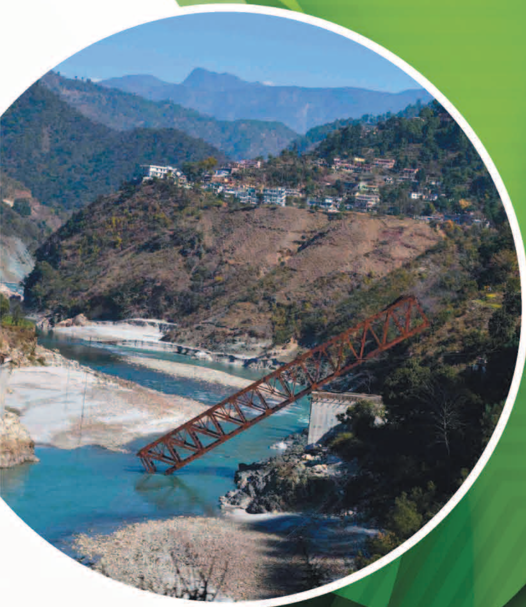
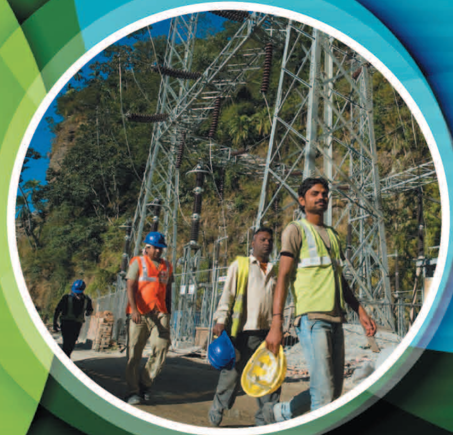


Assessing the Costs of Climate Change and Adaptation in South Asia

Assessing the Costs of Climate Change and Adaptation in South Asia

Mahfuz Ahmed
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from the British people

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Foreword

Climate change poses a formidable threat to the sustainable development of Asian Development Bank (ADB) developing member countries (DMCs) in the Asia-Pacific. South Asia DMCs are particularly vulnerable to climate change due to high population density, poverty, and lack of resources for adaptation. The region exhibits a broad range of extremes: in topography, from the tallest mountains to the largest deltas to atolls barely above level; in precipitation, from arid lands to vast plains subject to unpredictable flooding; and in the environment, from glacial to tropical. Climate change projections for South Asia by the Intergovernmental Panel on Climate Change indicate that warming is likely to be above the global average, that monsoon rainfall is likely to increase, and that an increase in the frequency of intense precipitation events is likely. Climate change impacts in the South Asia DMCs are therefore numerous and multifaceted. DMCs face a huge challenge to deal with climate change impacts and avoid greater social, economic, and environmental damages.

In line with its *Midterm Review of Strategy 2020: Meeting the Challenges of a Transforming Asia and the Pacific*, ADB is committed to assist DMCs to reduce impacts of climate change. ADB is actively supporting low-carbon and climate-resilient strategies in Asia. It has taken a leadership role in helping the region with cost-effective solutions to mitigate the causes, and adapt to the consequences, of climate change. Further, ADB is undertaking climate and disaster risk screening of projects, assisting in the integration of climate change in national development, and strengthening capacities in adaptation planning and implementation.

This book discusses the economic costs and benefits of unilateral and regional actions on climate change adaptation in ADB's six South Asia DMCs, namely Bangladesh, Bhutan, India, the Maldives, Nepal, and Sri Lanka. It provides an estimate of the total economic loss throughout the 21st century to the South Asia DMCs. The study takes into account the different scenarios and impacts projected across vulnerable sectors and estimates the magnitude of funding required for adaptation measures to avert such potential losses. It centers around the economic aspects of climate change impacts, envisioned to strengthen decision-making capacities, and improve understanding of the economics of climate change for the countries in South Asia. The study was coordinated with other ongoing and planned climate change initiatives in the region and builds on existing studies. It is hoped that with improved knowledge and information on climate change, policy makers in the region will be able to undertake the necessary measures and select concrete and appropriate economic policies.

This report has shown that even under optimistic climate change scenarios, huge impacts are likely on vulnerable sectors across South Asia, resulting in significant losses in gross domestic product (GDP) and, hence, in economic growth and poverty reduction. The study illustrates that South Asia on average could lose nearly 2% of its GDP by 2050, rising to a loss of nearly 9% by 2100 under business-as-usual (BAU) scenario—higher still if losses due to extreme weather events are added. It further reveals that a significant part of the losses could be avoided if an agreement along the Copenhagen–Cancun proposal could be implemented sooner than later. The likely acceleration of climate change impacts over time means that costs of adapting to and mitigating these impacts will increase at a greater rate if enhanced actions to address the impacts do not begin now.

The study shows that while adaptation need and investment requirement will depend on global mitigation efforts, an early investment in adaptation can help mitigate large damages to economies in later decades. The authors recommend actions that should begin by identifying the risks and vulnerabilities at the project or sector level, followed by determining feasible options for adaptation (and mitigation) measures that are economically sound. Climate change response policies (both adaptation and mitigation) are only effective when they are fully integrated within an overall sustainable development strategy and policy.

South Asia DMCs need to undertake a number of actions in responding to climate change: (i) sustaining economic growth and achieving Millennium Development Goals while also transitioning to low-carbon development; (ii) managing environmental, social, and economic shocks of climate change; (iii) establishing a systematic and efficient pursuit of climate knowledge and technology for development; and (iv) identifying sector-specific as well as nationally, subnationally, and regionally appropriate adaptation and mitigation responses.

We are grateful to the Government of United Kingdom for financing the regional technical assistance. We recognize the support and cooperation of the concerned governments in the conduct of this study. We also acknowledge the experts, specialists, and scientists who provided the technical inputs and advice for the study. We hope that the information and knowledge gained through this study will help South Asia DMCs in their quest for ways to adapt to the impacts of climate change.

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A steering committee comprising a focal ministry from each of the six countries provided guidance during the implementation of the in-country activities. These include the Ministry of Environment and Forests (Bangladesh), National Environment Commission (Bhutan), Ministry of Environment and Forests (India), Ministry of Environment and Energy (the Maldives), Ministry of Environment, Science and Technology (Nepal), and Ministry of Environment (Sri Lanka).

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Abbreviations

ADB	Asian Development Bank
AR4	IPCC Fourth Assessment Report
AR5	IPCC Fifth Assessment Report
BAU	business as usual
BGDDyn	Bangladesh dynamic computable general equilibrium model
C–C	Copenhagen–Cancun
CGE	computable general equilibrium
CMIP3	Coupled Model Inter-comparison Project Phase 3
CPI	consumer price index
DMC	developing member country
DSSAT	Decision Support System for Agrotechnology Transfer
ECHAM	European Centre/Hamburg Model, Germany
GCM	general circulation model
GDP	gross domestic product
GIS	geographic information system
GLOF	glacial lake outburst flood
IPCC	Intergovernmental Panel on Climate Change
MW	megawatt
NPP	net primary production
PAGE09	Policy Analysis of Greenhouse Effect version 9
RCM	regional climate model
RECCSA	Regional Economics of Climate Change for South Asia
SRES	Special Report on Emission Scenarios

Executive Summary

South Asia, home to about 1.5 billion people, nearly a third of whom are still living in poverty, faces a major challenge in achieving rapid economic growth to reduce poverty and attaining other Millennium Development Goals in an era of accentuated risks posed by global climate change. The impacts of climate change are likely to result in huge economic, social, and environmental damage to South Asian countries, compromising their growth potential and poverty reduction efforts.

Countries in the greater Himalayas region—which includes Bangladesh, Bhutan, northern India, and Nepal—are facing increased frequency and magnitude of extreme weather events resulting in flooding, landslides, damage to property and infrastructure, devastation of agricultural crops, reduction of hydropower generation, and negative impact on human health. The coastal areas of Bangladesh, India, the Maldives, and Sri Lanka are at high risk from projected sea level rise that may cause displacement of human settlements, saltwater intrusion, loss of agricultural land and wetlands, and a negative impact on tourism and fisheries.

This Asian Development Bank (ADB) study examined the economic costs associated with the impacts of climate change and the cost and benefits of adaptation in Bangladesh, Bhutan, India, the Maldives, Nepal, and Sri Lanka. The study aimed to (i) assess the biophysical impacts of climate change in the region, including individual country impacts, and (ii) estimate the total economic loss to the countries in the region by 2100, taking into account the different scenarios and impacts projected across vulnerable sectors, and then to estimate the magnitude of funding for adaptation measures required to avert such potential losses. Results of the study will aid development of future policies and programs for climate change adaptation in the region, including initiatives for regional cooperation and capacity building in climate change management. The study covered the following sectors: agriculture, terrestrial ecosystems, water, marine and coastal resources (except Bhutan and Nepal), health, and energy. The study was coordinated with other ongoing and planned climate change initiatives in the region and builds on existing studies. However, no previous study of the whole region exists.

Methodology

The study approach involves (i) scoping and review of existing knowledge and initiatives in South Asia, (ii) consultation with stakeholders, and (iii) quantitative modeling of climate change, its impact and adaptation, and the economic implications.

The analysis is based on a three-step modeling approach: (i) regional climate modeling (ii) physical impact assessment, and (iii) economic assessment (using the integrated assessment model and the computable general equilibrium model). The modeling was conducted under different emission scenarios consistent with those developed by the Intergovernmental Panel on Climate Change (IPCC) *Fourth Assessment Report* (2007) as well as policy scenarios consistent with recent development of climate change negotiations under the United Nations Framework Convention on Climate Change process. The estimates used in this study were based on how future scenarios will unfold, and how societies value the future and future generations, among other things.

Regional Climate Projections

A regional climate model was used over the South Asia domain at a 30-kilometer (km) grid resolution. The A2, A1B, and B1 scenarios from the 2001 Special Report on Emission Scenarios (SRES) of the IPCC, representing high, medium, and low emission futures, respectively, were adopted, with three time periods—2030s, 2050s, and 2080s.

Model simulations under different scenarios indicate a significant past warming trend of about 0.75°C per century in annual mean temperatures over the region. Future temperature projections indicate a steady increase in temperatures across the three periods, with anomalies reaching 4°C–5°C for the high-emission scenarios by the 2080s. Warming is widespread throughout the region by end of the 21st century.

Spatial patterns of rainfall change indicate future increases over eastern and northeastern areas. Even though precipitation is projected to increase, it is not very consistent across time periods. The increase in precipitation becomes distinct only toward 2080.

Changes in oceanic heat storage and distribution of ocean salinity cause the ocean to expand or contract, resulting in changes in the sea level both regionally and globally. Global mean sea level change results from two major processes that alter the volume of water in the global ocean: (i) thermal expansion and (ii) water flow from other sources, such as melting of glaciers, ice caps, and ice sheets, and other land water reservoirs. All these processes cause geographically uneven sea level change.

Impacts on Vulnerable Sectors

Agriculture. Agriculture in South Asia has progressed in recent years, allowing a large number of people to be fed from relatively small areas. However, South Asian agriculture is extremely vulnerable to climate change. Higher temperatures eventually reduce yields of desirable crops while encouraging weed and pest proliferation. Changes in precipitation pattern (timing and amount) increase the likelihood of short-run crop failures and long-run production declines, posing a serious threat to food security. Although there will be gain in some crops in some regions, the overall impacts of climate change on agriculture are expected to be negative and need to be much better understood.

Increases in both temperature and carbon dioxide (CO_2) level are projected to cause an increase in rice production in the colder hills and mountains of Nepal by as much as 16% by 2080. Rice yield in Bhutan and India is projected to increase to 2030 but by 2050, rice yield will begin to decline. Tropical and subtropical regions of Bangladesh, Bhutan, India, and Sri Lanka are projected to be vulnerable to increasing temperature and CO_2 level, with a decline in rice yield of as much as 23% by 2080.

Coastal and Marine Areas. The changes in climatic events that have been observed to have significant impacts on coastal and marine resources in South Asia region include the rise in air and ocean temperature, sea level rise, and an increase in precipitation, as well as the intensified extreme weather events (e.g., heat waves, intense rainfalls, droughts, and tropical cyclones). The impacts on marine and coastal areas have been observed in the alteration of ocean circulation, coral reef ecosystems, ocean and estuarine salinity, fisheries, and recreation and tourism activities. The effects also include dryland and wetland losses, which impose both physical and economic risks on coastal communities. In particular, alterations of ocean circulation patterns affect mangrove tree distribution and the genetic structure of mangrove populations, whereby the changes may affect the mangrove community and its biodiversity by altering the gene flow of the mangrove populations. The impact on the community structure of the mangrove population may have further impact on biodiversity, with economic implications in view of the importance of mangrove forests to commercial fisheries in certain coastal areas.

Climate-driven sea level rise has also exacerbated the occurrences and severity of tropical cyclones, extratropical storms, and tsunamis, which have resulted in increased flood events, gradually inundating and eroding tidal wetlands, sand dunes, river deltas, and other low-lying land forms.

Energy. Climate change alters the dynamics of energy security in the region in terms of both power supply and demand, while increasing the vulnerability of the poor by depriving them of the benefits of both energy and economic development. A rise in average warming will increase energy requirements for space cooling (but reduce energy needed for warming), while increasing energy demand for irrigation. On the supply side, there is a direct influence on hydropower and thermal power generation through availability of water and the temperature of cooling water, respectively. Increases in intensity and frequency of extreme events like storms and sea level rise may cause more electrical system failures. However, climate change effects on energy supply and demand will depend not only on climatic variables, but also on other factors like patterns of economic growth, land use, demography, technological change, and social and cultural trends in each country.

Forest and Other Ecosystems. Climate change will affect forest carbon pools in some countries of the region. Under most greenhouse gas emission scenarios, there would be gains for Bhutan and India, but little alteration in Bangladesh and Nepal. Net primary production in Bhutan and Nepal is expected to increase considerably under all scenarios due to warmer temperatures. India would gain to a small extent, while Bangladesh and Sri Lanka should remain largely unchanged in this respect.

Health. The cities of South Asian countries are vulnerable to water- and vector-borne infectious diseases that are climate sensitive. Diseases like cholera, dengue, diarrhea, and malaria are generally sensitive to climate change. Effects of global warming can develop suddenly, producing "climate shocks" that likely will have grave consequences for human health.

Climate and anomalous weather events are expected to cause a general increase in the number of cases of both vector- and water-borne diseases. The modeling results suggest that the mortality rate for the region caused by dengue, malaria, and diarrhea would increase over time as a consequence of climate change. Morbidity and deaths from such diseases could increase in the future under all scenarios.

Water. Although the monsoon-dominated annual precipitation cycle is expected to remain unchanged over South Asia, future decades are predicted to have drier and warmer winter months with reduced snow cover, while the summer/monsoon months are predicted to become wetter and warmer. The wetter monsoon months will coincide with accelerated glacial melting, causing river flows to increase even more, particularly during the rainy season. The seasonal pattern of flows over the year could become more erratic, and an increased volume of sediments will be carried by these rivers. This will have serious consequences on the large rivers of South Asia. Due to rising temperatures, a greater proportion of the precipitation will fall as rain. Snowmelt will start earlier and the winter season will be shorter. Reduced water availability will have serious impacts on agriculture and hydropower generation. Initially, it is projected that the river flows derived from glaciers will increase during the dry season as ice melting accelerates; this can give wrong signals to policy makers and delay climate change adaptation measures. In time, as the remaining glaciers disappear, dry season flows will be dramatically reduced. River flows will become more erratic as rainfall is immediately converted to runoff instead of being stored as ice.

Economic Damage and Losses

Economic findings using integrated assessment model suggest that the total climate change cost in South Asia will increase over time and will be prohibitively high in the long term. Without global deviation from a fossil-fuel-intensive path, South Asia could lose an equivalent 1.8% of its annual gross domestic product (GDP) by 2050, which will progressively increase to 8.8% by 2100 on the average under the business-as-usual (BAU) scenario. The model suggests that the Maldives will be hardest hit in GDP loss, while Bangladesh, Bhutan, India, Nepal, and Sri Lanka are projected to face 2.0%, 1.4%, 1.8%, 2.2%, and 1.2%, respectively, loss of annual GDP by 2050.

However, should the global community take actions along the Copenhagen–Cancun agreements to keep the global mean temperature rise below or within 2°C, the region would only lose an average of 1.3% of GDP by 2050 and roughly 2.5% by 2100. The difference between the results from the two scenarios indicates the benefits from a global shift toward the Copenhagen–Cancun (C–C) scenario.

The computable general equilibrium model illustrates country and regional implications of climate change and its future impact on other relevant macroeconomic, sectoral, and household parameters. The impacts are quite heterogeneous across countries, with lower-income countries being more adversely affected by agrifood-related constraints (crops, water, and land), because these countries have higher shares of GDP in agriculture and much higher expenditure shares on agrifood products. When price impacts are taken into account (higher for agrifood products especially), real consumption is more significantly affected across the region. In general, analyses suggest that costs of climate threats to 2050 are moderate, implying less than 10% lower real GDP for the economies considered. However, impacts on food security generally, and on the poor in particular, could be much more severe.

For Bangladesh, the mean economic cost of climate change by 2100 would be about 2% of GDP under C–C conditions but more than 9% of GDP under the BAU scenario. To increase GDP growth rate by 1%, according to the current incremental capital–output ratio of Bangladesh, the country would need to increase the investment–GDP ratio by 4%. To compensate for the reduction in real GDP, the investment-GDP ratio would have to rise an additional 0.03% in 2030, 0.075% in 2050, 0.17% in 2080, and 0.23% in 2100.

To avoid the damage and economic losses from climate change under the BAU scenario, the region needs to provide an average adaptation expenditure of 0.48% of GDP per annum ($40 billion) by 2050 and 0.86% of GDP per annum ($73 billion) by 2100. Obviously, regional adaptation costs under the C–C scenario are much lower than the BAU scenario as it only requires an average of 0.36% of GDP per annum ($31 billion) by 2050 and 0.48% of GDP per annum ($41 billion) by 2100. The study took into account investment in building adaptive capacity in anticipation of future climate change as well as climate proofing measures in key sectors toward climate-resilient development.

Adaptation Options, Policies, and Strategies

It is evident that adaptation needs depend on global mitigation progress. It will be more challenging and costly to adapt to climate impacts under the BAU scenario than to adapt to lower-emission scenarios. The region's adaptation response need not be confined to symptomatic treatment of threats to traditional patterns of economic activity. More efficient regional economic diversification can create entirely new patterns and supporting infrastructure to take their place. In other words, policy makers need to take early action to adapt to climate risks, and this action needs to be informed by rigorous and timely evidence.

The South Asia developing member countries have by now developed their adaptation strategy. In some countries, such as India, state and subnational action plans have also been developed, allowing for integrating climate change adaption options in local project and facilities development. Building resilience to the impacts of climate change requires identifying the risks and vulnerabilities of sector and area development projects and programs, followed by developing the options for adaptation and mitigation measures that are socially, environmentally, and economically sound.

Climate change response policies (both adaptation and mitigation) are most effective when they are fully integrated within an overall national development strategy. Most importantly, adequate funding and technology transfer are important in ensuring success of any climate action and initiative.

Finally, climate change adaptation is a huge risk management challenge involving many uncertainties. A flexible learning approach to crafting policies for climate adaptation is a good approach when dealing with uncertainty, starting with measures that will not be regretted.

PART I
Situation Analysis and Methodology

1 Introduction

South Asia stretches from the northern Himalayan peaks of Bhutan and Nepal to the Hindu Kush in the west and the vast delta of Bangladesh in the east, the Indian peninsula, and the islands of Sri Lanka and the Maldives in the Indian Ocean. The region faces the Bay of Bengal, the Indian Ocean, and the Arabian Sea.

South Asia's economy has been accelerating since the early 1990s. Powered by the dynamic growth of the Indian economy, it is one of the fastest-growing areas in the world today. Economic growth has contributed to significant reduction in poverty in the region, and the potential for sustained growth is high.

In recent years, the economic performance of South Asian countries has been impressive. After the 2007 global financial crisis, these economies recovered quickly, reaching an average growth rate of 7.8% in 2010. Country-specific growth rates, however, varied greatly, with India growing at 8.6% and Nepal at 4.0%. The region is projected to achieve average growth rates of 7.5% in 2011 and 8.1% in 2012 (ADB 2011).

Notwithstanding the high rates of economic growth and the steady progress in poverty reduction, nearly half of the world's poor are in the region. Climate change impacts are emerging as significant risks to sustained growth.

South Asia is home to varied and extensive geographical features, such as glaciers, rainforests, valleys and deltas, deserts, and grasslands. The climate varies considerably from tropical monsoon in the south to temperate and alpine in the north, according to a combination of altitude, proximity to the coast, and the seasonal impact of the monsoons.

Climate Change

Climate change projections made by the Intergovernmental Panel on Climate Change (IPCC) *Fourth Assessment Report* (AR4) (IPCC 2007) for South Asia as a whole show that warming is likely to be above the global mean. Rainfall in the summer season is likely to increase and it is very likely that there will be an increase in the frequency of intense precipitation events in parts of South Asia. Extreme rainfall and winds associated with tropical cyclones are also likely to increase, according to the assessment.

Climate change is projected to affect the main systems that shape the region's climate, including the strength and timing of the Asian monsoon. The retreating Himalayan glaciers are believed to be speeding up climate warming in the region due to the alteration of the overall albedo and surface energy balance.

Due to rising temperatures in the Himalayas, a greater proportion of the precipitation now falls as rain. Snowmelt starts earlier and the winter season is shorter. Such changes will have significant effects on river flows, water-related natural hazards, local water supplies, infrastructure (especially hydropower), agriculture, and natural ecosystems. The most serious impacts are related to increased frequency and magnitude of extreme weather events—on the one hand, intense rainfall leading to flash floods, landslides and debris flow; and on the other, severe droughts.

The South Asian economies are becoming increasingly vulnerable to the many climate risks. Coastal areas and megacities are exposed to rising sea level and intensifying storm surges, while many inland regions will have to cope with heightening climate variability that results in too much or too little water. The rising temperature, coupled with increased variation of extreme temperature, increases economic burdens, ranging from health risks to electricity bills. In parallel, local air and water quality continue to deteriorate. Extreme weather events only exacerbate the situation.

Water-related hazards in the region are bound to increase with climate change. Between 1990 and 2008, more than 750 million people in South Asia were affected by at least one type of natural disaster, resulting in almost 230,000 deaths. Half of the disaster events have been due to floods and landslides, in turn associated with extreme weather events. Climate change is predicted to make such extreme weather events more destructive, in particular through the intensified Asian monsoon system. The Himalayan region of the Indian subcontinent has become even more vulnerable to natural disasters spawned by melting glaciers, which form high-altitude lakes that can suddenly breach and cause catastrophic flooding downstream. The frequency of such events, called glacial lake outburst floods (GLOF), has increased in recent decades. At the other end of extreme weather events is a predicted increase in duration and intensity of droughts, particularly in the arid and semi-arid areas of Bangladesh and India.

Increased incidence of flooding, storm surges, and intense rainfall could worsen erosion and landslide problems in the region. For instance, 26% of India's coastline is prone to erosion; a similar problem is apparent in Sri Lanka. In the mountain areas of Bhutan, India, and Nepal, landslides are bound to increase, causing debris flow in the rivers and threat to lives and infrastructure. Increased coastal erosion and landslide occurrence will accompany increased rainfall and intensified cyclones predicted with climate change.

Increasing temperatures and water stress could lead to reduction in crop yields. Given that glacial melt water is estimated to supply a large fraction of the flow in the Indus River, for instance, the implications of dry season water stress on the region's agriculture would be massive. Not only would water supplies diminish, crop water demand would simultaneously rise due to rising temperatures. The 2007 IPCC AR4 indicated that cereal crop production in South Asian countries could decline by 4%–10% by 2100.

The mountain ecosystems of South Asia, which are highly vulnerable to fragmentation, are particularly sensitive to changes in climate due to the short distances in which climatically different climate zones and microhabitats occur. A significant threat is increased incidence of forest fires and pests as temperatures rise and drought incidence increases.

Climate change may shift the boundary of the farming-pastoral regions in northern high-altitude parts of the Indian subcontinent. A shift to more dryland ecosystems due to global warming may increase the area for farming and livestock production (due to reduced frost and cold damage), but could also increase the risk of desertification. There is still much uncertainty about climate impacts on the vegetation and animal productivity in high-altitude dryland ecosystems. Increased evaporation, reduced snow cover, and precipitation fluctuation tend to degrade high-altitude dryland ecosystems.

Abnormal monsoon patterns and more frequent and intense storms have aggravated natural disasters and climate change impacts in recent years. Bearing the brunt of these are the more than 600 million absolute poor—more than half of the world's total poor—living in the region, who depend on climate-sensitive sectors including agriculture, forestry, and traditional fishing for much of their day-to-day needs. With changes in the global climate system likely to continue into the next century, geography, high population density, and immense poverty will continue to make South Asia especially vulnerable.

About This Study

Economic information concerning climate change is critical in supporting development and climate actions in South Asia. In order to improve living standards and achieve sustainable development, steps taken now and in the future must take into account climate change and its potential consequences.

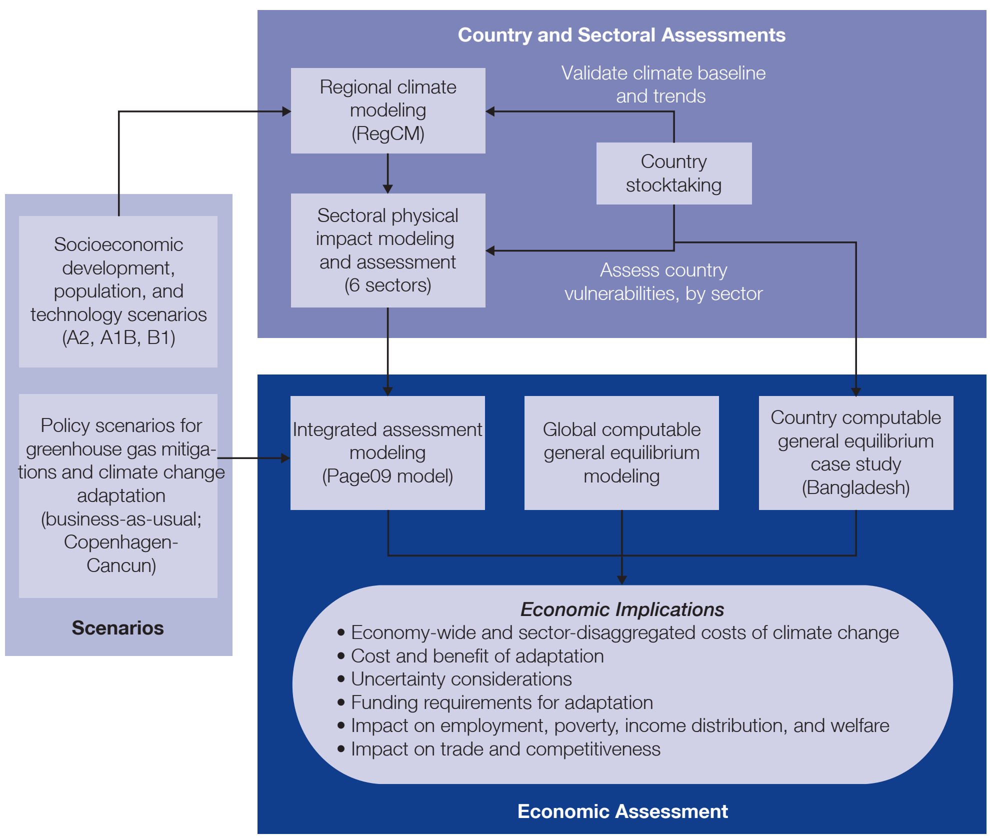
This study examines the adaptation side of climate change management: vulnerability and adaptation options covering Bangladesh, Bhutan, India, the Maldives, Nepal, and Sri Lanka. The study aims to (i) assess the biophysical impacts of climate change in the region, including individual country impacts; (ii) estimate the total economic loss to the countries in the region toward the year 2100, taking into account the different scenarios and impacts projected across vulnerable sectors; and then (iii) estimate the magnitude of funding for adaptation measures required to avert such potential losses. Results of the study will aid development of future policies and programs for climate change adaptation in the region, including initiatives for regional cooperation and capacity building in climate change management.

2 Methodology

Approach and Framework

The study approach involves (i) scoping and review of existing relevant knowledge and initiatives in South Asia; (ii) consultation with stakeholders; and (iii) quantitative modeling of climate change, its impact and adaptation, and economic implications. The approach framework is shown in Figure 1.

Figure 1: **Impact Modeling and Assessment Framework**



The modeling was conducted under emission scenarios consistent with those developed by the *IPCC Fourth Assessment Report* (AR4) as well as policy scenarios consistent with recent development of climate change negotiations under the United Nations Framework Convention on Climate Change process. Climate projections are undertaken for 2030, 2050, and 2080, and analyzed with respect to the baselines. The IPCC AR4 A1B scenario is used as a reference case in sector analyses, while other scenarios are also analyzed and discussed in comparison throughout the report.

The analyses are based on a three-step modeling approach: (i) climate downscaling, (ii) physical impact assessment, and (iii) economic assessment.

For each study country, stocktaking was done to review the literature on climate change vulnerability concerns and responses, including observations on current climate patterns and perceived changes that were used to validate climate change projections derived from the modeling. Key sectors affected by extreme weather occurrences, as well as slow-onset climate changes (e.g., higher temperatures) were examined. Responses being taken by governments were also reviewed, with reference to each National Adaptation Program of Action and IPCC communications, as well as initiatives by the nongovernment sector. Ongoing coping and adaptation measures, including constraints to building adaptive capacity, were also reviewed. The stocktaking provided information to assess baseline conditions for the sector impact modeling.

Sector-based physical impact modeling, supported by a comprehensive literature review, was carried out to generate information for use in the study's subsequent step of evaluating economy-wide impacts of climate change, and in formulating policy recommendations. The indicators used for impact assessment are shown in Table 1.

Table 1: **Sectors Analyzed and Physical Impact Modeling Parameters**

Sector	Physical Impact Modeling Parameters
Agriculture	Changes in crop yield; optimal crop growing temperature; shifts in cropping calendar
Coastal and marine	Loss of dryland and wetland areas due to sea level rise; extent of coastal areas temporarily inundated by high tides and storm surges
Energy	Impact on hydropower generation capacity; changes in energy demand (cooling and heating requirements)
Forests and other land ecosystems	Change in total carbon storage; change in net primary productivity; change in vegetation types
Human health	Mortality and morbidity due to water-borne and vector-borne diseases; mortality and morbidity due to extreme cold and heat
Water resources	Dependable water resource; length of projected water deficits; average annual water deficit volumes

Models and Scenario Assumptions

Models Used in the Study

Regional Climate Modeling

Climate change scenarios for this study were generated using dynamical downscaling from a general circulation model (GCM) used in the IPCC AR4's scenario projections. The dynamical downscaling was accomplished using a one-way nested regional climate model (Box 1).

Box 1: **Regional Climate Model (RegCM4)**

The modeling system used for this study is the regional climatic model (RegCM4) developed at the International Centre for Theoretical Physics (ICTP), Trieste, Italy, available as open source. The RegCM system is widely used for climate change scenario studies over different geographic domains (Giorgi and Anyah 2012). Although ICTP developed and maintained the system in its early period, its support and development have been taken over by the community of researchers called REGCNET. The RegCM4 is the latest updated version of the model.

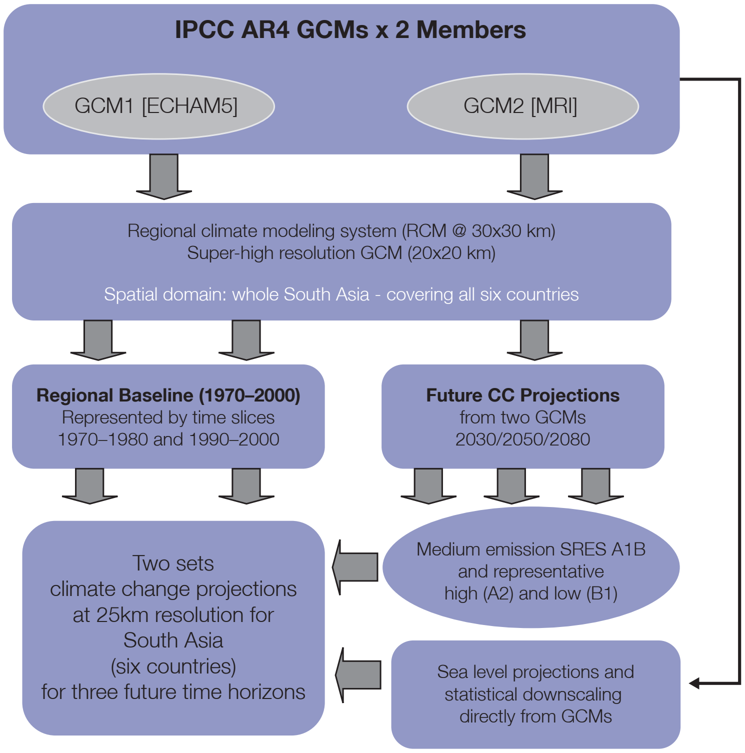
The RegCM system has been used for regional climate change projections to study impacts on health, hydrology, and agriculture. Results of these studies illustrate the model's ability to generate robust, high-resolution simulations over a variety of distinct climate regimes capturing the complex variations caused by complex topography and coastlines. The RegCM4 model can be driven by lateral boundary conditions from analyses fields based on observations as well as different general circulation models.

The approach uses available data directly from a GCM. Accordingly, available results from a super-high resolution GCM with a comparable spatial resolution as that of the downscaled regional climate model were obtained. These GCM datasets were downscaled to 30 kilometers (km) resolution over South Asia. Three IPCC AR4 emission scenarios—A2, A1B, and B1, representing high, medium, and low emission futures—were used. Three time periods—2030, 2050, and 2080—were used for the projections. Before starting the scenario runs, baseline conditions were simulated. These results are included in the climate change scenario analysis presented in this report. Figure 2 summarizes the approach for providing climate change projections for the study.

Sector Impact Modeling

Detailed physical impact assessments were undertaken for six sectors (Table 1), with data input from the climate downscaling exercise. The agriculture sector physical impact modeling used a dynamic crop simulation model, the Decision Support System for Agrotechnology Transfer (DSSAT), which is a licensed software that assesses the impacts on crop production and integrates the effects of climate, soil, crop phenotype, weather, and management options, and simulates the results.

Figure 2: **Schematic Representation on Production of High-Resolution Regional Climate Change Scenarios**



A1B, A2, and B1 = projected emission scenarios; CC = climate change, ECHAM5 = European Centre/Hamburg Model, GCM = general circulation model, IPCC = Intergovernmental Panel on Climate Change, km = kilometer, MRI = Meteorological Research Institute, RCM = regional climate model, SRES = Special Report on Emission Scenarios.

For the coastal sector impact modeling, a geographic information system (GIS) was used to assess the potential inundated areas resulting from projected sea level rise. Due to the limitation of elevation data resolution, the sea level rise considered for the inundation modeling was set to 1 meter (m). To project the temporary inundated area by extreme storm surge, past storm surge data were reviewed and extreme storm surge was identified according to different parts of South Asia. The inundation analysis used the ASTER Global Digital Elevation Model, taking into account trends from satellite altimetry, future sea levels from global climate models, and high-tide patterns.

The energy sector impact modeling, carried out for each study country, focused on the impacts of climate change on power supply and demand. The demand analysis was designed to calculate changes in electricity use due to the most important impacts of climate change, especially heating and cooling due to projected temperature changes. For the power sector supply assessment, only hydropower generation changes were assessed due to data limitations.

For the forest sector impact modeling, a dynamic global vegetation model, MC2, was used to simulate the potential impact of climate change on forests and other natural vegetation. The MC2 model simulates vegetation and wildfire dynamics as a function of site characteristics and monthly climate data. "MC2" is an acronym for "MC1 version 2," as it is a re-implementation of the MC1 model (Bachelet et al. 2001).

The magnitude and extent of projected health impacts of climate change in the region were estimated by extrapolation of relatively simple cause-effect models. The impact modeling concentrated on the pattern of future climate change, and patterns of morbidity and mortality with regard to vector- and water-borne diseases as well as respiratory and cardiovascular diseases caused by heat stress.

Apart from temperature and precipitation data, vector- and water-borne disease information was required for the study. National mortality and morbidity data for both water- and vector-borne diseases were used for GIS-based mapping of disease incidence and their future projection for different time periods. Climate change projections from the regional climate modeling were used to project changes in future temperature and precipitation, using the three IPCC AR4 scenarios (A2, A1B, and B1).

GIS grid modeling was done to estimate water resource impacts, using projected climate data from the regional climate modeling for the following: (i) dependable water resource, (ii) duration and frequency of droughts, and (iii) water balance (i.e., water surpluses and deficits). Water resources analysis used a water balance model, the Soil and Water Assessment Tool framework.

Economic Assessment

For the economic assessment, we adopted the (i) integrated assessment model to analyze long-term economic impacts of climate change and estimate the magnitude of funding required in South Asia to respond to climate change, in tandem with (ii) a computable general equilibrium (CGE) model (for Bangladesh) to evaluate intercountry and regional implications of climate change and its future impact on other relevant macroeconomic indicators, such as commodity prices, competitiveness, and income distribution in South Asia.

The purpose was to synthesize the existing and new estimates of impact and adaptation to provide a long-term perspective of climate change implications in South Asia, while taking into account possible ranges of uncertainties involved in climate impact processes, based on a probabilistic approach. Furthermore, the integrated assessment model allowed the analysis to consider strategic policies with adaptation and mitigation linkages. The Policy Analysis of the Greenhouse Effect version 9 (PAGE09) was the main integrated assessment model used for all the countries covered in this study (ADB 2009a, 2013; Hope 2011), while CGE was used to derive the macroeconomic, sectoral, and household impacts of different changes in climate parameters.

PAGE09 is stochastic in nature and is used to analyze the economic implications of climate change and responses, taking into account uncertainties associated with climate process, physical impacts, and economic parameters, and the possibility of catastrophic risk. The model is a new integrated assessment model that values the impacts of climate change and the costs of policies to abate and adapt to it. It is designed to help policy makers understand the costs and benefits of action and inaction. It is a top-down model that provides estimates of the future economy-wide impact of climate change and policies.

The parameterization of PAGE09 has been made to include the latest scientific and economic information at the time of the study, primarily of the *IPCC Fourth Assessment Report* (AR4) (IPCC 2007). The model uses simple equations to simulate the results from more complex specialized scientific and economic models. It does this while accounting for the profound uncertainty that exists around climate change. Calculations were made for eight world regions and ten time periods to the year 2100, for four impact sectors (sea level, economic, noneconomic, and discontinuities). PAGE09 was modified to split out the six South Asian countries covered under this study. Its parameters were updated with the modeling results from the sector-specific impacts of climate change.

The model estimated impacts through damage function linking gross domestic product (GDP) loss with temperature rise. The impacts were driven mainly by three factors: (i) region-specific temperature rise, which was determined by radiative forcing from global greenhouse gas concentrations—including carbon dioxide (CO_2) from energy-related and land-use change and forestry, nitrous oxide methane, and sulfur hexafluoride—and regional sulfates; (ii) regional impact parameters, which are a function of region-specific geographic characteristics; and (iii) region-specific adaptive capacity, which is determined by per capita income. The possibility of future large-scale discontinuity is modeled through a linearly increasing probability of occurring as the global mean temperature rises above a threshold. The business-as-usual anthropogenic greenhouse gas emissions of the version used in this study are consistent with IPCC's high-emission scenarios (within the range of A1FI and A2 scenarios) (Box 2).

