from more severe future cyclones. Assuming the investments are phased in over the next 40 years, the cost to adapt to the additional risks from climate change average $85 million, gradually rising from $60 million to $110 million by 2050.

Implications for Adaptation Strategy

Cyclones hit the coastal regions of Bangladesh every year. The risk from cyclones and the storm surges they induce spans the entire coastline. Public investments in protective infrastructure measures such as polders, cyclone shelters, early warning systems (complemented with awareness raising), and disaster preparedness systems have reduced damages and losses from these storms. Despite these investments, an average severe cyclone with a 10-year return period currently can result in damages of around 2.4 percent of GDP. Most of the damages result from the cyclone-induced storm surges that inundate coastal areas. Economic expansion is expected to expose additional assets to inundation risk by 2050, nearly doubling the damages and losses

58 The radiosonde is a balloon-borne instrument platform with radio transmitting capabilities. It contains instruments capable of making direct in-situ measurements of air temperature, humidity, and pressure with height, typically to altitudes of approximately 30 km. These observed data are transmitted immediately to the ground station by a radio transmitter located within the instrument package. The ascent of a radiosonde provides an indirect measure of the wind speed and direction at various levels throughout the troposphere. Ground-based radio direction finding antenna equipment track the motion of the radiosonde during its ascent through the air. The recorded elevation and azimuth information are converted to wind speed and direction at various levels by triangulation techniques.

59 The awareness raising program costs approximately Tk 10 million ($142,857) per district and an additional Tk 20 million ($285,714) for coordination annually.

TABLE 3.14 COST TO INCREASE GEOGRAPHIC PRECISION OF CYCLONE AND SURGE WARNINGS

	Investment Upgrades		Investment for Expansion		Annual O & M
Items	Quantity	Cost (Million USD)	Quantity	Cost (Million USD)	Cost (Million USD)
BMD observatories	35	6	30	12	3
BMD radiosonde stations	3	-	5	2	2
BMD workshop and laboratory	1	7			-
BMD training institute facilities	1	3			-
Topographic survey, LIDAR & RTK GPS survey	23,500 sq km	5			-
Mathematical modeling	1	3			-
Total cost		24		14	5

TABLE 3.15 COST OF ADAPTING TO CLIMATE CHANGE BY 2050 ($ MILLIONS)

Adaptation Option	Baseline Scenario	Climate Change Scenario		Additional Cost due to Climate Change	
	Investment Cost	Investment Cost	Annual Recurrent Cost	Investment Cost	Annual Recurrent Cost
Polders	2,462	3,354	18	893	18
Foreshore afforestation		75		75	
Cyclone Shelters		1,219	24	1,219	24
Cyclone Resistant Housing		200		200	
Early Warning & Evacuation System		39	8+	39	8+
Total	2,462	4,888	50+	2,426	50+

in real terms from a similar storm. Damages and losses account for around 0.3 percent of the 2050 GDP, due to expected structural shifts in the economy away from climate sensitive sectors and due to private adaptation as households are able to afford cyclone-resilient housing.

Climate change is expected to further increase the risk of inundation-related damages. A warmer ocean is likely to intensify cyclone activity and increase the height of storm surges, resulting in greater inundation depths and inundation of areas further inland. Surges will be further elevated by a rising sea level as thermal expansion and ice cap(s) continue to melt. While there is some uncertainty about the magnitude of these changes, estimates based on plausible scenarios in the scientific literature indicate that areas at risk of inundation over 3 meters will increase by 69 percent and up to 1 meter by 15 percent. Additionally, the increased severity of the cyclone will also span a larger proportion of the at-risk areas. As a result, damages and losses from an average severe cyclone with a 10-year return period in 2050 are expected to double due to climate change to around 0.6 percent of GDP.

To address the added risks from climate change, the starting point for an adaptation strategy is the significant public investment made over the

TABLE 3.16 SEQUENCING OF ADAPTION OPTIONS FOR TROPICAL CYCLONES/ STORM SURGES

	Near term	*Short term*	*Medium term*	*Long term*
Early warning system		Upgrade equipment and observatories; Improve geographic precision of forecasts and warnings	Expand observatories and equipment to cover new areas	
Relief operations	Strengthen decentralized operations	Update programs to communicate existing and new risks	Extend awareness raising programs to new areas at risk	
Polders: All existing polders	Fully fund O&M, Undertake maintenance			
Polders: at risk of overtopping baseline scenario	Assess polder-specific avoided damages and human toll; prioritize polders for strengthening	Strengthen polders in order of priority, building in flexibility to account for added risk with climate change		
Polders: at risk of overtopping climate change scenario		Assess polder-specific avoided damages and human toll; prioritize polders based on avoided damages and costs	Strengthen polders in order of priority, building in flexibility to account for added risk with climate change	Reassess risk of overtopping; strengthen polders as appropriate
Cyclone shelters: All existing shelters	Fully fund O&M; undertake maintenance	Adapt shelters to better match resident needs		
Cyclone shelters: at risk of overtopping baseline scenario	Take stock of shelters under construction and planned construction; assess location-specific shelter capacity gaps	Construct multipurpose cyclone shelters, prioritizing areas with large existing gaps in shelter capacity	Reassess gaps in capacity to meet long-term future capacity needs; add capacity as needed	
Cyclone shelters: at risk of overtopping climate change scenario		Assess location-specific gaps in shelter capacity	Construct multipurpose cyclone shelters, prioritizing areas with large existing gaps in shelter capacity	Reassess gaps in capacity to meet long-term future capacity needs; add capacity as needed
Cyclone-resistant housing		Research in innovative housing designs and financial mechanisms	Identify areas where program can substitute for additional shelter construction; develop CRH program with effective targeting and minimized leakages	Implement CRH program in lieu of constructing cyclone shelters
Foreshore afforestation		Prioritize areas to be afforested; pilot afforestation program; develop institutions arrangements	Implement afforestation program	
Land use planning and zoning		Set up institutions to promote settlements away from high-risk areas	Implement institutional arrangements	

past 35 years in disaster risk mitigation measures, which have included construction of polders and cyclone shelters, and the establishment of early warning and evacuation systems. They have been protecting virtually all of the populated areas in the coastal regions of Bangladesh from tidal waves and storm surges. While these investments have protected populations and assets during numerous cyclones, experience from Cyclone Sidr indicates that the existing measures are not sufficient to fully protect coastal areas even against historical risks, much less the added risks under climate change. Toward this end, the government of Bangladesh, development partners, and NGOs are already undertaking the construction of hundreds of new cyclone shelters to partially address the existing adaptation deficit.

Moving forward, the detailed polder level information available on the overtopping risks and the cost of strengthening them enables a finer level of sequencing as summarized in Table 3.16. The prioritization recognizes (a) the certainty of the existing inundation risk; (b) the uncertainties around the magnitude of the impacts due to climate change; and (c) the manifestation of the added risks due to climate change gradually over the next 40 years and beyond, and (d) the lack of localized damage assessment that is directly comparable to the costs.

The sequencing presupposes sound development policies that promote growth and reduction in poverty that enables increasing number of people to afford climate-resilient housing. A no-regrets strategy to make Bangladesh climate resilient would start by addressing the existing adaptation deficit expeditiously first through adequate funding of operations and maintenance costs for existing infrastructure. This needs to be accompanied by efforts to reduce the uncertainties surrounding the added risks due to climate change research to improve the temporal and spatial resolution of forecasts. Pending the availability of added information, a localized assessment of damages can be taken to assess the potential damages from inaction or delayed action. Specific adaption measures can be expedited for actions that have sufficiently high avoided damages-per-cost ratios. Upon addressing the existing risks, actions can be taken to address the added risks from climate change. These investments have to also be accompanied by institutional mechanisms that address any perverse incentives that it may create in attracting population and activities toward areas of higher risk. Stronger institutional capacity is also essential to reduce uncertainties through improvements in the knowledge base, and in turn to adjust the selection and sequencing of adaptation actions in response to changes in knowledge.

FOUR

Inland Flooding

Historical Vulnerability of Inland Flooding

Bangladesh is one of the most flood-prone countries in the world. The literature on floods in the country is extensive.[60] Due to its location in the low-lying deltaic floodplains at the convergence of three Himalayan Rivers, heavy monsoon rainfall concomitant with poor drainage often results in annual flooding. These river systems drain a catchment area of about 1.7 million km^2. The intensity of the floods depends on the magnitude and pattern of precipitation in the three river sub-basins. At the peak discharge of the three rivers, the Brahmaputra contributes the greatest volume (58 percent), while the Ganges and Meghna contribute about 32 percent and 10 percent, respectively. These floodplains are home to a large population (most of which is rural and poor) whose life is intricately linked to the flooding regime.

Floods in Bangladesh can be classified into four categories based on their origin: flash floods, river floods, rainwater floods, and coastal floods, as described in Annex 9. The Bangladesh Water Development Board has designated areas of Bangladesh vulnerable to various categories of flood (see Annex 10). Mirza (2002) has classified floods in terms of impacts (see Table 4.1, Annex 11). About 21 percent of the country is subject to annual flooding and an additional 42 percent is at risk of floods with varied intensity (Ahmed and Mirza 2000). Annual regular flooding has traditionally been beneficial, providing nutrient-laden sediments and recharging groundwater aquifers, while low frequency but high magnitude floods can have adverse impacts on rural livelihoods and production.

A classified list of all floods in Bangladesh since 1954, together with the extent of inundation, is shown in Annex 12. There have been above-normal floods in 22 of 54 years, of which four were exceptional and two catastrophic (Figure 4.1).[61] Annex 13 contains a more extended chronology and brief descriptions of the above-normal floods since 1781.

Table 4.2 summarizes key statistics for the exceptional and catastrophic floods since 1954 (see also Annex 13). The exceptional flood of 1998 was the worst on record and lasted from the first week

60 For an excellent historical discussion of floods in Bangladesh please refer to Hofer and Messerli (2006)

61 Since 1954, Bangladesh has had a normal flood on average every two years. There have been no floods in only 6 of the last 54 years.

TABLE 4.1 FLOOD CLASSIFICATION IN BANGLADESH

Types of Flood	Flooded area range (km2)	Inundated area range (%)	Probability
Normal	31,000	21	0.50
Moderate	31,000–38,000	21–26	0.30
Severe	38,000–50,000	26–34	0.10
Catastrophic	50,000–57,000	34–38.5	0.05
Exceptional	> 57,000	> 38.5	0.05

Source: Mirza (2002).

TABLE 4.2 IMPACTS AND LOSSES FOR RECENT EXCEPTIONAL OR CATASTROPHIC FLOODS

Year	1974	1987	1988	1998	2004	2007
Affected area ('000 sq km)	53	57	90	100	56	62
Affected (million)	30	30	47	31	33	14
Fatalities	28,700	1,657	2,379	918	285	1,110
Houses damaged ('000s)	na	989	2,880	2,647	895	1,000
Roads damaged (km)	na	na	13,000	15,927	27,970	31,533
Crops damaged (million ha)	na	na	2.12	1.7	1.3	2.1
Asset losses (million US$)	936	1,167	1,424	2,128	1,860	1,100
GDP current (million US$)	12,459	23,969	26,034	44,092	55,900	68,400
Asset losses as % GDP	7.5	4.9	5.5	4.8	3.3	1.6
Estimated return period (years)	9	13	55	90	12	14

Source: Islam and Mechler (2007), BWDB (2007)

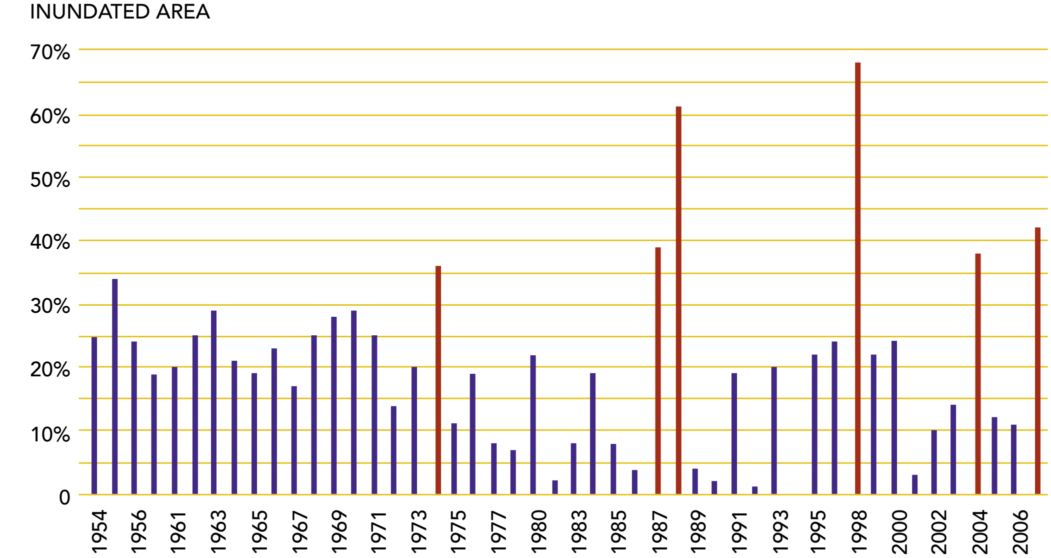
of July to the third week of September; it was the most severe both in terms of depth and duration (see Annex 14) . It inundated nearly 70 percent of the total land and caused severe damage. This flood alone caused 1,110 deaths. It flooded nearly 100,000 sq km, which included 6,000 km^2 of standing crop lands. It affected 31 million people and impacted the property of about 1 million households. It also damaged 16,000 km of roads and 6,000 km of embankments.

The relative severity of the impacts of severe floods in Bangladesh has decreased substantially since the 1970s as a result of improved macroeconomic management, increased resilience of the poor, and progress in disaster management and flood protection infrastructure. The 1974 flood was a 1-in-9-year event, which resulted in damages of 7.5 percent of GDP. In comparison, the 1998 flood was a 1-in-90-year event, inundating nearly twice the area but resulting in damages of 4.8 percent of GDP.

The increased resilience of Bangladesh to floods is also apparent when recent GDP and agricultural growth rate trends are examined with respect to the timing of flood events (Figure 4.2). Major flood events are shown in the figure as black dots. Until the 1990s, GDP and agricultural growth rates sharply declined following major flood events. However, the relative effects of major floods have diminished after 1990.[62] Growth rates actually remained positive after the excep-

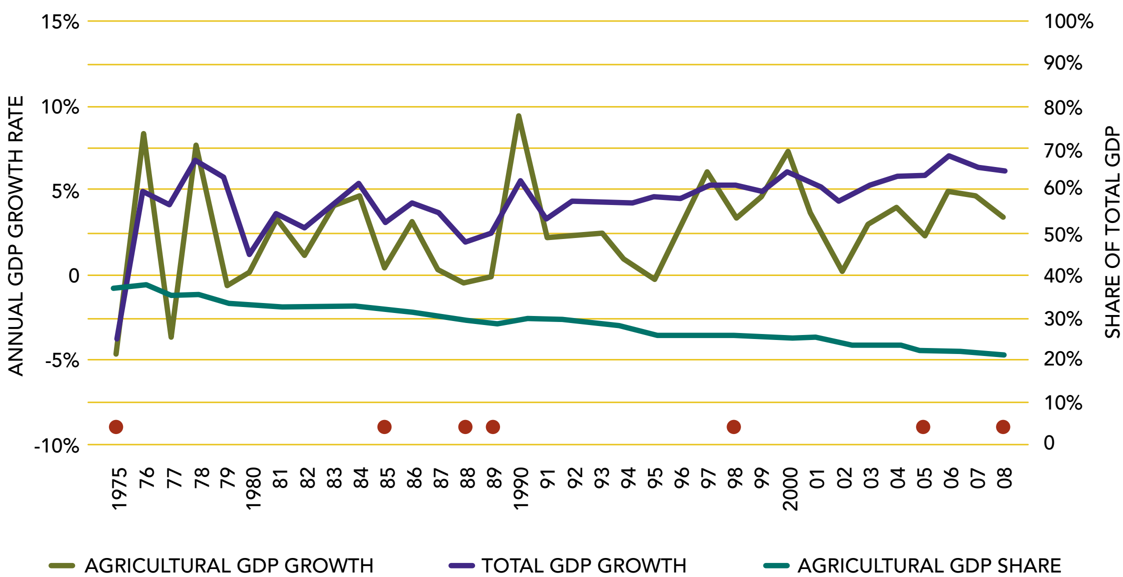
62 Despite several major disasters, Bangladesh remains among the few countries that have avoided a single year of negative growth since the 1990s.

FIGURE 4.1 EXTENT OF ABOVE-NORMAL FLOODING IN BANGLADESH, 1950–2009



Source: CEGIS

FIGURE 4.2 GROWTH TRENDS IN TOTAL GDP AND AGRICULTURAL GDP IN RELATION TO MAJOR FLOOD EVENTS



Source: Yu, W.H. et al. (2010)

tional 1998 flood, which resulted in damages of nearly 4.8 percent of GDP. Changes in cropping patterns (the shift from deepwater aman rice to boro rice), adequate reserves of food grains, and an increase in rice imports by both the public and private sectors have all contributed to diminishing the relative impact of major flood events.