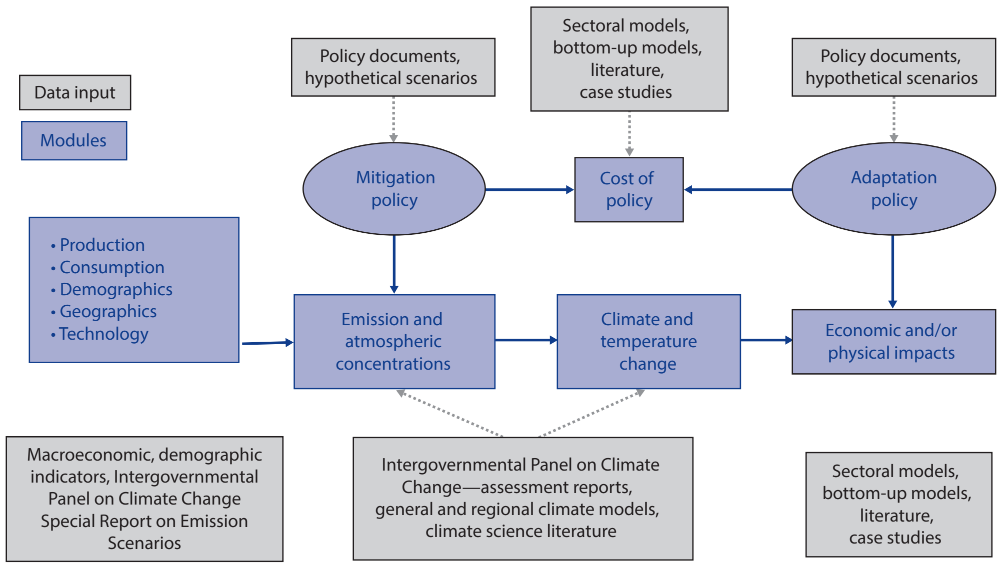
The Bangladesh dynamic CGE (BGDDyn CGE) model was built using the Partnership for Economic Policies standard recursive dynamic CGE model (Decaluwe et al. 2010). The BGDDyn CGE model has both static and dynamic components. The static model presents the behavior of economic agents in the economy and the dynamic model shows the transition path of the economy due to any external shock. The BGDDyn CGE model uses the latest Social Accounting Matrix of Bangladesh as the dataset.

Figure 3 is a simplified schematic representation of the integrated assessment model. The model starts by building scenarios on production and consumption patterns, demographic and geographic conditions, and technology status. Based on these, the model projects emissions and concentrations. This links to the climate module, which calculates climate-related parameters, such as temperature changes and sea level rise. Finally, the model calculates economic and/or physical impacts depending on the model structure. Mitigation and adaptation policies and their cost-benefit implications can be analyzed. Data were taken from existing bottom-up sectoral studies. For example, AR4 GCMs are used to calibrate the emission and climate modules. Sectoral bottom-up models and case studies provide parameters for the impact and economic modules.

Emission Scenarios

The emission scenarios used to create climate change projections for the regional climate modeling and physical impact assessment were the A1B, A2, and B1 scenarios from the

Figure 3: **Simplified Schematic Representation of the Integrated Assessment Model**



2001 Special Report on Emission Scenarios (SRES) prepared by the IPCC (Box 2). The primary purpose of developing scenario families is to explore the uncertainties behind potential trends in global developments and greenhouse gas emissions, as well as the key drivers that influence these.

Unlike other regional climate and physical impact modeling using climate-based scenarios, the scenario design in the economic assessment focuses on policy-based (action-based) scenarios. The integrated assessment models are simulated to the year 2100 to take into account the inertia in the climate systems, long atmospheric life of greenhouse gas emissions, and the need to take a long-term view on climate actions (such as infrastructure investment, adoption of new and cleaner technologies, and the implementation of transformational policies). The analysis and results discussed here consider discounting as one of the probabilistic variables, unless otherwise stated. Below are the scenarios chosen for the economic assessment:

- **Business-as-usual (BAU) scenario.** The economic and population growth of the six countries follow IPCC's AR4's A1FI scenario, while the BAU's emissions path is consistent with the range of IPCC's AR4's high-emission scenarios, such as A1FI and A2. The BAU scenario assumes that there is no mitigation effort or investment beyond the current level. Although a "no-action" assumption may be unrealistic, the scenario creates a benchmark against which scenarios with actions (adaptation and/or mitigation) are evaluated.
- **Copenhagen–Cancun scenario.** This scenario assumes decoupling of greenhouse gas emissions from BAU economic growth, and imposes the implementation of Copenhagen Accord pledges (toward 2020) with a long-term vision that is in line with the Cancun Agreements, aiming at keeping the global mean temperature rise below 2°C.

Box 2: **The Emission Scenarios of the IPCC Assessment Reports**

IPCC Fourth Assessment Report (2007)

A1. The A1 storyline and scenario family describes a future world of very rapid economic growth, global population that peaks in mid-century and declines thereafter, and the rapid introduction of new and more efficient technologies. Major underlying themes are convergence among regions, capacity building, and increased cultural and social interactions, with a substantial reduction in regional differences in per capita income. The A1 scenario family develops into three groups that describe alternative directions of technological change in the energy system. The three A1 groups are distinguished by their technological emphasis: fossil-intensive (A1FI), non-fossil energy sources (A1T), or a balance across all sources (A1B) (where balanced is defined as not relying too heavily on one particular energy source, on the assumption that similar improvement rates apply to all energy supply and end use technologies).

A2. The A2 storyline and scenario family describes a very heterogeneous world. The underlying theme is self-reliance and preservation of local identities. Fertility patterns across regions converge very slowly, which results in continuously increasing population. Economic development is primarily regionally oriented and per capita economic growth and technological change more fragmented and slower than other storylines.

B1. The B1 storyline and scenario family describes a convergent world with the same global population, that peaks in mid-century and declines thereafter, as in the A1 storyline, but with rapid change in economic structures toward a service and information economy, with reductions in material intensity and the introduction of clean and resource-efficient technologies. The emphasis is on global solutions to economic, social, and environmental sustainability, including improved equity, but without additional climate initiatives.

B2. The B2 storyline and scenario family describes a world in which the emphasis is on local solutions to economic, social, and environmental sustainability. It is a world with continuously increasing global population, at a rate lower than A2, intermediate levels of economic development, and less rapid and more diverse technological change than in the B1 and A1 storylines. While the scenario is also oriented toward environmental protection and social equity, it focuses on local and regional levels.

The emission scenarios in the special report do not include additional climate initiatives, which means that no scenarios are included that explicitly assume implementation of the United Nations Framework Convention on Climate Change or the emissions targets of the Kyoto Protocol.

Source: IPCC. 2001. *Special Report on Emissions Scenarios*. A Special Report of Intergovernmental Panel on Climate Change (IPCC) Working Group III. Cambridge, UK: Cambridge University Press.

IPCC Fifth Assessment Report (2013): Representative Concentration Pathways

The IPCC Fifth Assessment Report defined a set of four new scenarios, denoted Representative Concentration Pathways (RCPs), which are identified by their approximate total radiative forcing in year 2100 relative to 1750, ranging from 2.6 W/m^2 to 8.5 W/m^2. These four RCPs include one mitigation scenario leading to a very low forcing level (RCP2.6), two stabilization scenarios (RCP4.5 and RCP6), and one scenario with very high greenhouse gas emissions (RCP8.5). The RCPs can thus represent a range of 21st century climate policies, as compared with the no-climate policy of the Special Report on Emissions Scenarios (SRES) used in the Third Assessment Report and the Fourth Assessment Report. For RCP6.0 and RCP8.5, radiative forcing does not peak by year 2100; for RCP2.6 it peaks and declines; and for RCP4.5 it stabilizes by 2100. Each RCP provides spatially resolved data sets of land use change and sector-based emissions of air pollutants, and it specifies annual greenhouse gas concentrations and anthropogenic emissions up to 2100. RCPs are based on a combination of integrated assessment models, simple climate models, atmospheric chemistry and global carbon cycle models. While the RCPs span a wide range of total forcing values, they do not cover the full range of emissions in the literature, particularly for aerosols.

Source: IPCC. 2013: Summary for Policymakers. In: *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

The recently released *IPCC Fifth Assessment Report* (AR5) features the results of new data and models. While confirming the trends of the fourth report, it considers four basic scenarios, called representative concentration pathways, that have similarities with some of the SRES scenarios of the AR4 used in this study (Box 2). Since the representative concentration pathways are not fully developed scenarios, in a strict sense they cannot be compared with the earlier emissions scenarions. However, A1B and B1 scenarios may be roughly equated to the two medium stabilization pathways, RCP6 and RCP4.5, respectively.

It is important to note at the outset that, like other climate change studies, the estimates are highly sensitive to a number of assumptions. For example, the total economic cost of climate change depends on the coverage of sectors and impacts in the models. Although key sectors, such as agriculture, water, coastal, energy, human health, ecosystems, and extreme events, are considered in most cases, there are still many missing and unknown impacts. Estimates are also contingent on how future scenarios unfold, the time horizon envisaged, and how societies value their futures and future generations, among other things. Therefore, the results should always be interpreted in association with scenario storylines, and should be taken as indicative rather than a forecast.

Limitations

Some caution should be exercised when interpreting the findings of the present study, due to data limitation and large scale of the study area, as well as different projections (but similar trends) in the IPCC AR5. Relationships among variables must be interpreted with caution. For instance, for the energy sector, instead of detailed modeling of hydropower sites in each country, it followed a simplified procedure: if the inflow of water into the reservoir is reduced by 1%, it assumed that hydroelectric energy generated will also be reduced by 1% (and vice versa for increased inflows). The water inflows were assumed to be directly related to precipitation. There are many technical shortcomings with this assumption,[1] but in the absence of detailed modeling, it is the simplest and most robust one. Changes in energy transmission and distribution were not estimated due to unavailability of relevant data.

The model estimated the net impacts of climate change on the power supply–demand balance during 2025–2035 (2030s) and 2046–2055 (2050s), starting from the baseline 1970–1980 and 1990–2000 under IPCC AR4 climate scenario A1B, A2, and B1. Most energy (demand/supply) projections are only up to about 2030. Simple extrapolation to 2050 was made using existing trends, but the results are rather speculative. It is infeasible to even consider 2080 because it is far too distant and conditions are very uncertain.

Due to the above limitations, the study focused on estimating the electricity demand change, based on the results of previous studies. The most important impacts were

[1] Almost all major hydropower sites have reservoirs; otherwise, increases in water flows that cannot be stored may exceed turbine capacity and will not generate extra energy. Even with storage, the water inflows may be so excessive that spilling from the reservoir occurs, again without generating extra energy. Also, the energy generated depends on the water level in the reservoir, and not simply on the volume of water stored. Evaporation of water from the surface of reservoirs is another impact of climate change and may lead to reduced water for hydropower. However, the effects of climate change on evaporation rates are not straightforward.

on power use for heating and cooling due to projected temperature change caused by climate change.

For the marine and coastal sector, it should be noted that the estimates were conservative because the study has not taken future shoreline erosion and sedimentation into account due to large geographic coverage and lack of available data. The resolution of elevation data limited the ability to analyze the affected land and population (notably for the Maldives). Assessment of inundated areas at less than 1-meter increments could not be done due to the limited vertical resolution of the available elevation data.

For example, uniform sea level rise and storm surge level were assumed and do not account for potential geographical differences (IPCC 2007). Geological uplift and subsidence processes also differ, depending on the regional response. The study did not consider the effect of existing protection, such as dikes, and future adaptation infrastructure that would reduce the risk of sea level rise.

For the water sector, a limitation was the use of precipitation and evapotranspiration projections from only one climate model. An ensemble of downscaled climate models would have provided greater confidence in the data for the climate variables used to estimate dependable water resource. Hence, the results of the gridded accounting of country and state-level renewable water resources should be taken as indicative, and should be used mainly for purposes of assessing spatial patterns and differences, long-term trends, and sensitivity to different climate change scenarios. Part of the water demand from agriculture is already accounted for in the evapotranspiration estimates (or the consumptive use of water) for cropped areas. Consequently, the demand estimates for irrigation used in the calculation are on the high side.

For the regional modeling, regional dynamical downscaling was done using the RegCM4. However when the model was run, it was found that a 30-second time step was required, instead of the typical 90-second time step to attain a stable model configuration. It was planned to generate another set of regional climate model projections using lateral boundary conditions from a second GCM. However, due to time constraints and limitation of computing time, the second downscaling runs were not undertaken. As a mid-course alternate strategy, projections from a super high-resolution GCM available at 20-kilometer spatial resolution were used.

For the economic assessment, the regional estimate was dominated by the findings on India. Note that the model excludes extreme events, such as storms, floods and droughts, and there were missing impacts that are not captured in the model. Thus, the estimates could be considered as lower-bound estimates.

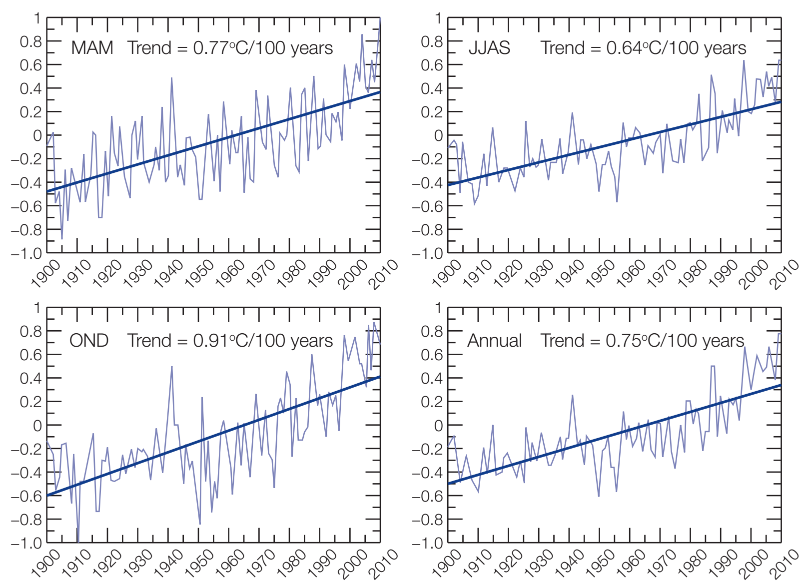
In the light of the abovementioned limitations, further research and study using the AR5 scenarios could provide a more updated analysis.

3 Climate Change Scenario in South Asia

Observed Climate Trends in South Asia

A significant warming trend of about 0.75°C per century has been observed in past annual mean temperatures over South Asia. In recent years, accelerated warming has been evident, as seen in the pronounced warming trend observed during the decade 1998–2007. This warming is mainly contributed by the winter and post-monsoon seasons. Figure 4 shows observed trends in seasonal mean temperatures for different seasons during the past 100 years. The warming trend observed over South Asia is consistent with global temperature trends.[2] The warming trends over the century are also highest

Figure 4: **Trends in Mean Surface Air Temperatures over the South Asian Landmass during 1900–2012 for Different Seasons**



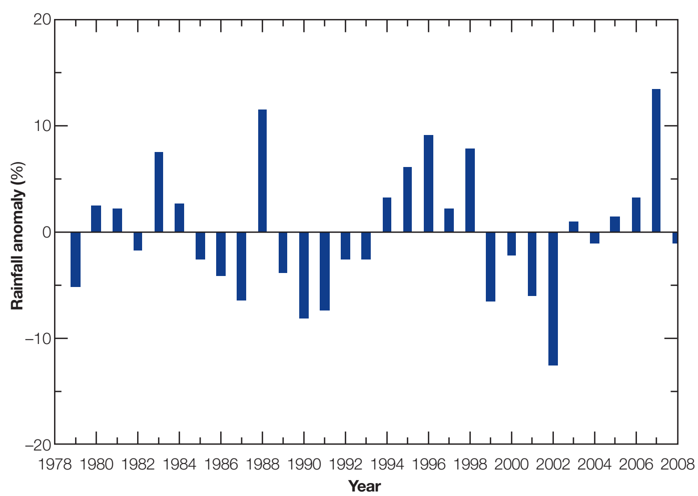
JJAS = June–July–August–September; MAM = March–April–May; OND = October–November–December.

[2] This analysis is based on a historical global temperature dataset compiled from global meteorological observations by the Climatic Research Unit at the University of East Anglia, UK.

(0.91°C) during the post-monsoon (October–December) and lowest (0.64°C) during the monsoon season (June–September).

Observed rainfall during the southwest monsoon season shows substantial year-to-year variability over the South Asian domain. The monsoon rainfall does not show any clear long-term trend (Figure 5). Recent studies (Bollasina et. al. 2011, Zhang and Zhou 2011) on specific periods and spatial domains within long-term global rainfall datasets indicate increasing trends prior to the 1950s and decreasing trends during the latter half of the 20th century. Analysis of observed long-term monsoon rainfall to date reinforces the knowledge of their being stable rain-bearing systems for the South Asian region. There may, however, be trends in total rainfall or spatial and temporal variations that may be noticeable at specific locations. Apart from the year-to-year variations, monsoon rainfall shows considerable variations within the monsoon season, typically on a 30–60 day time scale. Such intraseasonal variations significantly impact agricultural operations, water availability, and the socioeconomy of the region. It has been difficult to discern tendencies (beyond the natural variability) in intraseasonal variations of monsoon rainfall over the region (Tuner and Annamalai 2012).

Figure 5: **Percentage Deviations from Long-Term Average Monsoon Rainfall during 1979–2008 over South Asia**

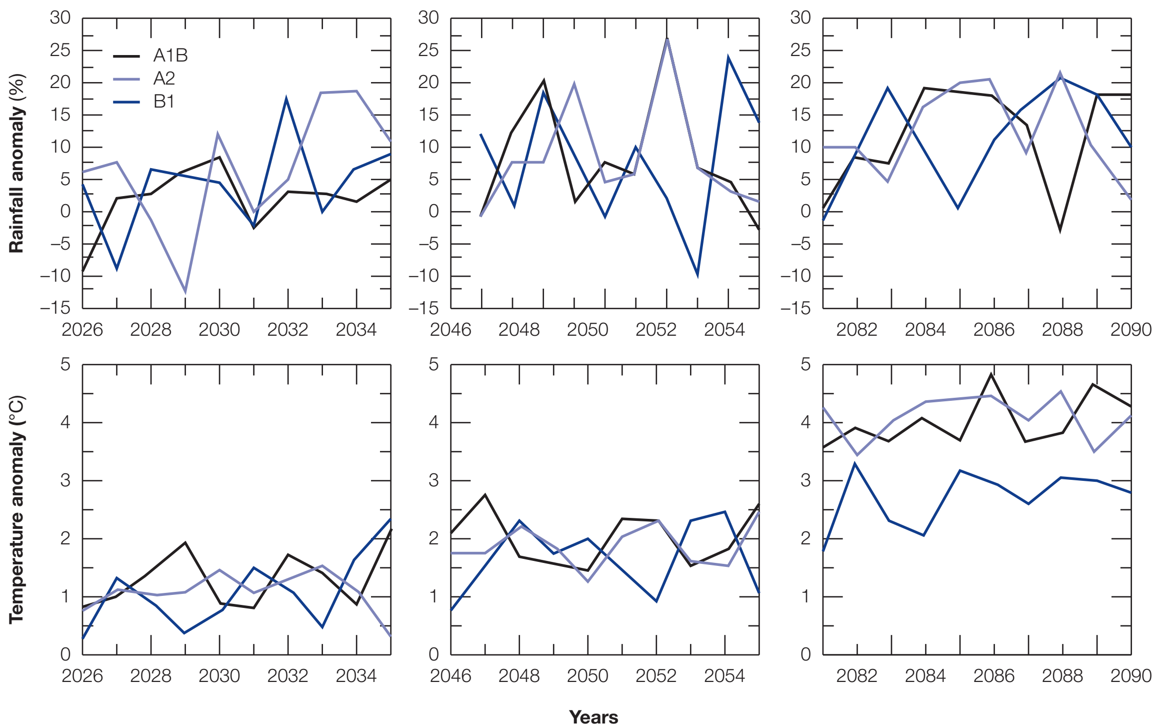


Projected Climate Change Impact in South Asia

Temperature

As simulated by the regional climate model downscaling of the European Centre/ Hamburg Model 5 (ECHAM5) GCM projections and employing the scenarios from the IPCC Special Report on Emissions Scenarios (SRES) for the different time periods, there will be a steady increase in temperatures with anomalies reaching 4°C–5ºC for the

Figure 6: **Interannual Variations in Regional Climate Model Simulations for Different Periods and Emission Scenarios for Monsoon Rainfall** (upper) **and Annual Mean Surface Temperature** (lower) **over South Asia**



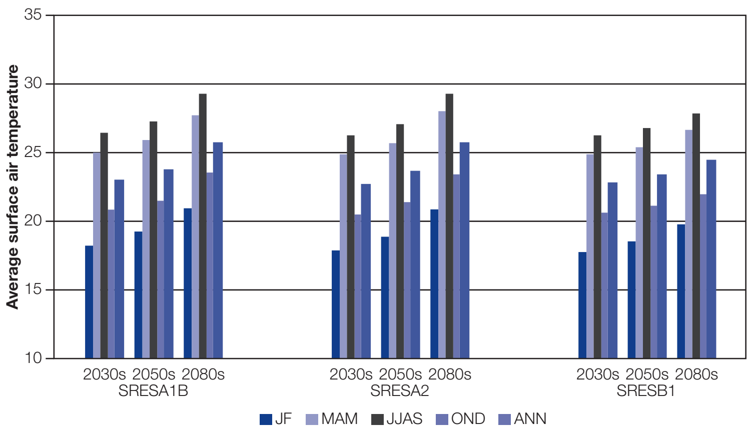
Note: The changes in rainfall (%) and temperature (ºC) are with respect to the baseline.

high-emission scenarios during the 2080s (Figure 6). Regionally, climate is influenced by numerous competing factors that could introduce nonlinearity that results in natural variability that may mask the climate change signal. The latest IPCC AR5 Working Group 1 report (IPCC 2013[3]) notes in more general context that discernable differences in the different emission scenarios become apparent only after the mid-century. This assessment perhaps extends to longer time horizons in the tropical context.

The differentiation between the low-emission and high-emission scenarios becomes more marked only during the 2080s (Figure 7). Even in 2050, the differences in climate variables between some scenarios are not well marked. The regional climate model temperature simulation for 2080 indicates an all-round warming over the whole subcontinent associated with increasing greenhouse gas concentrations (Figure 8). The warming seems to be pronounced over western and central India. Such spatial variations of projected changes become more evident in the country analyses. The annual mean

[3] IPCC. 2013. Climate Change 2013: *The Physical Science Basis. Summary for Policymakers*. Switzerland: Intergovernmental Panel on Climate Change.

Figure 7: **Temperature Projections from the Regional Climate Model for Three Emission Scenarios and Periods in Different Seasons in South Asia**



A1B, A2, and B1 = projected scenarios from *IPCC Special Report on Emission Scenarios* (SRES), ANN = annual, JF = January–February, JJAS = June–July–August–September, MAM = March–April–May, OND = October–November–December.

surface air temperature rise by the end of the century is 3°C–5ºC in the A1B and A2 scenarios, and 2.0°C–3.5ºC in the "low" B1 scenario (Appendix 1).

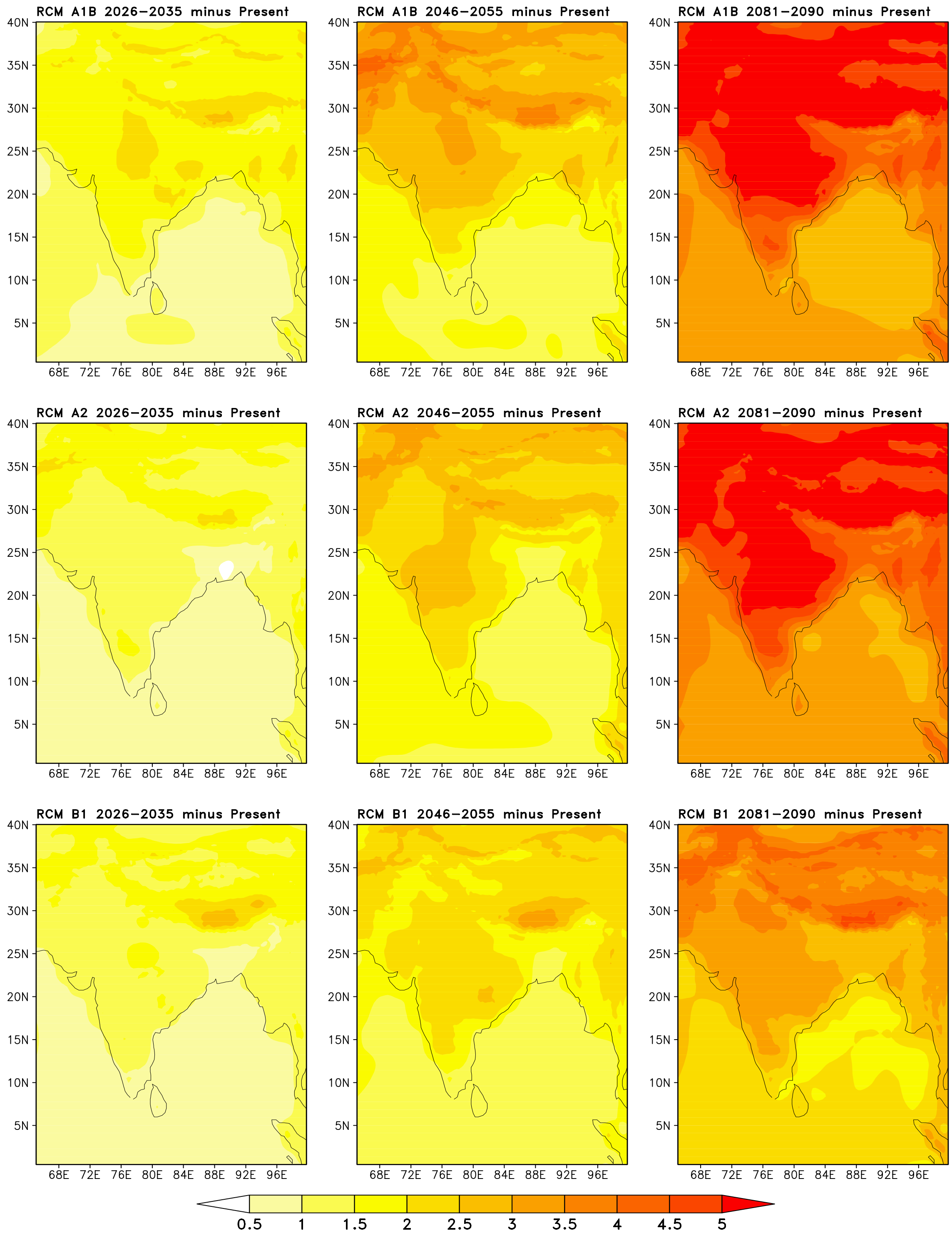
Rainfall

The mean annual cycles of mean precipitation and surface air temperatures for the three emission scenarios are presented in Figure 9. The model results indicate increase in rainfall as well as consistent increases in temperature. Unlike temperature, the patterns in rainfall changes are not consistent across time horizons or seasons. The signal of enhanced rainfall conditions during the monsoon months becomes strong only during the 2080s in all the three scenarios. During the dry winter months, there are smaller changes or decreasing tendencies in rainfall. The A1B and A2 scenarios show similar patterns, with B1 showing slightly reduced magnitudes. Figure 10 depicts changes in the spatial distribution of the seasonal mean monsoon rainfall for the three scenarios during the three time periods. Within the overall pattern of increasing rainfall, some areas become drier or wetter during the 2030s and the 2050s than in the baseline conditions. Spatial patterns of rainfall change (Figure 10) indicate increases over eastern and northeastern parts of the region for the three scenarios. Increase in rainfall is seen over Bangladesh, the Maldives, and Sri Lanka. The most change is noticed in scenarios A1B and A2.

Sea Level Rise

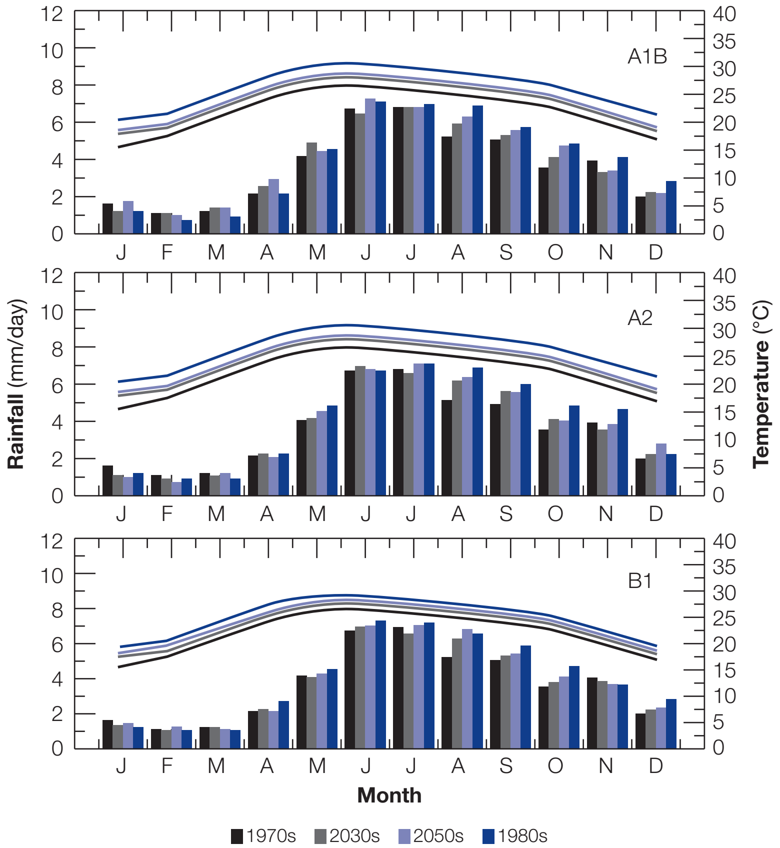
Changes in oceanic heat storage and distribution of ocean salinity cause the ocean to expand or contract, resulting in changes in the sea level both regionally and globally. On long time scales, global mean sea level change results from two major processes that alter the volume of water in the global ocean: (i) thermal expansion and (ii) water flow from other sources, such as melting of glaciers and ice caps, ice sheets, and reservoirs.

Figure 8: **Spatial Distribution of Projected Changes in Mean Surface Air Temperatures under Different Emission Scenarios** (top A1B, middle A2, and bottom B1) **for Three Future Periods in South Asia**



A1B, A2, and B1 = projected scenarios from *IPCC Special Report on Emission Scenarios*, RCM = regional climate model.

Figure 9: **Seasonal Cycles of Temperatures** (lines) **and Rainfall** (bars) **for Different Scenarios and Periods in South Asia**

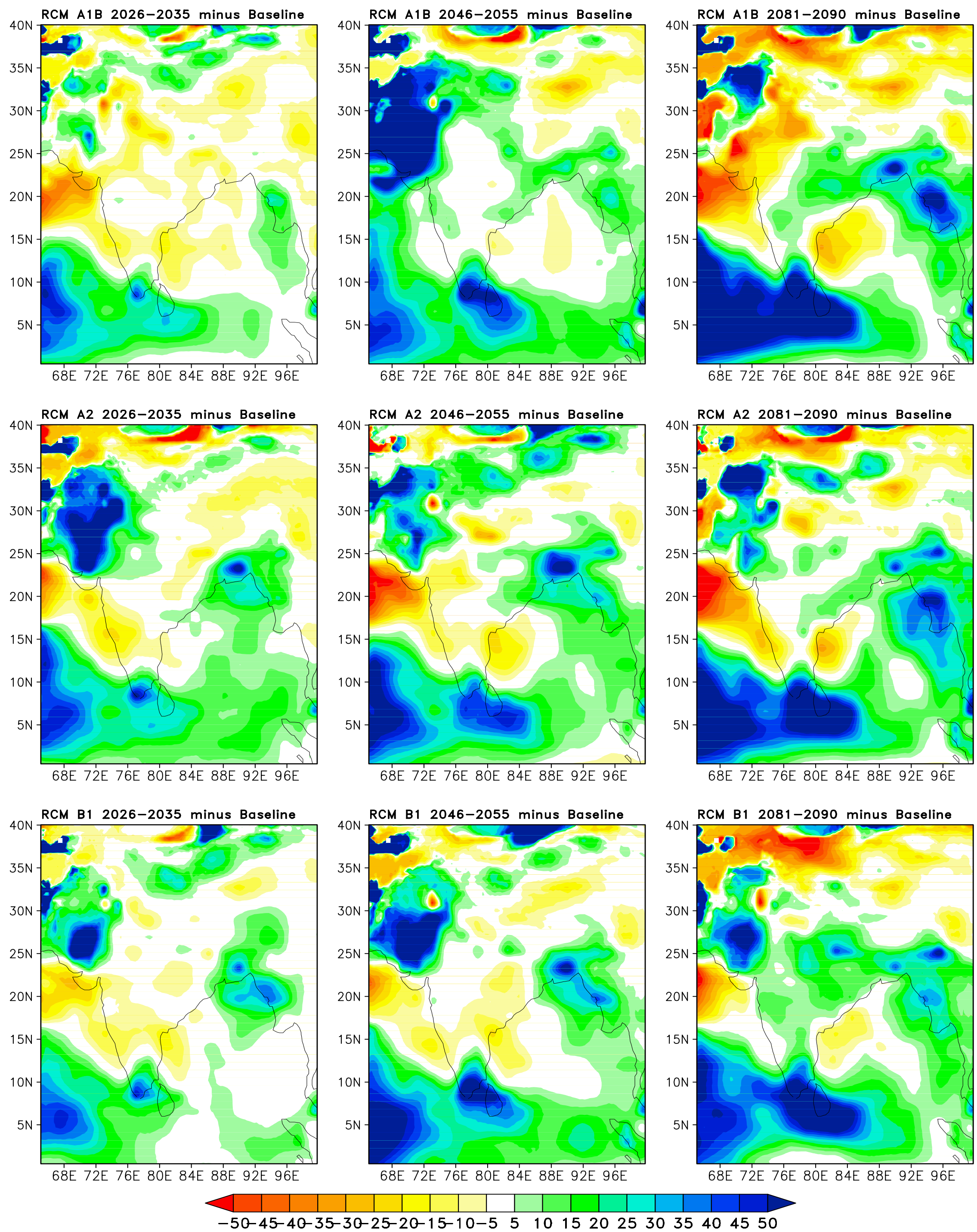


A1B, A2, and B1 = projected scenarios from *IPCC Special Report on Emission Scenarios*, mm = millimeter.

All these processes cause geographically uneven sea level change. Changes in ocean circulation or atmospheric pressure also affect sea level at the regional scale. Local sea level measurements are influenced strongly by vertical land movements due to tectonics, subsidence (caused by earthquakes, for example), and sedimentation; hence, accounting for these changes is important in detecting long-term trends.

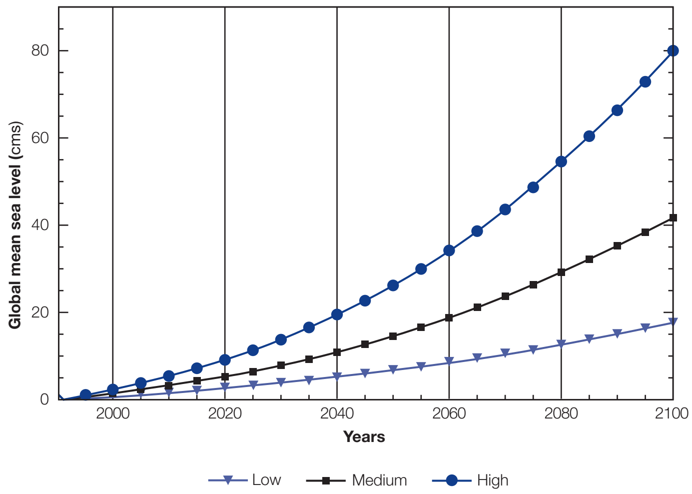
The global sea level rise projected by the Geophysical Fluid Dynamics Laboratory model for three emissions scenarios (Figure 11) shows a rise of 0.05–0.25 m for the 2050s and 0.18–0.80 m toward the end of the century. This is similar to the estimates given by the IPCC 2007 assessments of about 0.2–0.6 m rise across the different emission scenarios. The relative sea level data are dominated by seasonal and interannual variability, making it difficult to find clear trends. Regional sea level analysis is also compounded by many other factors, like land subsidence and localized impacts of groundwater extraction.

Figure 10: **Regional Climate Model Projected Changes in Mean Monsoon Rainfall during Different Periods and Scenarios with Respect to the Baseline** (top A1B, middle A2, and bottom B1) **in South Asia**



A1B, A2, and B1= projected scenarios from *IPCC Special Report on Emission Scenarios*, RCM = regional climate model.

Figure 11: **Projected Changes in Global Mean Sea Level to the End of the 21st Century for Three Emission Scenarios based on Geophysical Fluid Dynamics Laboratory Model Results**



cms = centimeters.

Projected Climate Change Scenarios by Country

Projected precipitation and temperature trends by country under three emission scenarios are shown in tables 2 and 3. Following are detailed accounts by country.

Table 2: **Precipitation Departure (%) in South Asian Countries for 2030, 2050, and 2080 from 2000 Baseline, under Different IPCC Emission Scenarios**

Country	2030			2050			2080		
	A2	A1B	B1	A2	A1B	B1	A2	A1B	B1
Bangladesh	12.9	–6.1	7.9	26.1	9.6	17.8	16.5	15.4	12.4
Bhutan	–3.3	–3.7	4.1	6.4	–1.1	0.9	0.2	0.1	1.1
India*	–10.1 to 16.3	–39.2 to 3.6	–17.0 to 9.5	–33.2 to 27.5	–23.6 to 21.2	–14.2 to 19.9	–30.5 to 32.1	–42.5 to 28.7	–22.8 to 33.8
Maldives	11.8	18.7	7.7	15.5	16.2	11.3	28.8	30.5	23.7
Nepal	–5.0	–3.9	–4.4	–1.7	–2.0	–1.7	–0.9	0.0	2.9
Sri Lanka	7.4	11.0	3.6	15.8	25.0	16.5	39.6	35.5	31.3

* For India, range of precipitation departure is for 28 states and 3 union territories.

Table 3: **Temperature Change (°C) in South Asian Countries for 2030, 2050, and 2080 from 2000 Baseline, under Different IPCC Emission Scenarios**

Country	2030			2050			2080		
	A2	A1B	B1	A2	A1B	B1	A2	A1B	B1
Bangladesh	0.9	1.9	1.0	1.6	2.5	1.6	4.2	4.2	2.9
Bhutan	1.5	1.9	1.7	2.3	2.6	2.2	4.5	4.4	3.2
India*	0.6–1.8	0.9–2.4	0.7–2.0	1.3–2.9	1.4–3.5	1.1–2.6	3.0–5.6	2.8–6.2	1.9–3.7
Maldives	0.9	1.0	0.8	1.6	1.5	1.3	3.3	3.2	2.2
Nepal	1.6	2.0	1.7	2.5	2.9	2.3	4.8	5.0	3.4
Sri Lanka	1.0	1.1	1.0	1.8	1.5	1.3	3.6	3.3	2.3

* For India, range of temperature change is for 28 states and 3 union territories.

Bangladesh

Bangladesh has a tropical monsoon climate with four main seasons: the pre-monsoon (March–May) with warmest temperatures; the monsoon (June–September), when the bulk of rainfall occurs; the post-monsoon (October–November), which, like the pre-monsoon season, is marked by tropical cyclones on the coast; and the cool and sunny dry season (December–February). About 80% of the total rainfall occurs during the monsoon, and the average annual precipitation is 2,320 millimeters (mm). This varies from 1,110 mm in the extreme northwest to 5,690 mm in the northeast. Mean annual temperature is about 25°C, with extremes as low as 4°C and as high as 43°C. The pre- and post-monsoon months are periods when the country's coastal areas are frequented by intense cyclones, often causing catastrophes.

The projected temperature changes for the three periods are: 2030, 0.9°C–1.9°C; 2050, 1.6°C–2.5°C; and 2080, 2.9°C–4.2°C. The ensemble mean[4] of temperature projections for all the Coupled Model Inter-comparison Project Phase 3 (CMIP3) GCMs is around 3.0°C–3.5°C by the end of the 21st century. The high degree of agreement across the GCMs makes the increasing temperature trend a very confident estimate.

Precipitation in Bangladesh shows an overall increasing trend over the three periods 2030, 2050, and 2080. In 2030, extreme scenarios A2 and B1 indicate precipitation increase would be 7.9%–12.9%, whereas the A1B scenario shows a decreasing trend of 6.1%. All the scenarios agree on a positive departure in the 2050s and 2080s. Precipitation departure in 2050 is likely to be 9.6%–26.1% and 12.4%–16.5% in 2080. An ensemble mean estimate from the GCMs for the 21st century is an increase of 5%–10% with a moderate to high agreement, or medium confidence.

[4] Average change projected for A1B scenario by 21 CMIP3 GCMs multi-model ensemble. Source: UK Met Office. 2011. *Climate: Observations, Projections and Impacts: India, Bangladesh*. London.

Bhutan

Bhutan encompasses a wide variety of climates in a relatively limited area, from humid and subtropical on the southern plains and the foothills to temperate in the Himalayan valleys and alpine in the higher mountains. Temperatures vary according to elevation. Average annual precipitation in Bhutan is roughly 2,200 mm, varying widely in various parts of the country. The summer monsoon lasts from late June through late September amounting to 60%–90% of the region's rainfall according to location.

Climate change projections for Bhutan show temperature changes of 1.5°C–1.9°C in 2030, 2.2°C–2.6°C in 2050, and 3.3°C–4.5°C in 2080. The CMIP3 ensemble mean estimate is an increase of 3.0°C–3.5°C by the end of the 21st century for the A1B scenario, which is consistent across the GCM ensemble. This lends high confidence to the increasing temperature change projections.

The regional climate model output indicates precipitation changes to be small and variable. In 2030 precipitation departure is likely to be –3.3% to 4.1%. Precipitation departure by 2050 is likely to be –1.1% to 6.4%. By 2080, the precipitation departure is likely to be 0.1% to 1.1%. These figures indicate the lack of any clear tendencies in rainfall changes. There is a lack of agreement across the GCM ensemble for rainfall projections, which range from 5% to 10% by the end of the 21st century. The rainfall projections are therefore of low confidence.

India

India has a tropical monsoon climate, with the rainfall during June–September accounting for about 80% of the annual rainfall over most of the country. However, in the southern coastal areas near the eastern coast (Tamil Nadu and adjoining areas), much of the rainfall is influenced by the northeast monsoon during October and November. The average annual rainfall over the country is around 1,170 mm, but varies significantly from place to place. Temperatures decrease from south to north during November to February. From March to May, the temperature can increase to 40°C in the northwest.

Projected temperature changes in India are 0.6°C–2.4°C in 2030, 1.1°C–3.5°C in 2050, and 1.9°C–6.2°C in 2080. Although there are considerable spatial variations in the temperature changes, the warming is generally more in the north and northeast than in the southern peninsular region. In 2030, the highest temperature change is seen in Mizoram (2.4°C), and Manipur and Madhya Pradesh (2.2°C), and lowest in the provinces of Andaman and Nicobar Island (0.9°C) and Tripura and Kerala (1.3°C); all other provinces are likely to experience changes from 1.5°C to 2.1°C. In 2050, the highest temperature change is seen in Himachal Pradesh (3.5°C) and in Uttranchal, Punjab (3.2°C), whereas Andaman and Nicobar Island (1.4°C) and Tripura (1.9°C) show less temperature rise; all other provinces are likely to have temperature changes of 2°C–3.1°C. In 2080, Himachal Pradesh (6.2°C), Haryana (6.0°C), and Delhi (6.0°C) are likely to experience maximum temperature rise; all other provinces will likely have temperature change from 3.8°C to 5.8°C. Andaman and Nicobar Island and Tripura consistently show far less temperature rise in all the time slices compared with other provinces. The ensemble mean temperature projections from the CMIP3 GCMs show high agreement (high confidence), with the warming by the end of the 21st century in the north about 4.5°C, decreasing to about 3.0°C in the south.

Projected precipitation changes show large variability over the different states. The overall summary of precipitation departures from the baseline are –39.2% to 16.3% in 2030, –33.2% to 29.7% in 2050, and –42.5% to 33.3% in 2080. In 2030, maximum decreases can be seen in Delhi (–39.2%), Goa (–31.2%), Rajasthan (–29%), Haryana (–28.4%), Madhya Pradesh (–11.2%), and Gujarat (–10.6%). Across the 31 states, the percentage change in precipitation will be within the –10% to 16.3% range. Kerala and the northeast provinces of Assam, Manipur, and Nagaland are likely to have increasing rates of change in precipitation. In 2050, Dadra and Nagar Haveli, Delhi, Goa, Haryana, Himachal Pradesh, Jharkhand, Maharashtra, and Rajasthan are likely to have a decline in precipitation by more than 10% from the baseline. Meanwhile, the maximum increase in precipitation of more than 20% is observed in Kerala, Manipur, Meghalaya, Nagaland, and Tripura. Similar to 2050, in 2080, Kerala, Manipur, Mizoram, Nagaland, and Tripura are likely to experience a maximum increase in precipitation of more than 20%. States in the north and northwestern regions such as Delhi, Goa, Haryana, Himachal Pradesh, Punjab, and Rajasthan are likely to have maximum decline in precipitation of more than 10%. Although an increasing tendency in rainfall is seen across many parts of the country (mostly in the 5%–10% range), the CMIP3 GCMs do not show clear agreement even in the sign (direction) of the change; thus, the rainfall projections are in the "low confidence" category.

The Maldives

The Maldives has a warm and humid tropical climate, dominated by two monsoon periods: the southwest monsoon (wet period, from May to November); and the northeast monsoon (dry period, from January to March). The temperature varies little throughout the year, with the annual mean temperature around 28°C ranging from 30.6°C to 26.2°C. The southern atolls receive, on average, 2,277 mm of rainfall annually, while the relatively drier northern atolls receive 1,786 mm.

Regional climate model projections of climate change indicate temperature increases of 0.8°C–1.09°C in 2030, 1.3°C–1.6°C in 2050, and 2.2°C–3.3°C in 2080. The ensemble mean from the CMIP3 GCMs shows a temperature increase of about 2.0°C–2.5°C by the end of the 21st century and there is a high agreement.

The Maldives precipitation shows positive departures in the three periods: in 2030, 7.7%–18.7%; in 2050, 11.3%–16.2%; and in 2080, 23.7%–30.5%. The GCM ensemble mean also shows an increase of 10%–20%, with a medium confidence.

Nepal

Complex topography with valleys and high-altitude mountain ranges transitioning over relatively short distances make Nepal's climate very varied. The temperature decreases from the lowland terai (northern part of the Ganges plain) to the high Himalayan region.

The mean annual rainfall is 1,500 mm, falling in two rainy seasons: summer (June to September), and winter (December to February). The southwest monsoon accounts for more than 75% of the total rainfall.

The regional climate model projections indicate temperature increases of 1.6°C–2.0°C in 2030, 2.3°C–2.9°C in 2050, and 3.4°C–5.0°C in 2080. For the terai region, the temperature change is likely to be 1.9°C in 2030, 2.5°C in 2050, and 4.6°C in 2080. The ensemble mean from GCMs indicates a temperature change of about 3.0°C–4.0°C by the end of the 21st century with high agreement (high confidence level).

The country is likely to have negative precipitation departure over the three periods: –3.9% to –5.0% in 2030, –1.7% to –2.0% in 2050, and –0.9% to +2.9% in 2080. The A1B scenario indicates that precipitation departure for the terai region is likely to be –2.60% in 2030, –0.04% in 2050, and +3.72% in 2080. Precipitation projections for the 21st century from the GCM ensemble mean indicate wide variations and low level of agreement among models. Hence, there is very little confidence in the rainfall projections for the country.

Sri Lanka

Sri Lanka has a tropical maritime climate characterized by two monsoon seasons. Mean annual temperature is about 27ºC in the lowlands and 15ºC in the central highlands. There is considerable spatial variation of rainfall, which has a national annual average of 2,000 mm. The highest rainfall occurs in the central highlands, with several stations recording values exceeding 5,000 mm. Rainfall is lowest in the northwestern and southwestern lowlands, with minimum values around 1,000 mm.

Regional climate model projections for future temperature indicate consistent increases: 1.0°C–1.1°C in 2030, 1.3°C–1.8°C in 2050, and 2.3°C–3.6°C in 2080. The ensemble mean indicates a temperature increase of about 2.0°C–3.0°C by the end of the 21st century, with a high degree of agreement (high confidence) among the CMIP3 models.

All three scenarios agree that Sri Lanka precipitation is likely to increase over the three time periods: by 3.6%–11.0% in 2030, 15.8%–25% in 2050, and 31.3%–39.6% in 2080. The ensemble mean from the GCMs indicates a 5%–10% increase by the end of the 21st century, with low agreement. The rainfall projections therefore have low confidence.

PART II

Climate Change—Impact and Adaptation

4 Modeling Climate Change and Its Impacts on Sectors

This study used the results of country-specific climate vulnerability assessments and climate change modeling in evaluating physical impacts of climate change on key sectors (agriculture, water, energy, forestry, coastal and marine, and human health). The country vulnerability assessments and sector-based climate modeling results are presented in this chapter.

Country Vulnerabilities and Physical Impacts on Sectors

Bangladesh

Agriculture

Agriculture plays a significant role in the country's economy, contributing around 20% of the GDP and employing 48% of the labor force. The total farm holdings are about 14.7 million hectares; cultivable land is nearly 8 million hectares. Annual food production is 31.9 million tons. Although rice and jute are the primary crops, wheat, potato, maize, and vegetables are increasing in importance. Because of Bangladesh's fertile soil and normally ample water supply, three crops of rice can be grown each year in many areas. Bangladesh's labor-intensive agriculture has achieved steady increases in food grain production, despite the often unfavorable weather conditions. However, population pressure continues to place a severe burden on productive capacity, creating a food deficit. Besides population pressure, agricultural land is shrinking by around 1% per year due to rapid urbanization.

The agriculture sector is vulnerable due to variability of meteorological parameters (precipitation and drought) and extreme events, such as floods, cyclones, and storm surges. Between 1949 and 1991, droughts occurred in Bangladesh 24 times. Very severe droughts hit the country in 1951, 1957, 1958, 1961, 1972, 1975, 1979, 1981, 1982, 1984, and 1989. Past droughts have typically affected about 47% of the area of the country and 53% of the population.

Flood is one of the major causes of crop devastation in Bangladesh almost every year. Floods affect about 80% of the land. In a normal year, 20%–25% of the country is inundated by river spills and drainage congestion. Devastating floods of 1987, 1988, and 1998 inundated more than 60% of the country. The 1998 flood alone caused 1,100 deaths, inundated nearly 100,000 square kilometers, rendered 30 million people

Table 4: **Impact of Major Floods in Bangladesh**

Event	Impact
1954 floods	Affected 55% of the country
1974 flood	Moderately severe, over 2,000 deaths, affected 58% of the country, followed by famine with over 30,000 deaths
1984 flood	Inundated 52,520 square kilometers, damage estimated at $378 million
1987 floods	Inundated over 50,000 square kilometers, estimated damage of $1.0 billion, 2,055 deaths
1988 floods	Inundated 61% of country, estimated damage $1.2 billion, more than 45 million homeless, 2,000–6,500 deaths

homeless, damaged 500,000 homes, and caused heavy losses to infrastructure. In 2004, floods inundated 38% of the country. Table 4 shows some impacts of major floods.

The coastal regions of Bangladesh are subject to damaging cyclones almost every year. They generally occur in early summer (April–May) or late rainy season (October–November). Tropical cyclones in coastal systems and low-lying areas account for 86% of mortality in Bangladesh (Murray et al. 2012). Though the strongest storms (categories 3–5) are comparatively rare, they are generally responsible for the majority of damage. Cyclones and storm surge cause serious damage to crops.

Every year, climate-induced natural disasters cause either partial or total loss of crops in different areas of Bangladesh. For example, Cyclone Sidr, which hit Bangladesh in 2007, caused more than 3,000 deaths and the damage to agriculture was estimated to be in excess of $3 billion (Hasegawa 2008). A summary of agricultural losses in Bangladesh in different years is presented in Appendix 2, based on information from the Disaster Management Bureau.

The effect of temperature on agriculture is complex due to a number of interplaying factors. However, while higher carbon dioxide levels and solar radiation theoretically can increase food production, heat stress, shorter growing seasons, and higher evapotranspiration resulting in soil moisture levels being lowered counteract the former influences, leading to overall lower production of most foodstuffs, including most varieties of rice, wheat, and potato. Reductions in production could potentially be as high as a 17%–28% for rice and 31%–68% for wheat (Karim et al. 1999).

Coastal and Marine Resources

The majority of the coastal area of Bangladesh lies within the delta of the Ganges–Brahmaputra–Meghna river system. The coastline of Bangladesh is 710 km long. The coastal zone covers an area of 47,201 square kilometers and was inhabited by 36.8 million people as of 2001, increasing 8.1 million from a century earlier. The coastal population is projected to grow to about 43.9 million in 2015 and 60.8 million in 2050. The zone has diverse natural resources, including coastal fisheries (especially in the Bay of Bengal), forests, salt, and minerals. It has sites for export processing zones, harbors, airports, land ports, and tourism complexes, and opportunities for other industries. This zone also has high potential for exploitation of both onshore and offshore natural gas. The coast also contains several ecosystems that have important conservation value.

The coast of Bangladesh is known as a zone of vulnerabilities as well as opportunities. It is prone to natural disasters like cyclones, storm surges, and floods. The combination of natural and human-made hazards, such as erosion, high arsenic content in groundwater, water logging, earthquake, water and soil salinity, various forms of pollution, and risks from climate change, have adversely affected lives and livelihoods in the coastal zone and slowed down the pace of social and economic development in this area. Weather and climate extremes put an additional risk to many of the fastest-growing coastal urban areas in Bangladesh (McGranahan et al. 2007, Smith 2011). Storm surges generated by cyclones have destroyed coastal embankments and saline water has engulfed large swathes of densely populated areas.

Despite reasonably effective disaster management programs compared with those in many other developing countries, institutional weaknesses have surfaced during and after cyclones. Some destroyed embankments were still not repaired 2 years after Cyclone Aila in 2009. Many affected people were yet to be rehabilitated (Kartiki 2011). The groundwater aquifers in the coastal districts are under growing stress of salinization resulting from overextraction. Sea level rise and low river flows substantially contribute to that stress. Winter agriculture in the coastal areas is dependent on groundwater.

Energy

Energy security is crucial for the economic growth of Bangladesh. In 2012–2013, a total of 38,229 million kWh net energy was generated, of which 78% came from gas sources (Power Division, Ministry of Power, Energy and Mineral Resources). An additional 1,200 MW captive power production is taking place which is also gas-based. Besides natural gas, imported oil and coal are the two main sources of energy production in Bangladesh. Renewable energy produces close to 20 MW of electricity with solar being the dominant source. Table 5 provides a list of sources for generating energy in Bangladesh.

Some 23 onshore and offshore gas fields are known in Bangladesh. However, only 12 are in operation, with remaining reserves estimated at 12.9 trillion cubic feet. The total recoverable reserve is estimated at 20.1 trillion cubic feet. Five coal fields have been identified in Bangladesh. Known reserves and resources are around 2,700 million tons. However, the country still awaits the adoption of a national coal policy before any coal extraction will take place. Major political debate is taking place over extraction methods, etc.

Table 5: **Sources of Energy Production in Bangladesh**

Energy and Power Source	Source Use 2008
Natural gas	600 bcf
Oil	3.7 million tons
Coal	3.5 million tons
Hydropower	1.0 TWh
Biomass	55 million tons
Solar photovoltaic	18 MW
Wind	1.0 MW

bcf = billion cubic feet, MW = megawatt, TWh = terawatt hour.

Solar energy is the most explored renewable energy option. Country-wide wind studies at heights up to 6 meters indicate that onshore wind speed is too slow to have significant commercial potential for wind energy. Biogas is believed to hold significant potential in Bangladesh. However, very limited experience with large-scale biogas systems exists.

Bangladesh's 160 million residents have seen growth rates of around 6% annually for the last decade. In 2009, GDP growth was estimated at 5.8%, with that in 2010 estimated at around 6%. Per capita power generation is about 321 kilowatt hours (kWh) (as of 2013), among the lowest in the world. Close to 40% of the population do not have access to gas and electricity. The government has developed a Power System Master Plan 2010, based on which about 4,432 MW of power (as of September 2013) has been added to the grid in the 2010-2013 period (Power Division, Ministry of Power, Energy, and Mineral Resources). At present, 3,800 MW is produced each year, while demand is soaring at around 5,500 MW and growing at about 500 MW a year.

Projected climatic changes can affect both energy generation (especially hydropower and thermal) and energy demand during hot summer seasons (especially during peak hours). Further, regular cyclones and floods cause power supply failures and infrastructure damages.

Energy demand for rural irrigation is an important component in Bangladesh. An increase in drought conditions can have severe impacts on energy demand, as pumping load rises with falling water tables. Currently, the energy demand–supply gap worsens during irrigation periods, when the system is already suffering from 600–1,200 MW of "load shedding" (REIN 2009). This can produce a negative feedback loop where poor farmers are economically hit hard due to both the reduced harvest and energy supply shortages

Climate-induced energy demand for space heating or cooling depends mostly on already existing air-conditioning or heating infrastructure. With 80% of the population rurally based, the quantifiable impact on energy demand may be less than in other countries. However, this means that living conditions of poor people may worsen, as they may have to tolerate excessive heat or cold due to climate change.

Forest and Other Ecosystems

Forests provide materials like timber, pulp, pole, fuelwood, food, and medicine; habitat for wildlife; and a primary base for biodiversity. They also provide oxygen, control or reduce the intensity of the cyclones and tidal surges in the coastal areas of Bangladesh, and influence rainfall and water yield in the river systems. Besides these, forests are used for hunting and ecotourism. Of the total area of Bangladesh, agricultural land makes up 65% of its geographic surface, forest lands (2.52 million hectares) account for almost 17%, and urban areas are 8%. Water and other land use account for the remaining 10%.

Bangladesh's floodplains form some of the world's most important wetlands, which are home to hundreds of species of unique plants, fish, birds, and other wildlife. These wetlands provide critical habitat for migrating birds and most importantly are a source of income and nutrition for millions of people in Bangladesh. The floodplain fishery plays a vital role in cushioning rural poverty and supplying animal protein to the poor; it is an integral part of the culture and lifestyle of the Bengali people.

Many of the anticipated adverse effects of climate change, such as sea level rise, higher temperatures, and an increase in cyclone intensity, will damage the forest resources of the country, put pressure on many climate-sensitive species, and cause increased erosion and deterioration of soil quality in many upland forested areas. The world largest mangrove forest, the Sundarbans, is extremely vulnerable to climate change. Sea level rise will increase saltwater intrusion and negatively affect the forest. Smith et al. (1998) calculated that a 25 cm sea level rise would result in a 40% mangrove loss. Loucks et al. (2010) predict a 96% decline in tiger habitat in Bangladesh's Sundarbans mangroves with a 28 cm sea level rise if sedimentation does not increase surface elevations. Considering that the salinity regime inside the forest will significantly change as a consequence of climate change, it has been argued that increased salinity would have discernible adverse impacts on forest regeneration and succession (Khan et al. 2008).

Health

Health levels of Bangladesh's people remain relatively low although they are improving due to the decrease of poverty. Most Bangladeshis continue to live on subsistence farming in rural villages. Health problems abound, springing from poor water quality and prevalence of infectious diseases. The water crisis is acute, with widespread bacterial contamination of surface water and arsenic contamination of groundwater. Common diseases include malaria, leptospirosis, and dengue.

Under climate change, people are exposed directly to changing weather patterns and indirectly through changes in the quality of water, air, and food; and changes in ecosystems, agriculture, industry, human settlements, and the economy. Water-borne diseases, such as diarrhea and dysentery, and vector-borne diseases, such as malaria and dengue, are climate sensitive. Climatic factors like temperature and precipitation are considered to be the key determinants of the distribution of many disease-carrying vectors.

Water

Bangladesh is mostly a deltaic country characterized by a dense network of rivers, *khals* (floodplain channels), and wetlands. Water resources play a significant role in the rural economy, where over three-quarters of the population live. A large section of the rural poor is dependent on natural water bodies in floodplains and watersheds for livelihoods—food production, fishing, harvesting wetland plants, operating boats, and other activities depend on water resources.

Because 92% or more of Bangladesh's annual runoff enters the country from outside its borders, there is a high degree of uncertainty about the amount of water that will be available from transboundary rivers in future. River flows have very large seasonal variations. In the monsoon season, the combined flow of the Ganges and the Brahmaputra reaches a peak of 80,000–140,000 cubic meters per second (m^3/s) in the July–August or early September period. Dependable flow (80%) in the Ganges (according to Ganges Water Treaty) can be less than 1,000 m^3/s from February to April. In the Brahmaputra, the dependable flow is less than 4,000 m^3/s during March and April (WARPO 2001).

Climate change will cause four major types of problems that will affect natural water resources of Bangladesh. The increased glacier melt due to higher temperatures will increase runoff from the neighboring Himalayas into the Ganges and Brahmaputra rivers. Given the altitude of the mountains and the enormous size of the glaciers, this problem will most likely continue over the century. The second problem is due to the increased precipitation as forecast by many climate models. While this is not certain, increase of precipitation would increase runoff in the Ganges, Brahmaputra, and Meghna rivers. This would aggravate flood-related disasters. The third problem is sea level rise, which will result in coastal flooding and prolong riverine flooding by causing more backing up of water in the three rivers. Finally, the increased intensity of cyclones and precipitation will enhance storm surges and coastal flooding.

Bhutan

Agriculture

In Bhutan's 9th Five-Year Plan[5] period (2002–2007), the agriculture sector contributed 12% to GDP growth, of which 33% came from agriculture, 22% from livestock, and 45% from forestry (Ministry of Finance 2002). Until 2006, agriculture led the economy, contributing 22% to GDP growth, but has since been declining with increase in the growth of electricity and tourism (National Statistics Bureau 2009). The agriculture sector provides livelihood to 66.6% of the Bhutanese population (National Statistics Bureau 2010).

According to the GEF and World Bank-funded Land Cover Mapping Project (MoAF 2010), cultivated agricultural land accounts for 2.93% of the total land, of which dryland (*kamzhing*) dominates with 61.90%, followed by wetlands (*chhuzhing*) with 27.86%, and horticulture land with 10.24%. The area of cultivated agricultural land has decreased by 2,020 km^2 from 40,077 km^2 since the assessment by the Land Use Planning Project (1995).

Agriculture depends heavily on the monsoon and temperature patterns. According to the National Adaptation Program of Action (NEC 2006), climate change may cause crop failure and stress on livestock rearing, which will affect the rural poor who depend on crops and livestock. Occurrences of glacial lake outburst floods (GLOFs), due to glaciers retreating with increase in temperature, would also cause much damage to cropland as well as death and injury to livestock, and eventually lead to food insecurity in the country. Considering that 31% of the agricultural land is located on slopes, the country is also likely to face increasing landsides and land degradation.

Energy

Bhutan’s economy is based on hydropower resources; 99% of the electricity supply is from hydropower generation and the electricity sector contributes 31% of national revenue (MoF 2010). The country is highly vulnerable to climate change due to its mountain ecosystems and high dependency on hydropower. The impacts on hydropower could include threats from glacier melting and perturbation in natural water resources.

[5] Bhutan's 9th Five-Year Plan is the country's national economic development plan published by the Department of Planning, Ministry of Finance, Royal Government of Bhutan.

Forest and Other Ecosystems

Forests play an important role in the socioeconomic development of Bhutan, as integral parts of the farming systems. They protect watersheds and catchments crucial for generation of hydropower.

Health

Malaria is an important vector-borne disease in Bhutan, especially in the southern lower-elevation regions, and is likely to spread as suitable temperatures reach higher altitudes. Climate-related events in Bhutan like GLOFs and landslides have indirect effects on the health status of Bhutanese communities due to the resulting food insecurity.

Water

Bhutan is endowed with a number of rivers fed by glacial lakes originating from the medium to the high Himalayas, with long-term average annual flows of 73,000 million cubic meters per year. The major rivers provide water for hydropower and tourism/recreation. Tributaries and streams provide for all other uses with emphasis on water supply and irrigation. Subsurface sources, in the form of springs and aquifers, provide water for domestic supply and small-scale irrigation. The country has not recorded water shortages until now as it has 109,000 cubic meters per capita mean annual flow availability of water (Climate Summit for a Living Himalayas Bhutan 2011). However, there are reports of drying out of smaller streams putting at peril the water sources for irrigation and drinking.

At least 24 glacial lakes pose potentially high risk of GLOFs (ICIMOD 2010b). The melting ice from retreating glaciers is increasing the volume of water in glacial lakes. The melting of ice-cored dams is destabilizing the lakes. Also, future erratic and unpredictable rainfall patterns would reduce the ability of catchments to retain water, leading to increased runoff and enhanced soil erosion. The potential risk of costly economic damage from GLOFs on key development sectors, such as agriculture, hydropower, and forestry, is mounting.

India

Agriculture

India is one of the largest agrarian economies in the world. The sector contributed approximately 14.2% to GDP during 2009/10,[6] providing employment and livelihood opportunities to most of the rural population and contributing to international trade. The net irrigated area of the country is approximately 20.3% of the total area.

Crops are categorized into two varieties. Those sown in the winter season are called *rabi* crops, which include wheat, barley, peas, gram, and mustard. Precipitation during winter months due to the western temperate cyclones helps in the success of these crops. Crops sown in the rainy season are called *kharif* crops, such as rice, maize, pulses,

[6] MoF (Ministry of Finance). 2011. *Indian Public Finance Statistics 2010–2011*. Economic Division, Department of Economic Affairs, Government of India. New Delhi. July.

groundnut, and sugarcane. These crops are sown during the beginning of the southwest monsoon season in India. Changes in temperature and precipitation, with extreme conditions resulting in floods and droughts, will significantly affect the crop production in the country.

Coastal and Marine Resources

India is rich in coastal and marine habitats, such as mangroves, coral reefs, and sand dunes. The coastline of about 8,000 km faces the Indian Ocean, Arabian Sea, and Bay of Bengal. The marine flora and fauna are of great importance to the nation's economy, since they are the source of food, fodder, fertilizers, chemicals, drugs, and various other commercial products. Rising sea levels will increase coastal erosion and lead to saltwater contamination of groundwater supplies, threatening the quality and quantity of freshwater access for a large percentage of the population.

The coastal wetlands play an important role in the economy of the nation, especially in fisheries. Also, mangroves and coral reefs are important nurseries for fish, shrimp, and crabs. Mangroves are mainly distributed along the east coast of the country and to a lesser extent along the west coast. With the exception of the mangroves of the Andaman and Nicobar Islands, mangroves are already considerably degraded. According to an estimate made by Parikh et al (1999), the mangrove cover of the country fell by 35% during 1987–1995 alone.

Climate change impacts on the mangrove ecosystems would result from sea level change, storm surges, freshwater flows in rivers both from precipitation in their catchments and from snow melt in the mountains, local precipitation, and temperature changes that would influence evapotranspiration. Increased snow melt in the western Himalayas could bring larger quantities of freshwater into the Gangetic delta. This would have significant consequences for the composition of the Sundarbans mangroves. Changes in local temperature and precipitation would also influence the salinity of the mangrove wetlands and have a bearing on plant composition.

Coral reefs are distributed in six major regions along the Indian coastline and are already under threat from anthropogenic and natural factors, including destructive fishing, mining, sedimentation, and invasion by alien species. Increased sea surface temperature (SST) results in 'bleaching' of corals. While bleaching is a normal event and is reversible, a prolonged increase in SSTs and/or intense bleaching may result in the death of the corals. In recent decades, the most widespread and intense bleaching of corals ('mass bleaching'), including in the Indian Ocean, occurred during 1997–1998 associated with El Niño when SSTs were enhanced by over 3°C, the warmest in modern record. The corals of the Lakshadweep islands were, however, significantly affected by this event with bleaching of over 80% of coral cover and mortality of over 25% of corals. The corals of the Gulf of Mannar were similarly affected. The most affected were shallow water corals, such as the branching Acopora and Pocillopora that were almost completely wiped out. Bleaching also affected the massive corals but these recovered and now dominate the reefs. The least affected coral reefs were those in the Gulf of Kutchh with an average of about 10% bleaching and little mortality. Changes in salinity and temperature and ocean acidification can compromise the calcification potential of coral reefs and hence, result in slow growth (Naseer 2006, MEEW 2007). Annual spawning of corals may be disrupted by “unseasonal” temperatures.

Energy

Primary energy demand in India was growing at 3.2% per year in 2000–2005. The International Energy Agency projects demand to more than double by 2030 in a reference scenario (i.e., no policies to slow demand) due to a projected annual growth rate for GDP of 6.3%. The primary energy demand growth areas will be industrial (mostly steel) and transport. In this scenario, India will become the world’s third-largest carbon dioxide emitter by 2030, although per capita emissions will still be comparatively low, since approximately 412 million people in the country are still without access to electricity (OECD/IEA 2011).

India’s current electrical system runs mostly on domestic coal. The transportation sector uses mostly imported oil; domestic production is 785,000 barrels/day against a demand of 2.45 million barrels/ day (2004 estimated).

The energy sector has an important role in the economic growth of India. The energy comprises both nonrenewable (coal, lignite, petroleum, and natural gas) and renewable energy sources (wind, solar, small hydropower, biomass, cogeneration, bagasse, etc.).

Some renewable energy sources, such as biomass fuels and hydropower, are under pressure from climate change. Although urban residential use of biomass is projected to decrease due to expansion of commercial fuels, rural biomass use is still expected to remain at high levels. Biofuel crops will be affected by climate change, although other socioeconomic pressures like deforestation for timber may have a much bigger impact. Hydropower, like other water uses, will be subject to impacts of climate change.

Energy-related water shortage will worsen, since Indian farmers have access to heavily subsidized power to pump water for irrigation (Shah et al. 2004). The low costs encourage wasteful water use, depleting water tables. As water tables lower, larger pumps require more power to access deeper water supplies. The energy demand for accessing water will grow with climate change due to higher temperatures and prolonged drought conditions. This will affect the socioeconomic conditions of already poor farmers.

Forest and Other Ecosystems

After agriculture, forests occupy the most land in India, and are an important natural resource for the country. Climate change can result in serious impacts on natural ecosystems. Increasing temperatures usually result in increasing forest fires and pest and disease infestation in forests. Intermittent occurrences of drought and floods also result in increase in soil erosion and degradation of watersheds, lowering forest cover. Climate change could cause shifts in forest boundaries, changes in species assemblage or forest types, changes in net primary productivity, possible forest dieback in the transient phase, and potential loss or change in biodiversity. Enhanced levels of carbon dioxide are projected to result in an increase in the net primary productivity of forest ecosystems over more than 75% of the forest area.

The effects of climate change have already begun to appear in the Himalayan region in the form of a shift in the arrival time of the monsoon, long winter dry spells (5–6 months as experienced in 2008 and 2009), increased frequency of forest fires during winter, and early flowering and fruiting of native trees. With the current level of increase in mean annual temperature over various parts of the Himalayas, an upward movement of plants is expected. There is evidence that high-altitude tree growth has accelerated in the last few decades (Borgaonkar et al. 2010).

The forest ecosystems of the Himalayan ecoregion are the most vulnerable to climate change. Coastal regions and the Western Ghats are moderately vulnerable to climate change, while forests in the northeast are projected to be minimally impacted by climate change in the short term.

Forest cover of India has been increasing steadily over the years due to the adoption of various conservation and climate-friendly policies of the government, despite the diversion of forest land for agriculture and development activities.

Health

Currently, India's public health care system produces relatively poor health outcomes. The healthy life expectancy, which includes adjustment for time spent in poor health, was 53 years for children born in 2003. Despite perceived strengths of the national public health system, implementation and monitoring of services are weak. Funding for control of communicable diseases has been deemphasized since the 1980s; several infectious diseases, such as tuberculosis and malaria, have reemerged as public health care concerns.

Water

India has abundant surface water and groundwater resources. The main water resources are precipitation, estimated to be around 4,000 billion cubic kilometers per year (BCM/year),[7] and 500 BCM/year in transboundary flows from the upper riparian countries. Of the total precipitation, the availability from surface water and replenishable groundwater[8] is estimated at 1,869 BCM/year. Extreme conditions from floods and droughts are a common feature in the country. The water requirement for various sectors as of August 2000 is shown in Table 6.

The National Water Mission, which is a part of the National Action Plan on Climate Change (MoWR 2010), identifies the following threats to water resources in India due to climate change:

- expected decline in the glaciers and snowfields in the Himalayas;
- increased drought-like situations due to the overall decrease in the number of rainy days over a major part of the country;
- increased flood events due to the overall increase in the rainy day intensity;

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7 One billion cubic meters (BCM) is equivalent to one cubic kilometer.

8 Replenishable groundwater is the exploitable quantity of groundwater, which is recharged annually.

Table 6: **Assessment of Availability and Requirement of Water in India**

	Water Demand (billion cubic meters)			
Sector	2000	2010	2025	2050
Irrigation	541	688	910	1,072
Drinking water	42	56	73	102
Industry	8	12	23	63
Energy	2	5	15	130
Others	41	52	72	80
Total	634	813	1,093	1,447

Source: CWC (Central Water Commission). 2000. *Report of the Standing Sub-Committee for Assessment of Availability and Requirement of Water for Diverse Uses in the Country*. New Delhi: CWC, Ministry of Water Resources, Government of India.

- influence on groundwater recharge due to changes in precipitation and evapotranspiration; and
- increased saline intrusion of coastal and inland aquifers due to rising sea levels.

The surface area of glaciers across the Tibetan Plateau is projected to decrease from 500,000 km^2 in 1995 to 100,000 km^2 in 2030, thereby threatening regional rivers and water resources. With glacial and snow retreat, many of the semi-arid mountains, inhabited by some 170 million people, will lose some of their local springs and streams, essential to villages and livestock grazing. In addition, increasing flash floods and rockslides degrade roads and trails. Most watersheds have experienced substantial deforestation and overgrazing, making the hillsides much more vulnerable to landslides, either during peak snowmelt or in relation to tectonic activity.

The Maldives

Agriculture

Agriculture is a crucial sector in the Maldives in terms of national development goals, poverty alleviation and sustainable livelihood, nutritional status of the people, retention of foreign currency, and employment. It is also a primary sector of the economy; growth in other sectors—transport and communication, construction, financial services, and real estate—is dependent on agriculture (MFA 2009). The total land area of 235 km^2 is divided among 1,192 coral islands that are unstable and subject to change in size, shape, elevation, and position on reef platforms (Shaig 2006a).

Crop production is naturally dependent on climatic conditions and therefore is vulnerable to changes in climate. Climatic risks to the agriculture sector are further exacerbated by limited cultivable land (27 km^2), low elevation (80% of total land area is less than 1 meter above mean sea level), poor soil quality, and scarce water resources. Nearly all the islands are less than 1 km^2 in area (Shaig 2006a).

The islands are at present affected by beach erosion resulting in loss of land and flooding due to storm surges. In May 2007, a series of storm surges hit 68 islands across 16 atolls of the Maldives, causing inundation up to 600 meters from the coastline (OCHA 2007).

Agriculture depends on groundwater, which is vulnerable to saltwater intrusion and flooding due to rising seas and extreme weather events (MEEW 2007). Water for irrigation is extracted by digging wells or ditches 1–2 meters deep and using pumps (MFA 2009). Use of groundwater for irrigation competes with extraction of groundwater for nonpotable purposes on inhabited islands. Due to the paucity of groundwater many farmers use rainwater as a supplementary source of water for agriculture (MFA 2009). The freshwater lens is unconfined in nature and depends on the recharge rate from rainfall, size of the island, and geological conditions (Falkland 2001). The lens is prone to infiltration of saltwater from sea level rise and ocean-induced flooding, resulting in a saline groundwater aquifer (Pernetta and Sestini 1989).

Coastal and Marine Resources

Coral reefs in the Maldives are crucial to the survival of the country as it is a nation of coral islands. These are also the first line of defense against sea level rise and severe weather. The coral reef ecosystem provides important goods and services that are linked to economic and social development. Two main activities of tourists, snorkeling and diving, are based on marine life.

Coral reefs are linked to the fisheries sector; the growing reef fishery has emerged as an important contributor to tourism (Adam 2006). Demand for reef fish has increased threefold in the last 15 years (Sattar 2008).

As in other tropical coasts, threats to the reefs from climate change include dilution of seawater and mortality of coral due to higher temperatures. Changes in SST and ocean acidification can compromise the calcification potential of coral reefs and hence, result in slow growth (Naseer 2006, MEEW 2007). Coral reefs are made further vulnerable due to dependency of reproduction on environmental conditions. Coral reefs reproduce by mass spawning that occurs in cycles. Spawning and recruitment in coral reefs are highly attuned to environmental conditions.

Energy

Although the Maldives has solid plans to increase electricity usage, the geography of the country works as a barrier to grid connection. The country is dependent on imported fossil fuel to meet the national energy demand, including for power generation, transportation, lighting, and food preparation. The types of fuel used are diesel fuel oil, gasoline, aviation fuel, kerosene, and liquefied petroleum gas. In the absence of conventional energy sources, diesel-powered generators are the main source of power. The country depends significantly on tourism and providing energy for the sector remains vital for economic growth. Thus, the country's renewable energy sector is attracting huge attention, particularly solar and wind energy. Cost-effective renewable energy development is vital to the Maldives (Musthafa 2011).

Among the main factors increasing the pressure on energy demand are a high population growth of 3% per year, a high urbanization trend, and growing tourism.

All powerhouses and related infrastructure are at an elevation of 1.5 meters above mean sea level and generally within about 200 meters of the coast on either side; those on about 80% of both inhabited islands and resorts are within 100 meters of the coast (Shaig 2006b). The low elevation combined with the narrow width of the islands makes powerhouses and associated infrastructure vulnerable to flooding and damage from severe weather events.

Health

Vulnerabilities of human health to climate change in the Maldives are attributed to geographical, environmental, and socioeconomic factors (MHAHE 2001, Moosa 2005, MEEW 2007). The changes in weather conditions associated with climate change create favorable environments for vector-borne diseases. This is evident from more frequent dengue outbreaks in recent years. Conditions that encourage outbreak of vector-borne diseases are further exacerbated by congestion in settlements.

The low elevation and small size of islands make human settlements susceptible to stormy weather and flooding (MEEW 2007, MHAHE 2001), causing physical injuries and damage to property, salinization of freshwater supplies, and disruption to water supplies, resulting in escalation of water-borne diseases (MEEW 2007), particularly among children under 5 years of age (Moosa 2005). Also, critical infrastructure, such as for healthcare, communications, and transportation, is located close to the coastline at high risk from sea level rise and storms

Water

Groundwater is an important source of freshwater for nonpotable purposes like irrigation for agriculture, but it is vulnerable to saltwater intrusion. Rainwater has become the main source of drinking water for an estimated 77% of people and in 92% of households due to deteriorated groundwater in many islands. Approximately 30% of the atoll population suffered water shortage in 2004. However, rainwater resources are susceptible to changes in rainfall patterns.

Nepal

Agriculture

Agriculture is the major sector of the Nepalese economy. It provides employment opportunities to 66% of the total population and contributes about 39% of the GDP. The country's agricultural systems depend on water sourced from snow, ice, and glacial melt. The prospects of reduced water supply during the dry season are becoming imminent, as recent winter droughts are showing the effects of water scarcity. The western regions will be the most affected because these parts depend heavily on winter rains rather than on the summer monsoon.

Increased temperatures and rainfall variability have already resulted in shifts in Nepal's agroecological zones, prolonged dry spells, and higher incidence of pests and diseases. Studies show that new alien and invasive species are emerging, and their habitats are spreading fast. Farming communities have reported experiencing seasonal changes in the sprouting, flowering, and fruiting of crops. In some cases, these changes have benefited communities by expanding the ecological range of cultivation of certain crops. In other cases, climatic changes have had negative impacts, for example, on the productivity of important crop and fodder species. Green grasses have also declined sharply in the Himalayan region.

The effects of climate change on agriculture in Nepal can be divided between systems that are dependent on the summer monsoon and those that are dependent on snow, ice, and glacial melt. The latter will see few years' increase in water supply, but will also be in greater danger of GLOFs that threaten crops, water infrastructure, and mountain livelihoods in general. Whether such an increase will consequently increase productivity in the short term is unknown, as very little exists in terms of water storage in Nepal to harvest such an excess supply of water. Long-term effects of reduced water storage and variability of supply from earlier thawing of the snowpack and deglaciation have the potential to be significant, with glacial melt accounting for 30% of per capita consumption in some lowland regions (Eriksson et al. 2009) and increases in temperature causing consequent increases in agricultural water demand (IPCC 2007). Unfortunately, because these effects are not likely to be felt for decades, the short-term benefits of increased runoff will likely delay any comprehensive long-term proactive management plans.

For systems dependent on the summer monsoon, multiple scenarios are possible due to the pervasive uncertainty, where the monsoon could abruptly transition between "dry" and "wet" states. In the short term, however, there is more certainty that less precipitation is likely to occur during the summer months as the number of rainy days decreases, even though the frequency of intense rainfall events will increase (United Nations Environment Programme 2009). Increasing variability of precipitation patterns will have a significant effect on crop productivity, as farmers will have to adapt to changing onset and termination dates of the monsoon. Later start dates significantly impacted rice crops in 2009, as many seedlings were lost due to the delay in rainfall, and many did not have time to mature enough for a viable yield (Subedi and Singh 2008, Bartlett et al. 2010).

The impacts of less water during the dry months are much easier to visualize, as recent winter droughts have continued to show the effects of low water supply. During the drought of fall 2008 to spring 2009, agricultural systems experienced significantly reduced crop yields, resulting in food insecurity for millions. Such effects would be augmented by a more intense dry season. Western regions will be the worst affected because they rely heavily on winter rains and cannot depend as reliably on summer monsoon rains, which are not as intense in the west due to the natural pattern of rainfall intensity from east to west (Water and Energy Commission Secretariat 2005).