These recent gains may be at risk if the severity of floods increases with climate change, as predicted by the GCMs for the fourth assessment report of the Intergovernmental Panel on Climate Change. As discussed in Chapter 2, flooding in Bangladesh depends on the rainfall in the entire GBM basin due to the location of Bangladesh at the tail end of the basin.

Estimating Adaptation Cost

Adaptation options and costs for inland flooding are more difficult to determine than for storm surges, since flooding can have beneficial impacts as well as adverse impacts. This analysis is limited to what was tractable within the time and resources available—specifically, options and costs for climate proofing key infrastructure against the additional risks due to climate change from a 100-year flood. These steps would also protect against risks form smaller floods. Infrastructure accounted for about one-third of the damages and losses in the 1998 flood,[63] mostly from damaged roads, railways, embankments, drainage, and soil erosion. The limited scope of the analysis implies that the cost estimates are likely to be a fraction of the total cost of adapting to inland flooding.

Adaptation costs to protect the selected assets are estimated using a consistent economic development baseline for 2050, which includes a much larger economy together with structural changes away from agriculture toward industry and services. The adaptation costs are determined in the following four steps.

1) Demarcate inundation risk exposure zones from monsoon floods under the baseline and climate change scenarios.

2) Demarcate additional inundation risk due to climate change.

3) Identify assets and activities in the risk exposure zones.

4) Determine additional inundation risk due to climate change and estimate costs necessary to mitigate additional inundation risk.

Economic Development Baseline: The analysis is based on the projected development baseline as used in the coastal chapter.[64] Table 4.3 summarizes the key relevant changes in the Bangladesh economy between now and 2050.

Inundation risk exposure zones

Inundation risk exposure in an area is characterized by the highest inundation that is expected to occur during the year under a scenario. Two scenarios are developed—a climate change scenario and a baseline scenario, which is used as a counterfactual to determine the additional risk of exposure due to climate change.

Baseline Risk Scenario: The 1998 exceptional flood event with a return period of 100 years is the baseline scenario. It is the counterfactual against which future climate change risk is measured.

Climate Change Risk Scenario: Flood risk in 2050 is expected to change from the baseline scenario levels due to changes in temperature and precipitation levels and increases in the sea level. Changes in monthly precipitation and temperature

63 The economic impacts (crores taka) of the 1998 flood consisted of: agriculture (crop 3,675; livestock/fishery/forestry, 288); infrastructure including telecom (5,023); industry (5,000), other (230).

64 The development baseline builds on recent economic trends and extends them to 2050 based on normal economic development patterns.

TABLE 4.3 GROWTH TRENDS IN TOTAL GDP AND AGRICULTURAL GDP IN RELATION TO MAJOR FLOOD EVENTS

	Current Indicators			Indicators in 2050	
Indicator	Value	Year	Source/ Comments	Value	Source/comments
Population (million)	130	2001	BBS	228	BBS
Population average annual growth rate	1.58	1991-01	State of the Coast, 2006	1.15%	BBS (replacement fertility in 2021)
GDP (billions of constant 2009 USD)	$75	2007	WDI 2009	$1,614	Projected with growth rates in the following row.
GDP Avg. Annual growth rate	5.9%	2001-09	Ministry of Finance, GOB	7.5%	Various government announcements
Per capita GDP (constant 2009 USD)	$470	2007	WDI 2009	$6,395	Implied
Road length (km)	272,487	2007	BBS	340,609	Assumed 25% expansion
Share of paved roads	30%	2007	BBS	100%	Assumed
Railway track (km)	2,460	2006	BBS	3,415	Planned doubling of Dhaka & Chitagong districts
Embankment (km)	9,943	2006	BWDB, 2006	9,943	No change
Water regulating Structures	13949	2006	BWDB, 2006	16,199	Engineering estimate based on increased drainage requirement
Drainage canals (km)	5111	2006	BWDB, 2006	5111	No change
Rice Production (million metric tons)	27	2006	BBS	75	Yu et al. 2010, Existing Climate Variability Scenario

Notes: Current per capita GDP in Comparator countries: Brazil($5,860), Malaysia($6,420), Lebanon($5,800) and Uruguay($6,390).
Source : World Development Indicators, World Bank

predicted by the global circulation model (GCM, MIROC 3.2 under the A2 emission scenario between 1998 and 2050 for each 50km by 50 km grid) are applied to the corresponding observed monthly averages for 1998 over the entire GBM basin. The MIROC 3.2 results are used for this analysis, as it results in the largest increase in runoff among the five GCMs and two emission scenarios examined as part of the food security study by Yu et al. (2010) (see Chapter 2). The rise in sea level of 27cm by 2050 is based on UK DEFRA (2007).

Inundation risk exposure for each scenario is determined in three steps. First, the Ganges Brahmaputra Meghna (GBM) model is used to simulate the transboundary flows, while the Super model is used to generate the daily extent and depth of inundation during the monsoon period for each 300 m by 300 m grid point under each scenario.[65] All of the simulations include the existing flood protection measures, such as flood embankment, flood control, and drainage infrastructure in Bangladesh. Second, the daily inundation depth results are synthesized to determine the highest inundation depth for each grid point during the monsoon period. Finally, for the subsequent economic analysis, risk exposure zones are formed by grouping grid points into flood risk zones.

65 Detailed descriptions of the models are provided in Annex 15. The simulations do not include urban flooding, flash floods, and changes in the course of rivers due to difficulties in modeling them and have the effect of underestimating the cost of adaptation. Modeling urban floods requires the integration of urban drainage and sewer systems and the outfall rivers. Rivers in Bangladesh frequently change course during monsoon floods. This results in long-term submergence of newly inundated lands, but reclamation of the prior river bed as char land. Increased peak season flows resulting from climate change may increase the incidence of rivers changing course.

FIGURE 4.3 FLOOD MAP — 24 HOUR DURATION FLOOD (BASELINE SCENARIO)

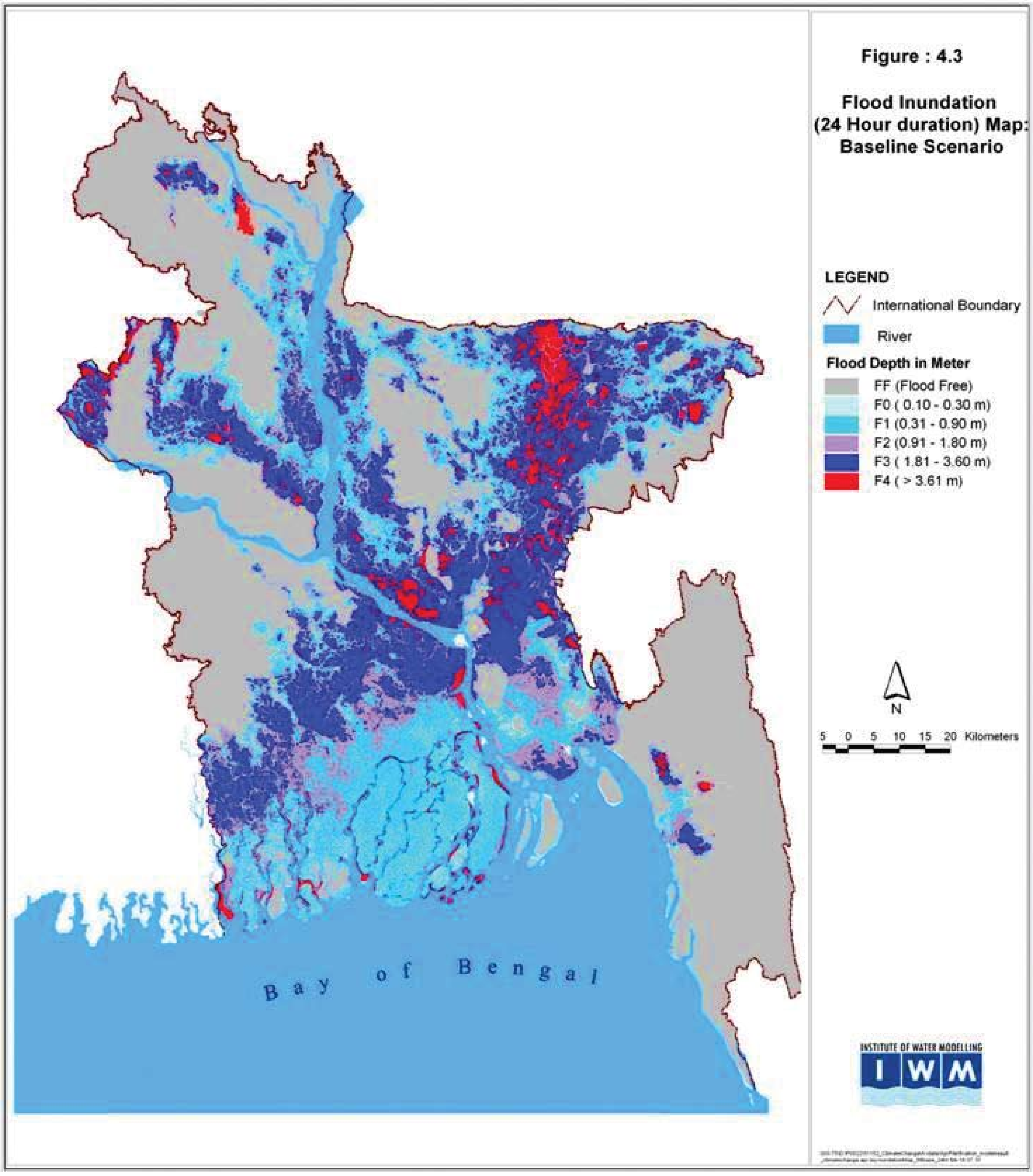


FIGURE 4.4 FLOOD MAP – 24 HOUR DURATION FLOOD (CLIMATE CHANGE SCENARIO)

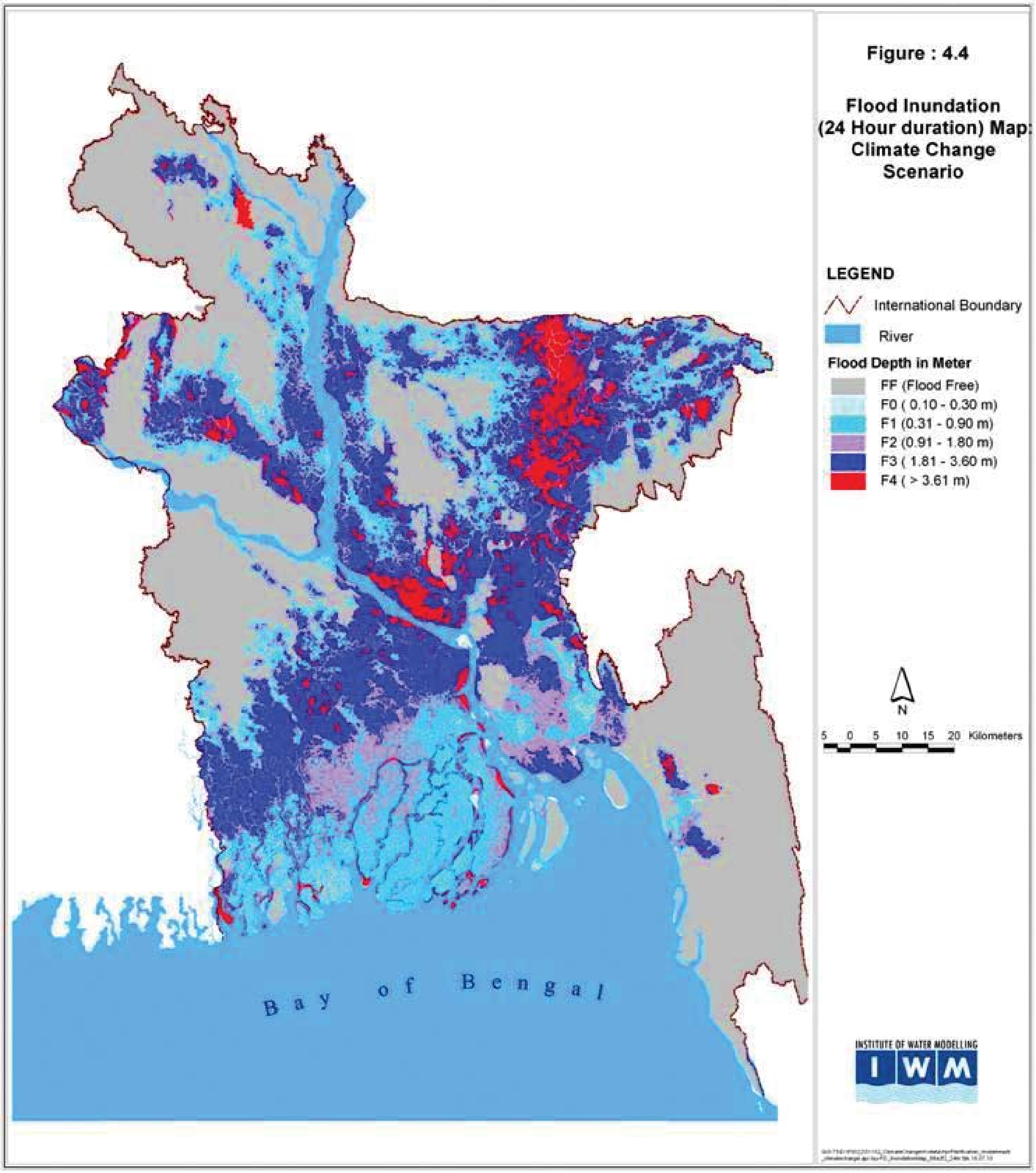


TABLE 4.4 FLOOD LAND CLASSES (BASED ON 24 HOUR DURATION INUNDATION)

Land Type	Baseline Scenario		Climate Change Scenario		Change in Inundated Area	
	(sq.km)	%	(sq.km)	%	(sq.km)	%
FF (flood free)	69,820	52	64,905	49	(4,915)	4
F0 (0.1m-0.3m)	2,953	2	2,256	2	(697)	-
F1 (0.3m-0.9m)	14,062	11	11,967	9	(2,095)	2
F2 (0.9m-1.8m)	19,014	14	20,609	15	1,595	1
F3 (1.8m-3.6m)	21,965	16	25,900	19	3,934	
F4 (>3.6m)	5,708	4	7,886	6	2,177	2
Total Flooded area (F1+F2+F3+F4)	60,750	45	66,362	50	5,612	4

TABLE 4.5 RURAL POPULATION EXPOSED TO INUNDATION RISK

	Baseline Scenario 2001 (a)	Baseline Scenario 2050 (b)	Climate change Scenario 2050 (c)	Percent change 100 * (c - b) / (b)
F0 (0.1m-0.3m)	1,009,898	843,729	681,031	-19
F1 (0.3m-0.9m)	6,721,555	5,615,588	4,566,517	-19
F2 (0.9m-1.8m)	8,490,523	7,093,488	8,108,952	14
F3 (1.8m-3.6m)	7,105,158	5,936,072	7,543,397	27
F4 (>3.6m)	669,027	558,945	899,066	61
Exposed Rural Population (F1+F2+F3+F4)	22,986,263	19,204,093	21,117,932	9

Figure 4.3 and Figure 4.4 show the flood risk exposure map of Bangladesh, as measured by the highest inundation levels for a 24-hour duration from the simulations, under the baseline and the climate change scenarios respectively. While the duration of a flood is an important metric for determining its impact, models to reliably determine the duration of a flood beyond a few days are not currently available.[66] The choice of 24 hours duration is based on the potential severe damages that road infrastructure, flood embankments, and rural houses usually are subject to from floods of such duration.[67]

The flood risk exposures under the two scenarios are summarized in Table 4.4 Under the baseline scenario, 45 percent of land is under at least 0.3 m of water. The total flooded area increases by 4 percent, exposing more assets and activities to risk under the climate change scenario. More importantly, the inundation depth increases in most flooded areas, correspondingly increasing the level of risk in these areas. Areas inundated to depths greater than 0.9m increase from 34 percent of the total area under the baseline scenario to 40 percent under the climate change scenario, or an increase of about 17 percent. The distribution of land based on inundation levels at the peak period is approximately the same as those for the 24-hour duration flood.

The number of people exposed to inundation risk of different depths under the two scenarios is estimated by overlaying the inundation risk maps with the population map for 2001 using geographic information system (GIS) software. About

66 Construction of flood maps of longer duration was not feasible within the resource constraints of the study.

67 Urban floods and flash floods are not accounted for in this analysis.

TABLE 4.6 RURAL POPULATION DENSITY BY FLOOD LAND CLASS (PEOPLE PER SQ KM)

	Baseline Scenario 2001 (a)	Baseline Scenario 2050 (b)	Climate change Scenario 2050 (c)
F0 (0.1m-0.3m)	342	286	302
F1 (0.3m-0.9m)	478	399	382
F2 (0.9m-1.8m)	447	373	393
F3 (1.8m-3.6m)	323	270	291
F4 (>3.6m)	117	98	114
Exposed Rural Population (Average (>0.3m)	378	316	318

23 million people lived in rural areas with estimated inundation depths greater the 0.3 meter in 2001 (Table 4.5).[68] Urban migration is expected to offset most of the increase in population in these areas, resulting in a decline in the number of rural inhabitants exposed to inundation risk to 19.2 million by 2050. An additional 1.9 million live in the newly inundated areas under the climate change scenario in 2050, resulting in a total of 21.1 million rural inhabitants that are exposed to risk of inundation greater than 0.3 meter by 2050.[69] This represents a 9 percent increase relative to the 2050 baseline scenario, but a decrease of about 9 percent relative to the population currently at risk.