Extreme poverty and high levels of malnourishment make even the slightest fluctuation in climate potentially disastrous to the economy. The population is thus extremely vulnerable, not only to longer-term climate change that will ultimately reduce water availability and limit crop productivity, but even more so to the immediate threats of increasingly frequent GLOFs, landslides, flash floods, and droughts.

Energy

Most (91%) of Nepal's power supply is based on hydroelectricity. Increased climate variability, including the frequency and intensity of flooding and droughts, could have a severe effect on the country's vital hydropower plants.

Nepal's development is severely restricted by lack of access to energy. Over 85% of the population relies on traditional biomass for energy supplies and 18 million people do not have access to electricity (ADB 2009b). Irregularities in stream flow affect the reliability of hydropower, and siltation from landslides and flood events further reduces power generation efficiency.

Glacier retreat causes greater variability (and eventual reduction) in stream flow, and GLOFs pose significant risks to hydropower facilities and downstream human settlements. A case in point was the near total destruction of the newly built Namche Bazaar hydropower facility in 1985. Similarly, flooding, landslides, and sedimentation from more intense precipitation events (particularly during the monsoon), as well as greater unreliability of dry season flows, pose potentially serious risks to water and energy supplies (OECD 2005).

Forest and Other Ecosystems

Because of the growing popularity of Nepal's varied cultural and ecological diversity, ecotourism is an attractive option for some communities. However, forest ecosystems are deteriorating and biodiversity is suffering from climate change, probably related to higher temperatures in lower altitudes, upward shifting of vegetation, encroachment of invasive species, and increased prevalence of disease and pests. The prolonged winter dry spells have increased the incidence of forest fires, which have destroyed large forest areas and forest biomass and increased the emission of carbon dioxide into the atmosphere.

Upward shifting of ecological belts is expected with the rise in temperatures. However, upward movement of species will be limited due to adverse environment for their growth (e. g., soil and moisture conditions). Tree line shifting is expected to be slow because of the limited natural dispersal of seeds. Therefore, high-altitude species, such as birch, Jatamansi, and Kutki, are likely to become more vulnerable with increased climatic and human-induced stresses. Habitats for mountain fauna, such as the snow leopard, are increasingly threatened due to increased temperature. Reduced snowfall, untimely rains, and increased dryness have altered the flowering and fruiting behavior of plants, which is closely related to the survival of wildlife. When seasons of food availability change, they change the periodicity of life cycle events of animals and insects, such as reproduction, migration, and hibernation. This results in serious vulnerability for wildlife and is a threat to the people who depend on biodiversity for their livelihoods.

Endemic poverty of the population and their dependence on subsistence agriculture have been the major causes of deforestation in Nepal although the rate of deforestation has slowed down in recent decades due to successful introduction of community forestry programs in the early 1980s. In a recent survey (Dahal 2005), villagers related climate change to warming in certain places that was not observed few decades ago; low-elevation crops are growing at a much higher elevation without the need for greenhouses. Also, snowfall has decreased, causing summer water shortages. Villagers also found more evidence of insect and pest infestation moving higher on some trees, such as apple and pear trees. In recent years, the yield of cardamom is decreasing due to more insect attacks caused by the warmer climate (Thakur 2009).

Health

Effects of climate change are evident in public health. With the rise in temperature, the risk of vector-borne and water-borne diseases also increases. The incidence of vector-borne diseases, such as malaria, kalazar, and Japanese encephalitis; and water- and food-borne diseases, such as diarrhea, dysentery, typhoid, cryptosporidiosis, giardiasis, amoebiasis, gastritis, jaundice, and infectious hepatitis, have been increasing with the rise in temperature (Department of Health Services 2007, 2009). Water- and food-borne diseases have shown increasing trends both at temporal and spatial scale (MoHP et al. 2007). The outbreak of diarrheal diseases has been attributed in part to water shortages due to winter drought and delayed onset of the summer monsoon (Oxfam 2009).

In addition to these disasters, temperature-related illness and death from cold and heat waves have been increasing in recent years (Department of Health Services 2009). The historical evidence in Nepal indicates that prolonged droughts and flash floods have triggered ecological disasters, famines, and disease outbreaks. The poor are the most vulnerable communities in Nepal. Those who are living along the banks of the rivers, over the steep slopes, and in slums and squatter settlements and remote areas are most vulnerable (CARE Nepal 2009).

Water

Nepal is endowed with abundant water resources. There are about 6,000 rivers, with a drainage area of 191,000 square kilometers, 74% of which lie in Nepal alone. There are 33 rivers whose drainage areas exceed 1,000 square kilometers (Water and Energy Commission Secretariat 2011).

The effects of the changes in precipitation and temperature are expected to change the balance between "green water"[9] and "blue water"[10]. Glacial melting and retreat, rapidly thawing permafrost, and continually melting frozen soils in higher elevations are already being observed (Eriksson et al. 2009). In the sub-basins dominated by glaciers, this will mean increased downstream flows in the short term, but in the long term, runoff is expected to decrease with the retreating glaciers, causing major reductions in flow and significantly affecting downstream livelihoods and ecosystems (Bates et al. 2008). In the past 90 years, a glacier in the Sagarmatha region has receded 100 meters vertically. Because of glacier melting, new glacial lakes have formed.

In the winter months, more precipitation is falling as rain, which also accelerates deglaciation, and in turn means a shorter winter and earlier snowmelt, ultimately affecting river basins and agricultural systems dependent on surface water diversion for the summer growing season. Another particularly significant threat directly correlated to rising temperatures in Nepal as in other Himalayan countries is the increasing potential for GLOFs.

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9 "Green water" is the water that is used or lost in catchments before it reaches the rivers.

10 "Blue water" is the runoff that reaches the rivers.

Sri Lanka

Agriculture

For more than 2,500 years, Sri Lanka has been an agrarian-based society and agriculture remains a key component of the economy as well as the island's cultural base. Despite the gradually declining economic importance of agriculture, the rural population, which constitutes the major segment of Sri Lanka's population, is dependent on rainfall-based sources of income, such as agriculture, livestock production, and inland fisheries.

Currently, more than 26,100 square kilometers are under agriculture. Much of the agricultural land is located in the water-deficient dry zone, where productivity of crops depends entirely on rainfall. The varied climatic conditions in farming systems have given rise to a wide range of crop species that are suited for varied conditions of soils, rainfall, and altitude as well as to diseases and insect pests.

Vulnerability of the agricultural community to climate change will be influenced by several socioeconomic factors, including level of poverty and food security, insecurity of land tenure, education levels, dependence on agriculture for livelihood, availability of irrigation water, supporting institutional framework, and government policies. Farming districts with heavy reliance on primary agriculture, few infrastructural and socioeconomic assets (or low adaptive capacity), and high level of exposure to historical hazards are the most vulnerable (Eriyagama et al. 2010). The vulnerability of rice crops to droughts is expected to increase, especially in the dry and intermediate zones. Tea plantations at low and medium elevations are more vulnerable to impacts of climate change than those at high elevations. Reduction of monthly rainfall by 100 millimeters (mm) could reduce productivity by 30–80 kg of tea per hectare (Wijeratne et al. 2007).

Extended dry spells and excessive cloudiness during the wet season can reduce coconut yield, with annual losses of $32 million to $73 million. However, during a high rainfall year, the economy could gain by $42 million to $87 million due to high coconut yields. Future projections on coconut yield suggest that production after 2040 may not be sufficient to cater to local consumption (Eriyagama et al. 2010).

Coastal and Marine Resources

Sri Lanka's coastal region covers about 23% of the island's land area (Coast Conservation Department 2006) and accommodates about 25% of the population, in addition to a heavy concentration of urban areas, tourism infrastructure, and industries that are vulnerable to impacts of sea level rise and increased frequency of storms and the intensification of coastal erosion due to climate change.

Much of the coastal zone lies within the dry zone, with an average annual rainfall of 1,250–1,750 mm and a temperature of around 28°C–32°C (Survey Department 2007). Sri Lanka is vulnerable to the risk of sea level rise and increased frequency of storms that can have major impacts on coastal ecosystems that support the marine food fishery. The increasing variability in temporal and spatial distribution of rainfall as well as the increasing temperature affect coastal areas and inland waters that are important for the food fishery industry.

Vulnerability of the fisher community to climate change will be influenced by several socioeconomic factors, including status of poverty and food security, education levels, present level of resources, alternative livelihoods, institutional support frameworks, and government policies. Some other factors that may aggravate vulnerability include use of unsustainable fishery practices (e.g., light fishing, blast fishing, and large-scale purse seining); overfishing; oil pollution from boats and ships; damage to mangrove and coral reef habitats due to overuse of mangrove resources, blasting of coral reefs, anchorage of boats near coral reefs, and dragging of nets; and haphazard construction and expansion of piers and fish landing points, which affect water flow and cause siltation of coastal waters and habitats. Some indirect activities that also increase the vulnerability of the coastal resources are sedimentation caused by inland soil erosion and land degradation; reclamation, sedimentation, and dumping of garbage in lagoons and estuaries; and construction of coast protection structures that alter patterns of sand movement.

Energy

Hydropower currently supplies 46% of Sri Lanka's energy needs but the major sites have all been tapped. Thus, there is increased investment in thermal (diesel, oil, and coal) power plants to meet expanding energy requirements. The current policy is to move from diesel and oil power plants to coal-fired power plants. Cleaner sources of power generation are also being promoted by the government through establishment of nonconventional renewable energy, such as solar, wind, and dendro-thermal power, and mini-hydropower.

Sri Lanka receives its highest rainfall (about 60%) during two seasons: the southwest monsoon and second intermonsoon period. Reservoirs used for hydropower normally recharge during these periods. Annual average rainfall has decreased over the last 57 years at about 7 mm per year, resulting in water scarcities in the dry zone (Rathnayake, et al. 2009). Lower rainfall during the first intermonsoon and changes in rainfall generally have affected hydropower generation (Rathnayake et al. 2009). This puts additional stress on the already insufficient energy resource base; this is in addition to high transmission and distribution losses. Increasing temperatures also mean higher demand for cooling buildings.

Forest and Other Ecosystems

Sri Lanka's rich and unique biodiversity forms the basis for the country's natural heritage, and is a core feature of its cultural heritage and economic advancement. Despite its relatively small size of 65,625 square kilometers (Survey Department 2007), the island exhibits an exceptional array of terrestrial and freshwater ecosystems that support a remarkable diversity of species as well as a high level of endemism among the wild flora and fauna (Ministry of Environment 1999).

The vulnerability of forest and other ecosystems is increasing due to pollution and siltation from unsustainable land-use practices, including deforestation; agricultural runoff; overextraction of water for irrigation; illegal sand mining; monoculture on steep lands, which causes large-scale soil erosion; large-scale logging in the already fragmented wet zone forests; salinity intrusion into coastal areas; degradation of coastal ecosystems, such as mangroves, lagoons, and estuaries due to unsustainable fishing practices;

overexploitation of resources; pollution; unauthorized encroachment and land reclamation; and coral mining and coral death due to bleaching from high temperatures.

Increasing population density puts pressure on natural ecosystems and species, especially in the species-rich wet zone where forests and wetlands are surrounded by human settlements. The boundaries of the dry zone may spread into the intermediate zone and the latter may spread into the wet zone under climate change.

Health

Sri Lanka has not reached its optimal potential in terms of nutrition status of the population. Climate change is envisaged to have severe impacts in terms of growth and development of children and productivity of older age groups and future generations.

Vulnerability of the health sector is intensified by dumping of solid waste, which creates unhygienic and vector breeding conditions, in contaminated surface and groundwater; overextraction of such resources as groundwater; poorly managed agriculture and land use; unplanned settlements, which lead to unsanitary conditions; poorly managed urban infrastructure, which enhances the spread of disease; and lack of political will and resources to effectively address issues. Some socioeconomic factors that could increase vulnerability include income insecurity, which hampers access to appropriate nutrition, sanitation, and medical facilities, and induces mental stress; inefficient use of water due to lack of awareness; low education levels among poorer communities and lack of awareness on simple sanitation techniques to prevent spread of disease; and low disaster/epidemic response capacity due to lack of a response mechanism and lack of coordination.

Water

Sri Lanka receives abundant freshwater from rain and inland waters. It is used for drinking and other domestic requirements, irrigated agriculture, hydropower, and a multitude of other uses, such as the inland food fishery, industry, recreation, tourism, and a source of foreign exchange through the export of freshwater ornamental fish.

However, climate change effects on rainfall regimes could put stress on the water resources. The vulnerability of water resources in Sri Lanka is intensified due to several factors other than climate change. These factors include saltwater intrusion in coastal areas due to overextraction of water from tube wells; overuse of ground and surface waters for irrigation and hydropower; reduced recharge of groundwater due to heavy runoff, coupled with minimal area for surface absorption as a result of expansion of built-up areas (mainly in urban areas); degraded water quality due to pollution of surface and groundwater with nitrates, industrial effluents, and agrochemicals, and spread of aquatic weeds in surface waters; lowering of water quality due to encroachment and inappropriate activities in water supply catchment areas; increasing pressure from population expansion and urbanization; and agricultural practices that require increasing amounts of water. In addition, there is an increase in sedimentation of rivers due to deforestation in catchments and riverbanks, improper cultivation practices in upper catchment areas of river drainage basins, and river sand and gem mining in catchment areas that results in increased siltation of tanks and reservoirs and reduction of water holding capacity.

Climate change increases competition for water resources used for irrigated agriculture and public use. This will mostly affect marginalized groups that have limited capacity to adapt to changes in their environment, especially when their incomes, health, and general living conditions are affected. Large-scale river diversion schemes have affected the long-term stability of water flow in rivers, and land-use changes in catchments have increased seasonal floods and siltation of water bodies.

A study by the Ministry of Environment and Natural Resources (2008) shows that availability of irrigation water is highly vulnerable especially in the dry zone due to the increase in droughts and the high dependence of agriculture. Vulnerability of drinking water to drought is also widespread. The south/south–central, northwestern, and north-central regions of the country are particularly vulnerable. Drinking water vulnerability to floods is prevalent in many areas of the country. Such areas have limited access to piped water and rely heavily on groundwater, resulting in high incidence of water-borne diseases.

Modeling Results

Agriculture

To analyze the impact of climate change on agriculture, a dynamic crop simulation (DSSAT) model was employed under the A1B scenario. The model integrates the effects of soil, crop phenotype, weather, and management options to simulate the results. Weather (observed and future climate), soil data (percentage of clay, silt and stones, organic carbon, cation exchange capacity, pH, etc.), and crop management details (time of sowing, season, time of transplanting, etc.) were used as inputs in the crop simulation model. Rice was the main crop chosen for this assessment for all six countries.

Bangladesh

Rice, the staple food grain of Bangladesh, is grown on nearly 11.25 million hectares (ha) of land. It accounts for 92% of the total food grain production in the country and provides more than 50% of the agricultural value, employing about 44% of the total labor force.

There are three major rice-growing ecosystems in Bangladesh—upland (direct-seeded, pre-monsoon *aus* season), irrigated land (mainly dry *boro* season), and rainfed lowland (mainly monsoon *aman* season). *Aman* season rice accounts for nearly 51% of total land area, followed by *boro* (40%) and *aus* (9%). Table 7 shows the impact of climate change on rice yield in Bangladesh.

Various studies indicate that a rise of 1°C–2°C in combination with lower solar radiation causes sterility in the rice spikelet. High temperature reduces yields of high-yielding varieties of *aus*, *aman*, and *boro* rice in all study locations and in all seasons. Climate change, especially in temperature, humidity, and radiation, increases the incidence of insect pests, diseases, and microorganisms.

Table 7: **Impact of Climate Change on Rice Yield in Bangladesh**

	Climatic Region						
	South Eastern Zone	North Eastern Zone	Northern Part of Northern Region	North Western Zone	Western Zone	South Western Zone	South Central Zone
Current Rice Yield (tons/hectare)							
Aus	3.38	2.95	1.86	2.12	2.08	2.08	2.99
Aman	3.76	3.68	2.54	2.67	2.33	2.44	3.24
Boro	4.33	4.43	3.48	3.17	2.79	2.67	3.86
Expected % Change in 2030							
Aus	(5.3)	0.8	0.6	(1.0)	(2.1)	(2.8)	(3.3)
Aman	(4.9)	1.1	1.3	0.4	(1.9)	(2.6)	(3.0)
Boro	(4.6)	1.5	2.0	0.6	(1.6)	(2.2)	(2.6)
Expected % Change in 2050							
Aus	(10.3)	(1.5)	2.5	(2.7)	(5.8)	(6.2)	(7.1)
Aman	(9.5)	(0.8)	3.5	(2.3)	(5.3)	(5.6)	(6.8)
Boro	(8.5)	3.5	5.2	1.9	(4.6)	(4.9)	(6.4)
Expected % Change in 2080							
Aus	(21.2)	(3.4)	4.2	(5.6)	(12.3)	(14.0)	(16.5)
Aman	(19.9)	(2.7)	5.5	(5.1)	(11.9)	(13.2)	(15.2)
Boro	(18.6)	6.4	7.3	3.6	(11.5)	(12.3)	(13.9)

( ) = negative.

The production of crops in Bangladesh is constrained by excess water during the wet season and too little during the dry season. Presently, the total irrigated area is 4.4 million ha, more than half the potentially irrigable area of 7.12 million ha. Irrigation coverage through shallow tube wells during the dry period has grown very fast following a policy of privatization and deregulation. As a result, the groundwater table in Bangladesh is declining at a rapid rate, causing failure of shallow tube wells in many parts of the country during the dry period. Lack of surface water during the dry season limits the function of low lift pumps.

A simulation study under the climate change country study assessed the vulnerability of food grain production due to climate change in Bangladesh. Two general circulation models, the Geophysical Fluid Dynamics Laboratory and Canadian Climate Change models, were used to develop the climate scenarios. The experiments considered the impact on three high-yielding rice varieties and a high-yielding wheat variety. Sensitivity to changes in temperature, moisture regime, and carbon dioxide fertilization was analyzed against the baseline climate condition.

The Geophysical Fluid Dynamics Laboratory model predicted about 17% decline in overall rice production and as high as 61% decline in wheat production compared with the baseline situation. The highest impact would be on wheat followed by rice (*aus* variety).

This translates to a reduction of 4.5 million tons of rice at the 2002 level of production. Of the three varieties of rice grown in Bangladesh, *aus* rice seems to be the most vulnerable. The other model, the Canadian Climate Change Model, also predicted a significant fall in food grain production. It should be noted, however, that the scenario was based on projecting existing cropping patterns into the future—which is not necessarily what will happen, as there are signs of significant changes in cropping patterns already occurring.

A temperature increase of 4°C would cause significant decrease in production: some 28% for rice and 68% for wheat. CO_2 fertilization would increase food grain production; doubling of atmospheric concentration of CO_2 in combination with a similar rise in temperature would result in an overall 20% increase in rice production and 31% decline in wheat production. *Boro* rice production would increase with doubling of atmospheric concentration of CO_2.

The apparent increase in yield of *boro* and other crops might be constrained by moisture stress. A 60% moisture stress on top of other effects might cause a decline in *boro* yield as high as 32%, instead of having an overall 20% net increase. It is feared that moisture stress would be more intense during the dry season, which might force the Bangladeshi farmers to reduce the area under *boro* cultivation. The associated shortfall in food grain production would severely threaten food security of the country.

Under a moderate climate change scenario the crop loss due to salinity intrusion could be about 0.2 million tons (Habibullah et al. 1998). The loss of production due to such effects may be higher than that under floods.

Bhutan

Twenty-one percent of agricultural lands in Bhutan are wetland (irrigated) and 43% are dryland (rainfed). One of the major crops cultivated in the irrigated land is rice, which accounts for 43% of total domestic cereal cultivation. Rice-producing regions have been categorized as: low altitude (38%), mid-altitude (50%), and high altitude (12%), totaling around 19,000 ha. Table 8 illustrates the impact of climate change on rice yield in Bhutan.

India

India ranks second worldwide in terms of agricultural output. The agriculture sector contributed approximately 14.2% to GDP during 2009/10. Fruits and vegetables together constitute about 92% of the total horticultural production in the country. The net irrigated area is approximately 20% of total land area.

A sensitivity analysis using the DSSAT model showed that in southern, central, and eastern Indian, any increase in temperature by more than 1°C from the current level would lower rice yields (Figure 12). However, the combined effect of temperature and CO_2 can alter these trends.

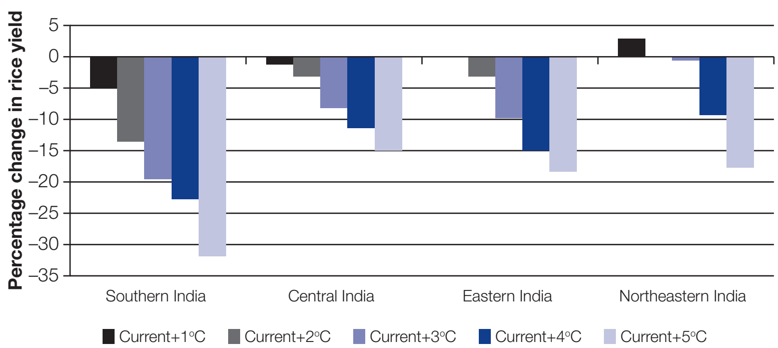
Climate change is expected to benefit rice production in most of the northeastern states, due to increased CO_2 concentration and resultant increase in temperature. In the southern

Table 8: **Impact of Climate Change on Rice Yield in Bhutan**

Climatic Region	Impact of Climate Change on Days to Maturity			
	Current Days to Maturity	Expected % Change in 2030	Expected % Change in 2050	Expected % Change in 2080
Low Altitude	124	(1)	(3)	(7)
Mid-Altitude	132	(2)	(4)	(7)
High Altitude	144	(2)	(5)	(8)
	Impact of Climate Change on Rice Yield			
Climatic Region	**Current Yield (kg/hectare)**	**Expected % Change in 2030**	**Expected % Change in 2050**	**Expected % Change in 2080**
Low Altitude	956	(3.2)	(12.6)	(22.5)
Mid-Altitude	1,592	(1.2)	(6.7)	(11.3)
High Altitude	1,609	7.5	2.3	(1.8)

( ) = negative, kg = kilogram.

Figure 12: **Mean Percentage Change in Rice Yield in Different Regions of India under Increasing Temperature**

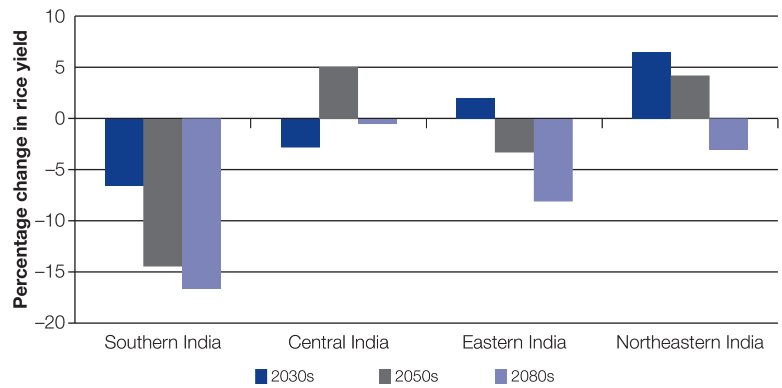


states, however, rice yields would decline by 5.0% in the 2030s, 14.5% in the 2050s, and 17.0% in the 2080s (Figure 13).

The Indian Network on Climate Change Assessment[11] reported that productivity of irrigated rice in the Western Ghats region is likely to change by –11% to +5% depending on location. Irrigated rice yield in the majority of the region is projected to decline by about 4%, whereas those in parts of southern Karnataka and the northernmost districts of Kerala are likely to gain. Rainfed rice yields are projected to change in the range of –35% to +35%, with a large portion of the region likely to lose up to 10% of rice yields. In addition, climate change is likely to reduce yields of maize and sorghum by up to 50% depending upon the region. Coconut yields are projected to increase by up to 30% in the

[11] The Indian Network on Climate Change Assessment (2010) reported that the west coast region will exhibit a wide variability in the change in precipitation under the 2030s scenario. The northern portion of the west coast, consisting of Gujarat and Maharashtra, shows an increase in precipitation for the 2030s scenario, varying from 4% to over 25%. However, areas of Karnataka and Kerala show a marginal decrease of up to 4%.

Figure 13: **Percentage Change in Rice Yield in India in the 2030s, 2050s, and 2080s**



majority of the region. (Increase in coconut yield may be mainly attributed to projected increase in rainfall [~10%] and relatively less due to increase in temperatures.) However, some areas, like southwest Karnataka, parts of Tamil Nadu, and parts of Maharashtra, may lose coconut yields by up to 24%.

Nepal

Agriculture provides employment opportunities to 66% of the total Nepalese population and contributes about 39% of the GDP. Therefore, development of the agriculture sector is key for the development of the national economy.

The effects of climate change on agriculture in Nepal can be divided between systems that are dependent on the summer monsoon and those that are dependent on snow, ice, and glacial melt. Agricultural systems dependent on water sourced from snow, ice, and glacial melt will see a near-term increase in water supply, but will also be in greater danger of GLOFs that threaten crops, water infrastructure, and mountain livelihoods. For systems dependent on the summer monsoon, several scenarios are possible due to the pervasive uncertainty; the monsoon could abruptly change between "dry" and "wet" states. Increasing variability of precipitation patterns will have a significant effect on crop productivity, as farmers will have to adapt to changing onset and termination dates of the monsoon. The combined effects of temperature and CO_2 increase on rice yields are shown in Table 9.

Sri Lanka

Vulnerability of the agriculture sector in Sri Lanka to climate change will be influenced by several socioeconomic factors and change in temperature. Droughts are expected to increase, especially in the dry and intermediate zones.

In the wet zone, solar radiation may limit the rice yield during the *yala* season (April–August, the drier season) due to high cloud cover arising from the southwest monsoon circulation; a similar situation could occur in the dry zone during the *maha* season (October–January, the period with heavy rainfall) due to overcast conditions that may result from weather

Table 9: **Combined Effect of Increase in Temperature and Carbon Dioxide Concentration on Rice Productivity in Nepal**

Region	Current Rice Yield (kilogram/hectare)	% Deviation in Rice Yield at Various Temperature Levels				
		1ºC	2ºC	3ºC	4ºC	5ºC
Carbon dioxide level (parts per million)	370	420	470	500	560	650
Terai	2,458	16.61	15.43	13.20	9.25	6.51
Mountain	2,105	12.22	12.11	14.75	17.37	17.46
Hill	1,733	17.52	33.21	35.68	37.55	38.93

Table 10: **Impact of Climate Change on Rice Yield in Sri Lanka**

Agro Climatic Zone	Current Rice Yield (kilogram/ hectare)		% Change in 2030		% Change in 2050		% Change in 2080	
	Maha	*Yala*	*Maha*	*Yala*	*Maha*	*Yala*	*Maha*	*Yala*
Dry–Low	3,498	3,863	(4.2)	(6.5)	(16.1)	(19.8)	(29.1)	(34.2)
Intermediate–Low	4,865	4,612	(2.7)	(3.5)	(10.6)	(15.1)	(24.8)	(31.5)
Intermediate–Mid	4,992	4,761	(1.9)	(3.1)	(9.3)	(12.7)	(22.5)	(30.3)
Intermediate–Upland	3,492	2,955	(1.3)	(2.7)	(7.5)	(11.4)	(20.3)	(27.5)
Wet–Low	3,910	3,711	(0.9)	(1.5)	(6.0)	(10.4)	(19.4)	(25.1)
Wet–Mid	3,538	2,795	(0.8)	(1.4)	(3.6)	(8.2)	(18.3)	(23.6)
Wet–Upland	3,134	2,706	5.7	3.1	2.1	(2.0)	(8.6)	(12.4)

( ) = negative.

systems in the Bay of Bengal and the northeast monsoon circulation. The effects of these conditions on rice yield are shown in Table 10.

Coastal and Marine Resources

The coastal and marine resources of South Asia have significant environmental and socioeconomic value. Given the vulnerability of coastal regions to the impacts of climate change, there could be great disruptions to physical processes, economic activities, and social systems in coastal regions.

Making use of the climate change data generated by the European Centre/Hamburg Model (IPCC 2001) under this study, sea level rise in 2100 under SRES scenarios in the South Asia region is shown and compared with global rise in Table 11. The projected rise in South Asia in each scenario is higher than the global projection. Note that the 2013 Working Group I Contribution to the *IPCC Fifth Assessment Report* has significantly

Table 11: **Projected Global and South Asia Mean Sea Level Rise by 2100**

	Sea Level Rise (meter)		
	B1	A1B	A2
Global	0.28	0.35	0.37
South Asia (Indian Ocean)	0.56	0.47	0.57

Table 12: **South Asia: Impact of 1-Meter Sea Level Rise in Bangladesh, India, the Maldives, and Sri Lanka**

	Inundated Area at 1-Meter Sea Level Rise	Temporary Inundated Land due to Storm Surge at 1-Meter Sea Level Rise
	Dryland Area (Total = 2,895,802 km^2)[a]	
Impacted dryland area (km^2)	20,932	91,862
% of total dryland area	0.72	3.17
	Wetland Area (Total = 491,756 km^2)[a]	
Impacted wetland area (km^2)	3,692	27,069
% of total wetland area	0.75	5.50
	Population (Total = 835,235,992)	
Impacted population	95,056,125	200,112,888
% of total population	11.38	23.96

km^2 = square kilometer.

[a] The total dryland and wetland areas presented do not include the land area of the Maldives.

increased projected sea level rise to mean heights of 0.40–0.63 m (5%–95% range 0.26–82.0 m).[12] However, elevation data resolution in climate models is only to 1 meter.

The results of the model indicate that approximately 0.72 % (20,932 km^2) of dryland and 0.75% (3,692 km^2) of wetland in the South Asian countries would be impacted by a 1-meter sea level rise. This would increase to 3.17% (91,862 km^2) when extreme storm surge is considered. These impacts cover a small percentage of land area, but would affect large numbers of people (Table 12).

Bangladesh

The coast of Bangladesh is prone to natural disasters like cyclones, storm surges, and floods. The combination of natural and human-made hazards, such as erosion, high arsenic content in groundwater, waterlogging, earthquakes, water and soil salinity, various forms of pollution, risks from climate change, etc., have adversely affected lives and livelihoods in the coastal zone and slowed down the pace of social and economic development in the area.

[12] IPCC (Intergovernmental Panel on Climate Change). 2013. *Climate Change 2013: The Physical Science Basis. Summary for Policymakers*. Working Group I Contribution to the Fifth Assessment Report. IPCC, Switzerland. October. www.ipcc.ch/report/ar5/wg1/docs/WGIAR5_SPM_brochure_en.pdf?bcsi_scan_e41ddc73166bc1eb=tFWrHjjimW7KcVUnMO0vsbcam+IBAAAARPnwAA==&bcsi_scan_filename=WGIAR5_SPM_brochure_en.pdf

Figure 14: **Bangladesh: Impacted Area and Population at 1-Meter Sea Level Rise**

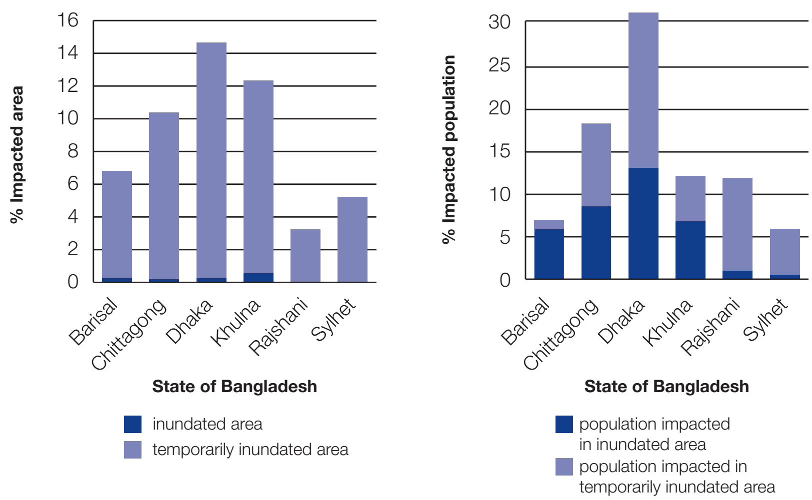


Figure 14 shows the impact in different states of Bangladesh under a 1-meter sea level rise. The inundated area (808 km^2 or 0.58%) would be greatest in Khulna while the temporarily inundated area (20,089 km^2 or 14%) would be greatest in Dhaka. Dhaka's population would face the highest risks.

India

India, with an 8,000-kilometer coastline, has 13 of 28 states prone to risks from sea level rise, as shown in figures 15 and 16. Among these states, Gujarat would have the largest inundated area (18,276 km^2), and West Bengal would have the largest temporarily inundated area (0.57%). Maharashtra would have the most affected population (9.55%) in temporarily inundated areas.

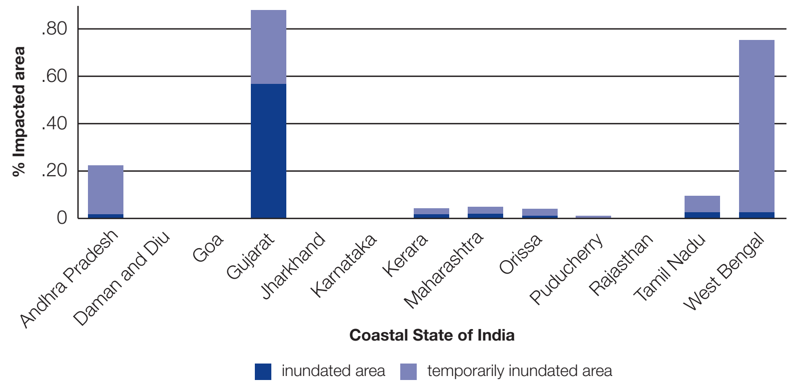
The Maldives

Low elevation and the unstable nature of the islands make the Maldives particularly vulnerable to sea level rise. A sea level rise of 1 meter would inundate 196 km^2 (66% of the total area) and an additional temporarily inundated area of 69 km^2 (considering 1 meter as the extreme storm surge) (Table 13).

Sri Lanka

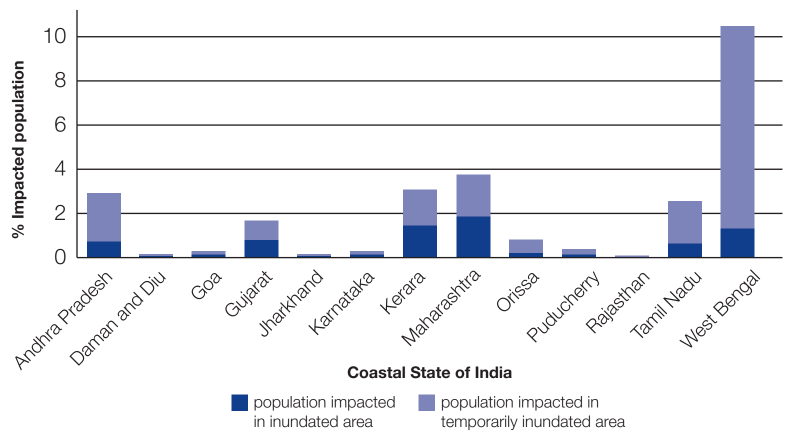
Much of the coastal zone of Sri Lanka lies within the dry zone, with an average annual rainfall of 1,250–1,750 mm and a temperature of 28°C–32^{0}C (Survey Department 2007). The increasing variability in temporal and spatial distribution of rainfall as well as the increasing temperature affects coastal areas and inland waters that are important for the food fishery industry.

Figure 15: **India: Impacted Area at 1-Meter Sea Level Rise**



Percentages for Daman and Diu, Goa, Jharkhand, Karnataka, and Rajasthan are almost nil.

Figure 16: **India: Impacted Population at 1-Meter Sea Level Rise**



As shown in figures 17 and 18, the impacts of a 1-meter sea level rise in Sri Lanka would be greatest in Jaffna, with an inundated area of 43.12 km^2 (0.07%) and temporarily inundated area of 398.91 km^2 (0.61%). Gampaha would have the most impacted area (683,858 km^2 or 4.45%) and population (9.42%) in temporarily inundated areas.

Energy Sector

Energy use in South Asia has been growing rapidly over the past few decades. The trend is expected to continue in the future, with electricity demand projected to grow fourfold by 2030. Aside from normal determinants such as population, technological advancement, and economic development, climate change will place a higher demand for energy. A rise in average temperature will increase energy requirements for irrigation in agriculture and for space cooling (and reduce energy needed for warming).

Table 13: **The Maldives: Area and Population Impacted by a 1-Meter Sea Level Rise**

	Area	Population
Total	298 km^2	327,798
Impacted by inundation	196 km^2	214,161
As % of total	65.77	65.33
Impacted by temporary inundation	69 km^2	75,394
As % of total	23.15	23.00

km^2 = square kilometer.

Figure 17: **Sri Lanka: Impacted Area at 1-Meter Sea Level Rise**

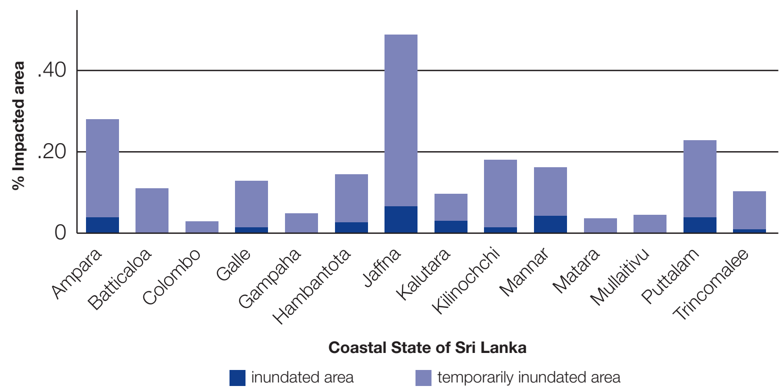
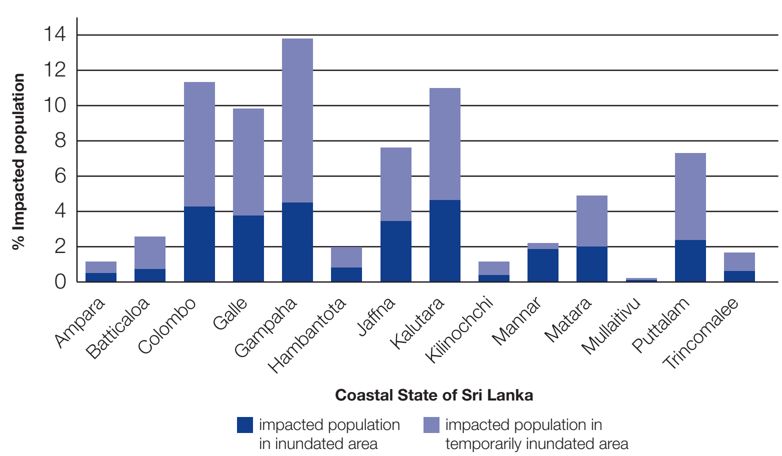


Figure 18: **Sri Lanka: Impacted Population at 1-Meter Sea Level Rise**



Meanwhile, energy supply is influenced by (volatile) world oil prices, power plant generation capacity and efficiency, and transmission and distribution system efficiency (including system losses and energy theft). In addition, weather conditions like droughts and high temperatures can directly influence hydropower and thermal power generation through the availability and temperature of cooling water. Increases in intensity and frequency of extreme events, such as storms, lightning, and sea level rise, may also cause more electrical system failures.

Bangladesh

In Bangladesh, persistent power sector problems, including extremely low coverage and frequent supply disruptions, slow industrial growth and cause continued fiscal drains due to the loss-making operations of power utilities (0.3% of total GDP in fiscal year 2003).

There is now growing understanding that the Millennium Development Goals cannot be met without major improvement in the quality and quantity of energy services. Access to energy services affects practically all aspects of sustainable development, including access to water, agricultural productivity, population levels, health care, education, job creation, gender equality, and climate change impacts.

Bhutan

As Bhutan's energy supply depends largely on hydropower, it is highly vulnerable to changes in climate that will affect the amount, timing, and geographical pattern of precipitation as well as temperature (rain or snow, and timing of melting).

India

Approximately 412 million people are without access to electricity in India. India's current electrical system runs mostly on domestic coal. The Organisation for Economic Co-operation and Development and the International Energy Agency characterized the overall energy system as fueled largely by coal and combined renewable and waste, with much smaller but growing shares of oil, gas, nuclear, and hydropower. Pressures to reduce greenhouse gas emissions could limit options for coal use in India, unless CO_2 capture and storage technologies can be implemented. This might lower the country's development rate.

Renewable sources, such as hydropower and biomass fuels, are projected to change from a current 54% share in urban households to 12%, but a smaller decline in their use in rural households means that the total amount of biomass used will increase. Biofuel crops, like other crops, will be affected by climate change; hydropower, like other water uses, will be subject to changes in precipitation under climate change.

The Maldives

The Maldives' energy vulnerabilities are related to the low elevation and small size of islands. Their low elevation and narrow width makes powerhouses and associated infrastructure vulnerable to flooding and damage from severe weather events. With the commitment to become carbon neutral by 2020, the country is increasingly investing in renewable energy technologies, particularly solar power, for which there is abundant solar energy—400 million MW per annum (Azwar n.d.).

Nepal

Most of Nepal's energy needs are met by hydropower. Increased climate variability, including in the frequency and intensity of flooding and droughts, could have a severe affect on hydropower plants in the country through changes in runoff.

Increasing spells of droughts result in forest fires, which also adversely impact forest resources and availability of fuelwood. Weather-induced hazards, such as landslides, can disrupt the supply of fuel and electricity to some extent when infrastructure like roads and transmission lines are damaged. An increase in mean temperature of 0.06°C per year would increase the theoretical hydropower potential by 5.7% by 2030 but it would then decrease and be down 28% by the end of the century (Chaulagain 2006).

Sri Lanka

Sri Lanka's energy sector is vulnerable to changes in climate both in terms of demand and supply. Extreme weather conditions, such as storms and cyclones, could affect the power supply infrastructure. A decrease and change in the quantity of precipitation will affect levels of hydropower generation. An increase in temperature will increase the demand for cooling in buildings.

In Table 14, the vulnerability of the power sector in each country is summarized in terms of the demand–supply gap that will emerge in the 2030s and 2050s due to net impacts of climate change, relative to the baseline power demand.

Forest and Other Ecosystems

In this report, modeling of forest ecosystems under the three IPCC emission scenarios is synthesized for five countries[13] for the near future (2026–2035), mid-21st century (2046–2055), and late 21st century (2081–2090), with respect to a late-20th century baseline (1991–2000). The study considered a number of variables (total ecosystem carbon pool, forest ecosystem carbon pool, net primary production, net biological productivity, carbon-bole, and physionomic class or vegetation type) to assess the potential change in forest ecosystems due to climate change. However, no single indicator appears to measure such impact in a complete manner. This report presents the results on forest ecosystem carbon pool, net primary production, and net biological productivity.

Forest Ecosystem Carbon Pool

In terms of the forest carbon pool index, Bangladesh is projected to witness neither a major gain nor loss, as would also be the case for Nepal under scenarios A1B and A2; in scenario B1, Nepal is expected to see a 10% decline by the end of the 21st century

[13] The Maldives could not be included because it is too small for the model's spatial resolution. Nonetheless, conclusions for the Maldives are likely to be similar to those observed for Sri Lanka, since these two countries are spatially analogous to each other.

Table 14: **Energy Demand–Supply Gap for South Asia in the 2030s and 2050s**

Country	Energy Demand-Supply Gap	2030s A1B	2030s A2	2030s B1	2050s A1B	2050s A2	2050s B1
Bangladesh	In TWh	4.13	1.29	1.86	13.08	7.76	8.05
	As % of the baseline demand	5.00	1.57	2.25	6.21	3.67	3.82
Bhutan	In TWh	0.47	0.36	0.70	0.47	1.46	2.20
	As % of the baseline demand	13.85	10.64	20.46	5.88	18.10	27.25
India	In TWh	147.54	86.93	103.80	302.14	258.01	370.62
	As % of the baseline demand	7.84	4.62	5.51	5.71	4.88	7.00
The Maldives	In TWh	0.032	0.03	0.026	0.12	0.13	0.10
	As % of the baseline demand	2.66	2.42	2.18	4.09	4.27	3.49
Nepal	In TWh	1.51	0.71	1.60	0.39	2.39	4.24
	As % of the baseline demand	24.40	11.54	25.81	2.96	17.91	31.78
Sri Lanka	In TWh	1.25	0.68	0.91	0.50	1.57	1.93
	As % of the baseline demand	5.57	3.02	4.05	1.09	3.42	4.22

TWh = terawatt hour.

(Table 15). Bhutan, however, may expect 13% gains under both A1B and B1 and almost 35% as much as the baseline level under scenario A2. For India, there will be significant increase in the forest carbon pool for all the scenarios, ranging from about 6% under scenario B1 to almost 15% under scenario A2. Overall, South Asia's forest carbon pool appears to increase by the 2080s, implying absorption of more carbon dioxide from the atmosphere.

Net Primary Production

Gross primary production is the rate at which the primary producers in an ecosystem capture and store a given amount of chemical energy as biomass in a given period of time. Net primary production (NPP) is the balance after some of the chemical energy is used by the primary producers for growth and maintenance respiration. In terms of NPP, both Bhutan and Nepal are to gain considerably with respect to their baseline levels. Under all three emission scenarios, Nepal is expected to gain 22%–36% and Bhutan 11%–13% (Table 16). Such gain in NPP can reasonably be attributed to the warming effect, which causes metabolic activity in plants to accelerate. Bangladesh and Sri Lanka are unlikely to witness any significant gain or loss in NPP; Sri Lanka is projected to suffer a 5% or 3% reduction under scenarios A2 and B1, respectively, due to likely increased damage from cyclones. India's NPP will vary widely across scenarios, ranging from a 1% loss under scenario A2 to about 4% gain under scenario A1B.

Net Biological Productivity

Net biological (or biome) productivity (NBP), an indicator of both productivity and quality of forest ecosystems, is the difference between the amount of carbon dioxide taken up (by the forest ecosystem) from the atmosphere by photosynthesis and that released by decomposition, forest fires, and/or logging. Across the three scenarios, NBPs for South

Table 15: **Forest Carbon Pool in South Asia under Scenarios A1B, A2, and B1**

Scenario	Country	Forest Carbon Pool (grams carbon/square meter)				% Change from 1991–2000 to 2081–2090
		1991–2000	2026–2035	2046–2055	2081–2090	
A1B	Bangladesh	20,135	18,611	18,394	19,133	(4.98)
	Bhutan	9,984	9,892	11,010	11,341	13.59
	India	11,171	11,117	11,383	12,363	10.67
	Nepal	8,066	6,766	6,832	7,947	(1.48)
	Sri Lanka	25,832	25,795	27,253	28,079	8.70
A2	Bangladesh	20,135	18,863	19,472	20,829	3.45
	Bhutan	9,984	10,673	10,855	13,439	34.61
	India	11,171	11,243	11,928	12,793	14.52
	Nepal	8,066	6,021	7,423	8,136	0.87
	Sri Lanka	25,832	25,980	26,900	27,960	8.24
B1	Bangladesh	20,135	20,829	20,920	19,491	(3.20)
	Bhutan	9,984	13,439	10,981	11,304	13.22
	India	11,171	12,793	11,715	11,813	5.74
	Nepal	8,066	8,136	7,054	7,206	(10.66)
	Sri Lanka	25,832	27,960	26,978	27,000	4.52

( ) = negative.

Table 16: **Net Primary Production in South Asia under Scenarios A1B, A2, and B1**

Scenario	Country	Net Primary Production (grams carbon/square meter/year)				% Change from 1991–2000 to 2081–2090
		1991–2000	2026–2035	2046–2055	2081–2090	
A1B	Bangladesh	1,643	1,899	1,971	1,648	0.30
	Bhutan	1,461	1,764	1,839	1,654	13.21
	India	1,067	1,213	1,318	1,106	3.66
	Nepal	657	861	924	893	35.92
	Sri Lanka	2,014	2,106	2,488	2,028	0.70
A2	Bangladesh	1,643	1,869	2,002	1,621	(1.34)
	Bhutan	1,461	1,747	1,946	1,616	10.61
	India	1,067	1,182	1,285	1,056	(1.03)
	Nepal	657	842	938	885	34.70
	Sri Lanka	2,014	2,213	2,261	1,909	(5.21)
B1	Bangladesh	1,643	1,621	1,851	1,703	3.65
	Bhutan	1,461	1,616	1,797	1,638	12.11
	India	1,067	1,056	1,259	1,064	(0.28)
	Nepal	657	885	853	800	21.77
	Sri Lanka	2,014	1,909	2,487	1,947	(3.33)

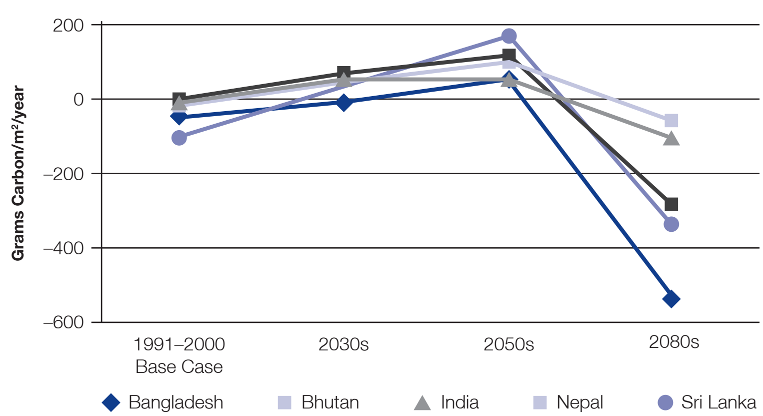
( ) = negative.

Asia in general appear to be positive and increasing by the 2030s and 2050s, but will be negative and declining by the 2080s (Table 17 and Figure 19). Bhutan's NBPs in particular indicate serious conditions by the 2080s compared to their 1991–2000 status under scenarios A1B and A2. The declining trend in NBP across the region implies that forest ecosystems will be unable to compensate for the rising metabolic losses due to increasing temperature.

Table 17: **Net Biological Productivity** (grams carbon/square meter/year) **for South Asia under Scenarios A1B, A2, and B1**

		Net Biological Productivity (grams carbon/square meter/year)				% Change from 1991–2000 to 2081–2090
Scenario	Country	1991–2000	2026–2035	2046–2055	2081–2090	
A1B	Bangladesh	(54.0)	(13.6)	48.2	(541.7)	(903.15)
	Bhutan	(8.5)	59.8	108.7	(290.4)	(3,316.47)
	Nepal	(18.8)	40.5	92.4	(60.7)	(222.87)
	Sri Lanka	(103.7)	35.1	163.3	(343.6)	(231.34)
A2	Bangladesh	(54.0)	(17.2)	97.0	(558.3)	(933.89)
	Bhutan	(8.5)	24.1	159.1	(405.8)	(4,674.12)
	Nepal	(18.8)	14.0	69.0	(61.7)	(228.19)
	Sri Lanka	(103.7)	77.8	44.6	(501.7)	(383.80)
B1	Bangladesh	(54.0)	(391.7)	60.7	(187.4)	(247.04)
	Bhutan	(8.5)	(264.0)	181.6	(38.5)	(352.94)
	Nepal	(18.8)	(182.1)	90.9	(83.6)	(344.68)
	Sri Lanka	(103.7)	(501.7)	163.3	(228.7)	(120.54)

Figure 19: **Projected Net Biome Productivity in South Asia under A1B Scenario**



m^2 = square meter.

The Maldives is not included because it is too small for the model resolution. Positive values indicate the removal (absorption or capture) of carbon dioxide from the atmosphere, while negative values show its release back to the atmosphere. A1B = projected scenario from Intergovernmental Panel on Climate Change (IPCC). 2001. *Special Report on Emissions Scenarios*. A special report of Intergovernmental Panel on Climate Change (IPCC) Working Group III. Cambridge, UK: Cambridge University Press.

Human Health

Climate and anomalous weather events are expected to cause a general increase in the number of cases of both vector- and water-borne diseases in South Asia. The modeling results suggest that the morbidity and mortality rates across the six countries due to dengue, malaria, and diarrhea would increase over time as a consequence of climate change (Table 18).

Bangladesh

In Bangladesh, additional morbidity per year from dengue due to climate change by 2090 under the B1 scenario could reach 23,876 persons and dengue fatalities 314, and higher under the other two scenarios (Table 19). The number of cases would be slightly higher during the monsoon months than in winter. The annual morbidity from malaria by 2090 could increase to 440,000 persons and fatalities could reach 2,525 with the A2 scenario (Table 19), though less under the other scenarios.

Bhutan

Dengue fever was first diagnosed and reported in Bhutan in July 2004 (Dorji et al. 2009). Dengue and viral hepatitis have been increasing in the last few years. Under the ECHAM5 scenarios, there will be a significant increase of dengue fever and malaria in Bhutan. Annual morbidity from dengue incidence may increase to 20,150 persons with 178 deaths by 2090 under the A1B scenario (Table 19).

Malaria affects more than half of the entire population, mostly those residing in the southern districts bordering the Indian states of Assam and West Bengal (Tobgay et al. 2011). Malaria is the second most fatal communicable disease in Bhutan and has been claiming about 18 lives annually since 1995 (Tschering and Sithey 2009). The annual number of malaria cases by 2090 under the B1 scenario could reach 11,299 and fatalities could reach 74 in 2030 (Table 19). The number of cases would be slightly higher during the monsoon period. Unusual and irregular rainfall patterns associated with early rains and dry spells have led to numerous localized malaria outbreaks.

India

In India, annual dengue morbidity by 2090 under the A1B scenario could increase to 54,290 and fatalities could reach 459 (Table 19). The number of cases would be slightly higher during the monsoon months.

India accounts for approximately two-thirds of malaria cases in Southeast Asia (Bhattacharya et al. 2006; Dhiman et al. 2008, 2010; Bush et al. 2011). Morbidity from malaria would decrease significantly under the A1B and B1 scenarios but increase under A2. However, fatalities would increase several-fold under all scenarios (Table 19). The number of cases would be slightly higher during the monsoon months.

Table 18: **Predicted Morbidity and Mortality from Vector- and Water-Borne Diseases in South Asia**

Vector- and Water-borne Diseases	No. of Cases by 2030 by Scenario			No. of Cases by 2050 by Scenario			No. of Cases by 2090 by Scenario		
	A1B	A2	B1	A1B	A2	B1	A1B	A2	B1
Dengue									
Morbidity	79,265	114,934	101,142	121,157	211,903	157,504	211,644	672,181	340,747
Mortality	665	964	849	969	1,695	1,260	1,574	4,999	2,534
Malaria									
Morbidity	2,719,519	3,943,302	3,470,160	1,921,305	3,360,362	2,497,696	1,377,479	4,374,873	2,217,741
Mortality	5,419	7,857	6,915	10,477	18,272	13,620	16,451	52,248	26,487
Diarrhea									
Morbidity	20,784,937	30,138	26,522,217	28,130,798	49,200,765	36,570,037	41,721,929	132,508,846	67,172,306
Mortality	3,686	5,354	4,703	5,972	10,445	7,764	9,573	30,404	15,413
TOTAL Morbidity	23,583,721	4,088,374	30,093,519	30,173,260	52,773,030	39,225,237	43,311,052	137,555,900	69,730,794
TOTAL Mortality	9,770	14,175	12,467	17,418	30,412	22,644	27,598	87,651	44,434

Table 19: **Predicted Morbidity and Mortality from Vector- and Water-Borne Diseases, by Country and Scenario in South Asia**

Country/ Scenario	Dengue			Malaria			Diarrhea		
	2030	2050	2090	2030	2050	2090	2030	2050	2090
Bangladesh									
A1B	3,315 (92)	5,236 (130)	14,830 (195)	101,450 (590)	119,750 (638)	138,600 (795)	2,820,000 (2,620)	3,340,000 (4,020)	4,310,000 (6,835)
A2	4,807 (133)	9,158 (227)	47,100 (619)	147,102 (855)	209,443 (1,116)	440,194 (2,525)	4,089,000 (3,828)	5,841,660 (7,031)	13,668,560 (21,708)
B1	4,230 (117)	6,807 (169)	23,876 (314)	129,450 (753)	155,675 (829)	223,146 (1,280)	3,598,320 (3,369)	4,342,000 (5,226)	6,939,100 (11,004)
Bhutan									
A1B	6,024 (87)	10,075 (126)	20,150 (178)	33,245 (58)	43,270 (77)	70,180 (126)	144 0	251 0	522 0
A2	8.735 (126)	17,621 (220)	63,996 (565)	48,205 (84)	75,679 (135)	222,892 (400)	209 0	439 0	1,658 0
B1	7,686 (111)	13,097 (164)	32,441 (287)	42,421 (74)	56,251 (100)	11,299 (203)	184 0	326 0	840 0
India									
A1B	23,730 (198)	33,987 (276)	54,290 (459)	2,548,760 (4,520)	1,711,905 (9,360)	1,091,052 (14,430)	17,631,290 (971)	24,256,415 (1,804)	36,571,286 (2,539)
A2	34,408 (287)	59,443 (483)	172,425 (1,458)	369,570 (6,554)	2,994,122 (16,371)	3,465,181 (45,830)	25,565,370 (1,408)	42,424,470 (3,155)	116,150,404 (8,032)
B1	30,279 (253)	44,183 (359)	87,407 (739)	3,252,218 (5,768)	2,225,476 (121,680)	1,756,593 (23,233)	22,497,526 (1,239)	31,533,339 (2,345)	58,879,770 (4,072)
The Maldives									
A1B	4,025 (34)	6,030 (54)	10,875 (102)	34 0	45 0	72 0	18,253 (3)	39,617 (7)	63,240 (13)
A2	5,836 (49)	10,546 (94)	34,539 (324)	49 0	79 0	229 0	26,467 (4)	69,290 (12)	200,850 (41)
B1	5,136 (43)	7,839 (70)	17,509 (164)	43 0	58 0	116 0	23,291 (4)	51,502 (9)	101,816 (21)
Nepal									
A1B	46 0	77 (0	124 0	29,560 (23)	35,075 (67)	46,300 (558)	147,320 (53)	209,750 (109)	364,745 (147)
A2	67 0	135 0	394 0	42,862 (33)	61,346 (117)	147,049 (1,772)	213,614 (77)	366,853 (191)	1,158,430 (467)
B1	59 0	100 0	200 0	37,718 (29)	45,597 (87)	74,543 (898)	187,980 (68)	272,675 (142)	587,239 (237)
Sri Lanka									
A1B	42,125 (254)	65,752 (383)	111,375 (640)	6,470 (228)	11,260 (335)	31,275 (542)	167,930 (19)	284,765 (32)	412,136 (49)
A2	61,081 (368)	115,000 (670)	353,727 (2,033)	9,381 (331)	19,694 (586)	99,329 (1,721)	234,498 (27)	498,054 (56)	1,308,944 (156)
B1	56,751 (324)	85,477 (498)	179,314 (1,030)	8,256 (291)	14,638 (435)	50,353 (873)	214,279 (24)	370,194 (42)	663,539 (79)

Note: Figures in parentheses indicate fatalities from water-borne diseases (dengue, malaria, and diarrhea) based on A1B, A2, and B1 scenarios and population growth factor for Asian countries.

The Maldives

Vector-borne diseases have emerged as major communicable diseases of public health concern in the Maldives. Dengue is now endemic in the country with seasonal outbreaks. Epidemiological data show changes in the seasonal nature of dengue, spreading across the atolls, and leading finally to epidemic proportions. This trend is linked to increased rainfall intensity. Morbidity from dengue incidence in the A2 scenario by 2090 could increase to 34,539 with 324 deaths per year.

Malaria is not so prevalent in the Maldives. During 1990–2003, the number of malaria cases averaged 16 per year, with no fatalities. Annual morbidity due to malaria incidence under the A2 scenario by 2090 could reach more than 200. The number of potential fatalities cannot be predicted from the models.

Nepal

Dengue and malaria are common in many parts of Nepal (Agrawala et al. 2003, ADB/ ICIMOD 2006, Regmi et al. 2008). During 2006–2011, the average annual number of cases of dengue was 1,300, and there were 19 fatal cases in 2010. Dengue morbidity under the A2 scenario by 2090 could reach nearly 400 annually (Table 19). The number of potential fatalities cannot be predicted from the models.

Malaria risk exists year-round and some 71.1% of the population are considered at risk. During 1990–2009, the average annual number of cases of malaria was 10,377; there were 10 fatal cases during 2001–2007. Annual malaria morbidity in the 2080s under the A2 scenario could reach more than 147,000 with nearly 1,800 deaths (Table 19).

Sri Lanka

There has been a drastic increase in dengue in Sri Lanka with reported cases reaching 34,054 in 2010. Annual dengue incidence under the A2 scenario could increase to over 353,000 by 2090 with over 2,000 fatalities (Table 19). Annual malaria morbidity across the country by 2090 under the A2 scenario could reach almost 100,000 with 1,700 deaths (Table 19).

Under climate change, increase in rainfall intensity can cause water logging and thereby create favorable conditions for mosquito breeding. In addition, vulnerability of the health sector is amplified by other factors, including dumping of solid waste that contaminates surface water and groundwater and also creates vector breeding conditions; poorly managed urban drainage also enhances the spread of disease.

Water Resources

Although the monsoon-dominated annual precipitation cycle is expected to remain unchanged over South Asia, future decades are predicted to have drier and warmer winter months with reduced snow cover, and summer monsoon months that are wetter and warmer. The wetter monsoon months will coincide with accelerated glacial melting, causing river flows to increase even more, particularly during the rainy season. The pattern of flows over the year could become more erratic, and an increased volume of sediments will be carried by these rivers. These changes will affect the large rivers of South Asia, causing significant reduction in water availability and in turn seriously affecting agriculture and hydropower generation.

Initially, it is projected that the river flows derived from the glaciers will increase during the dry season as ice melting accelerates; this can give wrong signals to policy makers and delay climate change adaptation measures. In time, as the remaining glaciers disappear, dry season flows will be dramatically reduced. River flows will become more erratic as rainfall is immediately converted to runoff instead of being stored as ice.

A geographic information system (GIS) grid modeling approach was used to estimate the duration and frequency of droughts, and water balance (water surplus and deficit).[14]

Frequency of Drought Occurrence

A frequency analysis was done for drought occurrence. For each grid location, time period, and scenario, the maximum length of continuous dry days (i.e., precipitation less than 1 mm/day) was extracted for each year from the results of regional climate modeling. From these data, in addition to calculating the average number of continuous dry days in each time period, an extreme value frequency distribution (Gumbel type 1 distribution) was fitted to estimate the durations of continuous dry days within 1 year, with a return period or average frequency interval of 10 years and 25 years.

Table 20 shows the number of consecutive dry days averaged for each time period, and calculated for 10- and 25-year return periods under the A1B scenario in South Asia.

Table 20: **Number of Consecutive Dry Days per Year for the A1B Scenario in South Asia**

	Baseline 1991–2000			2026–2035			2046–2055			2081–2090		
Country	Average	10-Year Return Period	25-Year Return Period	Average	10-Year Return Period	25-Year Return Period	Average	10-Year Return Period	25-Year Return Period	Average	10-Year Return Period	25-Year Return Period
Bangladesh	76	100	114	74	102	118	79	108	124	77	108	126
Bhutan	28	51	59	32	52	63	28	47	58	32	49	59
India	108	139	156	106	142	162	110	143	162	112	147	168
The Maldives	41	67	81	46	74	90	44	74	91	68	97	114
Nepal	33	51	61	36	56	67	35	54	66	38	54	63
Sri Lanka	49	75	90	51	79	95	50	83	101	57	89	107

A1B = projected scenario from *IPCC Special Report on Emission Scenarios*.

[14] Unfortunately, due to the sensitivity of delineating disputed international borders in the region, the GIS output maps cannot be shown; such maps are ideal for appreciating spatial patterns and differences. Tabulated results from the GIS modeling are instead presented.

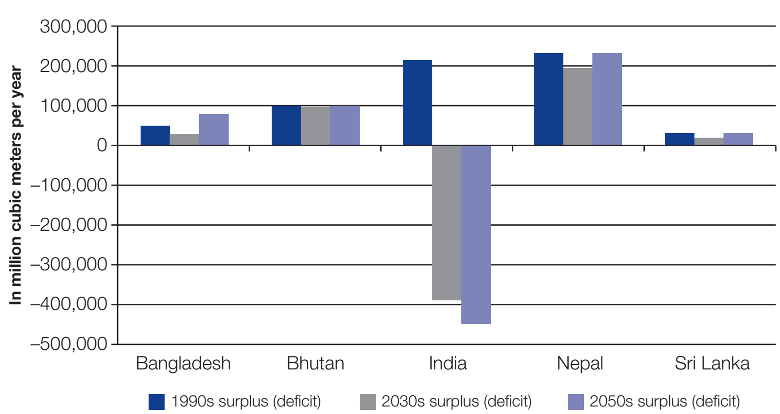
Water Balance (Water Supply and Demand)

Baseline data (year 2000) on water demand, which is available on gridded GIS maps, were obtained from the *United Nations World Water Development Report* (UNESCO 2006). The gridded baseline water demand maps were rescaled so that these could be overlaid on dependable water resource maps to calculate annual water balance (surplus or deficit) for each 30x30 km grid cell. Water balance was calculated for each grid cell as the difference between the annual dependable water resource and the annual water demand. This was done for each climate change scenario, but only for the periods 2026–2035 and 2046–2055. Water balance was not projected for 2081–2090 due to the absence of reliable water demand projections that far into the future.

Results of the gridded water balance assessment should however be regarded as very conservative because of the possible underestimation of dependable water resources (e.g., for India, significant external water resources (river flows from the People's Republic of China and Nepal) are not taken into account), and because the irrigation demand estimates possibly double count consumptive water use from evapotranspiration from cropped areas that is already included in the dependable water estimate. The results, showing only annual averages, are valid mainly for assessing spatial patterns and differences in relative water balance, long-term trends, and sensitivity of different regions to the three climate change scenarios.

Figure 20 shows the water balance (surplus or deficit) per grid cell for five countries, corresponding to the A1B scenario and time periods up to mid-century. The Maldives was not included because it is too small for the modeling resolution using the regional climate model climate data and gridded water demand data. A different water balance approach is also warranted because the Maldives has no surface storage and relies on groundwater recharge for water supply (not considering existing water supply adaptation measures involving seawater desalination and rainwater harvesting by households). The

Figure 20: **Water Balance for Scenario A1B in South Asia**



A1B = projected scenario from *IPCC Special Report on Emission Scenarios*.

groundwater is in shallow lenses that are vulnerable to sea level rise (and to pollution insofar as quality for drinking purposes is concerned).

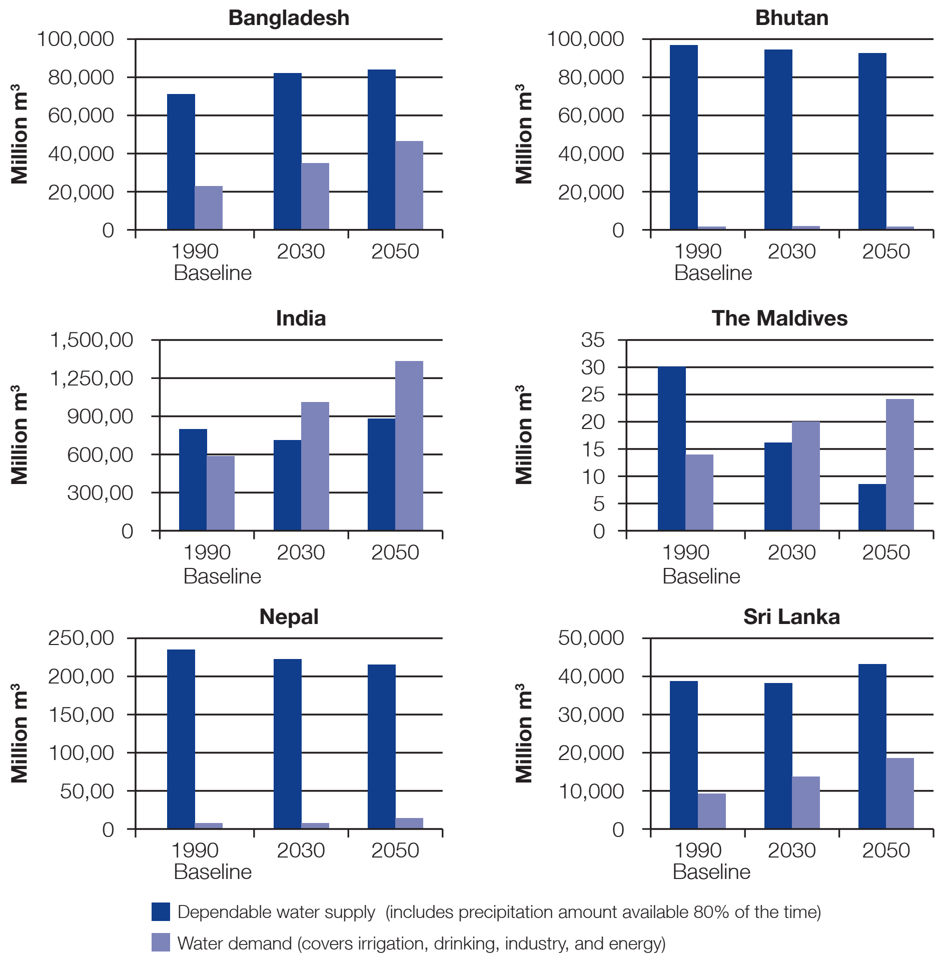
Under A1B scenario, water supply in Bangladesh, Bhutan, Nepal, and Sri Lanka are likely to be higher due partly to the positive effects of increased rainfall. On the other hand, due to variations in intensity and distribution of rainfall, the region as a whole will experience water deficit, particularly in India where water deficit will be roughly 300 billion m^3 and 400 billion m^3 by 2030s and 2050s respectively (Figure 21).[15]

Studies on impacts of climate change indicate that the quantity of surface runoff would vary across India's river basins and sub-basins by the 2050s. An increase in precipitation in the Brahmani, Cauvery, Ganga, Godavari, and Mahanadi basins has been projected under the A1B and A2 climate change scenarios. However, the corresponding total runoff for all these basins does not increase (Indian Network on Climate Change Assessment 2010). This may be due to increased evapotranspiration with projected higher temperatures and variations in rainfall distribution.

Agriculture makes up a disproportionately large fraction of existing water demand and projected demand increase in the region. In India, irrigation accounts for 85% of the present water demand but is projected to slightly decline to 83% and 74% by 2025 and 2050, respectively. The country's irrigation water demand is projected to grow by 68% in 2025 and almost double by 2050 from the 2000 baseline. In Bangladesh and Sri Lanka, agriculture accounts for 88% and 87% of the current water use respectively.

[15] According to 2030 Water Resources Group, India's water deficit may reach 750 billion cubic meters by 2030 even without the adverse impacts of climate change (2030 Water Resources Group 2009).

Figure 21: **Water Supply and Demand in South Asia under A1B Scenario**



A1B = projected scenario from *IPCC Special Report on Emission Scenarios*.

Sources:

1990 Baseline data is from United Nations. 2006. *Water: A Shared Responsibility: The United Nations World Water Development Report 2.* United Nations Educational, Scientific and Cultural Organization (UNESCO) and Berghahn Books.

Water demand data for India is from Planning Commission. 2004. *Report of the Inter Ministry Task Group on Efficient Utilization of Water Resources*. http://planningcommission.nic.in/aboutus/taskforce/inter/inter_uwr.pdf

Water demand data for Bangladesh, Bhutan, the Maldives, and Nepal are from Reddy, M., V. Char, N. Afzal, S. Qutub, D. Basnyat, J. Karmacharya, M. Miah, S. Mukherjee, J. Nickum, K. Rahman, and K. Rasheed. 2004. *Water Demand–Supply Gaps in South Asia: Approaches to Closing Gaps*. Project on Water and Security in South Asia, implemented by the South Asia Program, School of Advanced International Studies, Johns Hopkins University, Washington, DC.

5 Economic Implications of Climate Change in South Asia

Modeling the Economy-Wide Impact of Climate Change

Climate-related economic information is critical in supporting development and climate actions in South Asia. Steps taken now and in the future to improve living standards and achieve sustainable development must take into account climate change and its potential consequences. Based on sectoral assessments undertaken in the previous chapters and existing literature, this chapter uses (i) integrated assessment models to analyze long-term economic impacts of climate change and estimate the magnitude of funding required in South Asia to respond to climate change, and (ii) computable general equilibrium (CGE) models to evaluate country and regional implications of climate change on other relevant macroeconomic indicators such as commodity prices, competitiveness, and income distribution in South Asia.

It is important to note at the outset that, like other climate change studies, the estimates are highly sensitive to a number of assumptions underlying the analysis. For example, the total economic cost of climate change depends on the models' coverage of different sectors and impacts. Although key sectors, such as agriculture, water, coastal, energy, human health, ecosystems, and extreme events, are considered in most cases, there are still many missing and unknown impacts. Estimates are also contingent on how future scenarios unfold, the time horizon envisaged, and how societies value their futures and future generations, among other things. Therefore, the results should always be interpreted in association with scenario story lines, and should be taken as indicative rather than as a forecast.

Results from Integrated Assessment Models

Damage Costs to the Economy

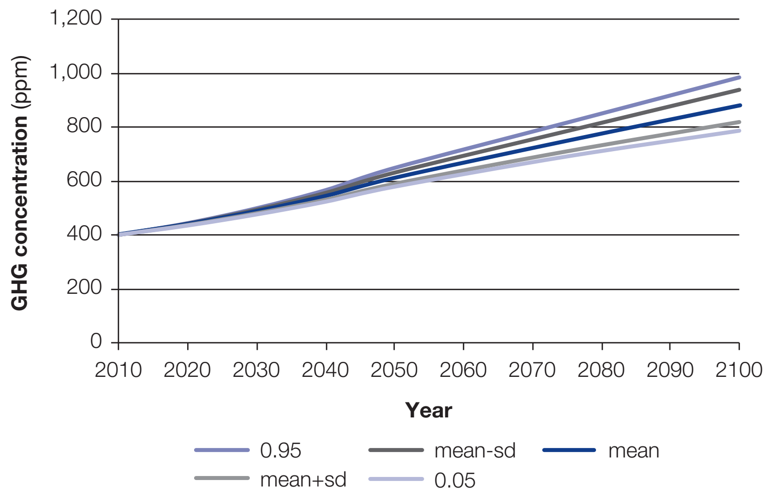
This section discusses, for each scenario, integrated assessment model results on (i) key climate parameters, such as the projections of greenhouse gas concentration level, temperature change, and sea level rise; and (ii) economic implications of climate change, including sector-specific and total (economy-wide) economic losses, with emphasis on the uncertainties surrounding climate change literature. The results are presented in probabilistic terms, covering the 90% confidence interval (from the 5th to the 95th percentile) with mean outcomes and their standard deviations, unless otherwise stated.

Note that the 2013 *IPCC Fifth Assessment Report* projects mean global surface temperatures in 2018–2020 to rise by 0.3°C–1.7°C to 2.6°C–4.8°C (BAU) relative to 1986–2005.[16]

Business-as-usual scenario

The Policy Analysis of Greenhouse Effect version 9 (PAGE09) projects that the global greenhouse gas concentration level will continue to rise under the BAU scenario from approximately 400 parts per million (ppm) today to more than 450 ppm in 2025 (Figure 22). The greenhouse gas level is projected to reach 880 ppm in 2100 and to continue to rise beyond the end of the 21st century. This will inevitably have a significant impact on global temperatures.

Figure 22: **Global Greenhouse Gas Concentration under the BAU Scenario in South Asia**



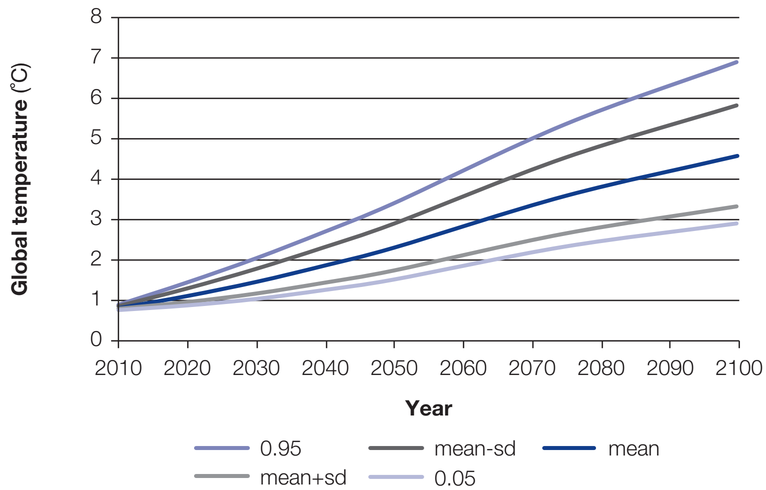
BAU = business as usual, GHG = greenhouse gas, ppm = parts per million, sd = standard deviation.

Figure 23 shows that there is a 50% probability for global mean temperature rise to exceed 2°C by 2050. PAGE09 projects that the global community will experience a 4.6°C rise on average by 2100 from the pre-industrial level (the average land temperature rise would be 5.8°C and average sea temperature rise, 4.1°C). There is a large uncertainty in the projections about future climate and what we know about future climate.

At the country level, variation in temperature increase is observed (Figure 24). The average temperature rise in Bangladesh, Bhutan, India, and Nepal is projected to exceed 2°C by 2050. By 2100, these countries are expected to face around 4.8°C rise—a level higher than the global average increase. This is due to their geographical location (higher latitude and inland). The Maldives and Sri Lanka are projected to experience a milder and similar temperature rise, approximately 4.3°C, by 2100.

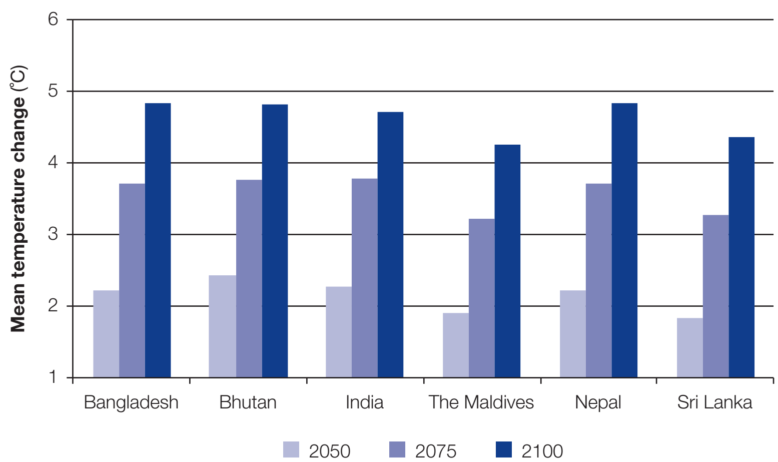
[16] IPCC (Intergovernmental Panel on Climate Change). 2013. *Climate Change 2013: The Physical Science Basis. Summary for Policymakers*. Working Group I Contribution to the Fifth Assessment Report. IPCC, Switzerland. October. www.ipcc.ch/report/ar5/wg1/docs/WGIAR5_SPM_brochure_en.pdf?bcsi_scan_e41ddc73166bc1eb=tFWrHjjimW7KcVUnMO0vsbcam+IBAAAARPnwAA==&bcsi_scan_filename=WGIAR5_SPM_brochure_en.pdf

Figure 23: **Global Mean Temperature Change under the BAU Scenario in South Asia**



BAU = business as usual, sd = standard deviation.

Figure 24: **Mean Temperature Change under the BAU Scenario in South Asia**

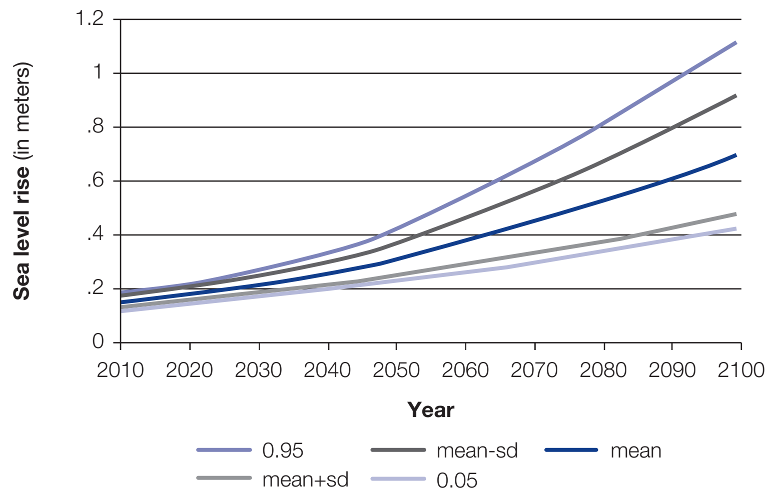


BAU = business as usual.