The decrease in the number of people exposed to inundation risk, however, does not necessarily imply an absolute reduction in total risk. Most people living in inundated areas are exposed to higher inundation depths under the climate change scenario. The population in areas with inundation depths greater than 0.9 meter increases from 13.6 million under the baseline scenario to 16.6 million under the climate change scenario, or an increase of 22 percent due to climate change. Correspondingly, this is offset by a 19 percent decrease in the population living in areas inundated by less than 0.9 meter.

These estimates are based on expected growth rates in the rural and urban populations applied uniformly across the country. However, rural residents have historically avoided higher inundation risk areas through their location choices, as evidenced from the lower population density in higher risk areas (Table 4.6). Assuming rural residents appropriately perceive the additional inundation risk from climate change, location choices made autonomously by residents can be expected to decrease the number of people at risk as they move away from higher risk areas.

Additional inundation risk due to climate change
Figure 4.5 shows a map of the areas with additional inundation risk determined by taking the difference in inundation depth under the baseline and climate change scenarios using geographic information system (GIS) software (for each 50 by 50 km grid). Climate change increases inundation depth in about half of the country, but the inundation depth increases are less than 15 cm for most areas. Increases in inundation depths larger than 15 cm occur in only 544 sq km, or less than 0.5 percent of Bangladesh (Table 4.7).

Assets and activities exposed to additional inundation risk

The current spatial distribution of assets and activities are projected forward to 2050 based on

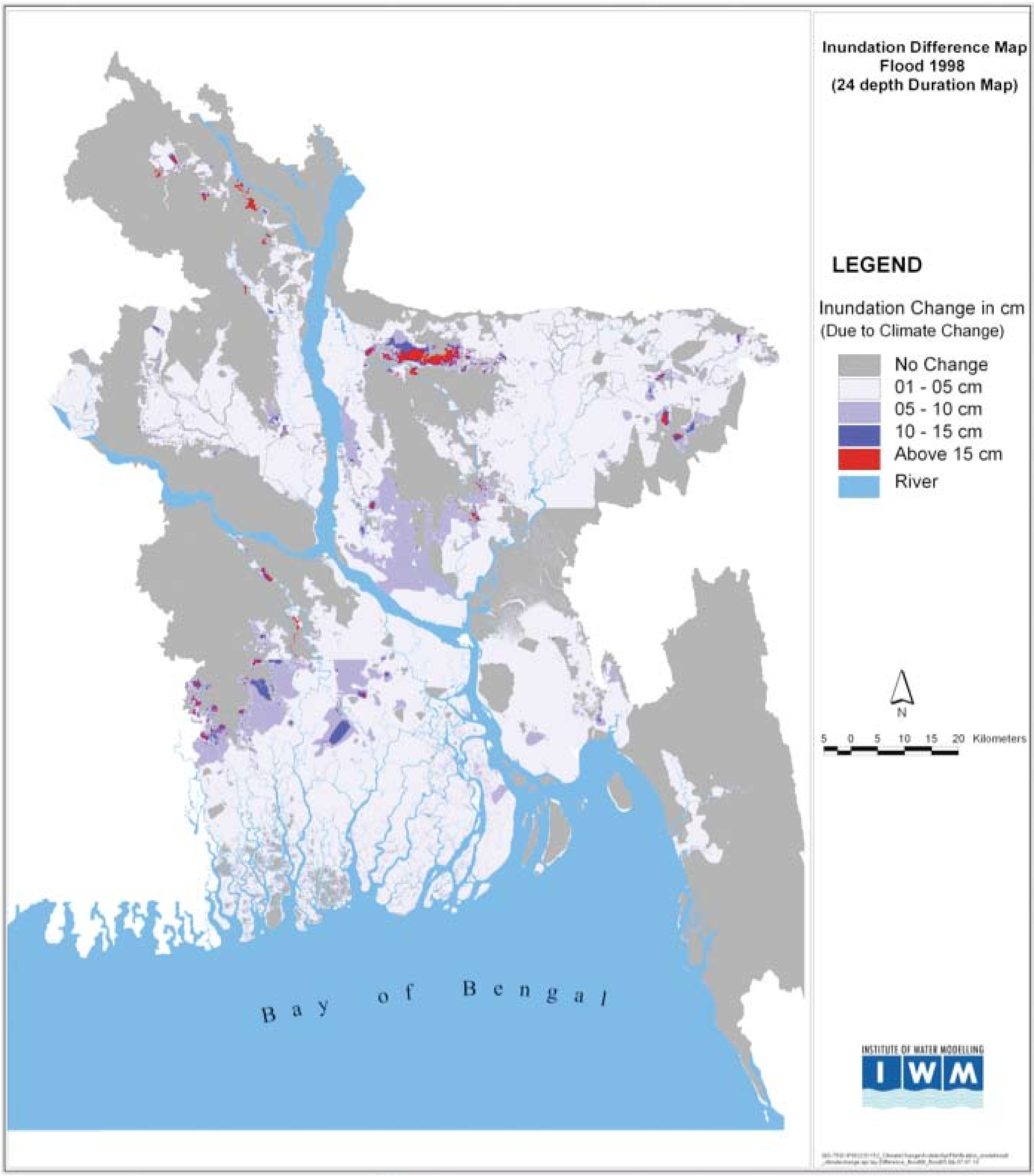
68 The exposed population count is estimated at the thana level, which is the lowest administrative unit, using the population density and the total area that falls into each risk zone. The total exposed population count is the sum of the exposed population across all thanas.

69 The rural and urban population growth rates to 2050 are applied uniformly to existing rural and urban areas respectively.

TABLE 4.7 AREAS WITH CHANGES IN INUNDATION DEPTH DUE TO CLIMATE CHANGE

Additional Inundation Depth due to climate change (cm)	*Area (sq km)*	*Share of total area (%)*
No Change	70,249	52.6
01–05 cm	56,102	42.0
05–10 cm	5,841	4.4
10–15 cm	786	0.6
More than 15 cm	544	0.4
Total	133522	100.0

FIGURE 4.5 CHANGE IN INHUNDATION DEPTH DUE TO CLIMATE CHANGE



expected changes in the Bangladesh economy[70] applied uniformly across the country. The additional inundation exposure risk due to climate change is overlaid on the projected assets and activities map using geographic information system (GIS) software to determine the extent of exposed assets and activities. The assets and activities considered for the analysis include national highways, regional highways, feeder roads (type A), feeder roads (type B), railways, bridges, embankments, and drainage systems. The assets and activities exposed in each inundation risk zone for most assets (e.g. culverts) is a count of the number of assets located in that risk zone. For assets with a large spatial extent, the exposure estimate is measured by the spatial extent of the assets (land surface in square kilometers; road, railways, and embankments in kilometers).

The best available spatially disaggregated maps and data for these activities are available from various public sources, including Bangladesh Railways, the Bangladesh Water Development Board, the Local Government Engineering Department (LGED), the Center for Environmental and Geographic Information Services (CEGIS), the Public Works Department, the Roads and Highways Department, the Water Resources Planning Organization, and the World Bank.

Detailed tables of assets exposed to different levels of additional risk are presented together with the cost estimates in the next section.

Additional adaptation costs

The adaptation costs are estimated for climate proofing the following assets from the additional inundation risk due to climate change:

1) Transport (roads)
    a. Height enhancement
    b. Additional cross-drainage facility
2) Transport (railways)—height enhancement
3) Embankments—height enhancement
4) Coastal polders—additional cross-drainage facility
5) High-value assets—strengthen erosion control programs

In each case, the costs are for adaptation only and not for the associated base investments. For instance, the base costs of expanding the road network are not included, but the costs of adapting the entire future network (existing as well as new roads) are included.

TRANSPORT (ROADS)

All national and regional roads in Bangladesh were previously designed to lie above the highest flood level (HFL) with a return period of 50 years, and feeder roads were constructed to lie above normal flood levels (NFL) (Siddiqui and Hossain 2006). These standards have not been sufficient to prevent large losses in recent major floods. Road damages accounted for 15 percent of the total damages, or about 0.7 percent of GDP during the 1998 flood (Islam and Mechler 2007). The increase in inundated area and inundation depths due to climate change increases the flooding risks of roads.

The length of roads (km) exposed to additional inundation risk due to climate change for different types of roads is determined based on GIS overlays of the maps of additional inundation risk zones with the existing road maps for each category. By 2050, the road network is expected to expand by 25 percent, a less than proportional increase compared to population or GDP. Bangladesh already has one of the densest road networks in the world, leaving little room for extensive growth in the road network. As a result, most new investments in the road infrastructure are likely to be for upgrading roads to higher standards, for

70 These include population and income growth and structural shifts in the economy away from agriculture and toward industry and services.

TABLE 4.8 LENGTH OF ROAD BY TYPE AT ADDITIONAL INUNDATION RISK FROM CLIMATE CHANGE IN 2050 (KM)

Additional Inundation Depth (m)	*Feeder Road-Type A*	*Feeder Road -Type B*	*National*	*Regional*	*Rural*	*Total*	*Share of Total (%)*
0–0.5	6,175	4,203	998	587	11,065	23,027	87
0.5–1.0	734	515	194	86	1,315	2,844	11
1.0–1.5	72	68	11	6	189	346	1
1.5–2.0	24	19	1	3	89	137	1
2.0–2.5	7	4	0	1	17	30	-
2.5–3.0	8	2	1	0	8	19	-
All exposed	7,020	4,810	1,205	683	12,683	26,402	100
Share of all exposed (%)	27%	18%	5%	3%	48%	100%	

instance by paving unpaved roads rather than for expansion. The assumed 25 percent expansion of the road network is applied uniformly across the existing network.

Table 4.8 summarizes the total length of roads that are subject to various degrees of additional inundation due to climate change. Less than 2 percent of roads in 2050 are subject to more than 1 meter of additional inundation due to climate change, while almost all (87 percent) roads are expected to be inundated by up to 0.5 meters due to climate change.

Table 4.9 provides the total cost to raise the entire road network to offset the additional inundation risk due to climate change for different types of roads.[71] National and regional roads account for about 12 percent of the total costs of Tk 149 billion, while the remaining 88 percent is required for rural and feeder roads. **The cost for elevating the entire road network to offset additional risk due to climate change is Tk 148.56 billion, or $2.12 billion.**

CROSS-DRAINAGE FACILITY FOR ROADS[72]

The natural flow of flood water currently is obstructed due to an inadequate number of culverts and regulators to allow cross-drainage for roads. The increased volume of flood water under a changing climate requires the construction of additional drainage structures. Additionally, some existing culverts need to be raised to facilitate the free flow of water. Climate change is expected to increase the deeply inundated areas (greater than 0.9 meters) by an additional 7,736 sq km.[73] Each drainage structure—about 1.5m X 1.8m in size—can drain a 10 sq km area and costs Tk. 15 million.[74] As a result, **775 additional drainage structures are required to drain the additional deep inundated areas due to climate change at a total cost of Tk. 11,625 million, or $166.07mn**. A total of 315 additional culverts need to be raised to avoid additional inundation from climate change at a cost of Tk. 1 million

71 The total cost of raising roads to avoid further inundation due to climate change is calculated using the following: DBS-wearing course 50 mm thick on average (Taka 8,350 per m3), DBS-base course 50 mm thick on average (Taka 7,899 per m3), aggregate base Type I-100 mm (Taka 2,819 per m3), aggregate base type II-100mm (Taka 2,232 per m3), roadway excavation (Taka 184 per m3), and earth fill from borrow pit (Taka 124 per m3).

72 The cost of cross-drainage for railways was not estimated for several reasons. First, unlike road culverts, most railway bridges are currently located well above ordinary flood levels. Second, the height of specific bridges and culverts in relation to ordinary flood levels was not available. Third, the added risk of flooding due to climate change is concentrated in a limited area, making it difficult to ascertain when additional cross-drainage facilities are warranted.

73 These are areas with the F2-F4 classifications.

74 Experts from IWM

TABLE 4.9 ADAPTATION COST FOR ROADS BY TYPE OF ROAD (TK MILLIONS)

Additional Inundation Depth (m)	Feeder Road-Type A	Feeder Road -Type B	National	Regional	Rural	Total	Share of total
0–0.5	51,169	21,647	10,093	6,883	47,292	137,084	92%
0.5–1.0	3,298	1,459	776	579	3,349	9,461	6%
1.0–1.5	440	208	154	35	594	1,432	1%
1.5–2.0	73	-	5	11	88	178	0%
2.0–2.5	76	38	5	9	107	235	0%
2.5–3.0	87	14	7	7	55	171	0%
All exposed	55,144	23,366	11,040	7,525	51,486	148,560	100%
Share of all exposed (%)	37%	16%	7%	5%	35%	100%	

TABLE 4.10 RAILWAY TRACK AT RISK OF ADDITIONAL INUNDATION DUE TO CLIMATE CHANGE BY 2050 (KM)

	Additional Inundation Depth (m)							
Railway track (in km)	0–0.5	0.5–1.0	1.0–1.5	1.5–2.0	2.0–2.5	2.5–3.0	>3.0	Total
Meter gauge	173.3	10.8	2.4	1.7	-	-	-	188.1
Broad gauge	205.8	35.0	7.0	-	-	0.4	0.3	248.5
Meter gauge double	224.7	43.0	2.6	0.5	0.3	0.4	-	271.4
Total track	603.8	88.8	11.9	2.1	0.3	0.8	0.3	708.1

each.[75] **The total for raising culverts is Tk. 315 million, or $4.5 million.**

RAILWAYS

The length of railways (km) exposed to additional inundation risk due to climate change for different types of rail tracks is determined based on GIS overlays of the maps of additional inundation risk zones with existing railway maps. The rail network has not changed significantly in the past fifty years. Aside from doubling the railway track between Dhaka and Chittagong in the next few years, Bangladesh Railways does not have any other plans for changing its network for the foreseeable future. The rail network in 2050 is assumed to be the same as now with this planned expansion. Railway tracks in Bangladesh are either broad gauge or meter gauge. Additionally, there are a few tracks that can be used for either broad gauge or meter gauge trains.

Table 4.10 summarizes the total kilometers of railway tracks subject to various degrees of additional inundation risk due to climate change. Less than 2 percent of railway tracks in 2050 are subject to more than 1 meter of additional inundation due to climate change, while almost all tracks (85 percent) are expected to be inundated by up to 0.5 meters due to climate change. Nearly all of the tracks that are at additional risk from climate change are meter gauge tracks.

Raising rail tracks entails the following six tasks: (1) remove and replace ballast, (2) remove and replace rail and other heavy iron works, (3) dismantle and re-lay track, (4) earth work with sand, (5) procure 15 percent ballast and spreading, and (6) mechanical temping at four stages. The cost per kilometer for raising railway tracks 0–0.5 meter for different gauges of track are shown in

75 Rebuilding the flat part cost Tk. 700,000 on average, and other remodeling costs are Tk. 300,000.

TABLE 4.11 COST PER KILOMETER TO RAISE DIFFERENT RAILWAY TRACKS UP TO 0.5 METERS ($/KM)

Description of cost component	*Meter gauge*	*Broad gauge*	*Double gauge*
CARRIAGE COST			
Remove and replace ballast	741	892	892
Remove and replace rail &other heavy iron works	463	498	498
PERMANENT WAY			
Dismantle and Re-lay of track	12,745	17,039	17,039
Earth work with sand	5,607	6,846	6,846
Procure 15% ballast & spreading	6.786	10,143	10,143
Mechanical temping at four stages	2,871	3,468	3,468
Total cost [75]	29,212	38,886	38,886

TABLE 4.12 COST OF EARTHWORK ($ PER KM) BY TYPE OF RAIL TRACK AND INUNDATION DEPTH (M)

	Additional Inundation Depth (m)						
Railway track	*0 - 0.5*	*0.5 - 1.0*	*1.0 - 1.5*	*1.5-2.0*	*2.0-2.5*	*2.5-3.0*	*>3.0*
Meter gauge	5,607	16,821	28,036	39,250	50,464	61,679	67,286
Broad gauge	6,846	20,539	34,232	47,925	61,618	75,311	82,517
Meter gauge double	6,846	20,539	34,232	47,925	61,618	75,311	82,517

TABLE 4.13 ADAPTATION COST FOR RAILWAYS ($ MILLIONS)

	Additional Inundation Depth (m)							
Railway track	*0 - 0.5*	*0.5 - 1.0*	*1.0 - 1.5*	*1.5-2.0*	*2.0-2.5*	*2.5-3.0*	*>3.0*	*Total*
Meter gauge	5	0	0	-	-	0	0	6
Broad gauge	8	2	0	0	-	-	-	10
Meter gauge double	9	2	0	0	0	0	-	11
All tracks	22	4	0	0	0	0	0	27

TABLE 4.14 EMBANKMENTS EXPOSED TO ADDITIONAL INUNDATION RISK DUE TO CLIMATE CHANGE (KM)

	Additional Inundation Depth (m)					
	0–0.5	*0.5–1.0*	*1.0–1.5*	*1.5–2.0*	*> 2.0*	*Total*
Length of embankment (km)	5,088	304	25	4	0	5,421

76 The cost of removing and replacing ballast, cost of removing and replacing of rail and other heavy iron works, and cost of dismantling and re-laying of tracks have been counted twice because during the construction work another diversion track will be required to sustain continuous movement of trains.