PAGE09 projects a 0.70-meter sea level rise by 2100 on average relative to the pre-industrial level, with a 90% level of confidence that it will range between 0.42 and 1.12 meters (Figure 25).[17] The result reflects thermal expansion of the oceans as well as the melting of West Antarctic and Greenland ice sheets. Such magnitudes of warming and sea level change will have significant repercussion across vulnerable sectors/areas, including agriculture, water resources, coastal zones, infrastructure, human health, and the energy sector.

[17] As noted earlier, the 2013 *IPCC Fifth Assessment Report* projects mean global sea level to rise in 2100 by mean heights of 0.40–0.63 m (5%–95% range) above the 1986–2005 level. http://www.climatechange2013.org/images/uploads/WGI_AR5_SPM_brochure.pdf

Figure 25: **Global Sea Level Rise under the BAU Scenario in South Asia**



BAU = business as usual, sd = standard deviation.

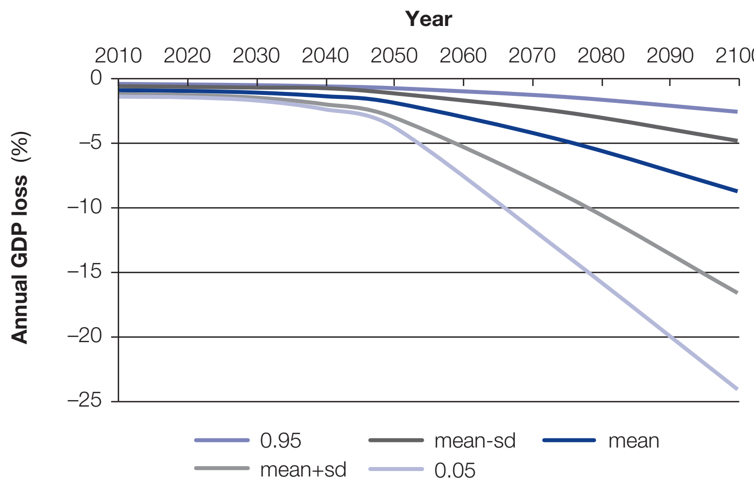
Note that although the global mean temperature by 2100 is projected to be 4.6°C on average (after taking into consideration a wide array of existing climate models), there is a 5% chance that the temperature level could go up beyond 6.9°C by 2100 under the BAU scenario. Similarly, there is a 5% chance that sea level will rise above 1.1 meters by 2100.

Based on the BAU climate parameters discussed, the model simulates the total economic loss to the countries in South Asia toward 2100, taking into account the impacts across the vulnerable sectors. The model projects that the total loss due to climate change impacts to the region will be relatively small (1.8% of annual GDP) up to 2050, but the losses will accelerate in the second half of the century to 8.8% of the region's annual GDP by 2100 on average under BAU (Figure 26). In the worst case (i.e., with 5% chance), the region could experience 24% annual GDP loss equivalent by 2100. It is worth pointing out that the regional estimate is dominated by the findings on India. Note also that the model excludes extreme events, such as storms, floods, and droughts, and there are missing or unknown impacts that are not captured in the model. Thus, the values could be considered lower-bound estimates.

Figures 27 and 28 show total economic loss due to climate change for each of the six countries of South Asia in 2050 and 2100, respectively. The model suggests that the Maldives, being the most vulnerable among the six countries, will be hardest hit in GDP loss. The mean outcome of the simulation indicates that the economic damage will be around 2.3% of GDP in 2050, ranging between 0.9% and 5.0% of GDP within the 90% confidence interval. By 2050, annual GDP losses are projected under the BAU scenario for Bangladesh (2.0%), Bhutan (1.4%), India (1.8%), Nepal (2.2%), and Sri Lanka (1.2%).

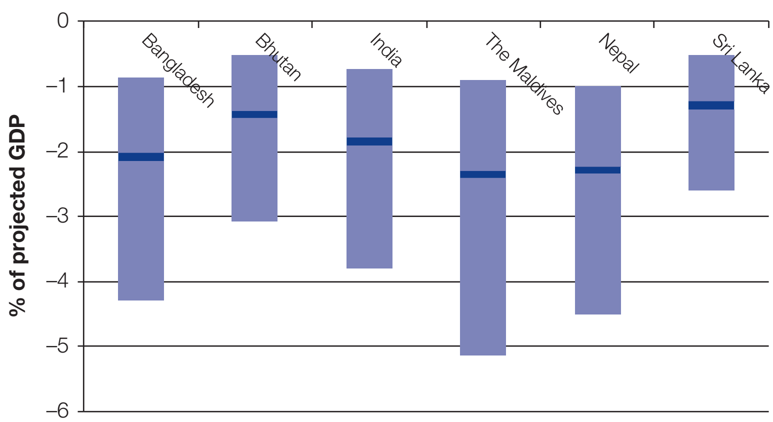
In the longer term, the total economic costs associated with climate change impacts are likely to increase in all countries. If no action is taken to adapt to and mitigate

Figure 26: **Total Economic Cost of Climate Change for South Asia under the BAU Scenario**



BAU = business as usual, GDP = gross domestic product, sd = standard deviation.

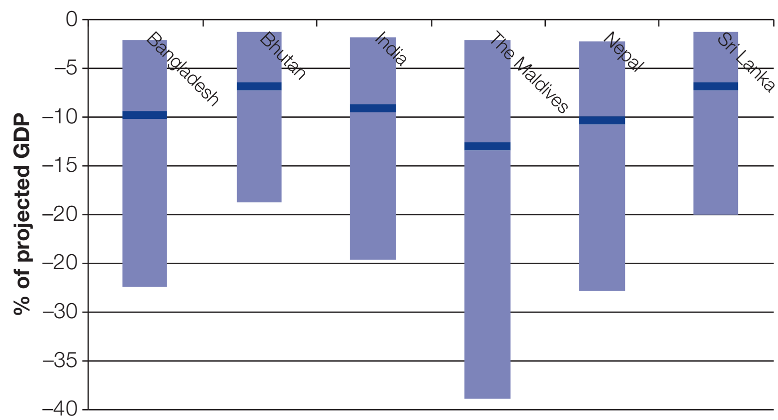
Figure 27: **Total Economic Cost of Climate Change under the BAU Scenario in 2050 in South Asia**



BAU = business as usual, GDP = gross domestic product.
Dark blue bars show mean.

global climate change, the average total economic losses are projected to be 9.4% for Bangladesh, 6.6% for Bhutan, 8.7% for India, 12.6% for the Maldives, 9.9% for Nepal, and 6.5% for Sri Lanka (Figure 28). The Maldives could encounter as high as 38.1% GDP loss equivalent (5% chance). Long-tailed distributions of economic impacts are found for all the countries, meaning that catastrophic events could happen, though with low probability.

Figure 28: **Total Economic Cost of Climate Change under the BAU Scenario in 2100 in South Asia**



BAU = business as usual, GDP = gross domestic product.
Dark blue bars show mean.

Copenhagen–Cancun scenario

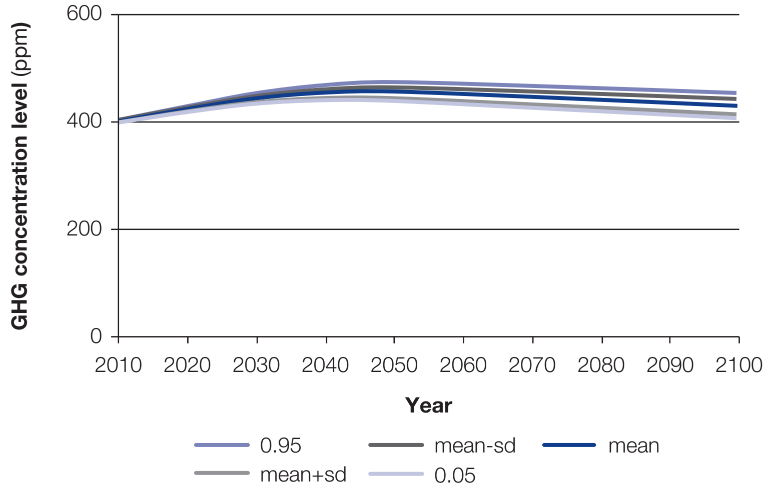
The Copenhagen–Cancun (C–C) scenario assumes decoupling of greenhouse gas emissions from BAU economic growth and imposes the implementation of Copenhagen Accord pledges, together with immediate complementary actions toward a long-term vision in line with the Cancun Agreements, aiming at keeping the global mean temperature rise below 2°C.[18]

The global climate under the C–C scenario would look very different from that under the BAU scenario. In the C–C case, the global greenhouse gas concentrations are projected to peak at 455 ppm in 2050, then drop to 430 ppm in 2100 (Figure 29). PAGE09 projects that the warming will increase beyond 2°C (relative to the pre-industrial temperature) around 2075—35 years after the BAU scenario. The rate at which the global mean temperature rises will slow down and reach 2.1°C in 2100 on average (Figure 30) as against the 4.6°C rise by 2100 under the BAU scenario. Although the warming is not as severe in the case of C–C, the probability of temperature rise growing beyond 2°C increases over time. Therefore, delay or underachievement of the C–C scenario is not an option.

Under the C–C scenario, the model simulates a lower economic loss to the region toward 2100 than under the BAU scenario. Figure 31 shows that the region would lose an average of 1.3% of GDP by 2050 and roughly 2.5% by 2100—these could only be achieved if the region adapts its actions to fulfillment of the Cancun Agreements in keeping the global mean temperature rise below or within 2°C. However, there is a 5% probability that the region could experience an economic loss of 6% of annual GDP equivalent on average by 2100.

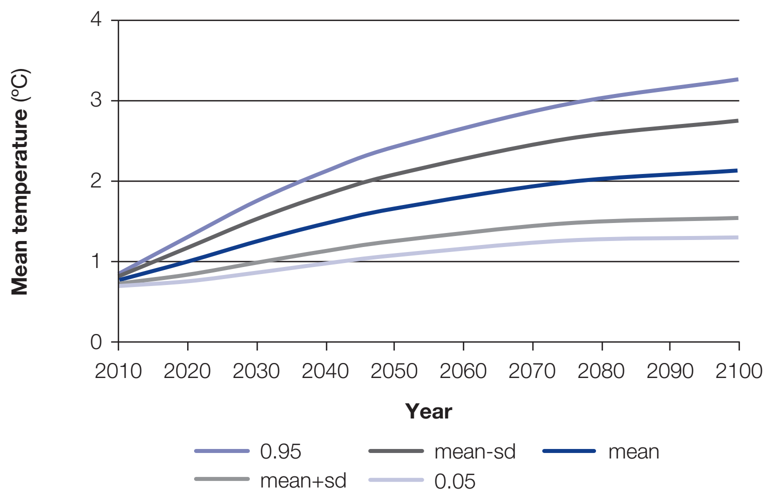
[18] Although the Copenhagen pledges themselves are insufficient to transform the global economy toward a Copenhagen–Cancun path, the vision to achieve this target is rooted in the 15th Conference of Parties in Copenhagen.

Figure 29: **Global Greenhouse Gas Concentration under the Copenhagen-Cancun Scenario in South Asia**



GHG = greenhouse gas, ppm = parts per million, sd = standard deviation.

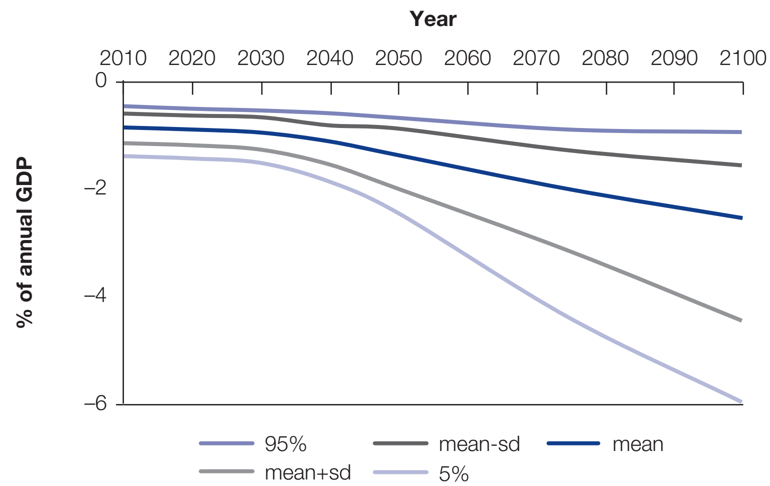
Figure 30: **Global Mean Temperature Change under the Copenhagen-Cancun Scenario in South Asia**



sd = standard deviation.

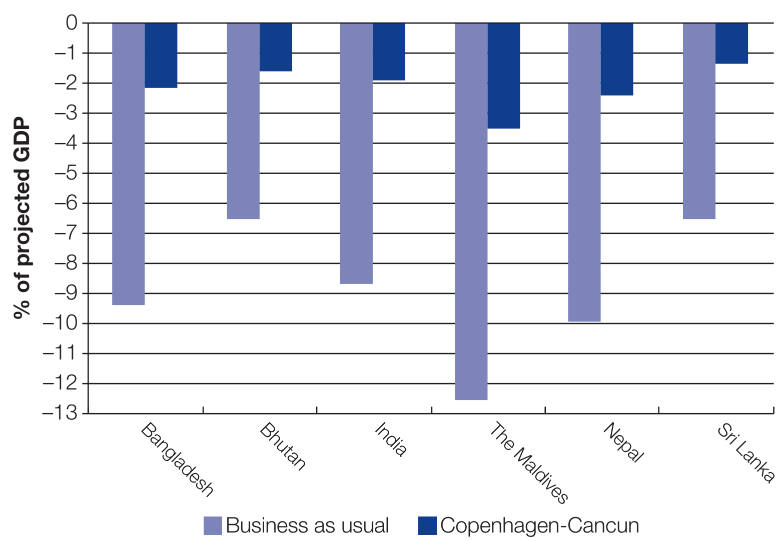
Figure 32 shows country-specific climate change damages in 2100 under the BAU and the C–C scenarios, based on the average simulation outcomes. Under the C–C scenario, the total economic costs of climate change will be kept to manageable levels across the countries in South Asia. The differences between the results from two scenarios indicate the benefits in the six countries from the global shift toward the C–C scenario. The Maldives will benefit most if the global transformation to the

Figure 31: **Total Economic Cost of Climate Change for South Asia under the Copenhagen–Cancun Scenario**



GDP = gross domestic product, sd = standard deviation.

Figure 32: **Mean Economic Cost of Climate Change under the BAU and Copenhagen–Cancun Scenarios in 2100 in South Asia**



GDP = gross domestic product.

C–C scenario materializes. In such a case, the Maldives will be able to avoid economic damage equivalent to 9.1% of GDP in 2100. Bangladesh is projected to regain 7.3% of annual GDP equivalent by 2100 from the paradigm shift, while Bhutan, India, Nepal, and Sri Lanka will avert 4.9%, 6.8%, 7.5%, and 5.1% loss of annual GDP, respectively, in the same period.

Cost of Adaptation in South Asia

This section provides estimates of adaptation costs associated with different climate scenarios and adaptation targets in South Asia. Table 21 presents annual average cost between now and 2050 and the range of estimates within the 90% confidence interval, both in terms of absolute monetary values and as a percentage of GDP.

Table 21: **Annual Average Adaptation Cost during 2010–2050 for South Asia**

		$ billion		GDP (%)	
Policy Scenario	Adaptation Target	Annual Average Cost	Range	Annual Average Cost	Range
BAU_1	2100 worst case (6.9°C, 1.1 m SLR)	110.9	51.2–198.0	1.32	0.64–2.29
BAU_2	2100 (4.5°C, 0.70 m SLR)	72.6	33.1–127.8	0.86	0.42–1.46
BAU_3	2050 (2.5°C, 0.30 m SLR)	40.2	18.3–71.5	0.48	0.23–0.81
$C–C_1$	2100 (2.5°C, 0.55 m SLR)	40.6	18.8–71.4	0.48	0.24–0.82
$C–C_2$	2050 (1.9°C, 0.30 m SLR)	31.0	14.2–54.5	0.36	0.18–0.62

BAU = business as usual, C–C = Copenhagen–Cancun, GDP = gross domestic product, m = meter, SLR = sea level rise.

The region requires funding with the magnitude of 1.3% of GDP on average per annum between 2010 and 2050 under the BAU_1 scenario, which refers to a 6.9°C temperature rise and to 1.1-meter sea level rise by 2100 (worst case scenario). The cost could rise to up to 2.3% (upper range) of GDP per annum taking into account climate uncertainties.

To avoid climate change impact under the BAU_2 scenario (i.e., adapting to 4.5°C temperature rise and to 0.7 meter sea level rise) toward 2100, adaptation cost of around $73 billion per annum on the average is required between now and 2050. Considering uncertainties associated with climate change, the annual adaptation cost may rise to approximately $128 billion or 1.46% of GDP during the same period. Despite this investment, South Asia will still be facing economic loss due to residual damage equivalent to 2.5% of GDP per annum by 2100 on average. However, adapting to a lower temperature under the BAU_3 scenario (i.e., 2.5°C temperature rise and 0.3 meter sea level rise) only requires adaptation cost of roughly $40 billion (0.48% of GDP) on average per annum. If one includes uncertainties for the same period, the cost can rise to as high as $72 billion (0.81% of GDP).

Adaptation cost under the C–C scenario (i.e., adapting to 2.5°C temperature rise and 0.6 meter sea level rise) by 2100 is projected to be 0.24%–0.82% of GDP per annum on average within the 90% confidence interval and with a mean outcome of 0.48% of GDP. Likewise, adapting to a much lower temperature for 2050, the region would only require $31 billion on average per annum. Obviously, adaptation costs are lower under the C–C scenario.

It is evident from Table 21 that adaptation need and investment requirement depend on global mitigation efforts. It is more challenging to adapt to climate impacts under the BAU scenario than to adapt under lower-emission scenarios as costs will be higher and uncertainties will also be higher.

Investment costs of adaptation in individual sectors are difficult to establish. The cost of adaptation in the energy sector in South Asian countries, however, could be determined in terms of the expected demand–supply gap in each country (Table 22).

Table 22: **Summary of Average Energy Demand–Supply Gap and Adaptation Cost for South Asian Countries**

	Average Energy Demand–Supply Gap (TWh)		Adaptation Cost ($ million)	
Country	2030s	2050s	2030s	2050s
Bangladesh	2.43 (2.94)	9.86 (4.56)	89.3	3,634
Bhutan	0.51 (15)	1.38 (17)	11.2	30.5
India	112.76 (5)	310.25 (5.8)	7,797.8	21,456
The Maldives	0.03 (2.42)	0.12 (3.95)	9.9	38.6
Nepal	1.27 (20.6)	2.34 (18)	118.75	218.8
Sri Lanka	0.94 (4.2)	1.33 (2.91)	105.4	149.0

TWh = terawatt hour.

Note: Figures in parentheses are the percentage values of energy demand–supply gap against baseline energy demand.

Costs of specific adaptation measures are difficult to determine and vary widely across the region. Bhutan provides an example. There are at least 25 dangerous glacial lakes in the country. A target has been set for lowering the water level of the Thorthormi glacial lake by 5 meters. After 2 years beginning in 2009, the lake level was lowered by about 2.3 meters. The cost is estimated to reach $3.45 million. A glacial lake outburst flood (GLOF) hazard zoning map was prepared for the riverside areas where major settlements are located, costing around $230,000, and a GLOF early warning system was installed at a cost of $1.4 million.

Results from Computable General Equilibrium Model

The following presents an analysis of country and regional implications of climate change and its future impact on other relevant macroeconomic, sectoral, and household parameters through the use of a computable general equilibrium (CGE) model.

Regional Analysis

Climate costs appear to be relatively moderate as they represent only a fraction of overall real GDP. It should be emphasized, however, that offsetting structural and resource shifts at the macro level may conceal serious adjustment costs for some stakeholder groups within economies. Impacts are quite heterogeneous across countries, with lower-income countries being more adversely impacted by agriculture-related constraints (crops, water, and land); because these countries have higher shares of GDP in agriculture and much higher expenditure shares on agrifood products, agriculture-related climate impacts hit low-income economies harder. This fact, coupled with their more limited financial, institutional, and other means for adaptation, indicates that lower-income Asia generally and South Asia in particular will face higher-than-average climate adaptation challenges.

In a stable energy price environment, even moderate agricultural productivity growth can more than offset median case climate adversity at the aggregate level, at least until 2050. This implies policy makers have a first line of adaptation defense right in front of them: continuation and extension of agricultural productivity growth. Merely sustaining historical trends of agrifood innovation would more than offset the adverse effects of median trend climate change (Table 23).

Table 23: **Real GDP Impacts of Climate Change in South Asia**
(cumulative percent [%] change from baseline, 2010–2050)

	Crops	Water	Land	EPrice	AgProd
Bangladesh	(1.1)	(2.2)	(3.2)	(11.4)	6.8
India	(0.9)	(2.1)	(3.9)	(21.9)	3.0
Nepal	(3.7)	(7.7)	(12.0)	(20.3)	16.4
Sri Lanka	(1.9)	(4.3)	(6.1)	(20.4)	17.9
Other low-income Asia	(1.3)	(2.7)	(4.0)	(12.6)	9.5
Other high-income Asia	(0.4)	(0.9)	(1.4)	(41.6)	0.7
All Asia	(0.9)	(2.2)	(2.4)	(16.8)	4.3

( ) = negative, AgProd = productivity growth in agriculture and related food industries, EPrice = energy price escalation, GDP = gross domestic product.

A more detailed perspective on macroeconomic adjustment is given in Table 24. These results show real GDP component changes for the land scenario, which combines the three main climate change drivers of lower crop yields, water scarcity, and arable land changes. As observed, aggregate real GDP changes vary significantly, but impacts are generally single-digit percentages. As low-income countries are driven by higher agrifood prices to reduce demand for other products, real output declines more sharply than value added. This implies a reversion to agrarianism, where rising food prices crowd out domestic demand for less essential goods and services. Movements in aggregate exports and imports are generally in the same direction, with a dominant regional trend of lower trade than baseline trends.

When price impacts are taken into account (higher for agrifood products especially), it will be observed that real consumption is more significantly hit across the region. Nepal is

Table 24: **Climate Impacts on Macroeconomic Aggregates**
(cumulative percent [%] change from baseline, 2010–2050)

Scenario: Land	Real GDP	Output	Exports	Imports	Cons	CPI
Bangladesh	(3)	(12)	(5)	(4)	(8)	25
India	(4)	(27)	(8)	5	(1)	5
Nepal	(12)	(13)	(12)	(17)	(11)	8
Sri Lanka	(6)	(25)	(6)	(5)	(2)	4
Other low-income Asia	(4)	(22)	(5)	(2)	(2)	2
Other high-income Asia	(1)	20	(1)	(2)	(1)	1
All Asia	(2)	(12)	(5)	(1)	(3)	3

( ) = negative, CPI = consumer price index; Cons = consumption; GDP = gross domestic product.

particularly hard hit in value added because water scarcity inhibits its energy production, escalating electricity prices.

In general, analyses suggest that costs of climate threats to 2050 are moderate, implying less than 10% lower real GDP for the economies considered. However, detailed results suggest that impacts on food security generally, and on the poor in particular, could be much more severe. Clearly, the region's adaptation response need not be confined only to symptomatic treatment of threats to traditional patterns of economic activity. More efficient regional economic diversification can create entirely new patterns and supporting infrastructure to take their place. In other words, policy makers need to take early action to adapt to climate risks, and this action needs to be informed by rigorous and timely evidence.

Impact Assessment through a Dynamic Computable General Equilibrium Model—Bangladesh

A country case for Bangladesh is illustrated below to show the macroeconomic impact of climate change on various sectors of the economy based on the different parameters as provided in the sector impact assessment in Chapter 4.

The Bangladesh CGE model uses both static and dynamic models in its simulation. The static model presents the behavior of the economic agents in the economy whereas the dynamic model shows the transition path of the economy due to any external shock. In the following analyses, the study applied shocks on rice yield, land quantity (sea level rise and inundation), labor supply, infrastructure, water quantity, and electricity supply to show climate change impacts (positive or negative) on all sectors of the economy due to the rise or fall of the microeconomic parameters in 2030, 2050, and 2100. Results of these shocks are illustrated below.

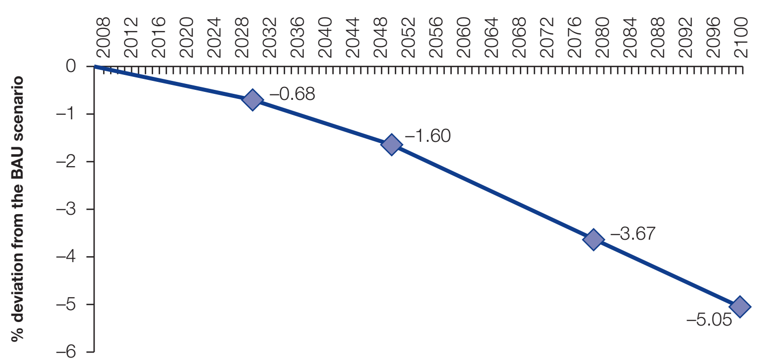
Overall, the Bangladesh dynamic CGE (BGDDyn CGE) model shows that mean economic cost of climate change by 2100 would be about 2% of GDP under C–C conditions but more than 9% of GDP under the BAU scenario—the same results as that of the integrated assessment model illustrated earlier in Figure 32. The government, in the

Sixth Five Year Plan (2011–2015) and in the Perspective Plan, plans to achieve a high GDP growth rate. Based on the country's current incremental capital–output ratio (which is roughly equal to four), Bangladesh would need to increase the investment–GDP ratio by 4%. To compensate for the reduction in real GDP in 2030, 2050, 2080, and 2100, the investment–GDP ratio would have to rise further by 0.03%, 0.075%, 0.17% and 0.23%, respectively.

Impact on Paddy Yield

Paddy production is the most dominant productive activity in Bangladesh. Simulations showed that under the BAU scenario, due to the reduction in yield, paddy production would fall by 1.60% in 2050 and 5.05% in 2100. The decline in paddy yield due to climate change will bring a negative impact on real GDP of Bangladesh by 0.67% in 2050 and 0.93% in 2100 under the BAU scenario. Given the high prevalence of poverty, food security in the country is closely linked to "rice security." A fall in rice production, as indicated in Figure 33, would increase its price, which would then place upward pressure on the overall consumer price index (CPI) of the economy (i.e., decline in total exports, rise in the import of rice, and decrease in household real consumption). This would put additional pressure on the government in maintaining the country's long-term food security.

Figure 33: **Impact of Paddy Yield Shock on Rice Production in Bangladesh**



BAU = business as usual.

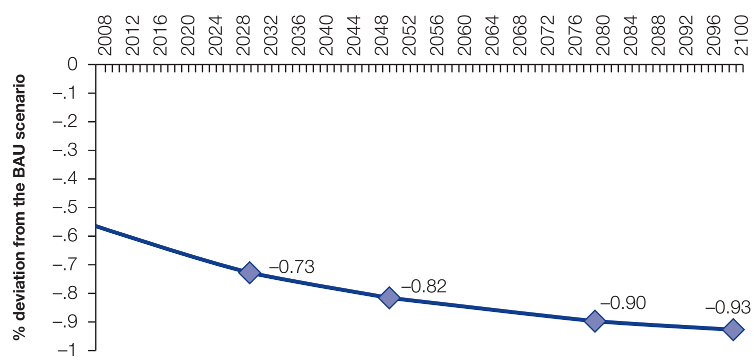
Impact on Land Quantity (Sea Level Rise and Permanent Inundation)

The vulnerability assessment conducted under this study indicated that 0.9% of Bangladesh dryland is expected to be permanently inundated. Degradation of land is a vital issue as it is a threat to agricultural productivity, job creation, and poverty reduction in general.

The fall in production in all sectors in the economy due to the land quantity shock would lead to a fall in real GDP (Figure 34). Under the BAU scenario, real GDP would fall by 0.73% in 2030 and by up to 0.93% in 2100. The negative impacts on real GDP would be high because land is a critical factor of production for almost all sectors of the economy. Unless the productivity of land is increased substantially in the coming years, such negative impacts on the economy would persist and undermine potential economic progress in the future.

The negative impacts on the economy due to land quantity shock would also be manifested through a rise in CPI and fall in overall exports and imports. This suggests that the impact of climate change through the reduction in available land (inundation) would put pressure on the stability of the balance of payment of Bangladesh.

Figure 34: **Impact of Land Quantity Shock on Real Gross Domestic Product in Bangladesh**



BAU = business as usual.

Impact on Labor Quantity and Productivity

The macroeconomic, sectoral, and household level results of labor supply shock are provided in Table 25, which shows that the labor supply shock, with unchanged labor productivity, would have a negative impact on all sectors in the economy and the magnitude of the negative effects would continue to increase over time. In general, the industrial subsectors would experience larger negative impacts than the agricultural and services subsectors. Labor productivity is considered to be very low in Bangladesh compared with many other countries. However, increasing labor productivity is a daunting task that requires changing the current labor-intensive production processes in most of the agricultural and industrial sectors to more capital-intensive production processes. Also, sustained investments are needed in enhancing skills of the labor force. But unless significant improvement in productivity of labor is achieved in the coming years, climate change will exert negative impact on the overall economy through reduced production in most sectors.

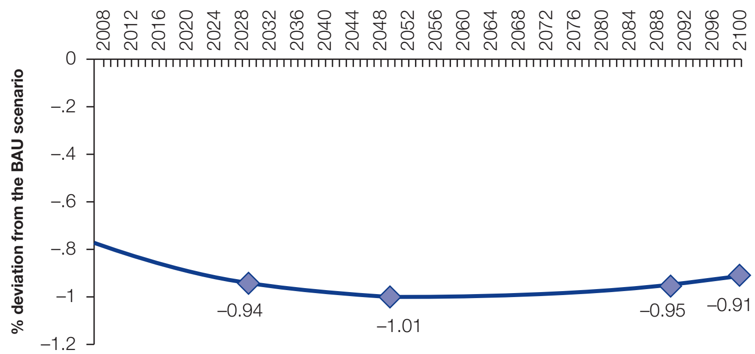
As production in all sectors would decline, real GDP under the BAU scenario would also fall, by 0.94% in 2030 and by a further 0.91% in 2100 (Figure 35). Fall in sectoral production and real GDP would lead to a rise in the CPI and a fall in both exports and imports. All major export-oriented sectors, especially knitting and woven garments, would

Table 25: **Impact of Labor Supply Shock on Sectoral Production in Bangladesh**

Sectors	% Deviation from the Business-as-Usual Scenario			
	2030	2050	2090	2100
Paddy	(0.87)	(0.92)	(0.87)	(0.84)
Other crops	(0.85)	(0.95)	(0.96)	(0.94)
Livestock rearing	(0.57)	(0.62)	(0.59)	(0.57)
Poultry rearing	(0.66)	(0.71)	(0.67)	(0.64)
Fishing	(0.67)	(0.71)	(0.67)	(0.64)
Forestry	(0.72)	(0.79)	(0.76)	(0.74)
Rice milling	(0.81)	(0.85)	(0.81)	(0.78)
Grain milling	(0.82)	(0.87)	(0.81)	(0.78)
Food processing	(0.97)	(1.03)	(0.97)	(0.93)
Leather	(0.92)	(0.98)	(0.91)	(0.87)
Yarn	(1.43)	(1.57)	(1.56)	(1.52)
Cloth milling	(1.07)	(1.12)	(1.02)	(0.98)
Woven ready-made garments	(1.23)	(1.29)	(1.18)	(1.13)
Knitting	(1.12)	(1.19)	(1.11)	(1.07)
Toiletries	(1.30)	(1.38)	(1.28)	(1.22)
Cigarette	(0.79)	(0.84)	(0.78)	(0.75)
Furniture	(1.04)	(1.14)	(1.09)	(1.05)
Paper, printing, and publishing	(1.44)	(1.55)	(1.45)	(1.39)
Pharmaceuticals	(0.79)	(0.85)	(0.80)	(0.77)
Fertilizer	(1.46)	(1.63)	(1.59)	(1.53)
Petroleum	(1.05)	(1.14)	(1.08)	(1.04)
Chemicals	(1.50)	(1.65)	(1.57)	(1.51)
Glass	(0.98)	(1.06)	(1.01)	(0.97)
Earthenware and clay	(0.89)	(0.98)	(0.94)	(0.91)
Cement	(1.25)	(1.38)	(1.33)	(1.29)
Metals	(1.38)	(1.51)	(1.44)	(1.39)
Miscellaneous	(1.29)	(1.39)	(1.32)	(1.27)
Mining and quarrying	(0.95)	(1.05)	(1.01)	(0.97)
Construction	(0.87)	(0.96)	(0.93)	(0.90)
Electricity and water generation	(0.80)	(0.87)	(0.82)	(0.79)
Gas extraction and distribution	(0.81)	(0.89)	(0.85)	(0.82)
Wholesale and retail trade	(0.99)	(1.05)	(0.99)	(0.96)
Transport	(1.11)	(1.19)	(1.12)	(1.08)
Health service	(0.78)	(0.84)	(0.78)	(0.75)
Education service	(0.92)	(0.92)	(0.79)	(0.75)
Public administration and defense	(1.03)	(1.00)	(0.84)	(0.79)
Bank, insurance, and real estate	(1.08)	(1.15)	(1.08)	(1.04)
Hotel and restaurant	(0.86)	(0.91)	(0.84)	(0.81)
Communication	(0.99)	(1.05)	(0.98)	(0.94)
Information technology and e-commerce	(1.04)	(1.11)	(1.03)	(0.99)
Other services	(0.90)	(0.97)	(0.91)	(0.87)

( ) = negative.

Figure 35: **Impact of Labor Supply Shock on Real Gross Domestic Product in Bangladesh**



BAU = business as usual.

experience falls in production and exports. The impact on imports would be smaller than that on exports, aggravating the stability of balance of payments.

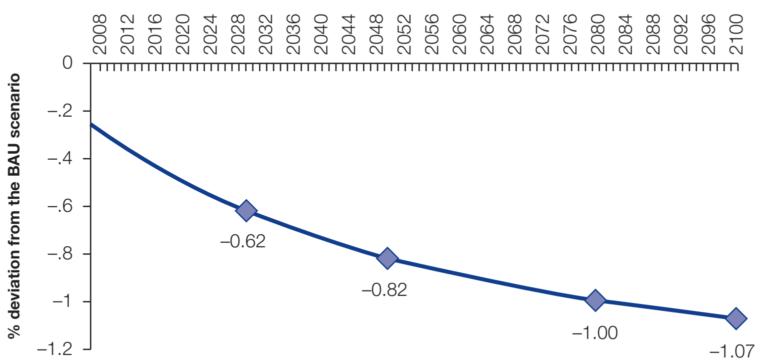
Impact on Infrastructure

Climate change and the resultant floods and cyclones will have a significant impact on infrastructure in Bangladesh. In the absence of any exact estimates of the projected loss on infrastructure, it is assumed in the BGDDyn CGE model that due to the impact of climate change, the capital stock in the construction sector would be depleted by 0.05% annually until 2100. Simulation shows that the infrastructure shock would have a negative impact on all sectors in the economy. In general, larger impacts would be observed in the industrial and services sectors and the magnitude of these negative effects would intensify beyond the end of the century.

An efficient supply of infrastructure is arguably one of the critical factors for economic growth in low-income countries like Bangladesh. Efficient infrastructure can promote sustainable economic and social development. Infrastructure is the capital stock that provides public goods and services. It produces various effects, including those on production activities and quality of life for households, which thus permeate the entire society. The development of infrastructure is likely to alleviate poverty if it improves the quality of life for the poor. Infrastructure services are crucial to poverty reduction and the achievement of the Millennium Development Goals in Bangladesh. Access to better infrastructural services can improve health and education outcomes.

Therefore, a negative shock on infrastructure as a result of climate change would have serious negative impacts on the overall economy of Bangladesh. The sectors closely linked to the construction sector, such as forestry, cement, metals, and mining, would experience large falls in production. Figure 36 shows that real GDP would continue to fall by 0.62% in 2030 and 1.07% in 2100. Under the Sixth Five Year Plan (2011–2015), Bangladesh aims to achieve 8% growth in real GDP by the end of the plan period. However, the poor status of infrastructural development is a serious binding constraint to

Figure 36: **Impact of Infrastructure Shock on Real Gross Domestic Product in Bangladesh**



BAU = business as usual.

realizing that growth target. Improving the country's infrastructural system will be essential for achieving high economic growth. It is evident that the negative impacts of climate change would create extra hurdles, through depleting the country's infrastructure, in achieving the growth targets in Bangladesh.

Impact on Water Quantity

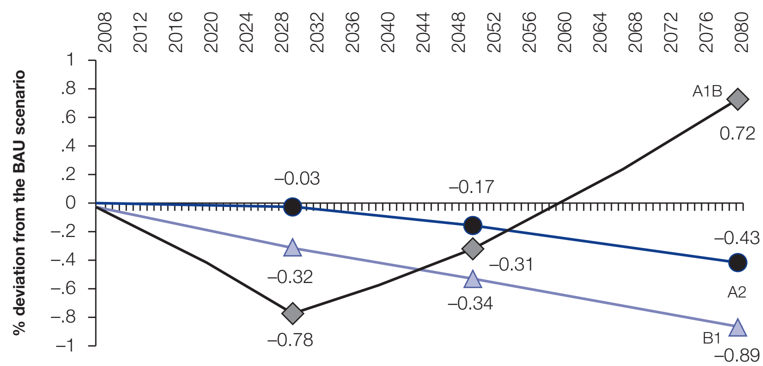
Simulation shows that under the A1B scenario, all sectors would suffer by 2030. However, after 2030, the situation would improve as there will be positive impacts on production in all sectors because there would be significant improvement in the availability of water by 2050. In contrast, under the A2 scenario, there would be negative impacts in 2030 on sectoral production that would intensify up to 2080. This is because the availability of water would fall by a small margin by 2030, but by a larger margin by 2050. The directions of impacts of the B1 and A2 scenarios would be similar. However, negative impacts would be much larger under the B1 scenario than under the A2 scenario.

Under the A1B scenario, real GDP would fall by 0.78% in 2030 (Figure 37). By 2050, the situation would improve from a –0.31% loss to an increase of 0.72% in 2080 compared with the BAU scenario. This is due to the significant improvement in water availability in the 2050s. Under the A2 scenario, due to the small impact on sectoral production to 2030, real GDP would fall by small margin at first but will increase in 2050 and 2080. The same direction of impact is expected under the B1 scenario but the negative impacts would be larger under the B1 scenario than those under the A2 scenario.

In the A1B scenario, both exports and imports would fall until 2030 (Figure 38). They would continue to fall, though at a reduced rate, until 2060 and after that they would rise. The impacts on exports would be larger than those on imports.

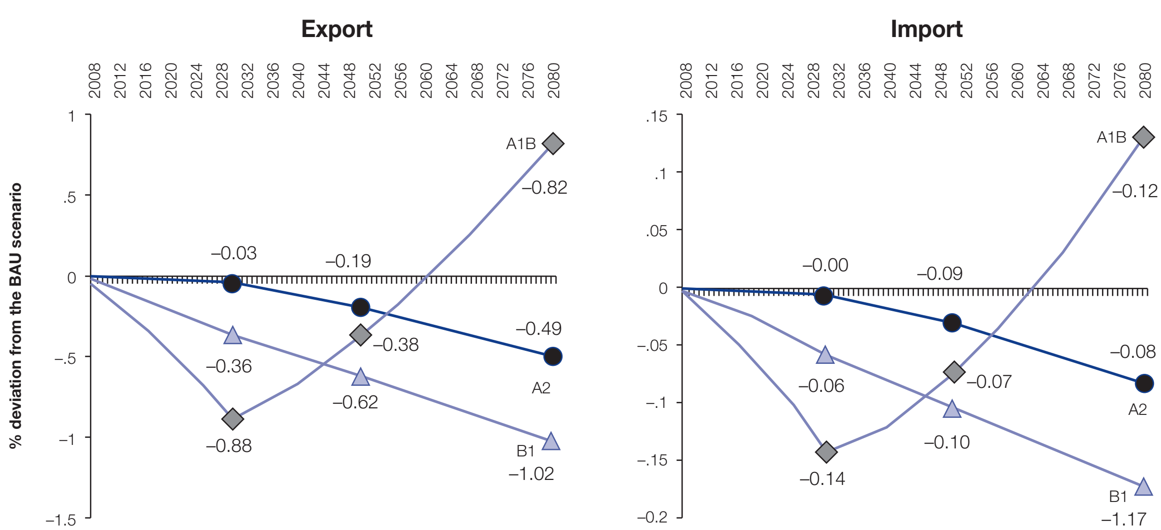
During the period of reduced water supply, most of the export-oriented sectors would contract compared with their expected performance under the BAU scenario. However, from the mid-2060s, with increased water availability, these export-oriented sectors would

Figure 37: **Impact of Water Quantity Shock on Real Gross Domestic Product in Bangladesh**



A1B, A2, and B1 = projected scenarios from *IPCC Special Report on Emission Scenarios*, BAU = business as usual.