TABLE 4.15 ITEMIZED COST FOR RAISING EMBANKMENTS ($ MILLIONS)

	Additional Inundation Depth (m)					
	0–0.5	0.5–1.0	1.0–1.5	1.5–2.0	> 2.0	Total
Earthwork	55	9	1	0	0	65
Compaction	26	4	1	0	0	31
Turfing	0	-	0	-	-	0
Total cost (million Taka)	81	13	2	0	0	96

Table 4.11. The cost for broad gauge and double gauge are $38,886 per km, while the cost for meter gauge is somewhat lower at $29,212 per km.

Earthwork is the only cost component that increases when rail tracks have to be raised more than 0.5 m. The cost of earthwork per km of rail track by type of track and inundation depth is shown in Table 4.12. The estimated **total cost of raising railway track is $27 million** (Table 4.13).

EMBANKMENTS

Structural measures such as embankments and water regulating structures have dominated water and flood management practices in Bangladesh. The Bangladesh Water Development Board (BWDB) maintains a total of 9,943 km of embankments, 5,111 km of drainage canals, and 13,949 flood control/regulating structures (BWDB 2006). Embankments are used to protect agricultural land, major cities, and small towns from 10-year, 15-year, and 50-year return period floods respectively.

The length of embankment (km) exposed to additional inundation risk due to climate change is determined based on GIS overlays of the maps of additional inundation risk zones with the map of existing embankments. The length of embankments is not expected to expand further through 2050. Table 4.14 summarizes the total kilometers of embankments that are subject to various degrees of additional inundation due to climate change. Less than 1 percent of embankments in 2050 are subject to more than 1 meter of additional inundation due to climate change, while almost all (94 percent) are expected to be inundated by up to 0.5 meters due to climate change.

The total cost of raising embankments to avoid further inundation due to climate change is calculated using cost estimates available from the BWDB for earth work (Taka 125/ m^3), compaction (Taka 60/ m^3) , and turfing (Taka 25/ m^2). Table 4.15 provides the total cost to raise the affected embankments to offset the additional inundation risk due to climate change by cost component and additional inundation depth. Most of the costs are for earthwork. **The total cost for raising embankments to offset the additional risk due to climate change is $96 million (or Tk 6,727 million).**

DRAINAGE WITHIN COASTAL POLDERS[77]

Water regulators are used to prevent drainage congestion in coastal polders. Not all existing water regulators are currently operational. Reliable statistics are not available on the quantity or quality of existing regulators. The costs of rehabilitating existing structures or adding new ones to meet the drainage needs under the baseline scenario are not part of adaptation cost. The higher precipitation level and rising sea levels under the climate

77 Additional upgrades to drainage systems within coastal polders in response to storm surges are not needed if (a) the embankments are raised sufficiently to ensure polders are not overtopped, and (b) the congestion from inland flooding is larger than the congestion that would occur in case there is some overtopping.

change scenario are expected to increase drainage congestion in coastal polders. A total of 1,475 additional vents—each costing Taka 20 million—are required to drain the affected polders[78] that are likely to face increased drainage problems under the climate change scenario. **The total cost of additional drainage regulators in the coastal areas is Taka 29,500 million, or $421.4 million.**

SCOUR CONTROL

Increases in the maximum discharge is directly correlated with increased erosion of unprotected river banks (CEGIS 2009) and scour depth for protected river banks. More than 60 towns and cities are currently under the erosion control program. While additional towns are likely to encounter erosion and scour concerns, the adaptation cost estimates only include the additional costs for the existing protected towns due to availability of data. Similarly, lack of data has also precluded estimation of the cost of protecting unprotected river banks from erosion. The only cost estimates are for the influence of discharge on scour depth for currently protected banks. Three case studies on bank protection on the Brahmaputra, the Ganges, and the Meghna basins found that climate change would induce likely increases in the maximum discharge of 17 percent in the Ganges, 20 percent in the Brahmaputra, and 8 percent in the Meghna, which would increase scour depths by 1.87 m, 0.96 m, and 1.13 m respectively (BWDB 2003).

78 An increase in the water level inside a polder creates drainage congestion in the polder. Trial simulations were conducted with four polders to determine the average number of additional vents needed per overtopped polder. Each simulation consisted of adjusting the length of opening under the climate change scenario to reduce the water depth inside each polder to the level under the baseline scenario. The adaptation measure is the additional length of opening needed to ensure the same drainage conditions under both scenarios. Additional numbers of vents are computed by dividing the length of opening with 1.52 m (i.e. width of each vent). The four trials indicate 7, 17, 24, and 51 additional vents are needed to reduce water levels under the climate change scenario down to the levels under the baseline scenario. Details of this estimate are in Annex 8.

Lacey's formula is used to predict local scour depths. Increases in scour depth increase the yearly operation and maintenance cost due to the additional requirement of launching apron. The additional cost is a function of the increased discharge, silt factor, and nature of location of scour sites. Increases in the expected peak discharge will result in a 6.8 percent increase in the annual operation and maintenance cost of the existing bank protection project for providing additional protection against scour.

BWDB's average annual operation and maintenance costs for scouring during the last three years (2007–09 to 2009–10) were Tk. 1,045 million ($14.9 million). Increased discharges due to climate change are expected to increase annual scour costs by 6.8 percent (Tk. 71 million), or $1.0 million per year.

Adaptation cost for inland flooding

Table 4.16 summarizes the costs of protecting selected infrastructure against the additional risk of inundation from the inland monsoon resulting from climate change by 2050. They provide a lower bound on the actual costs of adaption as they do not include additional adaptation in urban areas. Over four-fifths of the total adaptation cost is required to raise the height of roads. Additional drainage structures in coastal areas account for an additional 14 percent of costs, while the remaining measures account for less than 5 percent of the total cost of adaptation for inland flooding.

Implications for Adaptation Strategy

Rural households have adapted their farming systems to the normal inundation by switching to high-yielding rice crops instead of low-yielding deepwater rice. As a result, agricultural

TABLE 4.16 TOTAL ADAPTION COST FOR INLAND FLOODING ($ MILLIONS)

Description of cost component	Investment	Annual Recurrent
Transport – Road height enhancement	2,122	42
Transport – Road cross-drainage	5	-
Transport – Railway height enhancement	27	1
Embankment – height enhancement	96	2
Coastal Polders – cross drainage	421	8
Erosion Control Program		1
Total Costs	2,671	54

production has actually risen over the past few decades. Severe flooding, however, has resulted in significant damage to the Bangladeshi economy in terms of crop losses, destruction of roads and other infrastructure, disruption to industry and commerce, and injuries and loss in human lives from severe inland monsoon floods once every three to five years.

Increased monsoon precipitation, higher trans-boundary water flows, and rising sea levels resulting from climate change are expected to increase the depth and extent of inundation. The impacts of climate change are measured based on simulations that compare inundation levels under the climate change scenario with the 1998 floods. With climate change, the total flooded area increases by 4 percent, exposing more assets and activities to risk. While the inundation depth increases in about half of the county, the increases compared to the baseline scenario are greater than 15cm in only 544 km^2, or less than 0.5 percent of the country. Since these areas also have a higher density of assets and activities than the remainder of the country, the damages will be larger than the small areal share may suggest. The rural population exposed to flooding, however, is expected to decline from current levels due to the rural-to-urban migration that is projected to occur by 2050. While significant, these increases are a small fraction of the existing risks of inland flooding.The damages from flooding in the agriculture sector and for the overall economy are estimated in Chapter 5.[79] Damage estimates from the agriculture and food security component of this study indicate that climate change increases the existing damages by about one-third, with commensurate increases in economy-wide losses as well. Similar comparisons were not completed for other sectors.

While the cost of protecting against the existing risks of severe inland monsoon flooding were not estimated, the incremental cost to climate proof (a) road networks and railways, (b) river embankments and embankments to protect highly productive agricultural lands, (c) drainage systems, and (d) erosion control measures for high-value assets such as towns are substantial (estimated at $2,671 million in investment costs and $54 million in annual recurrent costs). Full protection in 2050 will also require addressing the existing risks of flooding, which are likely to be of the same of order of magnitude or larger.

A prudent no-regrets strategy would begin by strengthening existing flood embankments, supplemented by improvements in the spatial and

79 The flooding results in Chapter 5 are based on the average severe flood, which is useful for determining average effects over time. The risk and cost estimate in this chapter is measured against a baseline level created from the 1998 flood and is useful for examining extreme events. Adaption costs estimated in this chapter will also protect against the less severe floods.

temporal resolution of flood forecasting and early warning systems as indicated in the BCCSAP. Once existing risks have been addressed, the adaptation strategy would either relocate the assets and activities in the at-risk areas, or target them for climate proofing.

Finally, given the location of Bangladesh at the tail end of the GBM basin, a longer term adaptation strategy has to also include the development of institutions and mechanisms for the sharing of water resources with neighboring countries located in the GBM basin.

FIVE

Agriculture and Food Security

Background

Agriculture is a key economic sector in Bangladesh, accounting for nearly 20 percent of GDP and 65 percent of the labor force. The achievement of food self-sufficiency remains a key development agenda for the country and is the first of six pillars in the Bangladesh Climate Strategy 2009 (GOB 2009). Prior to the start of the EACC study, the World Bank had initiated a separate multiyear study on climate change and food security in Bangladesh. Given the significant overlap in the objectives and methods between the two studies, the food security study was augmented with additional analyses focused on adaptation. The relevant portions of the enhanced study have been incorporated into the EACC study as summarized in this chapter.[80]

The performance of the agriculture sector is heavily dependent on the characteristics of the annual flood. Regular flooding of various types (e.g. flash, riverine, coastal) has traditionally been beneficial. However, low frequency but high magnitude floods can have adverse impacts on agricultural production and rural livelihoods, especially of the poor, for whom the agriculture sector is a critical source of livelihood and employment.[81] An important determinant of the overall magnitude of flooding is the timing of the peaks of the three major river systems (Ganges, Brahmaputra, and Meghna). Historical data reveals that climate variability plays a critical role in observed erratic agricultural growth despite some evidence of diminishing variability. Overall production declines during major flood events are primarily driven by area changes for the aman (monsoon season rice) and aus (inter-season rice) crops; these losses have increasingly been offset by increased boro production (dry season rice). As a result, agricultural GDP has become less sensitive to current climate variability compared to pre-1990 levels.

In addition to floods, the livelihoods of much of the rural population are also threatened by droughts, salinity, storm surges, cyclones and other natural disasters. Regional droughts and coastal inundation from sea level rise can have consequences for agriculture production as large as those from floods.

Despite these climate hazards, rice and wheat production have tripled from about 10 million

80 The augmented study is now complete and is available separately as Yu et al. 2010.

81 Between 1991 and 2000, 93 major disasters were recorded in Bangladesh, resulting in billions of dollars in losses, much of which were in the agriculture sector. The 1998 flood resulted in crop losses of over 2 million MT.

metric tons (Mmt) in the early 1970s to almost 30 Mmt by 2001, partly due to the rapid expansion of surface and groundwater irrigation and the introduction of new high-yielding crop varieties. The challenge for Bangladesh is to continue the productivity enhancements of the past few decades, which ensures that the expected rise in demand for food (resulting from increased population and higher income levels) can be met despite the increasing pressures on available land and water resources from overuse, droughts, and quality changes (e.g. salinity).

Climate change poses additional challenges to agriculture beyond the existing risks from current variability. Long-term changes in temperatures and precipitation have direct implications on evaporative demands and consequently agriculture yields. Moreover, the changing hydro-characteristics (e.g. onset, duration, and magnitude) of extreme events may affect agriculture production significantly. Finally, sea level rise may have important implications on the sediment balance and may alter the profile of the area inundated and salinity in the coastal areas.

This study examines the impacts of climate change on agricultural yields, cropping patterns, and production, both from a sectoral perspective as well as in the context of the overall economy. The key innovations introduced by the study are (a) improved characterization of the changes in climate using a comprehensive set of climate projections, (b) use of agricultural impact functions developed from country-specific data, (c) integration of agricultural model results into a macroeconomic (CGE) framework to examine both direct and indirect impact and responses, and (d) examination of a range of climate risks, including the changing characteristics of floods, droughts, and potential sea level rise.

Projected Future Climatic Conditions

The direct impacts of climate on crop yields are estimated based on climate predictions from sixteen different Global circulation models for three emission scenarios for the 2030s, 2050s, and 2080s. These are compared to counterfactual scenarios based on the historical past (1970–99) for the respective models. The median model predictions are a warmer (1.55 °C) and wetter (annual precipitation increases of 4 percent) climate by the 2050s, with greater contrasts between the wet and dry seasons. Greater model uncertainty (in terms of magnitude and direction) exists with future precipitation than future temperature. Simulated future temperature changes significantly separate from the background temperature variations. Precipitation is subject to large existing inter-annual and intra-annual variations. Simulations of future rainfall do not significantly separate themselves from the historical variability for any month or season.

Primarily driven by increased monsoon precipitation in the GBM basin, models on average demonstrate increased future flows in the three major rivers into Bangladesh (as much as 20 percent).[82] Larger changes are anticipated by the 2050s compared to the 2030s. Larger changes are observed on average for the Ganges. The exact magnitude is dependent on the month. Given that most GCMs project both

82 A Ganges-Brahmaputra-Meghna (GBM) regional model and national hydrologic model are developed to simulate discharges and water levels into/in Bangladesh under various climate change scenarios for the flood monsoon months from May to September. Annex 15. Models used for flood hydrology a detailed description of these models. Bangladesh is divided into sixteen subregions to capture agro-ecological variations. Eleven are used for hydrologic modeling purposes. A delta approach is used to model future changes. The delta between the baseline and future time period for the climate parameter of interest (i.e. percentage change in precipitation and absolute change in temperature) is applied directly to the historical time series. This preserves the differences across subregions and maintains the day-to-day and year-to-year variability that is not captured accurately in the GCM historical outputs. A subset of five GCMs and two emissions scenarios were selected as model experiments.

an increasing trend of monsoon rainfall and greater inflows into Bangladesh, it follows that the flooding intensity would worsen. On average, models simulate increases in flooded area in the future (over 10 percent by 2050). This is primarily in the central part of the country at the confluence of the Ganges and Brahmaputra rivers and in the south.

Increases in yearly peak water levels are projected for the northern subregions and decreases are projected for the southern subregions. Not all estimated changes are statistically significant. More models demonstrate changes that are significant by the 2050s. In general, changes are less than a half meter from the baseline. Furthermore, across the subregions, most GCMs show earlier onset of the monsoon and a delay in the recession of flood waters.

The study also draws upon prior results using the MIKE21 two-dimensional estuary model (DEFRA 2007), which indicated that the total flooded area in the coastal districts would increase by 6 percent, 10 percent, and 20 percent under three scenarios—15 cm, 27 cm, and 62 cm—of sea level rise.

Direct Impacts on Agriculture

Dynamic biophysical crop models are developed (i.e. DSSAT) and validated using available information on climate, soils, cultivars, and management practices. Simulations of changes in crop yield include impacts from climate only (CO_2, temperature, and precipitation), mean changes in floods, and coastal inundation, both separately and in combination. The gap between actual yields and modeled potential yields is large. Replicating actual yields is secondary to estimating the changes from the baseline. Yields vary from season to season by 10 to 20 percent.

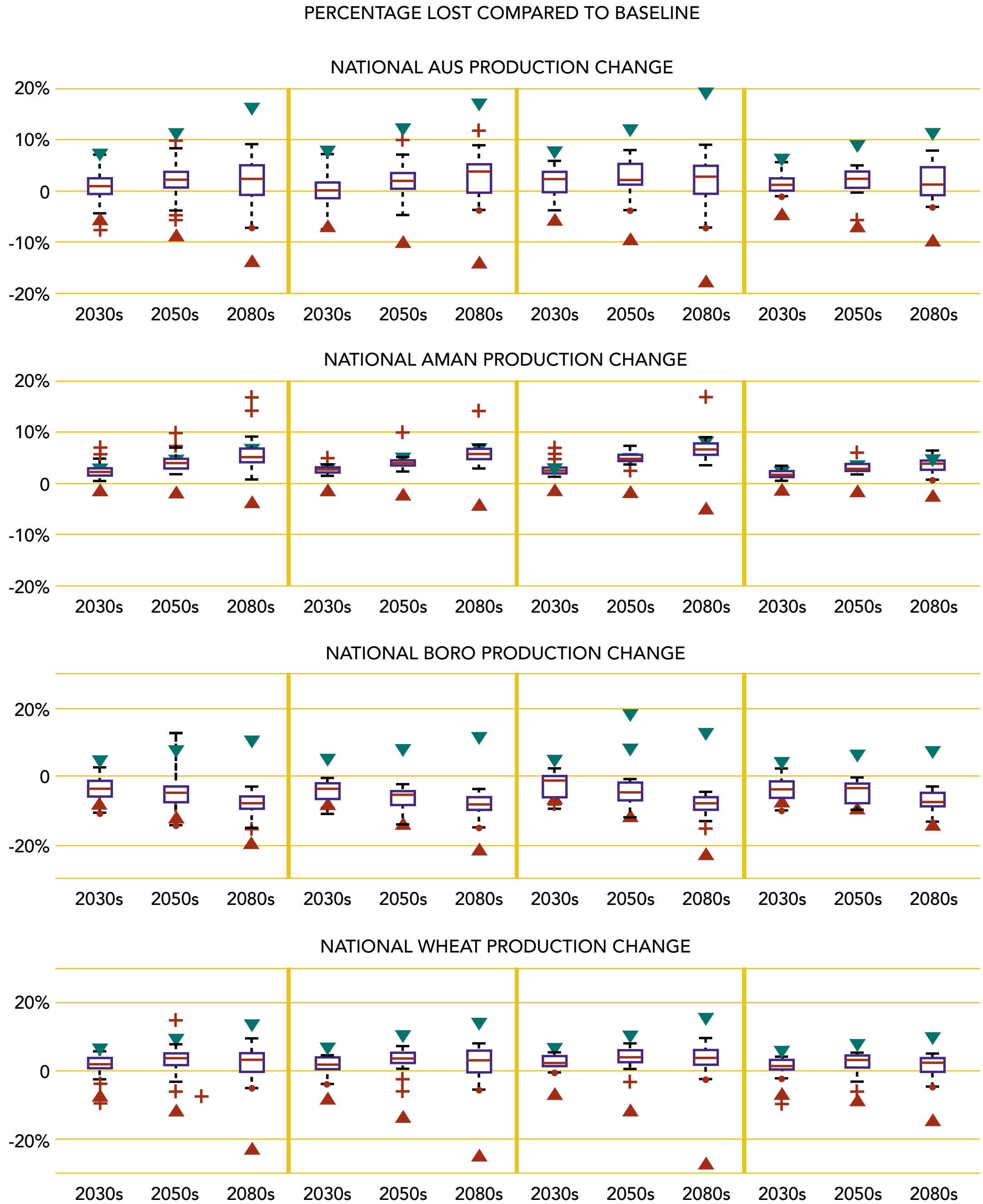
Elevated CO_2 concentrations can have a significant positive effect on yields for all crops and locations (Figure 5.1). Considering only temperature, precipitation, and CO_2 changes, aus and aman median production increases by 2 percent and 4 percent by 2030 and 2050 respectively across the model simulations. Wheat also increases, reaching a maximum of 4 percent by 2050.

These distributions range approximately +/- 2 percent. Boro production declines— around 8 percent by 2080—under climate change scenarios. These changes are conservative, as it is assumed that farmers have limitless access to irrigation. Mean shifts in floods are estimated to reduce production of aus and aman between 1 percent and 4 percent. The narrow model distribution of flood impacts projected by different GCMs suggest a robust change, although changes are small in comparison to year-to-year variability.

Production changes due to flood damages only are presented in Figure 5.2 for aus and aman rice. Boro and wheat are assumed to be unaffected by floods. Flood damages are projected to increase in most scenarios, particularly for the 2050s time period and for the aman crop grown at the height of the monsoon. Median additional losses across all scenarios are 1 percent and 2 percent in the 2030s and 2050s respectively. Maximum median flood losses occur in the 2050s A2, with national aman production falling 4 percent and national aus production dropping 2.4 percent. More modest crop losses are projected for the B1 scenario, reaching only 1 percent of aus production and 3 percent of aman production in the 2050s. The narrow distribution of flood damages projected by different GCMs suggests a robust change, although changes are small compared to the year-to-year variability in each time period. These results are likely to be optimistic, as changes in inter-annual variability between the baseline and future time periods are likely to produce larger flood damages and several sub-regions were not modeled.

Considering all climate impacts (CO_2 fertilization, temperature and precipitation changes, flood

FIGURE 5.1: PERCENTAGE CHANGE IN NATIONAL POTENTIAL PRODUCTION DUE TO TEMPERATURE, PRECIPITATION, AND CO_2



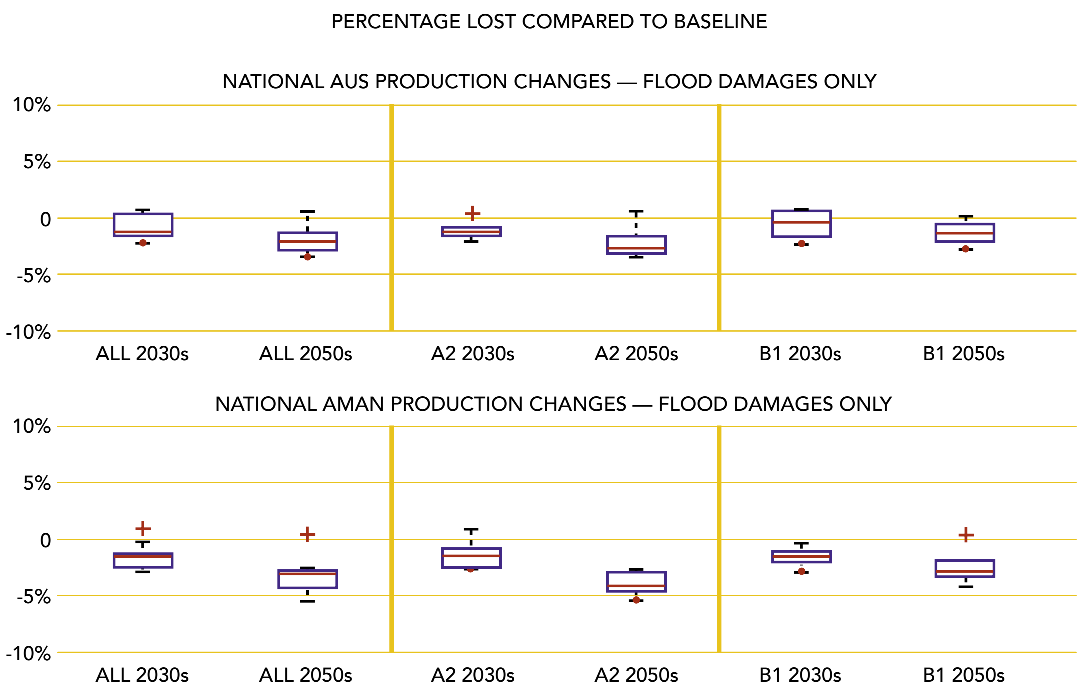
Notes: Potential production of each crop (aus, aman, boro, wheat) is compared relative to the baseline undamaged simulation. Each panel has four sections, each containing the three future time periods and presenting (from left to right) the combination of all emissions scenarios, the A1B, the A2, and the B1 scenario. The results of the CO_2 impact experiments are displayed as green triangles, while the median of the temperature and precipitation impact experiments is shown as a red triangle. The distribution of undamaged potential yields projected by GCMs are presented as a box and whiskers diagram, consisting of a red line representing the median value, a box enclosing the inter-quartile range (the middle 50 percent of models), dashed whiskers extending to the furthest model that lies within 1.5x the inter-quartile range from the edges of the box, and red plus symbols for additional models that are perceived as outliers. Source: Yu, W.H., et al. (2010)

changes, sea level rise), the median of all rice crop projections shows declining national production, with boro showing the largest median losses (Figure 5.3). However, for aus (-1.5 percent) and aman (-0.6 percent), the range of model experiments covers both potential positive gains and losses and does not separate convincingly from zero. Most GCM projections estimate a potential decline in boro production with a median loss of 3 percent by the 2030s and 5 percent by the 2050s.

Wheat production increases out to the 2050s (+3 percent). Boro and wheat changes are conservative, as it is assumed that farmers have limitless access to irrigation. In each subregion, production losses are estimated for at least one crop. The production in the southern subregions is most vulnerable to climate change. For instance, average losses in the Khulna region are -10 percent for aus, aman, and wheat and -18 percent for boro by the 2050s due in large part to rising sea levels. These production impacts ignore economic responses to these shocks (e.g. land and labor reallocation, price effects) which will provide a buffer against the predicted physical losses to some degree.

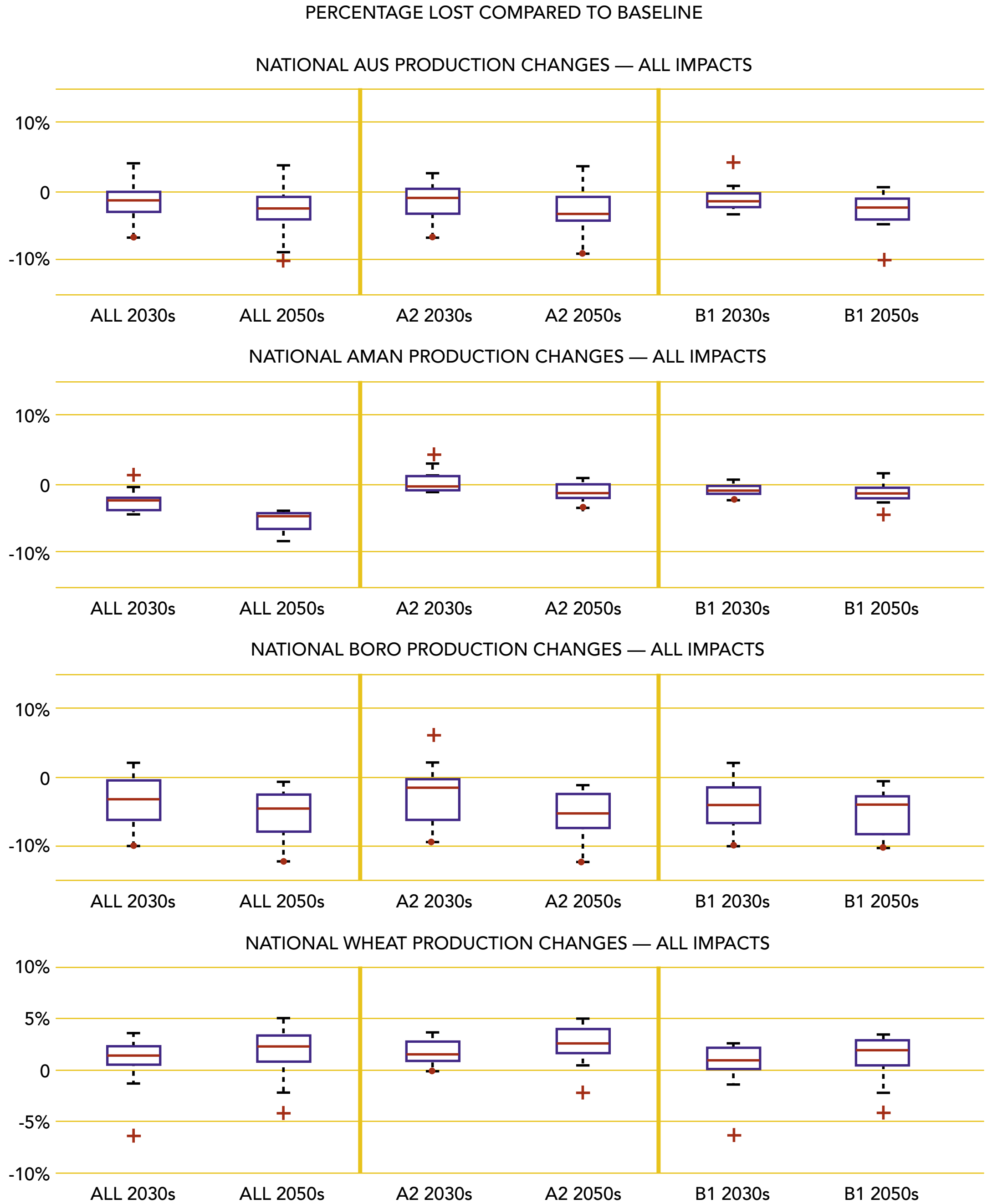
Climate change exacerbates the negative impacts of existing climate variability by further reducing rice production by a projected cumulative total of 80 million tons over 2005–50 (about 3.9 percent each year), driven primarily by reduced boro crop production. This is equivalent to almost two years worth of rice production lost over the next 45 years as a result of climate change. Uncertainty

FIGURE 5.2 PERCENTAGE CHANGE IN NATIONAL POTENTIAL PRODUCTION FROM FLOOD DAMAGES ONLY



Notes: Percentage change in national potential production for each crop (aus and aman) affected by basin floods relative to the baseline flood-only simulation. Boro and wheat are assumed to be flood-free. Each panel has three sections, each containing the two future time periods and presenting (from left to right) the combination of all emissions scenarios, the A2, and the B1 scenario. The distribution of flood-damaged potential yields projected by GCMs are presented as a box and whiskers diagram, consisting of a red line representing the median value, a box enclosing the inter-quartile range (the middle 50 percent of models), dashed whiskers extending to the furthest model that lies within 1.5x the inter-quartile range from the edges of the box, and red plus symbols for additional models that are perceived as outliers.
Source: Yu, W.H., et al. (2010)

FIGURE 5.3 PERCENTAGE CHANGE IN NATIONAL POTENTIAL PRODUCTION COMBINED EFFECTS



Notes: Percentage change in national potential production for each crop (aus, aman, boro, and wheat) with the combined effects of CO_2, temperature, precipitation, and basin flooding. Each panel has three sections, each containing two future time periods and presenting (from left to right) the combination of all emissions scenarios, the A2, and the B1 scenario. The distribution of potential yields projected by GCMs are presented as a box and whiskers diagram, consisting of a red line representing the median value, a box enclosing the inter-quartile range (the middle 50 percent of models), dashed whiskers extending to the furthest model that lies within 1.5x the inter-quartile range from the edges of the box, and red plus symbols for additional models that are perceived as outliers. Source: Yu, W.H., et al. (2010)

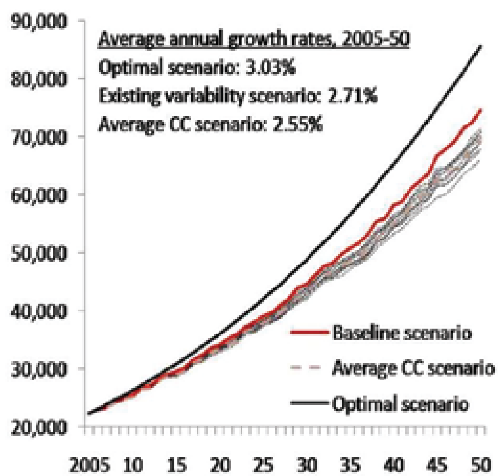
about future climate change means that annual rice production losses range between 3.6 percent and 4.3 percent. Climate change has particularly adverse implications for boro rice production and will limit its ability to compensate for lost aus and aman rice production during extreme climate events. This will further jeopardize food security in Bangladesh, necessitating greater reliance on other crops and imported food grains. Rice production in the southern regions of Patuakhali and Khulna is particularly vulnerable.

Economy-wide Impacts and Responses

These production impacts ignore economic responses to these shocks (e.g. land and labor reallocation, price effects). These economic effects will to some degree buffer against the physical losses predicted. A dynamic recursive computable general equilibrium (CGE) model is developed to estimate the consequences of climate variability and change on economic growth and household welfare. The Bangladesh economy is characterized by 36 sectors, 16 agro-climatic regions, rice split by seasonal varieties, national labor and capital markets, regional land markets, and three representative households (marginal, small-scale, and large-scale farms). The CGE captures the detailed sector and labor market structure of the Bangladesh economy—as well as the linkages among production, employment, and household incomes—and is run forward over 2005–50 in a recursive-dynamic manner. The climate impact channels captured by the CGE model include crop yield changes from the hydro-crop models, additional impacts of low-frequency extreme events, and sea level rise.

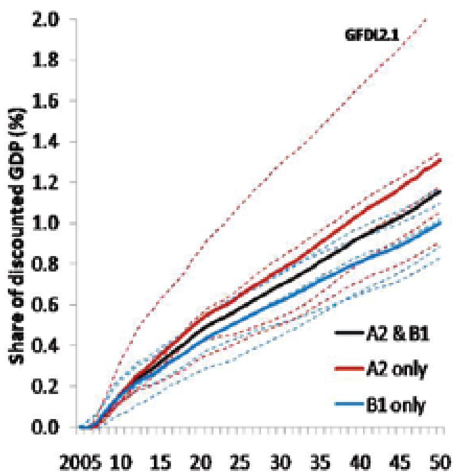
Overall, agricultural GDP is projected to be 3.1 percent lower each year as a result of climate change ($36 billion in lost value-added). Climate change also has broader economy-wide implications. This will cost Bangladesh $129 billion in total GDP over the 45-year period 2005–50, equivalent to $2.9 billion overall lost each year to climate change, or alternatively an average annual 1.6 percent reduction in total GDP. Average loss in agricultural GDP due to climate change is projected to be a third of

FIGURE 5.4 NATIONAL RICE PRODUCTION (METRIC TONS)



Source: Yu, W.H., et al. (2010)

FIGURE 5.5 SHARE OF DISCOUNTED GDP



Source: Yu, W.H., et al. (2010)

the agricultural GDP losses associated with existing climate variability. Uncertainty surrounding GCMs and emission scenarios means that costs may be as high as $5.1 billion per year over 2005–50 under less optimistic scenarios. Additionally, these economic losses are projected to rise over time.