Figure 38: **Impact of Water Quantity Shock on Total Export and Import in Bangladesh**



A1B, A2, and B1 = projected scenarios from *IPCC Special Report on Emission Scenarios*, BAU = business as usual.

expand and would result in a rise in overall exports until 2080. The pattern of impacts on imports would be consistent with the pattern of growth of the overall economy. Under the A2 and B1 scenarios, both exports and imports would fall by 2030 and continue to fall in larger magnitudes after 2030. The negative impacts would be larger under the B1 scenario than under the A2 scenario.

Under the A1B scenario, there would be negative impacts on real household consumption in 2030 and 2050 and poorer households would suffer more than the wealthier households (Table 26). By 2080, all household categories would experience some rises

Table 26: **Impact of Water Quantity Shock on Households' Total Real Consumption in Bangladesh**

IPCC Scenario	Year	Rural Landless Households	Rural Marginal Farmers	Rural Small Farmers	Rural Large Farmers	Rural Nonfarm Households	Urban Households with Low-Education Head	Urban Households with High-Education Head
		% Deviation from Business-as-usual Scenario						
A1B	2030	(0.49)	(0.53)	(0.51)	(0.53)	(0.61)	(0.59)	(0.37)
	2050	(0.20)	(0.21)	(0.21)	(0.22)	(0.25)	(0.23)	(0.15)
	2080	0.45	0.49	0.48	0.50	0.57	0.55	0.35
A2	2030	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.01)	(0.02)
	2050	(0.11)	(0.11)	(0.11)	(0.11)	(0.13)	(0.08)	(0.13)
	2080	(0.27)	(0.29)	(0.28)	(0.30)	(0.34)	(0.21)	(0.33)
B1	2030	(0.20)	(0.22)	(0.21)	(0.22)	(0.25)	(0.15)	(0.24)
	2050	(0.34)	(0.37)	(0.35)	(0.37)	(0.42)	(0.26)	(0.41)
	2080	(0.56)	(0.60)	(0.58)	(0.61)	(0.70)	(0.42)	(0.67)

( ) = negative.

in real consumption. The pattern of these impacts mirrors the pattern of impacts on the overall economy. Under both A2 and B1 scenarios, all categories of households would experience a fall in real consumption and the situation would deteriorate after 2030. The negative impacts would be stronger under the B1 scenario.

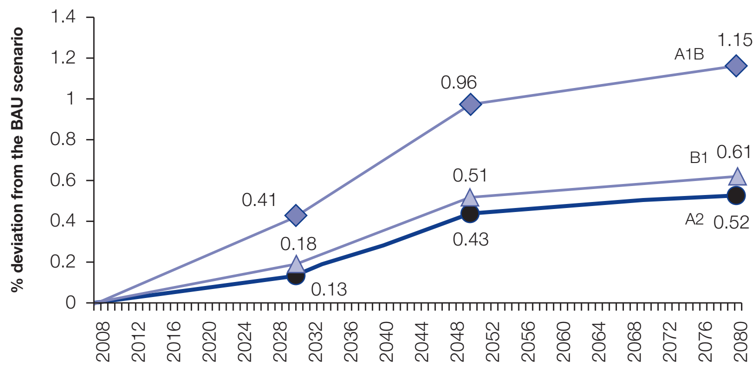
Impact on Electricity Supply

Since electricity is used in almost all sectors in the economy, it is assumed that the lack of electricity would affect the productivity of capital employed in most sectors in the economy. In the absence of any estimates of the relation between the lack of electricity and capital's productivity, it is assumed in the BGDDyn CGE model that the productivity parameter of capital would be affected by the similar magnitude of the excess demand for electricity after adjusting for the share of electricity in capital use in different sectors.

According to the Sixth Five Year Plan of the Government of Bangladesh (Planning Commission 2011), the frequency of power and gas outages is threatening citizen welfare and development prospects. The annual loss to production and income from power outages could well exceed 0.5% of GDP per year. The availability of domestic primary fuel supply is getting so scarce that it is forcing severe measures like shutting down fertilizer factories, rationing gas supplies for household and transport uses, and keeping installed power units idle. Every 1% of GDP growth is estimated to lead to a growth of 1.4% in electricity demand in a typical developing country. For a 5%–6% typical annual economic growth rate, this would imply a need for close to 7%–8% growth in electricity supply.

However, all three scenarios, A1B, A2 and B1, show increasing excess demand for electricity, indicating the possibility of negative impacts on economic growth, sectoral production, exports, and household welfare. As with other sectors, overall exports and imports would fall under the three scenarios. However, the CPI would continue to rise under all scenarios toward 2080 (Figure 39).

Figure 39: **Impact of Electricity Supply Shock on Consumer Price Index in Bangladesh**



A1B, A2, and B1 = projected scenarios from *IPCC Special Report on Emission Scenarios*, BAU = business as usual.

Policy Implications

Overall, in the simulation results using the BGDDyn CGE model, climate change would have significant negative impact on the export growth of different sectors in Bangladesh. In order to mitigate these negative impacts, government should adopt policies and programs to enhance the productivity of the export-oriented sectors. There are a number of cross-cutting issues, such as lack of infrastructure and high cost of doing business, which hamper the competitiveness of the export sectors. Policies and programs should be targeted at reducing the cost of doing business so that the export-oriented sectors become capable of adapting to the negative impacts of climate change. In addition to the structural causes of poverty, shocks induced by climate change, such as floods and cyclones, have a significant accumulated impact. There is some evidence to suggest that such severe and repeated shocks contribute to poverty traps in certain areas of the country.

The high incidence of climate-induced natural disasters warrants design of growth, employment, and poverty reduction strategies that can offset in the best possible way the adverse implications of these disasters. The rural and urban poor are highly vulnerable to post-disaster increases in food prices. The rising frequency and severity of climate-induced market shocks calls for safety net programs. By mitigating the impact of the shocks, a well-functioning safety net system would ensure that the considerable gains that some developing countries, such as Bangladesh, have achieved through rapid economic and social transformation are not eroded.

The CGE modeling approach focused on midterm sectoral and competitiveness effects of climate change. It provided a number of complementary policy parameters, such as trade, labor, and productivity effects with long-term GDP impacts using integrated assessment model. For instance, the food security implications of climate change are evident from the CGE analysis and warrant a number of policy responses, such as sustained commitments to agrifood research and development, continuing productivity improvements, and regional resource allocation through more open flow of capital, such as foreign direct investments. For long-term macroeconomic growth and stability, an appropriate policy response would be to commit to investment where costs or losses due to climate changes would outweigh the costs of adaptation.

PART III
Responses

6 Adaptation Options, Policies, and Strategies

Building resilience to the impacts of climate change requires identifying the risks and vulnerabilities in each project and sector; identifying the options for adaptation (and mitigation) measures that are possible and economically sound, particularly in priority sectors; and mainstreaming this process in future development to ensure implementation of the necessary measures. It is noted that successful adaptation depends not only on governments, but also on the active and sustained engagement of stakeholders, including national, regional, and local organizations; the public and private sectors; civil society; and other relevant stakeholders.

Qualitative information on the costs and benefits of economy-wide adaptation is currently limited. Adaptation costs are only an initial indicator of the level of vulnerability of the sector in each country. The ultimate consequences may be potentially much higher than the mere financial costs estimated, depending on future social and economic changes in the region, such as inflation, unemployment, (climate-induced) forced migration, and political unrest.

In South Asia, adaptation to current climate change and climate variability is weak and many communities are highly vulnerable. Efforts to mainstream climate change adaptation should not focus exclusively on future climatic projections. Current impacts also must be considered, taking into account that a systematic adaptation process could be based on several small steps. Otherwise, adaptation may require sudden and large costs that will force funds to be diverted from other pressing issues like poverty, and thereby further increase the vulnerability of the poor.

Development of a national policy framework to facilitate implementation of appropriate and effective mitigation measures and adaptation strategies is important. This will require institutional strengthening, community participation, and development of national capacity and local and regional expertise. It also will include developing locally appropriate methodologies for analyzing these effects and increasing understanding of current interactions of climate and environmental and socioeconomic effects and changes.

Adaptation Options

The preceding chapters have shown that South Asian economies will be increasingly vulnerable to climate risks. Coastal areas and megacities are exposed to rising sea levels and intensifying storm surges, while many inland regions will have to cope with heightening climate variability that results in too much or too little water. The rising temperature, coupled with increased variation of extreme temperature, adds economic burdens ranging from health risks to electricity bills. In parallel, local air and water quality continue to deteriorate. Extreme events exacerbate the situation. As a result, the countries face innumerable areas of vulnerability. Correspondingly, there are a great many possible options for climate change adaptation. Measures may be reactive or anticipatory, autonomous or planned, and private or public. Some key measures in vulnerable sectors follow.

Agriculture. Application of adaptation technologies, such as rice cultivation systems with improved water and nutrient-use efficiencies, should be promoted, including rescheduling irrigation and adjusting fertilizer application. Altering the time of sowing or planting can help farmers regulate the length of the growing season to better suit the change in climate, as well as help the plants to avoid heat stress during critical growth stages. As an example, the sources of climate vulnerability and possible adaptation options in the agriculture sector of Bangladesh are shown in Table 27.

Coastal and Marine Resources. The focus of adaptation measures on coral reefs has mainly been to reduce human impacts on them, to increase the chance for the reef system to adapt to changes in temperature and sea level rise naturally through "autonomous" adaption. Integrated coastal zone management is needed, which provides effective coastal protection by maximizing the benefits of coastal zones while reducing the conflicts and harmful effects of anthropological activities.

Energy. Adaptation measures include further investigation of energy sector vulnerability, analyses of adaptation costs that include climate change impacts on thermal power plants, and demand-side studies to improve management options. Investments are needed in demand-side management, increasing generation, and reducing transmission and distribution losses.

Health. Adaptation options and responses for human health protection include both reactive and proactive responses to climate change. Reactive responses include public health management reform, improved living conditions, and improved emergency responses. Proactive responses aim to reduce exposure to future climate change risks, such as improved disease and vector surveillance and monitoring, improving environment quality, and changing urban and housing design.

Water. An integrated water resources management framework is needed that includes reactive measures, such as protection of groundwater resources and water catchments; and proactive measures, like improved use of recycled water, improved water management, and water policy reform. Within the framework, climate change adaptation should be approached in two directions: top–down in terms of mainstreaming climate change concerns at the policy and institutional level, and bottom–top in terms of raising awareness and actually making provisions for climate change adaptation at the basin level.

The full range of adaptation options in each vulnerable sector is discussed and tabulated in Appendix 3.

Table 27: **Adaptation Options to Climate Change in the Agriculture Sector of Bangladesh**

Vulnerability Context	Vulnerability	Possible Adaptation Options
Drought	• Yield reduction or loss of production • Epidemic of diseases and increased pest infestation • Reduced cropping intensity due to lack of irrigation facilities • Increased pressure on groundwater • Loss of land productivity • Reduced employment opportunities	• Introduce drought-tolerant crops • Improve efficiency of water use • Use surface water for irrigation • Increase number of plantations • Introduce alternative income generation activities and create opportunities
Flooding	• Damage to standing crops • Yield reduction • Reduced cropping intensity • Crisis for seeds and seedlings • Waterlogging • Seasonal migration • Reduced or weakened income opportunities • Damage to infrastructure	• Introduce short-duration crop varieties • Introduce flood-tolerant crop varieties • Promote community-based seed preservation • Introduce raised seedbeds in highlands and floating seedbeds in low-lying areas • Construct flood-resistant infrastructure • Introduce alternative income opportunities
Flash flood	• Damage to standing crops • Yield loss • Soil degradation • Damage to infrastructure	• Introduce short-duration crop varieties • Construct flood-resistant infrastructure
Changes in temperature (cold wave, heat stroke, fogginess, etc.)	• Reduced yield (rice or wheat) • Reduced production of winter crops • Epidemic of diseases and increased pest infestation • Conflicts among water users groups • Reduced employment opportunities	• Make changes in crops (crop diversification, emphasis on heat- and cold-tolerant varieties) and cropping pattern • Practice integrated crop management • Adopt crop cultivation practices considering the changes in weather • Introduce alternative income opportunities
More extreme weather (erratic rainfall, longer duration of summer and monsoon, and shorter duration of winter)	• Damage to standing crops • Yield loss • Water logging and drainage congestions	• Diversify crops • Adjust crop cultivation considering the changes in weather • Facilitate drainage of runoff and create options for reserving surface water for irrigation
Riverbank erosion	• Loss of cultivable lands and homesteads • Damage to standing crops • Migration • Reduced or weakened income opportunities • Damage to infrastructure	• Construct and maintain infrastructure to protect riverbanks from erosion • Plant protective vegetation along riverbanks • Distribute land for lease among affected people • Introduce alternative income opportunities

continued on next page

Table 27 *continued*

Vulnerability Context	Vulnerability	Possible Adaptation Options
Sea level rise	• Reduced scope of freshwater aquaculture and *gher* (an integrated prawn-fish-rice joint culture, which is practiced widely in the southwest region of Bangladesh) systems • Reduced pasturing/grazing lands • Reduced employment opportunities in livestock subsector • Occupational shifting • Climate change refugees	• Promote community-based open water fisheries • Alternative options of aquaculture (e.g., cage aquaculture, pen culture, crab fattening, etc.)
Salinity intrusion	• Threatened freshwater aquaculture • Reduced natural breeding and grazing areas of freshwater fish species • Reduced pasturing/grazing lands • Reduced crop and vegetable production • Reduced productivity of lands • Loss of greenery • Reduced employment opportunities	• Domesticate marine and brackishwater fish species (e.g., sea bream, mullet) • Construct and rehabilitate climate-resilient water infrastructure • Introduce saline-tolerant crop and vegetable varieties • Use the raised bed system to cultivate seasonal vegetables and fruits and creeper vegetables on edges in all seasons
Cyclone and storm surges	• Loss of fish from flushed ponds/ *ghers* • Huge mortality of fish after cyclone and surge due to decomposition of plants • Loss of livestock and poultry • Damage to infrastructure • Outbreak of fish, livestock, and poultry diseases	• Construct and rehabilitate cyclone-resilient infrastructure • Increase veterinary support
Water logging and drainage congestion	• Loss of habitat for livestock • Reduced grazing land • Fish and other animal disease outbreak • Reduced employment opportunities in livestock subsector • Loss of crop lands	• Promote community-based fisheries management • Promote duck rearing • Introduce economically and nutritionally important aquatic crops • Improve drainage system

Policies and Strategies

Mainstreaming Climate Change in Development

Climate change response policies (both adaptation and mitigation) are most effective when they are fully integrated within an overall sustainable development strategy and policy. The elements and prerequisites of integration in South Asia include strengthening government coordination within and among countries and a regional framework to accelerate actions related to climate change.

Smooth integration is not easy, as indicated by many climate change adaptation studies all over the world. Many adaptation measures can be identified but prioritization is critical. For long-term benefits, climate change adaptation options need to be supported by an integrated, cross-cutting policy approach before being mainstreamed into sustainable development strategy. In mainstreaming, it is also important to see climate change both as a development issue and an environmental issue.

Maladaptation or failure to recognize critical areas of vulnerability can increase a country's dependency on climate-sensitive areas for higher economic growth and consequently increase its vulnerability. Such integrated adaptation processes require changes in the way government deals with policy making, budgeting, implementation, and monitoring at national, sectoral, and project levels.

South Asia, with many transboundary issues between countries of the region, requires greater cooperation and coordination not only within but also among the countries and a regional mechanism that will promote capacity building, research and development, and knowledge and best practice sharing. Finally, adequate funding and technology transfer are important in ensuring success of climate actions.

Identifying Risks and Vulnerabilities

Under climate change, whether considering adaptation options for existing situations or future development, traditional decision-making tools for assessing and managing the risks from the various vulnerabilities become less relevant; risk assessment and decision making must shift from a backward-looking paradigm to one based on forecasting current and future levels of risk. This involves (i) understanding the projected impacts of climate change on a given country, region, or locale as well as sector or area development projects and programs; (ii) exposure and sensitivity to climate risks, i.e., vulnerability; and (iii) resilience and adaptive capacity of social systems. Identifying options for adaptation that are socially, environmentally and economically sound should be part of the good practices in implementing development projects. Screening and assessment of development projects for climate-induced risks must be the first step toward adaptation action. Using extensive geophysical information and downscaled high-resolution climate data, the screening system enables localized climate impact assessments by analyzing both natural hazards in the project areas and climate-related risks to the project investment. As an example here, Box 3 summarizes the risk profile analysis and recommendations from the application of ADB's climate risk screening framework to the 140MW Tanahu Hydropower Plant Project in Pashchimanchal, Nepal.

Strengthening Government Coordination

Climate change is an issue that cuts across all parts and levels of government; thus, it requires leadership at the highest level of government. Climate change response policies (both adaptation and mitigation) are most effective when they are fully integrated within an overall sustainable development strategy. Addressing climate change requires strong intergovernmental policy coordination for the effective implementation of adaptation and mitigation policies. For effective coordination, there is a strong case for the government

Box 3: Climate Change Risk Screening in the Tanahu Hydropower Plant Project, Nepal

The Project. The Tanahu Hydropower Project in the West Region of Nepal is a hydropower generation and transmission project, based on a reservoir to be formed on the Seti River. The project aims to expand Nepal's access to clean and sustainable energy through increased efficiency and supply of reliable hydropower energy. It will be the country's first reservoir hydropower plant, with a 140-meter high concrete gravity dam and total water storage capacity of 295 million cubic meters. The project will (i) design and operationalize a 140-megawatt hydropower plant and related 37-kilometer, 220-kilovolt transmission system; (ii) expand the rural electrification area (covering 17,636 households); (iii) implement relevant community development programs; (iv) review and restructure the Nepal Electricity Authority; (v) undertake other sector reforms; and (vi) initiate an equity sale scheme for hydropower development.

Climate Change Risks Screening. The main task of the screening preparation step was to delineate the watershed upstream from the dam site using digital elevation data. By overlaying the watershed boundary onto natural hazard intensity maps, the relevant hazards were found to be earthquake, landslides triggered by precipitation, and flooding. As landslides and flooding are climate change related, the risks they pose were assessed by comparing baseline precipitation against that projected under the Intergovernmental Panel on Climate Change A2 scenario for the 2050s. Modeling results showed that precipitation would increase by about 8%, and would likely increase the risk of landslides, flooding (including fluvial flooding of the Seti River), flash flooding, and glacial lake outburst flood (GLOF).

Analysis of Climate Change Risks (Vulnerability Context). Water availability and sedimentation are two project aspects identified as being sensitive to climate variability and change. Although precipitation is projected to increase, the projected rise in annual mean temperature (as much as 3°C) will increase evapotranspiration, which will be partially offset by accelerated melting of glaciers. Overall, the net availability of water under changing climate may not change substantially. However, greater precipitation will worsen soil erosion, leading to increased sediment load in the reservoir, reduced water storage, and more frequent need for sediment flushing. The project's hydrological risk was found to consist of (i) a flood risk to dam safety and (ii) a drought risk to energy generation in the power plant.

Actions to Address the Climate Change Risks. To mitigate the risks posed by sedimentation, the project will adopt a modern and tested sediment flushing system, whose operational risks will be minimized by proper early warning systems, adequate technical inputs, and immediate actions. To reduce the risk of an unexpected increase in sedimentation, and based on the erosion hazard map, riverbank protection will be conducted and an early warning system (i.e., sirens) will be implemented along with a public awareness program.

Overall, the climate change-related hazards identified (landslides, flooding, runoff, soil erosion, sedimentation, seismic hazard, etc.) warrant further assessments that should consider all projected climate change scenarios. The tasks include (i) detailed assessment of risks posed by earthquakes, avalanches, landslides, and floods (including GLOF), and setting design standards for all project structures (dam, tunnel, power transmission lines); (ii) assessment of runoff characteristics of the Seti River within the watershed of the project's 7.26-square kilometer reservoir, under both current climate and future scenarios; and (iii) assessment of runoff due to melting of glaciers at the headwaters within the watershed over time. Based on the assessments, an early warning system to prevent dam overflow should be devised, and a large-scale (e.g., 1:50,000) map of projected soil erosion and sedimentation should be made in order to guide the design of measures to control the erosion of curbs and embankments of the Seti River. Climate change risk screening also showed the need to conduct a comprehensive assessment of water availability for the 2030s, 2050s, and beyond.

Source: ADB. 2013. *Nepal: Tanahu Hydropower Project Report and Recommendations of the President to the Board of Directors*. Manila as cited in SARD. 2013. Addressing Climate Risks in Development Interventions, *CASA Information Update No. 4*. ADB, Manila, Philippines. November.

agency responsible for formulating and implementing the development plan and strategy to take the lead, but all relevant ministries (e.g., economic, environment, and finance) should be involved. This way, it reduces the overlap in efforts and maximizes efficiencies and synergies of existing government units.

There is also a need for establishing or enhancing coordination, planning, and funding mechanisms between central government and local authorities to encourage local and autonomous adaptation actions, and to strengthen local capacity in planning and implementing adaptation initiatives. It is also essential to include fiscal stimulus packages—"green investment" programs—that combine adaptation and mitigation measures with current efforts to shore up the economy, create jobs, and reduce poverty. Some of the notable initiatives were as follows: Bangladesh Climate Change Strategy and Action Plans (2008); Strategizing Climate Change for Bhutan (2009); National (and State) Climate Change Action Plan for India (2008); Nepal's National Adaptation Programme of Action (2010); Low Emission Climate Resilient Development of the Maldives (2012); and National Climate Change Adaptation Strategy for Sri Lanka.

In this regard, steps toward mitigation of greenhouse gas emissions in South Asia can provide cost savings that can be transferred to adaptation costs. The study *Economics of Reducing Greenhouse Gas Emissions in South Asia: Options and Costs* (Shrestha et al. 2013) conducted in Bangladesh, Bhutan, Nepal, the Maldives, and Sri Lanka reveals excellent opportunities in low-carbon green growth by pursuing resource- and energy-efficient technologies that will lower emissions of greenhouse gases at low cost or even cost savings (benefits). These technologies range from solar cooking utensils to electric and more efficient diesel vehicles and use of solid waste for fuel. They could reduce greenhouse gas emissions by about 10% by 2020, relative to 2005 levels. Additional introduction of a climate policy based on stabilizing global greenhouse gas concentrations through a carbon tax would further lower emissions, for example by more than 22% at a carbon price of $50 per ton (although market mechanisms to attain this price are yet to be found). Policy and regulatory barriers, perverse subsidies on conventional fossil fuels, and uncertain future carbon prices currently reduce incentives to invest in technologies that reduce greenhouse gas emissions. However, these barriers can be overcome through various enabling policies and measures, such as subsidies on clean technologies; renewable energy promotion through regulatory frameworks, purchase obligations, certificates, and feed-in tariffs; energy efficiency and conservation codes for buildings; and sustainable transport.

Regional Cooperation

All South Asian countries have adopted adaptation measures to reduce the impact of climate change, but there is a serious shortage of strategies at the national level. Through the South Asian Association for Regional Cooperation (SAARC), countries have committed to a shared set of priorities in addressing climate change including ambitious targets for clean energy and low-carbon technology development, as well as commitments to improve resilience of communities and economies. Aside from this, SAARC also aims to promote better dialogue, higher cooperation, and identification of mutually beneficial investment options; and to support capacity of the member countries by promoting regional cooperation, emphasizing the need to increase its efficiency and effectiveness.

Developing a regional framework for climate change through knowledge sharing, fostering structured and regular dialogue at all levels, and ensuring synergies and coordination of current and future actions would not only enhance regional problem solving but also increase the effectivity of national and subnational actions dealing with transboundary issues related to climate change.

Regional cooperation could effectively address some climate change mitigation challenges, for example, by promoting clean energy and technology transfer, and doing regional benchmarking of clean energy practices and performance.

Capacity Development

To undertake climate actions successfully, South Asian countries will need a highly selective and transformation-driven capacity building program. Both governance and institutional capacity will require strengthening. Emphasis should be given to strengthening networking among governments, development partners, and regional and national centers of excellence to allow better assessment of capacity needs and facilitate implementation of activities. On a larger scale, improved capacities will raise public awareness toward public action and stakeholder engagement.

Research and Knowledge Sharing

South Asia has been strengthening its efforts in clean energy technologies and effectively promoting the overall development of the energy sector, but needs to do more. Basic research and development and technology transfer efforts will be important tools in climate change adaptation and mitigation. Researchers, engineers, entrepreneurs, and funding agencies have to work together to develop solutions that address energy needs and climate change concerns in South Asia. Various technologies have to be developed for using and integrating renewable energy resources, such as wind, solar, and tidal power, to satisfy the enormous energy demands.

Scientific information is essential to support adaptation, and information for adaptation needs to move from knowledge transfer to co-production of knowledge and integrating knowledge with action. Community-based adaptation can benefit greatly from know-how of local coping strategies developed anywhere in the project site. Experience gained from coping with past climate events provides valuable instructions for dealing with future climatic change.

For knowledge sharing among the countries to be useful, a climate change information base, high-quality knowledge products and decision-support tools, and guidelines for assessing climate risks and vulnerabilities will be needed, along with economic analyses like those presented in this report. These need to be accompanied by tracking and monitoring tools and a results framework, as well as a dissemination platform to ensure quality assurance of projects and uptake of lessons and experience.

Funding and Technology Transfer

Climate financing and technology transfer are fundamental to the realization of adaptation and mitigation efforts in South Asia. The region should enhance its capacity to utilize the existing and potential funding resources available through better information dissemination and technical assistance to facilitate climate change programs and actions identified. Given the urgency of and seriousness of climate change, the Green Climate Fund has been established as a new global financing mechanism to help developing countries address the major development challenges posed by climate change and to contribute to global emissions reductions, taking into account the needs of those particularly vulnerable to the adverse effects of climate change. The Green Climate Fund will provide simplified and improved access to funding, including direct access, and will encourage the involvement of relevant stakeholders, including vulnerable groups and addressing gender aspects. Appendix 4 provides a summary of the adaptation funding from various sources.

Technology transfer plays a critical role in an effective global response to the climate change challenge. Achieving global reduction of greenhouse gas emissions requires innovation to transform current technologies into cleaner and climate-resilient technologies. Technology needs vary greatly within and across the region. The international community will need to do more to facilitate the transfer of low-carbon technologies that have been identified. South-south cooperation and information sharing among neighboring countries in the region are also important, because mitigation and adaptation measures introduced by neighboring countries can utilize locally available materials and traditional environmental management skills.

Conclusions and Way Forward

This study shows that huge impacts are likely on vulnerable sectors across South Asia, resulting in significant losses in GDP. The cost of damage brought about by climate change to the region under the BAU scenario would average 1.8% of GDP in 2050. In the long term, if no action is taken to adapt to global climate change, the total economic costs are likely to increase to about 8.8% of GDP by 2100. Should the global community comply with the recent international consensus on the Copenhagen Accord pledges and Cancun Agreements, the South Asia developing member countries (DMCs) would face significantly lower economic losses—1.3% of GDP by 2050 and roughly 2.5% by 2100—than they would under the BAU scenario. The likely acceleration of climate change impacts over time means that costs of adapting to and mitigating these impacts will increase at a greater rate if enhanced actions to address the impacts do not begin now. Such risks to GDP loss can hinder the prospect for rapid economic growth of the South Asia DMCs and compromise efforts in poverty reduction and other Millennium Development Goals.

The study also demonstrates that there are varying degrees of public and private sector risk, and cross-sections of the population will have to contend with both of these risks. Increased storm and flood severity would displace and render destitute large numbers of people in vulnerable areas of South Asia. The people in general would also be affected due to more costly food, water, energy, and public goods and services. In all cases, it will be much less expensive to anticipate adaptation needs than to react to them.

South Asia DMCs thus face a huge investment challenge to adapt to climate change impacts and avoid greater loss to GDP. Average annual adaptation costs by 2050 could be as high as 0.86% of GDP under a business-as-usual scenario that predicts a 4.5°C temperature rise and a 0.7 meter sea level rise by 2100, whereas the same could be 0.48% under a global stabilization scenario that predicts 2.5°C temperature rise and 0.55 meter sea level rise by 2100. With increasing evidence and documentation of observed and projected impacts of climate change as well as adaptation options, following the IPCC *Fifth Assessment Report*, the area- and sector-specific investment requirements (e.g., water, food, health, and ecosystems) will grow further (IPCC 2014).

To prevent climate change's worst effects and adapt to impacts, a clear assessment of the investment level required for the South Asia DMCs and the region as a whole should be made, followed by channeling of investment funding and technical assistance for implementing actual climate change adaptation measures and abatement actions. Considering the diversity of the sectors, and an uneven distribution burden of the climate change impacts across sectors and the population as well as fiscal constraints, it will be a tremendous challenge for South Asia DMCs to meet the needed investment and enable a shift to low-carbon, climate-resilient development of their economies without considerable international assistance, private investment and domestic resource mobilization, and technology transfers through south–south and north–south cooperation

Addressing climate change threats must be mainstreamed into the national and subnational plans. Information on climate change impacts needs to be translated from the scientific research domain into language and time scales relevant for policy makers. Research on potential impacts of climate change needs to be supported in-country. This is to enable information to be improved and be passed in a suitable form and on a regular basis to policy makers, so that climate change adaptation can be mainstreamed into their ongoing and planned work. However, particularly for the continental countries of the region, unilateral actions cannot be fully effective on their own, because the environmental conditions that produce the threats do not stop at borders.

Appendixes

APPENDIX 1

Characteristics of Observed and Regional Climate Model-Simulated Seasonal and Annual Total Rainfall and Mean Temperatures for Three IPCC Emission Scenarios in South Asia

	Long-Term Averages									
	Rainfall (mm/day)					Temperature (°C)				
	JF	MAM	JJAS	OND	Annual	JF	MAM	JJAS	OND	Annual
Observed	1.13	2.13	5.28	2.77	3.61	15.68	21.70	23.95	18.28	20.46
Baseline	1.31	2.50	6.01	3.14	4.07	16.58	23.77	25.24	19.28	21.59
A1B										
2030	1.13	2.92	6.12	3.17	4.13	18.20	25.04	26.53	20.89	23.04
2050	1.32	2.87	6.50	3.46	4.45	19.22	25.92	27.24	21.48	23.79
2080	0.91	2.53	6.70	3.96	4.57	20.94	27.75	29.26	23.55	25.75
A2										
2030	0.99	2.55	6.40	3.33	4.28	17.83	24.87	26.30	20.45	22.72
2050	0.88	2.69	6.52	3.55	4.37	18.87	25.68	27.11	21.41	23.62
2080	1.12	2.73	6.74	3.95	4.64	20.87	28.00	29.35	23.41	25.74
B1										
2030	1.13	2.43	6.26	3.24	4.23	17.71	24.88	26.31	20.59	22.73
2050	1.32	2.46	6.48	3.29	4.40	18.56	25.41	26.88	21.10	23.35
2080	1.07	2.72	6.69	3.64	4.52	19.7	26.66	27.95	21.97	24.39

	Standard Deviation									
	Rainfall (mm/day)					Temperature (°C)				
	JF	MAM	JJAS	OND	Annual	JF	MAM	JJAS	OND	Annual
Observed	0.32	0.27	0.28	0.27	0.18	0.53	0.41	0.45	0.64	0.82
Baseline	0.34	0.41	0.34	0.46	0.18	0.51	0.38	0.29	0.44	0.25
A1B										
2030	0.48	0.64	0.31	0.35	0.20	0.61	0.55	0.51	0.44	0.46
2050	0.76	0.60	0.55	0.54	0.34	0.64	0.49	0.48	0.69	0.44
2080	0.52	0.53	0.51	0.59	0.24	0.58	0.44	0.45	0.33	0.36
A2										
2030	0.50	0.64	0.57	0.58	0.32	0.50	0.37	0.35	0.55	0.34
2050	0.34	0.67	0.52	0.49	0.27	0.65	0.41	0.37	0.41	0.32
2080	0.82	0.68	0.42	0.52	0.23	0.58	0.31	0.40	0.40	0.32
B1										
2030	0.54	0.50	0.42	0.61	0.28	0.62	0.63	0.66	0.51	0.52
2050	0.56	0.46	0.61	0.59	0.39	0.46	0.43	0.64	0.51	0.49
2080	0.40	0.57	0.45	0.44	0.27	0.51	0.35	0.53	0.47	0.42

A1B, A2, and B1 = projected scenarios from *IPCC Special Report on Emission Scenarios*; JF = January and February; JJAS = June, July, August, September; MAM = March, April, May; mm = millimeter; OND = October, November, December.

APPENDIX 2

Agricultural Losses in Bangladesh due to Natural Disasters in Different Years

Year	Disaster	No. of Affected District	No. of Affected Upazila	Crops Damaged Fully (Acre)	Crops Damaged Partially (Acre)	No. of Dead Livestock	Embankment Damages
1987	Flood/Erosion	50	347	2,983,362	1,873,207	370,129	1,272
1988	Flood/Erosion	23	165	755,740	90,469	49,976	67
1988	Flood/Erosion	52	345	364,258	9,902,967	348,042	1,651
1989	Flood/Erosion	27	70	58,568	102,716	51,548	–
1990	Flood/Erosion	17	58	37,987	125,089	8,716	125
1991	Flood/Erosion	7	35	276,896	117,795	5,551	339
1991	Flood/Erosion	23	97	160,549	239,024	6,428	124
1991	Flood/Erosion	28	170	782,780	708,225	34,327	186
1993	Flood/Erosion	33	224	778,513	521,204	29,512	1,013
1994	Flood/Erosion	15	40	55,325	48,133	8,666	18
1995	Flood/Erosion	40	259	1,369,358	986,754	14,221	2,398
1995	Flood/Erosion	22	88	598,808	229,216	41,816	211
1995	Flood/Erosion	14	100	855,585	807,344	2,063	267
1996	Flood/Erosion	48	222	404,456	605,312	47,946	448
1997	Flood/Erosion	37	180	167,586	384,666	4,726	586
1970	Cyclone	5	99	3,350,000	–	–	–
1985	Cyclone	9	30	39,500	86,590	2,020	10
1986	Cyclone	7	30	17,800	84837	1,050	1
1988	Cyclone	21	131	2,316,042	1,597,780	386,766	18
1989	Cyclone	33	71	38,712	38,629	2,065	–
1990	Cyclone	39	127	171,099	242,897	5,326	–
1991	Cyclone	19	102	133,272	791,621	1,061,029	707
1994	Cyclone	2	8	23,986	57,912	1,296	97
1995	Cyclone	28	67	2,593	42,644	1,838	–
1996	Cyclone	2	9	2,431	4,933	–	–
1997	Cyclone	10	66	254,755	59,788	7,960	122
1997	Cyclone	12	61	16,537	72,662	3,196	280
1998	Flood/Erosion	52	366	1,423,320	1,808,401	26,564	4,528
1999	Flood/Erosion	28	–	150,515	290,923	137	–
2000	Flood/Erosion	9	40	14,262	438,016	1,643	118
2002	Flood/Erosion	36	209	321,355	521,742	25,237	4,734
2003	Flood/Erosion	36	209	373,376	504,983	7,197	1,535
2004	Flood/Erosion	39	265	1,605,958	1,038,176	15,143	3,158
2007	Flood/Erosion	46	263	890,898	1,335,382	1,459	88
2007	Cyclone Sidr	30	200	461,819	1027,399	467,469	614

– = no data available.

Sources: Bangladesh Disaster Management Department and Ministry of Disaster Management and Relief.

APPENDIX 3

Economy-Wide and Sector-Specific Adaptation Options

Adaptation measures can be classified in various ways. They can be responses made after the observed climate change impacts (reactive) or deliberate decisions based on foresight (anticipatory). Adaption can be autonomous—made by natural, spontaneous adjustments—or planned, which refers to conscious intervention. Finally, adaptation can be private or public, with measures taken either on an individual/ private basis or initiated and implemented by governments directed at collective needs (Ravindranath and Sathaye 2002). Table A3.1 shows some adaptation measures in key vulnerable sectors highlighted in the national communications of developing countries to the United Nations Framework Convention on Climate Change.

Sector-Specific Adaptation Measures

Described below are climate change adaptation measures that are responsive to the main threats posed by climate change in the region, and oriented toward achieving economic development objectives. General approaches implemented in other regions to address climate change impact are also outlined.

Agriculture

In autonomous adaptation, farmers adjust the planting and harvesting season with changes in precipitation patterns so that the crop season coincides with the precipitation periods. Planned adaptation is on a large scale (structural changes) and includes strategy changes—such as introduction of new crop genotypes with resistance to water stress, excess water conditions, and high temperature. In general, climate models project increased precipitation by the end of the 21st century and in such situations diverting small amounts of irrigation to dryland crops would help in overcoming water stress. Maximizing water-use efficiency can be done by retaining crop residue, reducing soil erosion, increasing soil water holding capacity with improved technology, and increasing infiltration with reduced surface runoff.

Useful adaptation technologies include promotion of rice cultivation systems with better water- and nutrient-use efficiencies, rescheduling irrigation and fertilizer application to suit changing conditions, training on interpretation of weather forecasts for effective farm decision making, promotion of biofertilizers and mineral solubilizers for nutrient supplementation, highlighting the importance of blue-green algae in minimizing methane emission from paddy fields, and use of thermophilic bio-inoculants to sustain nutrient flow dynamics in warmer soils.

Table A3.1: **Reactive and Anticipatory Adaptation Measures in Key Vulnerable Sectors**

Vulnerable Sectors	Reactive Adaptation	Anticipatory Adaptation
Water resources	– Protection of groundwater resources – Improved management and maintenance of existing water supply systems – Protection of water catchment areas – Improved water supply – Groundwater and rainwater harvesting and desalination	– Better use of recycled water – Conservation of water catchment areas – Improved system of water management – Water policy reform, including pricing and irrigation policies – Development of flood controls and drought monitoring
Agriculture and food security	– Erosion control – Dam construction for irrigation – Changes in fertilizer use and application – Introduction of new crops – Soil fertility maintenance – Changes in planting and harvesting times – Switching to different cultivars – Educational and outreach programs on conservation and management of soil and water	– Development of crops that are tolerant or resistant to drought, salt, insect pests and diseases, etc. – Research and development – Soil–water management – Diversification and intensification of food and plantation crops – Policy measures, tax incentives or subsidies, free market – Development of early warning systems
Human health	– Public health management reform – Improved housing and living conditions – Improved emergency response	– Development of early warning systems – Better and/or improved disease and vector surveillance and monitoring – Improvement of environmental quality – Changes in urban and housing design
Terrestrial ecosystems	– Improvement of management systems including control of deforestation, reforestation, and afforestation – Promoting agroforestry to improve forest goods and services – Development or improvement of national forest fire management plans – Improvement of carbon storage in forests	– Creation of parks and reserves, protected areas, and biodiversity corridors – Identification and development of species resistant to climate change – Better assessment of the vulnerability of ecosystems – Monitoring of species – Development and maintenance of seed banks – Including socioeconomic factors in management policy

Source: United Nations Framework Convention on Climate Change. 2007.

Altering the time of sowing or planting can help farmers regulate the length of the growing season to better suit the change in climate, as well as helping the plants to avoid heat stress during critical growth stages.

To sustain crop productivity during climate change, farmers need different adaptation options. The adaptation toolbox for agriculture should include measures that farmers can practice now, together with a long-term strategy to suit different extreme weather patterns. Any new system should be simple and cost-effective and at the same time maintain farm productivity.

With climate change and variability increasing pressure on available water resources (and especially, net irrigation requirements), improved water management is one of the most important long-term adaptation options that countries must pursue. According to recent estimates, irrigation efficiency in developing countries is extremely low. Water-saving rice cultivation methods like aerobic rice and systems of rice intensification can be promoted as effective adaptation strategies in the future warmer climate. Studies have shown that the system of rice intensification can double or triple current rice yields. Adaptation options are shown in Table A3.2.

Table A3.2: **Some Adaptation Options for Agriculture and Food Security**

Climate Change Effect/Impacts	Adaptation Options
Increases in intense rainfall/ epidemics	• Awareness raising • Provision of food aid and clean drinking water • Promotion of community-level waste management • Promotion of emergency health care
Reduced rainfall and increased temperature/drought	• Identification of potential drought-prone areas • Weather forecasting • Livelihood diversification • Distribution of drought-resistant crop species • Provision of food aid
Reduced rainfall and increased temperature/forest fires	• Awareness raising • Conservation/promotion of afforestation/reforestation program • Forest fire control
Increased temperature/glacial lake outburst floods and avalanche	• Glacial lake outburst flood/avalanche mitigation • Awareness raising • Early warning system and forecasting
Increased temperatures/ heat wave	• Awareness raising • Reforestation/afforestation
Other/cold wave	• Awareness raising • Provision of warm clothes
Other/hailstorm/windstorm and lightning	• Provision of insurance • Community-based fund • Livelihood diversification • Weather forecasting

Source: Adapted from Nepal's Ministry of Environment, 2011.