These climate risks will have severe implications for household welfare. Around 80 percent of total losses fall directly on household consumption. About 80 percent of the economic losses occur outside of agriculture, particularly in the upstream and downstream agriculture value-added processing sectors. This means that both rural and urban households are adversely affected. Per capita consumption is projected to fall for both farm and nonfarm households.

The southern and northwest regions are the most vulnerable. The south sits at the confluence of multiple climate risks. These areas experience the largest decline in rice production due to climate change. This is for three reasons. First, these regions already experience significant declines in aus and aman rice production due to climate variability, which is expected to worsen under climate change. Secondly, boro yields are severely affected by the effects of changes in mean rainfall, temperature and mean shifts in the flood hydrographs. Thus, reductions in boro production limit the ability for these regions to compensate for lost aus and aman rice production during extreme events. The south is also affected the most by rising sea levels, which permanently reduces cultivable land. The largest percentage declines in per capita consumption are projected in these regions. Finally, the northwest is also vulnerable, as the lost consumption is a large fraction of existing household consumption. Adaptation measures should focus on these areas.

Implications for Adaptation Strategy

Some of the key results of the study are that the net impacts are that climate change will result in losses of about 3.1 percent in agricultural GDP and even larger economy-wide losses through 2050, with losses increasing over time. These losses are not evenly distributed across the country, with the southern coastal region and the northwest bearing much larger losses. Nearly 80 percent of the losses are borne by households, with the poor and the most vulnerable within these communities bearing the greatest burden. While warmer and wetter climates increase the yields of the primary rice crops—aman and aus—the impacts of severe floods is expected to result in a net decline in the total production of these crops. Higher precipitation and temperatures actually result in lower yields of the dry season boro crop which has been used in recent years to offset crop losses following severe floods.

While the cost of adaption to climate change in the agriculture sector was not directly estimated due to resource and time constraints. However, a number of implications of the study for adaptation cost and a strategy can be inferred and summarized below.

First, increased investments in adaptation in the agriculture sector are critical to ensuring continued growth and poverty alleviation. Bangladesh will continue to depend on the agriculture sector for economic growth. Rural households will continue to depend on the agriculture sector for income and livelihoods. Though the government has made substantial investments to increase the resilience of the poor (e.g. new high-yielding crop varieties, protective infrastructure, disaster management), these variability impacts may, as has been shown, be exacerbated by the long-term effects of climate change. The scale of current efforts remains limited and is not commensurate with the probable impacts. Significant additional investments in promoting these types of adaptations are still needed.

Second, a no-regrets strategy is to promote activities and policies that help households build resilience to existing climate risks today. Both processes—adapting to climate change and stimulating the agriculture sector to achieve rural growth and support livelihoods—require efforts to diversify household income sources; improve crop productivity; support greater agricultural research and development; promote education and skills development; increase access to financial services; enhance irrigation efficiency and overall water and land productivity; strengthen climate risk management; and develop protective infrastructure. Moreover, the current large gap between actual and potential yields suggests substantial on-farm opportunities for growth and poverty reduction. Expanded availability of modern rice varieties, irrigation facilities, fertilizer use, and labor could increase average yields at rates that could potentially more than offset the climate change impacts. Significant additional planning and investments in promoting these types of adaptations are still needed.

Third, the southern region is the most vulnerable. The south sits at the confluence of multiple climate risks. These areas experience the largest decline in rice production due to climate change. This is for three reasons: (a) these regions already experience significant declines in aus and aman rice production due to climate variability, which is expected to worsen under climate change; (b) boro yields are severely affected by the effects of changes in mean rainfall, temperature, and mean shifts in the flood hydrographs, so reductions in boro production limit the ability for these regions to compensate for lost aus and aman rice production during extreme events; and (c) the south is affected the most by rising sea levels, which permanently reduces cultivable land. The largest percentage declines in per capita consumption will be in these regions. Specific focus should be placed here.

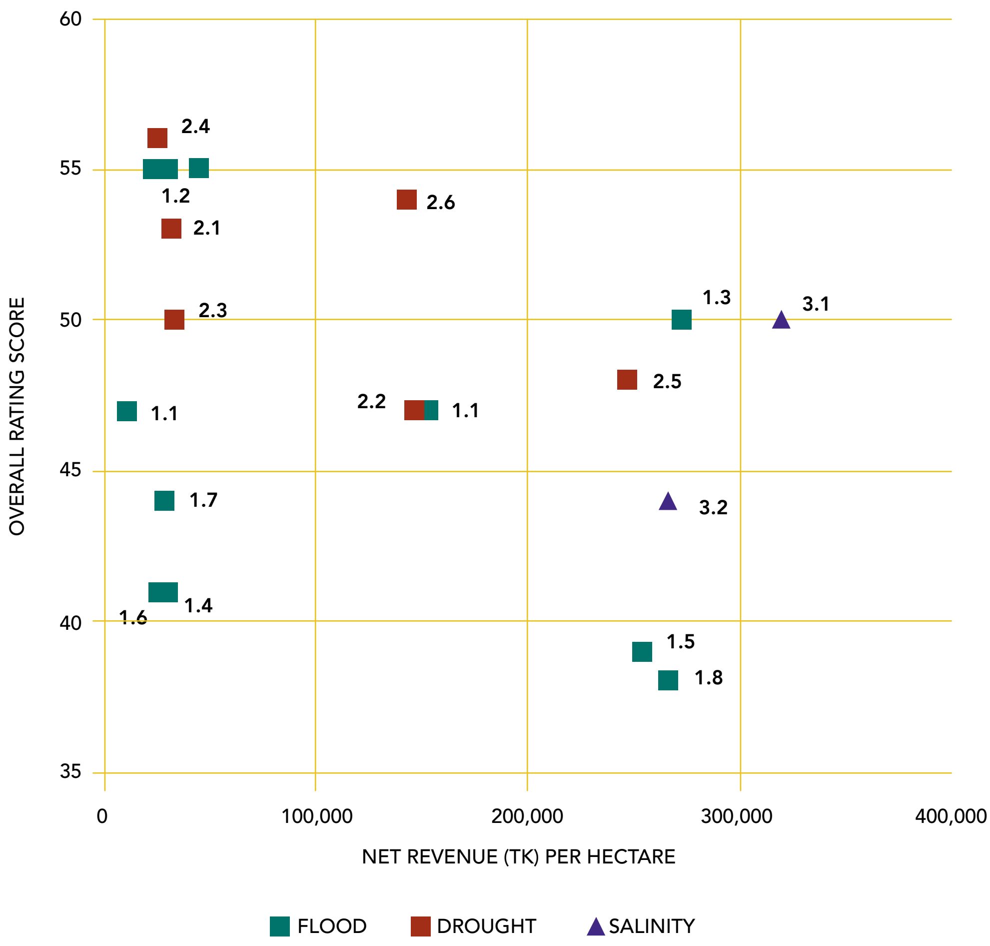
Fourth, while the public sector cost of adapting in the agriculture was not estimated, the relative merits of a number of short term adaptation measures – namely the extension of currently available options into new areas – are examined from the farmer's perspective. These measures primarily examine the merits of promoting existing crops from one area to another as the climate regimes shifts. The adaptations can focus on increasing crop productivity, improving irrigation efficiency or expanding water supply, crop diversification and intensification, generating alternative enterprises (either farm or non-farm sector) to diversify household income sources, and expanding access to training and credit. Sixteen adaptation options were identified through consultation with local officials, NGOs, and farmers to address the risks of flooding, drought, and salinity to agriculture.[83] Many of these measures are already in place in some regions of Bangladesh, or could be in place with some modification. They provide a low cost option for adapting to small changes in the climatic regime and may be suitable in the near term. Each of these measures are evaluated based on a set of criteria, including policy and institutional, socioeconomic, economic, and environmental. The net revenues to farmers of adopting these strategies are also estimated. These are summarized in Figure 5.6. Adaptation measures to the right and higher up in the graph provide larger private payoffs and need to be compared to the social cost of implementing these options.

Finally, the medium to long term adaptation strategy has to include flood control, given the significant crop damages and losses from severe floods (some of which has been costed in Chapter 4) and the development of alternative cultivars particularly to the *boro* crop in the southern region.

Finally, longer run strategies in the agriculture sector need to examine the development of new cultivars that are able to better withstand the new climate and to control floods. A key aspect of the latter will be the development of institutional mechanisms for the sharing of water resources with neighboring countries in the GBM basin.

83 These measures are (1) zero or minimum tillage to cultivate potato, aroid and ground nut with water hyacinth and straw mulch; (2) zero tillage cultivation of mashkalai, khesari, lentil, and mustard; (3) modified sorjan system (zuzubi garden) with vegetable cultivation; (4) floating bed vegetable cultivation; (5) cultivating foxtail millet (kaon); (6) parenga practice of t-aman cultivation system; (7) relay cropping of sprouted seeds of aman rice in jute fields; (8) raising vegetable seedlings in poly bags homestead trellises; (9) zero tillage maize cultivation; (10) zero or minimum tillage to cultivate potato with water hyacinth and straw mulch; (11) chickpea cultivation using a priming technique; (12) supplementary irrigation for T aman; (13) year-round homestead vegetable cultivation; (14) pond water irrigation for vegetable cultivation; (15) sorjan system of cropping of vegetables and fisheries; and (16) raising vegetable seedlings in poly bags homestead trellises.

FIGURE 5.6 NET REVENUES AND OVERALL SOCIAL PREFERENCE OF ADAPTION MEASURES



Source: Yu, W.H., et al. (2010)

SIX

Local Perspectives on Adaptation

Background

Bangladesh is exposed to a wide variety of climate change impacts and induced hazards including drought, river floods, flash floods, cyclones and tidal surges, salinity intrusion, water-logging and drainage congestion. Current climate variability already represents a profound threat to the livelihoods of the poor as they are often collocated in areas of highest risk (Figure 6.1) and are directly dependent on climate sensitive sectors of the economy such as agriculture and fisheries. The objective of this component is to examine the determinants of the adaptive capacity and practices of vulnerable populations, and solicit from local and national stakeholders – through participatory scenarios – the types of public support that would best enable the vulnerable population to cope with the potential impacts of climate change. The analysis uses a broad assortment of tools including a literature review, fieldwork consisting of focus groups and sample surveys in eight "hotspots", and a series of participatory scenario development (PSD) workshops at the local, regional, and national levels.

Overview of Hotspots

Based on a literature review, a total of eight study sites or 'hotspots' were selected to better understand the impact on the community of different climate-related hazards (see Figure 4).[84] While each 'hotspot' was selected for a primary hazard, many areas are in fact exposed to multiple hazards which reinforce the negative shocks of these hazards on the affected communities. Differentiated patterns of vulnerability to climate change also emerge from the uneven socio-economic development of the country. While the sites shown are large areas (districts) exposed to various types and magnitudes of climate hazards, actual fieldwork was conducted in particular villages or urban slums with different socio economic characteristics (Table 6.1, Figure 6.2). The selected hotpots exhibit variation in socioeconomic development, resource availability and exposure to natural hazards.[85] Experiences with coping strategies for climate hazards and the people's preferences for adaptation investments across locations were determined from fieldwork and participatory scenario development workshops as described in Annex 16.

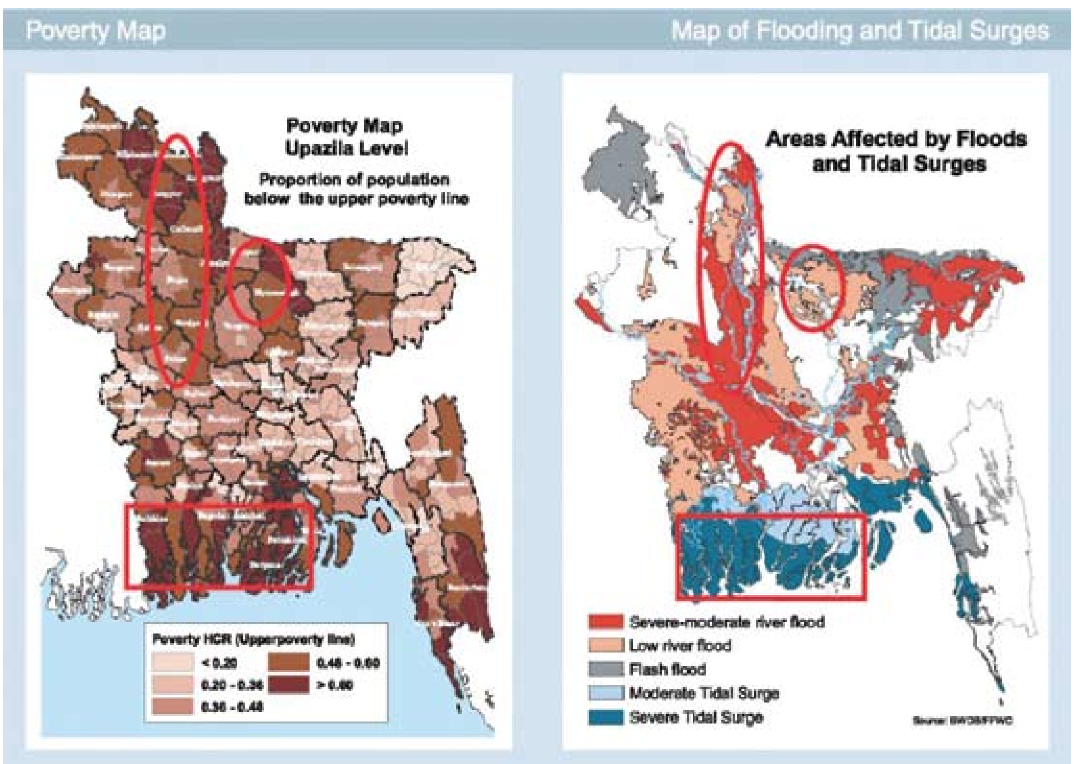
84 'Hotspots' refers to those regions already vulnerable to climate variability and likely to suffer substantial impacts in future from climate change, with poverty and vulnerability characteristics also present.

85 Pockets of high poverty incidence generally coincide with ecologically poor areas of Bangladesh: i. low-lying depression area, called *haor*, in the north-east; ii. drought-prone area on relatively higher land in the northwest; iii. several *upazilas* fringing the major rivers, particularly along the Jamuna River; and iv. several of the south-eastern *upazilas*, including the Chittagong Hill Tract

Agriculture is the most affected sector in all hotspots since crop cultivation is highly weather-dependent. In salinity and tidal-flood prone areas, crop cultivation is gradually becoming difficult due to an increase in salinity. In other areas such as Sirajganj and Sunamganj, people can now grow crops only in the *boro* season, and in waterlogged Jessore, farmers cannot cultivate at all in any season. Trees and vegetation are also severely affected by climate change in all rural areas; for example, in water-logged, river, and flash flood prone hotspots, trees cannot be grown due to excess water. Frequent cyclones in Bagerhot, Satkhira, and Cox's Bazaar cause trees to be uprooted and soil salinity prevents homestead gardening. Reduced vegetable and fruit cultivation hurts nutrition levels, especially for the poor, who cannot afford to purchase these items in the market.

Livestock also are an important asset for the poor, whether the products are consumed by the household or sold in the market. These assets are affected during extreme events: livestock often die in cyclones as people fail to move them to safe shelter. An indirect effect of climate change on livestock is the reduced ability to produce fodder for livestock due to declining crop cultivation. In some places, grasses cannot be grown; in others, grazing lands are flooded during the monsoon. The fisheries sector is highly affected in Bagerhat and Jessore, where cyclones and saline water have caused *ghers* to be damaged and fisheries to die. Infrastructure is also directly impacted by climate change. Frequent cyclones cause massive destruction of embankments, houses, roads, bridges, trees, crops and fisheries, as well as loss of human and animal lives. Entry of tidal water due to high

FIGURE 6.1 POVERTY AND CLIMATE HAZARDS



Source : BBS, World Bank and WFP 2009

TABLE 6.1: LOCATION OF EIGHT HOTSPOTS SELECTED FOR BASED OF HAZARD

Hotspot (hazard)	Region	District	Upzilla	Union	Village
Drought	NW	Naogaon	Porsha	Nitpur Sadar	Nitpur
Salinity	SW	Satkhira	Assasuni	Protapnagar	Sonatankathi
Cyclone	SW	Bagerhat	Shorankhola	Southkhali	Gabtala
River Flood	NW	Sirajganj	Kazipur	Natuar Para	Ghora Gacha
Flash Flood	NE	Sunamganj	Tahirpur	Dakshin Sreepur	Janjail
Waterlogging	SW	Jessore	Keshobpur	Safalakathi	Kalicharanpur
Tidal flood	SE	Cox's Bazar	Cox's Bazar Sadar	Khurushkul	Rastarpar
Drainage congestion	Dhaka	Dhaka	Mohammedpur	Adabor	Comfort House

FIGURE 6.2 MAP OF BANGLADESH SHOWING THE EIGHT HOTSPOTS

LIST OF SITES

1. *Porsha Upazila, Naogaon District,*
2. *Assasuni Upazila , Satkhira District*
3. *Shorankhola Upazila , Bagerhat District*
4. *Kazipur Upazila , Sirajganj District*
5. *Tahirpur Upazila , Sunamganj District*
6. *Keshobpur Upazila , Jessore District*
7. *Cox's Bazar Sadar Upazila , Cox's Bazar District*
8. *Mohamedpur Upazila, Dhaka District*

waves and breached embankments leads to inundation and salinization of agricultural lands and water bodies, which severely affects the livelihoods of the already disaster-displaced populace.

Vulnerability to Climate Change

Vulnerability was found to stem from exposure factors such as physical location and hazard-proneness (as in the riverine *char* islands); sensitivity factors such as economic geography and levels of regional development; socio-economic status and degree of economic "power" (e.g., in value chains), and social differentiation including gender. Socio-economic factors exacerbating sensitivity at the household level included: landlessness, illiteracy of adults and children, temporary migration status, large family size, and female-headed household status. At the community level, these included latent social conflict and lack of political voice (e.g., urban in-migrants).

Social capital and organizational presence are important inputs to household and area adaptive capacity. Urban respondents expressed more concern than rural residents about leaving assets unattended during floods, suggesting that urban households may take dangerous risks (i.e., not evacuating) due to a heightened sense of social insecurity. Fieldwork revealed that NGO presence was highly unequally distributed, with an overwhelming presence in cyclone-prone Bagerhat district (rebuilding houses, providing radios and delivering cyclone warnings) but no presence in saline Satkhira district that also suffered, secondarily, from cyclones. Here, failure to consider the role of overlapping hazards meant that neither disaster response infrastructure, nor the social learning that accompanied it, as in Bagerhat were present in the saline area.

Area Asset Status, including infrastructure: Poor communication and transport facilities decrease people's mobility and livelihood options as in the northeast region, where lack of road infrastructure also left villages isolated and suffering from underinvestment by government and NGOs. In Cox's Bazaar, poor communication meant that people could not travel to safe shelter easily and relief materials did not reach in time. Further, just as asset depletion can lead to chronic poverty at the household level, at the area level too repeated hazard events can reduce a region's adaptive capacity. For example, rising water levels can completely sever road links for months at a time, with consequent impacts on regional growth. Diversified structure of the regional economy is important in providing a base for effective adaptation. For example tourist areas offer a broader range of livelihood opportunities for area households than those solely reliant on agriculture, therein reducing vulnerability to climate impacts.

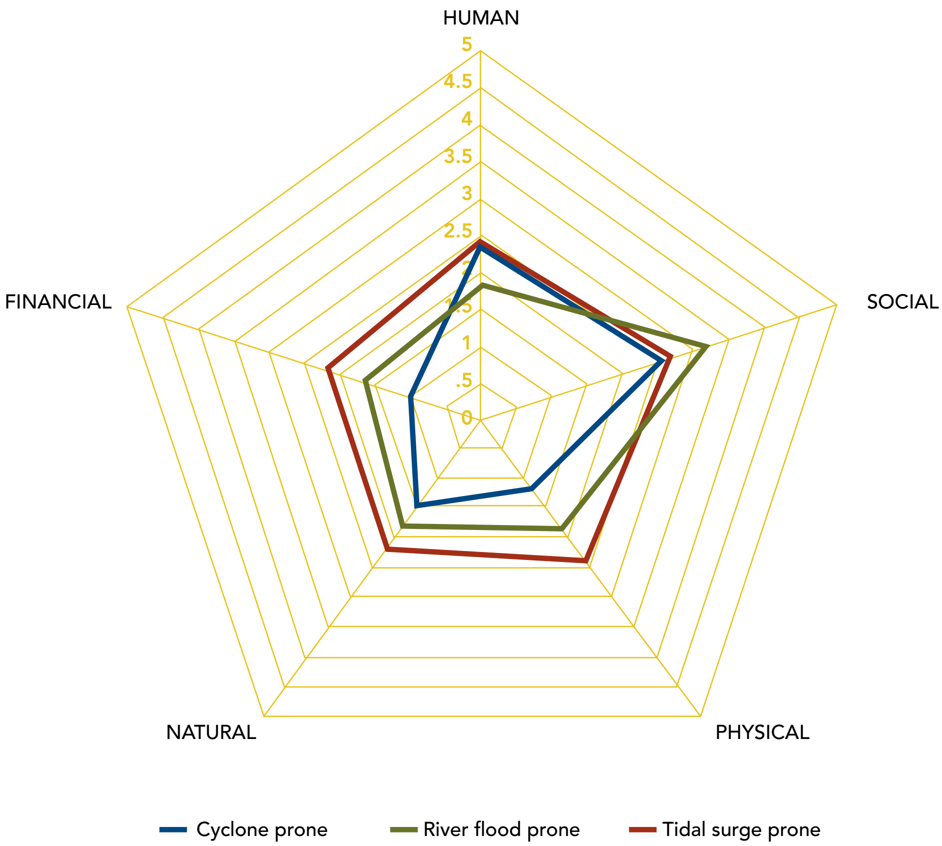
Climatic Shocks and the Effects of Multiple Hazards: Climate hazards subject households to economic shocks. Natural disasters were mentioned by more than half of all respondents in Bangladesh as the reason for sudden loss of household income, while illness or death of family members named by only 12 percent of households. It is important to consider the *temporal scale* of climate-related shocks i.e., rapid-onset (such as cyclones) or slow-onset (e.g., floods and waterlogging), and also their frequency. Multiple extreme events arriving one after another do not allow households sufficient time to recover their earlier asset base. Further, hotspots investigated were found to be doubly- or triply-exposed to hazards. For instance, river bank erosion leads to agricultural land loss in cyclone-prone areas, further reducing household ability to cope with frequent disasters. The compound effect of these events was often enough to tip households into chronic poverty status. None of the hotspots had particularly strong adaptive capacity given their poor asset bases that prevented livelihood diversification in times of crisis. Long-term adaptation planning (beyond short and medium-term measures as changing crop types and planting dates) includes the need for economy-wide diversification, as well as significant improvements in human capital levels to allow households to take advantage of risk-prevention strategies at household and area levels.

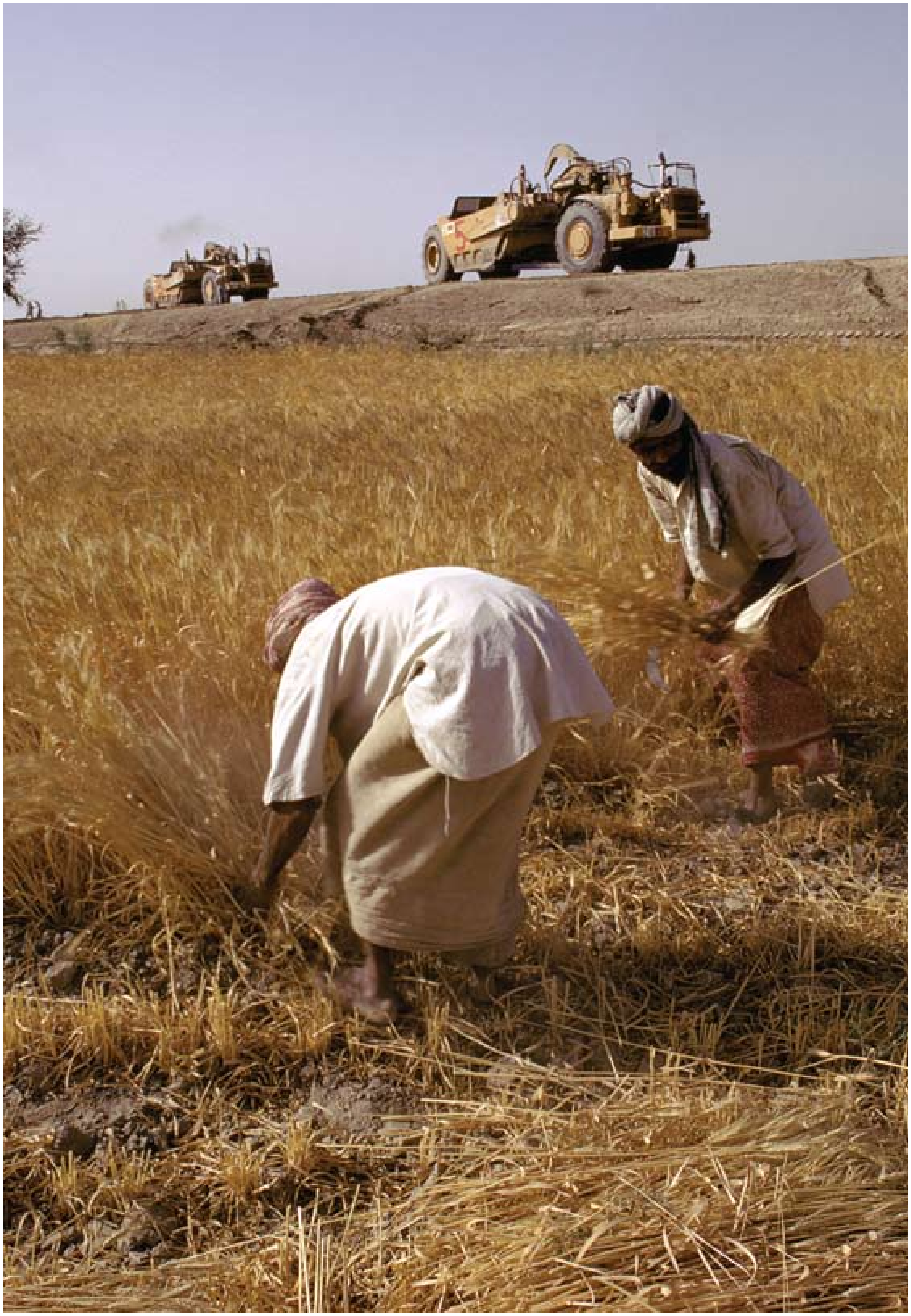
Adaptation Practices

Adaptation practices by households vary according to hazard type, location, and asset base holdings. Variations in the self-reported levels of different types of "capital" for households in different hotspots are show in Figure 6.3. None of the hotspots had strong adaptive capacity given their poor asset bases, which prevent asset transformation in times of crisis. Thus most households interviewed had little room for maneuver in adapting to climate change, due to the low asset base level from which they started. Poor urban dwellers face particularly few options for livelihood diversification and hold low social capital. Poor urban dwellers are typically not competitive on the labor market due to lack of education. Housing and health conditions for them remain poor, and access to services weak.

The most common form of rural adaptation is temporary migration for day labor work by adult men (undertaken by 37 percent of surveyed households, mainly to other rural areas). Storage of food and drinking water before an extreme

FIGURE 6.3 LIVELIHOOD CAPITAL ASSETS IN EIGHT HOTSPOTS





event is also a common coping strategy. Twenty-five percent of surveyed households reported building livestock platforms to guard animals during extreme events. Past adaptation practices also included moving to safe shelters such as high roads or cyclone shelters during floods and cyclones. Gender-specific coping strategies in the face of disaster include women changing from saris to *salwar kameez* when cyclone warnings come, to ease physical mobility.

Livelihood diversification is a common adaptation measure. Households dependent on crop agriculture alone supplement their income through production of handicrafts, fishing, homestead gardening, or sale of livestock products. Poor asset bases of households, however, often limit livelihood diversification options, and result in overcrowding and resource depletion when large numbers of household shift en masse to specific occupations—for example, from agriculture to fisheries—ultimately resulting in push-factor entry into day labor work.

Migration. Without adequate training, people cannot transition to more reliable employment in the service or manufacturing sectors. Those with some skills migrate to cities and hilly areas to work as rickshaw pullers, garment workers, carpenters, construction workers, cooks, and shrimp farm workers. Nonetheless, migration, even in the rural-to-rural unskilled labor form, is not an automatic "release valve" for climate-stressed regions and households. Multiple factors condition household decision making about migration. In Bagerhat, Satkhira, and flood-prone areas, men feared leaving their families alone due to the physical risk from river erosion, which could destroy their houses at any time and leave family members highly vulnerable. In low social capital areas, men also feared leaving female family members alone.

Household decision making, risk, and behavior. The uncertainties of natural hazards and their frequency make people vulnerable by inhibiting forward planning by households who become more risk-averse. In Sirajganj, those living on chars do not take longer-term approaches to adaptation, as the flood-prone nature of the islands makes for a very temporary mindset. In cyclone-prone Bagerhat, people are also reluctant to repair damaged assets because they are afraid another cyclone may damage everything again at any time.

While asset level patterns among households are difficult to improve, there is evidence of significant behavioral changes among individuals seeking to cope with climate variability and extreme events. Women, for example, will change from saris to *salwar kameez* suits to reduce their risk of drowning during cyclones. Some also cut their hair. This suggests disaster preparedness measures can be good investments for pro-poor impact.

Preferred Adaptation Options

Adaptation Preferences. Participants in local and national PSD workshops identified preferred adaptation options in environmental management, water resource management, infrastructure, livelihood diversification, social protection, education, agriculture, fisheries, governance, and gender-responsive disaster risk management. Hard adaptation options were identified with reference to specific areas: for example, building embankments to reduce the exposure of a community to floods or storms. Soft adaptation measures—such as diversifying livelihood opportunities generally—were viewed as necessary across all hotspots and closely aligned with local perceptions of good development practice. Participants in local PSD workshops also emphasized the need to invest in specific social policies to reduce local vulnerability, including empowering women and promoting female education; and ensuring access to social protection.

Participants in local and national PSD workshops identified similar adaptation preferences (e.g., in disaster risk management, fisheries support, agriculture, and governance arenas). However, local workshop participants particularly emphasized the need for social protection, livelihoods diversification and gender-specific support. Overall, preferred adaptation options were identified in:

- Environmental Management (mangrove preservation; afforestation; coastal greenbelts; waste management);
- Water Resource Management (drainage; rainwater harvesting; drinking water provision, and flood control);
- Infrastructure (roads; cyclone shelters);
- Livelihood Diversification;
- Social Protection (especially for fishers during cyclone season);
- Education;
- Agriculture (development of salt-tolerant and high-yield varieties; crop insurance);
- Fisheries (storm-resistant boats; conflict resolution between shrimp and rice farmers);
- Governance (especially access to social services for urban poor) and;
- Disaster Risk Management that is gender-responsive (e.g., for separate rooms for women in cyclone shelters; mini-shelters closer to villages; use of female voices in early warning announcements; and mobile medical teams in Char areas).

Implications for Adaptation Strategy

The poor and the socially most vulnerable are disproportionately affected by climate hazards, as they have the lowest capacity to cope with these losses. The most vulnerable population includes those with few assets, the subsistence farmers, the rural landless, the urban poor, fishing communities, women, children, and the elderly. They do not have sufficient resources to invest in preventive and protective measures such as flood-resilient housing, making them more vulnerable to the full effects of these hazards. Their access to public services, which might buffer them from some of the impacts, is also limited. In addition, their ability to better prepare themselves in the longer term is also often limited by the destruction of their asset base. These effects are further compounded if vulnerable households suffer from multiple extreme-event shocks one after the other, without sufficient time for recovery in between the shocks. To the extent that it increases the frequency of these events, climate change will only exacerbate these impacts.

Adaptation. The adaptive capacity of households is generally low, with poor urban dwellers the most disadvantaged due to the limited opportunities for livelihood diversification and low social capital. The most common forms of autonomous adaptation activities among surveyed households are temporary migration of adult men for day labor, construction of platforms to protect livestock, and storage of food and drinking water prior to extreme events.

The local and national Participatory Scenario Development process largely reaffirms the importance of the adaptation actions planned under the six themes of the BCCSAP 2009. The preferred adaptation options identified in the workshops include continued national investment in flood management schemes, flood protection and drainage, coastal embankments, cyclone shelters (though specifying the need for smaller shelters located at shorter distances from villages), comprehensive disaster management, agricultural research for drought and saline-resistant crop varieties, and coastal and urban greenbelts. Preferences from the PSD process, however, deemphasize activities under the research and knowledge management theme and instead emphasize softer approaches (e.g. governance), include more general options (e.g. education), and are more directly targeted toward community-level outcomes (e.g. use of mobile medical teams).

In addition, local and national stakeholders identified education and governance as two additional areas that were not included in the BCCSAP but that could strengthen the adaptive capacity of rural and urban households and communities. These cross-cutting issues also have instrumental outcomes (e.g., of improved employment outcomes for those whose livelihoods had been harmed by climate change such as farmers or fishers in the case of education, and improved delivery of urban services in the case of governance). Increased attention to these areas of local governance and education would increase resilience and decrease vulnerability of poor persons and women to climate hazards.

This component of the study also highlights the importance of complementing hard adaptation measures with soft measures such as improving disaster preparedness by establishing communication in local dialects, constructing redesigned cyclone shelters to appeal to those most in need and upgrading the resilience of roads in the hazard-prone areas. Enabling policies and institutions are essential for putting in these actions in place.

SEVEN

Limitations of the Study

One of the strengths of this study is its use of mathematical tools, which impose intellectual discipline. Examples of this discipline are the use of a well-defined baseline and the requirement under CGE models that the national income accounting identities balance at the end of each year. This mathematical approach is indicated when the objective of the exercise includes quantitative and monetary impact evaluation of costs and benefits. Apart from providing estimates of both, the models indicate the relative importance of some factors compared to others, and also the effects of changing certain variables on others. This is important for concretely supporting the decision-making process. By making a choice for quantitative rigor, however, all the well-known limitations of using econometric and other mathematical models apply.

A key limitation in the context of the EACC is that the models used channel researchers to ask and answer questions that can be answered by the models, when the most important questions may be institutional or cultural, or more likely a combination of these plus political factors: for example, how to influence the location of people away from high-risk or increasingly unproductive areas, how to improve the allocation of water and land, how to improve the quality of education. In this sense, economics is clearly not sufficient, although the study by definition was primarily interested in understanding the *economics* of adaptation, and not all aspects of adaptation to climate change.

Within the limitations imposed by the modeling frameworks, important limitations of this study derive from three sources of uncertainty: climate, economic growth, and technology.

Climate uncertainty. There is no consensus on the extent of severity of future extreme events such as cyclones or the rise in the sea level. As a consequence, information for helping decision makers to invest in assets with long useful lives of 20, 30, or even 40 years—such as dams, dykes, urban drainage, bridges, and other infrastructure is also limited. Adaptation costs are estimated as if decision makers know with certainty what the future climate will be. In fact the problem decision makers face is how to maximize the flexibility of investment programs to take advantage of new climate knowledge as it becomes available. A major finding of the study is that the potential damages from climate change are a fraction of the damages that Bangladesh already faces due to existing climate variability. However, these results are conditioned on the specific scenarios chosen, the worst climate scenarios for extreme weather events. However, these scenarios define what the climate scientists have explored so far.

To make calculations tractable, the study limits both the breadth of economic analysis and the length of the time horizon: the study investigates public sector adaptation only, and the investment horizon of the study is to 2050 only. Although climate science tells us that adaptation costs and damages will increase over time, and that major effects such as melting of ice sheets are more likely to occur well beyond this horizon, uncertainty with regard to both climate and economic growth make efforts to analyze adaptation beyond this period unproductive.

Growth uncertainty. The second major uncertainty concerns economic growth. Rapid economic growth exposes more assets to risk, but also enables the country to absorb and defend against climate-induced changes in productivity and adverse climate events. As is evident from events in the past decade, predicting economic growth is a fragile science. A key contribution of this study is to separate the costs of adaptation from those of development by defining a development baseline. The study assumes just one future development path, based on growth in population, GDP per capita, and urbanization, which drive the demand for food, investment in infrastructure, benefits of protecting coastal zones, and so on. How would the costs of adaptation change with a different trajectory? The global track analysis indicates that alternative assumptions about population and economic growth have only a slight impact on estimates of

the cost of adaptation in 2010–19, so the margins of error associated with the development baseline are not very important in the immediate future, although they may grow over time.

Technological uncertainty. Finally, technological change over the next 50 years will affect adaptation in currently unknowable ways. Most parts of the study do not allow for the unknowable effects of innovation and technical change on adaptation costs. In effect, these costs are based on what is known today rather than what might be possible in 20–40 years. Sustained growth in per capita GDP for the world economy rests on technical change, which is likely to reduce the real costs of adaptation over time. This treatment of technological change also contributes to an upward bias in the calculated costs.

EIGHT

Summary of Findings

Given the pervasive impacts of climate-related risks, both public sector investments and private actions have made Bangladesh more resilient over time. Bangladesh already has an extensive set of adaptation measures—such as early warning systems, embankments, and shelters—in place to protect against climate risks such as tropical cyclones/storm surges and flooding. The climate resilience of Bangladesh also derives from the ways households and business and society have adapted to climate risks. These include, for instance, the adoption of countercyclical cropping patterns immediately following severe floods, and the shift toward cyclone-resistant housing with rising incomes and migration of population and economic activity away from higher risk coastal areas.

Despite these investments and actions, damages from recent extreme events have made clear that substantial risks remain. A detailed assessment of the adequacy of costal protective measures indicates a significant deficiency in addressing existing risks from cyclone-induced storm surges. Climate change is expected to nearly double these risks. Further, the aggregate additional costs of the proposed adaptation measures needed to mitigate climate change risk from extreme events are generally smaller than the expected damages. While the damages from extreme events rise over time in absolute terms, in line with increases in the value of exposed assets, they decline in relation to the size of the economy as higher incomes make adaptation actions more affordable to future populations. The cost of adaption actions in response to the additional risk from climate change are generally less than the additional cost of adapting to existing risks, which remains substantial.

Further, the impacts of existing climate variability are concentrated in areas that also have higher concentrations of poor and socially vulnerable populations. Climate change is not expected to shift these distributions, but just to exacerbate them. The rural poor in the Southern region in particular are expected to face the largest declines in per capita consumption. In addition to the direct damage to lives and property from storm surges and cyclones, they are also impacted by declining productivity in the *aus* and *aman* rice crops; severe yield losses in the *boro* crop from changes in mean rainfall; temperature and mean shifts in the flood hydrographs, which have historically been used as a countercyclical measure against severe floods; and land losses due to increased salinity brought forth by sea level rise.

Increased investments in adaptation to reduce the impacts of climatic hazards are important to ensure continued growth. The concentration of climate impacts in areas with concentrations of the poor also means that these investments are essential for poverty alleviation. Rural households will continue to depend on the agriculture sector for income and livelihoods. Though the government has made substantial investments to increase the resilience of the poor—such as new high-yielding crop varieties, protective infrastructure, and disaster management—the scale of the current efforts remains limited and will need to be scaled up commensurate with the probable impacts from climate change.

In a fiscally constrained environment, with competing priorities, efforts to address climate related risks can easily be seaside. While the adoption of the Bangladesh Climate Change Strategy and Action Plan in 2009 recognizes the importance of addressing climate change, the commitment of public resources provides a focal point for starting these actions. However, the available resources are much smaller than the current needs even for the limited set areas analyzed and measures costed in this study. As a result, it may be necessary to sequence adaptation actions based on the degree of certainty and timing of the benefits or costs of actions. The analyses in this study can provide some guidance for developing an adaptation agenda for Bangladesh.

AN ADAPTATION AGENDA FOR BANGLADESH

Sound development policies provide the foundation for any action agenda on adaptation to climate change. This study presupposes specific future development baselines for Bangladesh based on a continuation of existing trends and patterns, which conditions both the size and types of potential impacts and the necessity and effectiveness of specific adaptation actions. It elaborates on the potential impacts and the specific actions in the BCCSAP, providing bottom-up cost estimates of undertaking these actions, and the potential losses if they are not undertaken. Large existing climate variability and significant uncertainties about the magnitude and timing of future impacts makes it prudent to appropriately sequence adaptation actions to provide essential protection without overinvesting in areas where the risks do not materialize. These investments have to also be accompanied by institutional mechanisms that address any perverse incentives that it may create in attracting population and activities toward areas of higher risk. Stronger institutional capacity is also essential to reduce uncertainties through improvements in the knowledge base, and in turn to adjust the selection and sequencing of adaptation actions in response to changes in knowledge. Strengthened regional cooperation on managing shared water resources in the GBM basin also has significant implications for adaptation actions within the country.

(1) Sequencing of adaption actions: a necessity in the face of uncertainties

The fundamental problem of policy making in the face of climate change is one of uncertainty with regard to climate outcomes. Shifting resources toward more productive uses and away from less productive ones in the context of uncertainty is already a principal aim of development for a fiscally constrained government. Climate change increases the importance of achieving this aim, but it makes the task more complex. This uncertainty has important effects in any assessment of the impact of climate change and on the selection and ranking of adaptation actions. Early investments to improve the information base and to reduce the existing uncertainties are also important to guide the evolution of adaptation actions over time. A prudent strategy would phase in additional actions based on the cost of inaction and the certainty of impacts across a wide range of climate outcomes. Table 1 illustrates the sequencing of immediate, short-term, and medium- to long-term investments envisioned in the BCCSAP that is consistent with these principles, focusing on reducing uncertainty in the near term and improving on protective

infrastructure for coastal polders near the medium. The risk analysis from this study provides additional spatially differentiated information to further refine the sequencing of the adaptation actions.

(2) Addressing current climate-related risks: a no-regrets strategy

Public investments in disaster risk reduction measures over the past 50 years have reduced the damages resulting from them, yet recent experiences indicate that climate-related disasters continue to have significant damages. Climate change is only expected to increase the risks and the associated damages in the future. A no-regrets strategy would address these current climate risks. One clear example concerns the impact of cyclones and the storm surges they induce in coastal areas. Despite the uncertainty over future rainfall, there is relative certainty that a warmer climate will lead to rising sea levels and increased intensity of storms. So steps taken to address current risks will eventually also protect populations and activities against future risks. The aggregate costs of strengthening existing polders against historical risks are of the same order of magnitude as the aggregate damages of a single severe cyclone. The detailed polder-specific risk assessment and cost estimate provided in the study should be combined with the assets and populations that they would protect to prioritize immediate actions to strengthen polders. The effectiveness of these efforts can be increased by complementing them with efforts to strengthen institutions for managing development in the vulnerable zones. Similarly, the efforts to shore up river embankments, elevate roads, or add culverts to accommodate drainage requirements for severe floods that exist today would not only provide immediate benefits but also protect against increased future flood risks.

(3) Research and Knowledge Building: key to improved targeting of future actions

While the direction of future climate risks in Bangladesh seems clear, its magnitude and timing is less certain. Given the high cost of infrastructure investments, and the expected gradual increase in climate risk over decades, a prudent strategy would be to focus on improving the spatial precision of current climate-related risks forecasting and associated early warning systems, which would enable better targeting of adaptation actions. These actions not only provide immediate benefits, but also improve the capacity to address climate risks in the future. This needs to be supplemented with additional research activities to reduce the large uncertainties about future climate risks. These efforts can provide guidance for the extent of adaptation and the prioritization of investments.

(4) Sound development policies: the foundation for any adaptation agenda

Development generates both the resources and opportunities to adapt to climate change at a relatively low cost. The Bangladesh economy has been growing at over 6 percent during the past decade and is expected to continue to grow at a comparable pace over the coming decades. Expected structural changes in the economy—away from climate-sensitive sectors such as agriculture toward industry and services—reduce exposure to climate risks, while urbanization provides new opportunities for managing them better. Investments to expand the road system and increase the share of paved roads yield high returns by lowering transport costs and expanding markets. At the same time, they lessen the impact of floods and enhance the ability of farmers to respond to changes in agricultural comparative advantage. Ensuring that the design and location of new infrastructure, buildings, and other assets consider the effects of climate change can extend their useful lives. Similarly, better management of water resources and an expansion of irrigation should increase agricultural yields and permit the adoption of new agricultural technologies, as well as enabling farmers to cope with greater variability of rainfall.

Eliminating poverty is central to both development and adaptation, since poverty exacerbates vulnerability to weather variability as well as climate change. Higher incomes enable households to autonomously adapt and better cope with climate-related disasters, by for instance, making climate-resilient housing more affordable. Rapid development leads to a more flexible and resilient society, so building human and social capital—including education, social protection and health, and skills training—are crucial to adaptation. In addition, the government has made substantial investments to increase the resilience of the poor through, for instance, the introduction of new high-yielding crop varieties, construction of protective infrastructure, and improvements in disaster management. However, risk reductions achieved through protective infrastructure improvements increase ground rents and often result in crowding out the poor. Inevitably, this adverse location selection will increase the concentration of the poor in unprotected areas, as can be seen in from the coincidence of poverty and disaster risk maps. Adaptation that directly assists the poor, such as early warning and evacuation services, basic education (particularly for women), and subsidized insurance to compensate for inevitable losses, will be essential for improved targeting of adaptation actions.

5) Adjustment of design standards for infrastructure: essential for future resilience

Infrastructure investments are long-lived and expensive and yield large benefits when designed appropriately. It is essential to develop appropriate standards commensurate with the likely climate risks over the expected lives of the assets and to update them over time based on new research results that become available. For example, the prospect of more intense precipitation has implications for unpaved roads, especially in rural areas, which are vulnerable to being washed away by floods and heavy rainfall. Single-lane sealed roads have a higher capital cost but they provide a more reliable all-weather network with lower maintenance costs. As research makes the risk of flooding in a location more apparent, the design standards for roads in these areas need to be increased accordingly. Similarly, polders need to be strengthened beyond their current protective capacity as the added risk from storm surges becomes more certain. Additional research may also be necessary in the medium to long term for the development of new varieties of crops and cropping patterns in accordance with the changing climatic conditions particularly in the southern coastal regions.

(6) Reducing perverse incentives: a necessity to increase effectiveness of infrastructure investments

As a general rule, investments—such as flood embankments or polders—designed to protect vulnerable assets should be subjected to careful consideration. Construction of a dyke is followed, almost by definition, by accumulation of physical capital in the shadow of the dyke because it is considered "safe." However, as the tragedy of New Orleans dramatically illustrated, a sufficiently extreme event will breach a polder. The combination of an increasing severity of extreme events, the high costs of providing physical protection, and the accumulation of capital behind such barriers can mean that the expected value of losses, including human suffering, may not be reduced—either at all, or by as much as expected by investments in protection.

Similar concerns apply to efforts to maintain the welfare of populations in areas where climate change alters the comparative advantage of agriculture and other resource-intensive activities. Short-term measures to prevent suffering must be complemented by long-term measures such as education, job training, and migration designed to reduce reliance on resources and assets whose value may be eroded by climate change. Adaptation should not attempt to resist the impact of climate change, but rather it should offer a path by which accommodation to its effects is less disruptive and does not fall disproportionately on the poor and the vulnerable.

The long-term challenge is to move people and economic activity into less climate-sensitive areas and to seek a strategic balance between protecting existing populations and encouraging the mobility of future populations. In 2050, the number of people living in cities will triple, while the rural population will fall by 30 percent. Current policies will determine where this urban population settles and how prepared it is to adapt to a changed climate. Many households have moved further inland, partly due to higher perceived risk, but strengthened embankments may change these perceptions, leading to increased exposure. Good policy needs to encourage future populations to move away from high natural risk areas, avoiding perverse incentives to remain in high-risk areas and adopting positive incentives to promote settlements and urban growth in low-risk areas. Strengthened education in rural areas is critical for rural migrants to be prepared for productive lives in new urban areas.

(7) Soft adaption approaches: a complement to hard investments

The distinction between "hard" (capital-intensive) and "soft" (institutions and policies) adaptation is easily exaggerated. The reality is that both approaches are necessary and complement each other as illustrated above, in terms of potential perverse incentives of investments in coastal embankments. This study has focused largely on the costs of hard measures. The challenge is thus to get the balance between hard and soft adaptation right. It is much simpler to estimate the costs of upgrading embankments or adding new culverts to protect against the effects of climate change than it is to estimate the costs of creating new institutions and implementing better policies. Evaluation of these "hard" adaptation investments, however, has been done within a framework of appropriate development policies and efficient institutional arrangements. Good policies, planning, and institutions are essential to ensure that more capital-intensive measures are used in the right circumstances and yield the expected benefits. In many cases, the latter costs are zero or negative in the longer run, because these changes provide benefits beyond adaptation to climate change and contribute to overall well-being. But they are much harder to quantify. In others, the absence of appropriate complementary institutional arrangements can actually worsen the impacts that the hard investment is designed to address. The importance of keeping infrastructure and urban development out of harm's way is a key illustration of the costs of creating perverse incentives that encourage behavior and investments that worsen rather than reduce the prospective impacts of climate change. Equally, however, experience shows that the difficulties of devising and implementing soft measures are often underestimated because these may involve changes in expectations or established (quasi-) property rights that are strongly resisted.

An important component of soft adaptation is the focus on governance and local stakeholder participation. The effectiveness of hard investments depends on the access to them and their uptake by targeted populations. Reaching women requires gender-sensitive designs of interventions such as the provision of separate facilities for women in cyclone shelters. Pro-poor adaptation investments include social protection, livelihoods diversification, and investments in human and social capital (including training, education and community-based disaster risk management) in order to strengthen local resilience to climate change.

(8) Development of climate-resilient cultivars and cropping: an option for long-term food security

Additional research will also be necessary for the development of climate-resilient cultivars and cropping patterns that are more suited to the future climatic conditions, particularly in the southern coastal regions, which are expected to be affected the most by climate change. Bangladesh already has an active network of agricultural research institutes that develop and test new crop varieties to increase national production and resilience against climate risks. The magnitude of the additional effort and the direction it takes will depend on the specific future climate that materializes.

(9) Strengthened regional cooperation: an essential option in the long term

Climate change may greatly increase the need for regional cooperation. Cooperation on the sharing of water resources with neighboring countries in the GBM basin is not a new issue for Bangladesh, but it is one whose importance may be greatly increased by climate change. As the stakes rise, effective steps taken now to promote and strengthen the cooperative management of the shared resources can not only provide immediate benefits to all parties but can also prevent the need for expensive and possibly disruptive solutions in the future.

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