Coastal Areas

An increased rate of coastal erosion is associated with rising sea levels, increased frequency and intensity of storm surges, and altered precipitation and run-off from rivers and delta regions—factors that cannot be humanly controlled. The integrated coastal zone management approach provides effective coastal protection with the aim of maximizing the benefits provided by coastal zones while reducing the conflicts and harmful effects of human activities, and promoting sustainable management of coastal zones. The general view for preventing coastal erosion includes construction of "hard" structures (i.e., dikes, levees, floodwalls, seawalls, floodgates, and tidal barriers) that require funding and maintenance, or revetments that possibly affect beaches, wetlands, and other intertidal areas. Furthermore, the implementation of many coastal policies in densely populated areas depends heavily on public acceptance.

Many reef systems are exposed to human-induced stresses, which aggravate the climate change stresses on reef-building corals, increasing the risk of permanent damage to reef ecosystems. Various nations have imposed "protected" status on reef systems to ensure no further human impact is caused from coral mining, overfishing, nutrient over-enrichment, and sedimentation.

The focus of adaptation measures on coral reefs has mainly been to reduce human impacts on them, to increase the chance for the reef system to adapt to changes in temperature and sea level rise naturally through "autonomous" adaptation. "Planned" adaptation responses could involve identifying and "seeding" particular reefs with species shown to have adapted to higher temperatures, sedimentation, pollution and/or freshwater flow. However, it is widely accepted that practical adaptation options for coral reefs are limited.

Estuarine and delta regions face increasing salinity from saltwater intrusion and an influx of nutrients, sediments, and pollution from increased river runoff. Each region will respond differently to the varying conditions. Adaptation measures include improvement of drainage quality and channel capacity, increasing the number of pumping facilities to lower the water table, and the construction of barriers across the mouths of rivers. Those practices can be applied to various ecosystems, implemented jointly with a water management and land-use strategy to ease and regulate salinity and the amounts of nutrients and sediments entering the estuaries.

Marine life is an essential source of livelihood and food worldwide; thus, sustaining fish populations is highly important in many countries. Establishment of national and international fishery management institutions is vital to manage changes expected as a result of climate change. Integration of fisheries and aquaculture management could increase the resilience of fish stocks to the impacts of climate change, while additionally reducing other stress factors, such as overfishing and pollution.

Expansion, modification, and improvement of various technologies used by the fishing industry, such as aquaculture and ocean ranching and predicting natural climate variability (e.g., El Niño Southern Oscillation), will further support fishery management and planning. Increasing sea and river temperatures are expected to affect fish breeding, migration, and harvesting; thus, it is vital that enough resources are allocated for investigating and breeding fish species that are tolerant of high temperatures and/or introducing and encouraging adaptable fish into the environment.

Wetlands and mangroves are essential habitats for many species and act as prevention and protection against land erosion. Survival of these areas depends heavily on maintaining natural flows of water and sedimentation. Managed coastal retreat involving reserve zones of land for autonomous mangrove migration and large-scale mangrove planting and restoration to compensate for anticipated loss from climate change are both viable and widely accepted adaptation methods.

Other options involve upstream control measures to regulate river discharge and sedimentation supply to control the accumulation of substrate. However, these actions can have an impact on water supply and flood control in downstream regions. Mangroves for the Future is an initiative adopted by countries that were affected by the 2004 tsunami, in recognition of the importance of sustained investment and management in this coastal region to maintain stability and develop resilience to the effects of climate change.

A summary of adaptation responses for marine and coastal areas is shown in Table A3.3.

Energy

Energy security is at the heart of the region's development agenda. It is estimated that the regional average economic growth rate of 6% per year is constrained by 2%–3% annually due to lack of energy resources, according to the National Bureau of Asian Research. Ironically, energy insecurity arising from climate change is almost never assessed in the region, especially at the policy-making level. Most of the energy-climate change analyses are mitigation oriented, looking at ways to switch the current energy development path toward a low-carbon path. Although mitigation and adaptation studies may overlap, an adaptation-oriented analysis would help to ascertain the vulnerability of the existing energy sector (and the people who depend on it) to projected climate change. The two perspectives (mitigation versus adaptation) lead to rather different goals. Climate change will have direct impacts on both the supply of and demand for energy, which require specific adaptive responses. To reduce vulnerability and adverse impacts, energy infrastructure must be resilient to climate change, which will require targeted adaptation measures.

Demand projections in the region basically look at traditional parameters, like population and gross domestic product (GDP) growth, while climate change is ignored. Therefore, changes in energy demand resulting from climate change is a hidden threat to energy security in the region.

Limited diversification of energy supply increases the vulnerability of the energy sector to climate change. The countries in the region, or states within them, depend mostly on a single energy source. In India, Nepal, and Sri Lanka, there have been numerous examples where power cuts were caused by lack of water for hydropower. Where dependence on imported oil is high, as in the Maldives and Sri Lanka, the increase in energy demand due to climate change increases vulnerability to external global dynamics, such as rising oil

Table A3.3: **Summary of Adaptation Responses to Climate Change in Marine and Coastal Regions**

Climate Change Impact		Adaptation Response	Source
Coastal erosion		• Relocation and land-use planning, e.g., setback, "no-build" coastal zones, population consolidation • Environmentally sustainable coastal protection infrastructure, e.g., use of geotextiles as groins • Soft engineering protections, e.g., multipurpose artificial coral reefs, beach nourishment, green belts	Mimura et al. 2007, McLean et al. 2001, Hedge 2010
Coral reef loss		• Reduction of human impacts on coral reefs through regulations, such as ban on coral mining, no fishing zones • Marine and coastal protected areas • Sustainable ecotourism and engagement of private sectors • User fees for protected reef areas	Mimura et al. 2007, Schuttenberg and Marshall 2008, Tongson and Dygico 2004
Damaged fish stocks and fisheries practices		• Breeding of fish species tolerant to high water temperatures • Capacity development for local government agencies in enforcing regulations for fisheries • Promotion of sustainable fishing methods among coastal communities • Diversification of livelihoods and alternate livelihoods for coastal communities	Cruz et al. 2007, Daw et al. 2009
Sea level rise	Estuarine salt-water intrusion	• Consideration of climate change in the national water management plan, targeting saltwater intrusion in the estuarial region • Building of flow regulators in coastal embankments • Use of alternative crops and low-technology water filters	Adger et al. 2007
	Intensity of floods and freshwater sources	• Building major embankments and dykes in delta regions and improving urban networks and irrigation systems • High ground refuges, flood warning systems, and flood proofing key buildings • Green belts and natural embankments (turfs, shrub, bamboos, etc.) • Mangrove plantations and/or restoration • Investment and further research on desalinization plants • Relocating treatment works and/or freshwater reservoirs	Douglas 2009; ADB 2011, 2012; Bates et al. 2008
	Loss of wetlands	• Green belts • Relocation and land-use planning, e.g., coastal retreat/setback, population consolidation • Wetlands restoration • Regulation of upstream water and sediment discharge	Gilman et al. 2008, Michel and Pandya 2010, Scavia et al. 2002

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Table A3.3 *continued*

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prices and dependence on oil-exporting countries, further exacerbating geopolitical risks. South Asian governments are investing in in-country renewable energy sources in order to reduce hydropower dependence and augment greenhouse gas mitigation. However, the scale of renewable energy expansion needed for strong energy security has not yet been reached.

One of the immediate adaptation actions is the further investigation of energy sector vulnerability, especially regional data gathering and information sharing. Further, analyses of adaptation costs that include climate change impacts on thermal power plants are critical, given the rate at which South Asia is moving toward coal- and oil-fired power generation. Social dynamics, such as demographic changes and increasing inflation, also will add to the climate sensitivity of the energy sector in the region. Demand-side studies must also focus on consumer categories, such as households (in various income groups), agriculture, and industry. Demand-side management options are not only useful, but also critical to the region considering South Asia's current and future drive for energy. Energy adaptation measures can be grouped into three categories: information actions, institutional actions, and physical/technical actions (Table A3.4).

Terrestrial Ecosystems

Adaptation depends on the level of vulnerability of a system. In the context of this study, adaptation involves sustainable management, particularly of forest ecosystems to ensure the well-being of the many forest-dwelling people whose livelihood depends on the sustainability of forests. Governments of the region should focus on proactive measures to mitigate the impacts of climate change on these ecosystems.

One of the most important proactive adaptation measures would be to increase plantations of species adapted to a wider range of climatic conditions that are also

Table A3.4: **Three Categories of Adaptation Measures for the Energy Sector**

Categories	Adaptation Options
Information Actions	• Gather and share meteorological and hydrometeorological data. • Analyze and model catchment areas that may be suitable for hydroelectric power generation. • Work with neighboring countries to understand regional risks from climate change and their implications for regional energy trading. • Conduct further research on climate change impacts through downscaling of global climate model data. • Research the impacts of changing seasonal conditions and extreme climate events. *Research and Development* also can be grouped under information actions and includes such options as the following: • Develop higher-resolution data on future climate variability and climate change for the region; data sharing in the region could be developed. • Develop more risk-based integrated climate change impact assessments, including cross-sector assessments exploring the interactions between water, agriculture, and energy. • Undertake research on the impacts of extreme climatic events and climate variability on energy assets. • Keep track of new developments in climate change research of relevance to the energy sector. • Continuously monitor and update regional weather and water resource availability. • Monitor and forecast regional energy demand and availability of shared energy from regional sources. • Share weather monitoring and forecasting data between countries. • Repair and adapt existing automated climate stations to provide continuous reporting, using, for example, solar panels to power them. • Share data regionally in return for regional information exchange. • Develop better understanding of the relationships between climate-related factors and energy demand. • Develop better understanding of the change in demand and change in residential and nonresidential sectors due to climate change. • Undertake cost–benefit analyses of adaptation. • Develop better understanding of the relationships between climate-related factors and the performance of hydropower plants. • Develop better understanding of impact of climate change on frequency and severity of drought and storm periods on hydropower plants. • Explore opportunities to improve weather/climate information services (seasonal forecasts, etc.). • Consider local downscaling of climate change scenarios benchmarked against past experience of climate and assess impacts on hydropower plant performance. • Develop risk-based integrated climate change impact assessments when designing thermal power plants; for coastal facilities consider sea level change and coastal storm surge in the assessment.

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Table A3.4 *continued*

Categories	Adaptation Options
	• Monitor impacts of climatic factors on performance of thermal power plants (e.g., reduction in efficiency during high-temperature periods). • Monitor impacts of climate factors on renewable energy assets. • Undertake climate risk assessment and cost–benefit analysis of adaptation measures when upgrading or developing new systems; critical climate data for design of new systems are minimum and maximum temperatures and wind conditions.
Institutional Actions	• Establish a process to ensure that future development design takes account of climate change effects. • Identify key assets at risk from climate change and plan for their future management. • Develop a national energy strategy that promotes diversification. • Establish a political climate for regional energy trading, which could help provide improved energy security; regional energy trading could help to spread risks of climate-related disruptions to supply. • Develop institutions to attract energy investments. • Encourage hydropower managers to improve their operations to better manage drought risks to production, by working with weather and climate experts. • Review government prioritization policy for such resources as water in the face of climate change.
Physical/Technical Actions	• Improve the way existing large hydropower plants are operated. • Upgrade existing assets to optimize performance and minimize decline in power generation due to climate change. • Construct new and diversified power generation assets. • Improve efficiency of generation, transmission and distribution, and use of water and energy. • Develop contingency plans to support a response to increasing risk of heat waves and drought. • Identify and consider developing energy technologies that are favored by future climate change conditions, e.g., increased solar potential due to increased sunshine hours.

suitable for multiple uses. In water-stressed areas, plantations should be planned with water-efficient species with fire-line breaks. Monoculture should not be promoted; rather, mixed plantations of different rotation lengths should be established. In addition, plantations could be designed based on suitable agroforestry systems. In this way, some of the detrimental practices—such as shifting cultivation, as practiced by the hill people in Bangladesh and some parts of northeastern India—could be minimized, as agroforestry would contribute to their food security.

Research investments are necessary for genetic mapping of the climatically most adaptable forest tree species as well as for knowledge development of nursery practices and plantation establishment strategies for such species. Industrial initiatives are needed to effectively combat the impacts of climate change by creating value-added forest products instead of producing and/or exporting primary forest products. This is applicable for all

South Asian countries, since forests are in decline in the region due to high dependence of a large number of people on forest resources.

As climate change starts affecting forest ecosystems, the flow of their services would be affected, forcing people to destroy more forests for their survival, particularly when there is no other way to survive. It is, therefore, vital for policy makers to create alternate livelihood measures like community-based forest industries and ensure proper marketing of products from such industries. Providing improved access to education and health care to forest-dwelling people is also important to protect forest resources from anthropogenic losses that are likely to accelerate under climate change. The strongest adaptation would come from creating economic resilience among forest-dependent people through education and training for value-added livelihood initiatives. Another strategy is to link community forestry programs with initiatives on reducing emissions from deforestation and forest degradation as well as their conservation and sustainable management (REDD+), to improve the prospects for project financing and to help economic resilience among forest-dependent communities.

Nonconsumptive uses of forests, such as ecotourism and selling carbon credits through REDD+ schemes, should be explored as a means of protecting and sustaining forest ecosystems.

Finally, raising awareness through media campaigns about climate change and how forests can be a helping hand in minimizing its impacts will be an important strategy. Governments should improve collaboration with nongovernment organizations in this regard. Also, governments should encourage tax-favored private investments in raising plantation forests on both government and privately owned lands. Some adaptation options for terrestrial ecosystems are shown in Table A3.5.

Table A3.5: **Some Adaptation Options for Terrestrial Ecosystems**

Area for Climate Change Effects/Impacts	Adaptation Responses
Community-based forest fire control	• Capacity building program for forest managers, awareness building program for communities, fire prevention program for forest managers, and policy reform for effective and easy implementation
Programs of forest pathogen control	• Identification of pathogens, study of life cycle of pathogens, developing appropriate mechanisms, training of forest managers
Control of invasive species	• Research to control invasive species, control mechanism dissemination
Integrated forest management for water	• Management of vegetation to increase in infiltration and decrease evapotranspiration • Increase in groundwater recharge through conservation ponds and control ditches • Protection of water sources from landslides, erosion, and other disturbances • Protection of forest water canals from excessive loss

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Table A3.5 *continued*

Area for Climate Change Effects/Impacts	Adaptation Responses
Integrated watershed management in context of climate change	• Vegetation management, conservation farming, improving recharge through conservation ponds and other mechanisms
Watershed conservation	• Identification and implementation of wind erosion-control activities such as shelterbelts, buffer strips, and promotion of water conservation measures through vegetation and land management
Wildlife management in relation to climate stress	• Identification of wildlife impacted by high temperature and drought, habitat improvement, development and implementation of conservation plans
Vulnerable species conservation	• Identification of species, preparing and implementing management plans
High-altitude rangeland conservation	• Identification of the management area, preparing rangeland management plan, training of local communities
Management at the landscape level	• Identification of threatened flora and fauna, establishment of corridors and connectivity, identification of activities for their movement and dispersal, preparing and implementing landscape-level conservation plan
Management of wetlands	• Preparation and implementation of wetland conservation plans with involvement of local communities
Management of herbs for poverty reduction	• Identification of risk region and species at risk, preparing and implementing management plans with involvement of local and indigenous communities
Conservation of riverine forests	• Identification of appropriate forest types, preparing and implementing management plans with participation of local communities
Trees outside the forests or agroforestry in communal and private land	• Identification of empty land owned by households and communities, promoting appropriate species according to needs, of local communities, awareness building for promotion of trees in private and community-owned land
Private land conservation forestry	• Identification of areas for promoting private forestry, training land owners in tree plantation and management, providing subsidy for private forest promotion
Collection and maintenance of biodiversity database	• Selection of pilot area, preparation of biodiversity database for the area
Payment for ecosystem services	• Establishment of forum for upstream and downstream communities' interaction for payment of ecosystem services, conservation of upstream resources
Awareness and capacity building of stakeholders	• Awareness building in communities and other local stakeholders on the potential climate hazards in the area, training communities to combat potential hazards
Policy reform	• Incorporation of forest sector policies that foster climate adaptation and mitigation, joining sector adaptation activities with mitigation
Research and development for adaptation	• Identification of research issues, conducting research with involvement of local communities

Source: Adapted Nepal, Ministry of Environment, 2010.

Health

Health effects of climate change are already evident. Concerns include increased frequency of climate-related extreme events (e.g., heat waves) and ecological changes (water- and vector-borne diseases). Von Hilderbrand (2009) emphasizes three steps that should be taken by the health sector at a national level in responding to climate change: (i) assess the potential impact of climate change, (ii) review the extent to which the existing health system can cope with the additional threat posed by climate change, and (iii) develop and implement adaptation strategies to strengthen key functions that already protect against climatic risks.

Scientific information is essential to support adaptation, and information for adaptation needs to move from knowledge transfer to coproduction of knowledge and integrating knowledge with action.

Multilevel prevention strategies are needed to reduce climate change impact on human health. Government agencies should initiate surveillance measures for climate-sensitive diseases separately, or include them as a separate component in existing national disease surveillance programs. It is also necessary to set up a dataset for climate-sensitive vector- and water-borne diseases, as well as a database on their geographical distribution so as to facilitate research and prediction. Strengthening the surveillance, research, monitoring, review, and feedback mechanisms for climate-related diseases are important proactive measures. A decentralized state-based system of surveillance of communicable and noncommunicable diseases may be more advantageous, so that any outbreak can be detected early in order to initiate rapid response to avert large numbers of morbidities and mortalities.

Strengthening disease surveillance activities and networking regional health offices for rapid transmission of information on climate-related health issues are areas that should be given close attention. Conducting research on climate-related health issues should be regarded as a priority. Education on vector- and water-borne diseases through school curricula are needed.

Increasing awareness, changing behavior related to personal hygiene, strengthening community capacity to reduce the risk of infectious diseases, implementing a warning and forecasting system, and preparing for adverse health effects at the macro level will have to be given priority in order to minimize the health risks from climate change. Health professionals need to be trained on climate change and its impacts on human health. The government, in association with universities, nongovernment organizations, and research organizations, can initiate training programs for health professionals. Community awareness programs on climate-related public health risks should be initiated. Early diagnosis, appropriate investigations, strict monitoring, and prompt supportive management for controlling infectious diseases are vital.

Community-based adaptation for health protection can benefit greatly from know-how of local coping strategies. Experience gained from coping with past climate events provides valuable lessons for dealing with future climatic change. The United Nations

Framework Convention on Climate Change "coping strategies database" that applies to specific hazards or climatic conditions of communities can be integrated with field-based information.

Public agencies can prepare for heat waves by informing the public, early and often, of the dangers, such as through an early warning system. In France, for example, the city of Paris keeps a registry of elderly persons, who are especially susceptible to heat stroke. A close watch on weather forecasts during summer will be helpful for individuals to prepare for the dangers of a heat wave.

Most adaptation options focus on altering and/or intensifying current public health programs and activities to increase their effectiveness in a changing climate (Table A3.6). Many early warning systems are not designed for monitoring and evaluating in a changing climate. In the short run, adaptation can be facilitated by new early warning systems, vaccines, and treated water supply facilities in disaster-prone regions, as well as awareness campaigns on disease risks (National Research Council 2010). In the long run, reducing health risks related to climate change may require new decision-support tools that affect public health. Education and training programs for health care professionals have been identified as important adaptation options to build capacity to address climate-related health needs, including post-disaster mental health needs (Frumkin et al. 2008, Jackson and Shields 2008). Both short- and long-term adaptation will require institutional changes in public health programs, training of health care professionals, and public awareness. In addition, health-related climate considerations must become a more integral component of urban planning and ecosystem management.

The extent of adverse health impacts related to climate change can be minimized with timing, efficiency, and effectiveness of both mitigation- and adaptation-linked strategies. A number of mitigation (emissions reduction) and adaptation strategies by governments can provide health benefits to their citizens.

Vulnerability to vector- and water-borne diseases strongly depends on basic health care, ability to take proper medical treatment, and ability to manage the natural environment. These factors are assumed to be linearly related to per capita income—economic growth reduces the incidence of these diseases. In addition, reducing the emission of greenhouse gases would be effective for climate change-related diseases.

Climate change adaptation by building adaptive capacity, taking specific adaptation actions in the climate-sensitive health sector, and assisting the poor to cope with climate change impacts should be critical parts of development and poverty reduction strategies in the five countries under this study. Three broad regionwide actions can facilitate mitigation of and adaptation to climate change: (i) global and regional awareness of climate change-related health arguments; (ii) making the health case for strong mitigation at national, regional, and international levels; and (iii) strengthening health systems to cope with the health threat posed by climate change.

Table A3.6: **Options for Facilitating Health Sector Adaptation to Climate Change**

Climate Change	Impact	Possible Adaptation Action	National	State/District	Local Government	NGO	Individuals
Changes in the frequency, intensity, and duration of extreme weather events (i.e. floods, droughts, windstorms)	Increased risk of injuries, illnesses, and death	• Develop scientific and technical guidance and decision-support tools for early warning systems (EWS) and emergency response plans, including appropriate individual behavior and medical services.	✓	✓	✓	✓	
		• Conduct education and outreach on emergency preparedness and response, including mental health needs following a disaster.	✓	✓	✓	✓	
		• Conduct tests of EWS and response plans before events.	✓	✓	✓	✓	
		• Monitor and evaluate the effectiveness of EWS.	✓	✓	✓	✓	
		• Provide scientific and technical guidance for building and infrastructure standards to reduce hazards.	✓	✓	✓	✓	
		• Monitor the air, water, and soil for hazardous exposures following floods, windstorms, and wildfires.	✓	✓	✓	✓	
		• Stay informed about impending weather events.		✓	✓	✓	✓
		• Develop guidance for emergency preparedness during and after an extreme weather event.	✓				
Increases in the frequency, intensity, and duration of heat waves	Increased risk of health-related illnesses and deaths	• Develop scientific and technical guidance and decision-support tools for heat wave EWS and emergency response plans, including appropriate individual behavior.	✓	✓	✓	✓	✓
		• Implement heat wave EWS and emergency response plans, taking climate change into account.	✓	✓	✓	✓	✓
		• Conduct education and outreach on preparedness during a heat wave.	✓	✓	✓	✓	✓
		• Develop education and training programs for health professionals on the risks of and appropriate responses during heat waves.	✓	✓	✓	✓	✓
		• Monitor and evaluate effectiveness of heat wave EWS.	✓	✓	✓	✓	✓
		• Improve urban design to reduce urban heat islands by planting trees, increasing green spaces, etc.	✓	✓	✓	✓	✓
		• Improve building design to reduce heat loads during summer.	✓	✓	✓	✓	✓

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Table A3.6 *continued*

Climate Change	Impact	Possible Adaptation Action	National	State/District	Local Government	NGO	Individuals
Increases in temperature	Increased risks of adverse health related to poor air quality	• Formulate and enforce air pollution regulations as necessary to take climate change into account.	✓	✓			
		• Develop EWS for poor air quality in urban areas.	✓	✓	✓	✓	
		• Increase public awareness about risks of exposure to air pollutants.	✓	✓	✓	✓	
		• Follow medical advice on appropriate behavior with high concentrations of noxious gases, particulate matter, and other pollutants.					✓
Changing in mean and extreme temperature and precipitation	Changes in the geographic range and incidence of water- and vector-borne diseases	• Formulate technical guidance and decision-support tools for EWS.	✓	✓	✓	✓	
		• Implement, modify, and sustain EWS for water- and vector-borne diseases to take climate change into account.	✓	✓	✓	✓	
		• Modify vector (and pathogen) surveilllance to take climate change into account.	✓	✓	✓	✓	
		• Modify and enforce safe water handling regulations to take climate change into account.	✓	✓	✓		
		• Disseminate information on appropriate individual behavior to avoid exposure to vectors, including eliminating vector breeding sites around residences.	✓	✓	✓	✓	
		• Disseminate information on signs and symptoms of disease to guide individuals on when to seek treatment.	✓	✓	✓	✓	
		• Evaluate consequences of placement of sources for possible contamination by water-borne pathogens.	✓	✓	✓	✓	✓
		• Follow guidelines on drinking water from outdoor sources.		✓	✓	✓	
		• Provide low-cost vaccinations to those likely to be exposed.					
Climate change in general	Institutional challenges	• Modify public health programs and activities focused on climate-sensitive health outcomes.	✓	✓	✓	✓	✓
		• Enhance education of health care professionals to understand the health risks of climate change, including diagnosis and treatment for health outcomes that may become more prevalent.	✓	✓	✓	✓	✓
		• Provide guidance for health organizations and agencies to effectively collaborate and coordinate on research, development of decision-support tools, and implementing activities.	✓				

EWS = early warning system, NGO = nongovernment organization.

Sources: Frumkin et al. 2008, Jackson and Shields 2008, National Research Council 2010.

Water Resources

Increasing water scarcity, particularly the projected large water deficits in India, necessitates adaptation measures that combine water-use productivity and efficiency measures (in agriculture, industry, and domestic uses) with new supply measures. However, additional supply measures are usually more expensive options, even if they are institutionally or politically easier to implement than efficiency measures that involve economic pricing of water to reflect scarcity values, which are often met with public opposition.

Adaptation measures focused on water-use efficiency need not, however, imply pricing strategies alone or as an emphasis. Numerous technical innovations and management measures are available that can improve the efficiency of water use for agriculture, industry, and domestic/municipal purposes. Emphasis should be put on agricultural water productivity as it makes up a disproportionately large fraction of existing water demand and projected demand increase in the region, with the exception of the Maldives.

In this context, agricultural productivity measures refer not just to the efficiency of water used for irrigation (e.g., avoiding system losses makes more water available), but also to measures that increase crop yields (since increased productivity reduces water demand per unit of output). In the McKinsey study on India, some 80% of the cheapest solutions to close the projected demand–supply gap in 2030 lie in agriculture; the remaining 20% lie in additional irrigation water supply/infrastructure.

There are numerous measures that can increase agricultural water-use efficiency in agriculture. These include canal lining to reduce seepage; introducing more effective controls to limit spill losses through better timing and scheduling of irrigation flows; drip irrigation methods that apply less water than by flooding; irrigation scheduling to prevent farmers from over-irrigating; covering the soil with protective plastic to reduce water evaporation; use of pipe for water conveyance to reduce losses; techniques to reduce tillage and reduce water percolation losses; use of sprinkler irrigation or microsprayers to increase water application efficiency; improved rice planting and irrigation methods; and threshing of plant residues instead of burning, which improves water retention and soil moisture condition. Rainwater harvesting by constructing small reservoirs for rainwater collection is yet another low-cost water scarcity adaptation measure that can be combined with water-use efficiency and conservation measures. A summary of adaptations is shown in Table A3.7.

Increased farm productivity reduces water demand by offsetting the need for additional land and additional irrigation in order to meet the food and feed requirements of the country. Cost-effective measures for this adaptation strategy include adequate drainage provision to increase yield and enable cultivation during the monsoon; breeding and genetic engineering to develop high-yielding plant and seed varieties that are well-adapted to the region's soil and changing climate conditions; optimal fertilizer application to improve mineral absorption; increasing crop resistance to pests through integrated management approaches, including innovative crop protection technologies; prevention of preharvest and postharvest losses during storage and transport; and adoption of the system of rice intensification, which combines improvements in rice

Table A3.7: **Some Adaptation Options for the Water Sector**

Themes within the Water Sector	Climate Adaptation Relevant Programs
Water-induced disasters	• Water-related disaster management policy and program • Risk and vulnerability mapping and zoning system • Disaster networking and information system improvement program • Community disaster preparedness programs • Relief and rehabilitation measures • Activation of inundation committees • Flood, drought, landslides or debris flow, glacial lake outburst flood, and avalanche adaptation program
Environmental action plan on management of watersheds and aquatic ecosystems	• Improve environmental database system • Map critically sensitive watersheds and aquatic ecosystems • Develop water and watershed quality standards and regulations • Implement climate change adaptation, water conservation, education, and awareness program • Implement climatically sensitive watersheds and aquatic ecosystems protection, rehabilitation, and management programs • Promote community participation in the management of watersheds and aquatic ecosystems to enhance climate change adaptation • Enhance institutional capacity and coordination • Develop watershed management policy
Water supply, sanitation, and hygiene	• Integrated program for irrigated agriculture • Improved management of existing irrigation schemes • Improved planning and implementation of new irrigation systems • Strengthening of capacity building of local institutions in planning and project implementation
Hydropower development	• Program to develop cost-effective micro,small, and medium hydropower units • Program to enhance rural electrification • Program to improve power system planning • Program for power and energy sector reform and development
Water-related information systems (decision support system for river basin planning)	• Management of existing hydrological and meteorological network at departments of hydrology and meteorology • Extension of hydrological and meteorological networks of departments of hydrology and meteorology • Funding and management of hydrological and meteorological networks at departments of hydrology and meteorology
Regional cooperation and networks	• Program to appraise and understand the water-related needs of neighboring countries • Program to pursue confidence-building measures with neighbors • Program to implement mutually beneficial activities
Policy and legal frameworks	• Policy and legislation related to water resources management reviewed, amended, and harmonized in the context of climate change
Institutional mechanisms	• Restructuring and activation of central planning organization • Institutional capacity building of central and local government agencies • Central institution for study, research, and development on climate change prediction, policy mainstreaming, and adaptation • Development of institutional framework for coordinated and integrated river basin development

Source: Adapted from Ministry of Environment. 2010. *National Adaptation Programme of Action (NAPA) to Climate Change*. His Majesty's Government of Nepal, Kathmandu.

planting techniques and water application and has been shown to increase yield significantly in some cases.

As temperatures warm, the accelerated melting of glaciers will increase the number and size of glacial lakes that form as the glaciers retreat, and consequently the risk that these lakes may be breached, causing severe flood damage to human settlements and infrastructure downstream. Adaptation measures for such potentially catastrophic events combine engineering solutions to reduce the threat of glacial lake outburst floods with disaster risk reduction measures. Engineering measures include artificial lowering of the level of water impounded in the glacial lakes where a critical level has been reached, zoning schemes to relocate people and vital infrastructure away from areas likely to be most impacted by a glacial flood outburst, and installation of early warning systems.

APPENDIX 4

Summary of Adaptation Funding Sources

Adaptation Funding Sources	Description	Sectoral Focus	Funding Source
Adaptation Fund	Established to finance concrete adaptation projects and programs in developing countries that are parties to the Kyoto Protocol. The fund is to be financed with a share of proceeds from Clean Development Mechanism project activities and receive funds from other sources. The share of proceeds amounts to 2% of certified emission reductions (CERs) issued for a Clean Development Mechanism project activity. The developing country parties to the Kyoto Protocol that are particularly vulnerable to the adverse effects of climate change are eligible for funding to assist them in meeting the costs of adaptation. The fund will finance concerete adaptation projects and programs that are country driven and based on the needs, views, and priorities of eligible parties.	Tourism, water, terrestrial ecosystems, population and human settlements, disaster risk reduction, education and training, food security, agriculture, forestry and fisheries, health, oceans and coastal areas	United Nations Framework Convention on Climate Change and Kyoto Protocol
Adaptation to Climate Change Initiatives	Aims to meet high-priority climate adaptation needs in vulnerable countries. To improve the information basis for appropriate climate change responses, particularly in Asia and the Pacific. An adaptation financing and implementation component of the initiative will build the capacity of institutions in the region to implement adaptation responses, and provide funding for immediate, practical adaptation work. This component will support bilateral and multilateral investments in high-priority adaptation activities. It will also include capacity support for institutions for implementing adaptation responses.	Terrestrial ecosystems, disaster risk reduction, education and training, food security, agriculture, forestry and fisheries, health, oceans and coastal areas, population and human settlements, tourism	AusAID
Benefit-Sharing Fund of the International Treaty on Plant Genetic Resources for Food and Agriculture	The focus of the fund is to help ensure sustainable food security by assisting farmers to adapt to climate change through a targeted set of high-impact activities on the conservation and sustainable use of plant genetic resources for food and agriculture.	Food security, agriculture, forestry and fisheries	United Nations

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Table A4 *continued*

Adaptation Funding Sources	Description	Sectoral Focus	Funding Source
Climate Investment Funds	The CIFs are being established by the World Bank jointly with the regional development banks (African Development Bank, Asian Development Bank, European Bank for Reconstruction and Development, and Inter-American Development Bank) to promote international cooperation on climate change and support progress towards the future of the climate change regime. The CIFs consist of the Clean Technology Fund (CTF) and the Strategic Climate Fund (SCF). The SCF will provide financing to pilot new development approaches or to scale up activities aimed at a specific climate change challenge through targeted programs. The first program to be included in the SCF would pilot national-level actions for enhancing climate resilience in a few highly vulnerable countries.	Disaster risk reduction, food security, agriculture, forestry and fisheries, education and training, health, oceans and coastal areas, population and human settlements, terrestrial ecosystems, tourism, water	Multilateral banks
Cool Earth Partnership	Assistance will be provided to developing countries, which are vulnerable to the adverse effects of climate change, to take adaptive measures (e.g., measures against disasters related to climate change [including disaster prevention] such as droughts and floods, planning of adaptation measures). Grant aid, technical assistance, and aid through international organizations will be provided to address the needs in developing countries. A new scheme of grant aid, Program Grant Aid for Environment and Climate Change, will be created as a component of this package. In the context of improved access to clean energy, a feasibility study on rural electrification projects with geothermal energy and "co-benefit" projects that address climate change will be conducted.	Food security, agriculture, forestry and fisheries, water, population and human settlements	Government of Japan
Cooperation Fund for the Water Sector	This fund finances a coherent program of activities designed to promote effective water management policies and practices in the Asia and Pacific region. The activities are focused on promotion and public awareness, knowledge and capacity building, pilot and demonstration activities, water partnernships. regional events and initiatives, program coordination, and monitoring and evaluation.	Water	Asian Development Bank

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Table A4 *continued*

Adaptation Funding Sources	Description	Sectoral Focus	Funding Source
Development Market Place	It aims to identify 20 to 25 innovative, early-stage projects addressing climate adaptation. The selected project could receive up to US$200,000 in grant funding for implementation over 2 years. The competition on climate adaptation focuses on three sub-themes: Resilience of Indigenous Peoples' Communities to Climate Risks; Climate Risk Management with Multiple Benefits; and Climate Adaptation and Disaster Risk Management.	Disaster risk reduction, education and training	World Bank
Global Climate Change Alliance	The alliance will help to ensure that poor developing countries most vulnerable to climate change, in particular the least developed countries, increase their capacities to adapt to the effects of climate change by fostering effective dialogue and cooperation on climate change. On the climate change adaptation front, the alliance aims to help developing countries improve their knowledge base on the effects of climate change and to develop and implement adaptation strategies.	Disaster risk reduction, terrestrial ecosystems, education and training, food security, agriculture, forestry and fisheries, health, oceans and coastal areas, population and human settlements, tourism, water	European Commission Development
Global Facility for Disaster Reduction and Recovery Facility	The GFDRR provides technical and financial assistance to high-risk low- and middle-income countries to mainstream disaster reduction in national development strategies and plans to achieve the Millennium Development Goals. GFDRR's Mainstreaming Disaster Risk Reduction in Development (Track II) provides technical and financial assistance to low- and middle-income countries to mainstream disaster risk reduction into their country assistance and poverty reduction strategies. Climate change adaptation is one of the key areas of intervention under this track.	Terrestrial ecosystems, disaster risk reduction, education and training, food security, agriculture, forestry and fisheries, health, oceans and coastal areas, population and human settlements, tourism, water	World Bank
Green Climate Fund	The Green Climate Fund was designated as an operating entity of the financial mechanism of the UNFCCC, in accordance with Article 11 of the Convention. In the context of sustainable development, the Fund will promote the paradigm shift towards low-emission and climate-resilient development pathways by providing support to developing countries to limit or reduce their greenhouse gas emissions and to adapt to the impacts of climate change, taking	All sectors, adaptation and mitigation	UNFCCC

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Table A4 *continued*

Adaptation Funding Sources	Description	Sectoral Focus	Funding Source
	into account the needs of those developing countries particularly vulnerable to the adverse effects of climate change. The Fund will provide simplified and improved access to funding, including direct access, basing its activities on a country-driven approach and will encourage the involvement of relevant stakeholders, including vulnerable groups and addressing gender aspects.		
International Climate Initiative	The ICI is a key element of Germany's implementation of fast-start financing. The Energy and Climate Fund launched by the German government in 2011 is a further source of finance for international climate projects and for activities to conserve biological diversity. Part of that funding is deployed through the ICI. That fund is replenished from the auctioning of emission allowances. This innovative source makes Germany well-prepared to deliver long-term financing for climate and biodiversity projects worldwide.	Water, food security, agriculture, forestry and fisheries, disaster risk reduction, health, population and human settlements, terrestrial ecosystems	Germany
International Development Association	The association's response to climate change has been developed as a part of the World Bank's Clean Energy Investment Framework. It funds projects supporting adaptation to climate change, including improved access to clean energy and transition to low carbon development.	Terrestrial ecosystems, disaster risk reduction, education and training, food security, agriculture, forestry and fisheries, health, oceans and coastal areas, population and human settlements, tourism, water	World Bank
Least Developed Countries Fund	The LDCF was established to support a work program to assist least developed country parties carry out, inter alia, the preparation and implementation of national adaptation programs of action.	Water, food security, agriculture, forestry and fisheries, oceans and coastal areas, health, disaster risk reduction	United Nations Development Programme, United Nations Environment Programme, International Bank of Reconstruction and Development
Millennium Development Goal (MDG) Achievement Fund	The MDG Achievement Fund is funded by the Spanish government and is implemented through UN agencies such as United Nations Development Programme, United Nations Children's Fund, and Food and Agriculture Organization. One of the thematic windows for the funding is environment and climate change; with special attention	Food security, agriculture, forestry and fisheries, water, terrestrial ecosystems, disaster risk reduction, health, oceans and coastal areas, population and human settlements, education and training, tourism	Government of Spain

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Table A4 *continued*

Adaptation Funding Sources	Description	Sectoral Focus	Funding Source
	to the organization and management of natural resources and the environment in the context of local rural development and food security. Through this window, the MDG Achievement Fund seeks to support interventions that improve environmental management and service delivery at the national and local levels, increase access to new financing mechanisms, and enhance capacity to adapt to climate change.		
Program on Forests (PROFOR)	PROFOR is funded by the World Bank. It funds projects at all levels that are typically less than 2 years in length and fall in any of the thematic areas: (i) forest governance, (ii) sustainable forest management, (iii) cross-sectoral cooperation, and (iv) livelihood approach to poverty reduction.	Food security, agriculture, forestry and fisheries	World Bank
Small Activities Scheme	The Small Activities Scheme aims to contribute to poverty reduction through small-scale interventions at the community level, especially in nationally recognized poverty stricken areas. It is a flexible grants program enabling quick and effective disbursement in rural and poorer areas.	Terrestrial ecosystems, disaster risk reduction, education and training, food security, agriculture, forestry and fisheries, health, oceans and coastal areas, population and human settlements, tourism, water	AusAID
Small Grants Programme	Aims to deliver global environmental benefits in the Global Environment Facility focal areas of biodiversity conservation, climate change mitigation, protection of international waters, prevention of land degradation (primarily desertification and deforestation), and elimination of persistent organic pollutants through community-based approaches.	Biodiversity and terrestrial ecosystems, water, population and human settlements, food security, agriculture, forestry and fisheries	Global Environment Facility
Special Climate Change Fund	The SCCF under the convention was established in 2001 to finance projects relating to adaptation; technology transfer and capacity building; energy, transport, industry, agriculture, forestry and waste management; and economic diversification. The Global Environment Facility is entrusted to operate this fund. With respect to adaptation, the SCCF assists developing countries, particularly the most vulnerable to the impacts of climate change, in implementing adaptation measures that reduce the vulnerability and increase the adaptive capacity of countries	Food security, agriculture, forestry and fisheries, population and human settlements, biodiversity and terrestrial ecosystems, oceans and coastal areas, health	Global Environment Facility

continued on next page

Adaptation Funding Sources	Description	Sectoral Focus	Funding Source
Strategic Climate Fund	The SCF will provide financing to pilot new development approaches or to scale up activities aimed at a specific climate change challenges through targeted programs. The fund is part of the Climate Investment Funds (CIF) being established by the World Bank jointly with the regional development banks (African Development Bank, Asian Development Bank, European Bank for Reconstruction and Development, and Inter-American Development Bank) in July 2008 to promote international cooperation on climate change and support progress toward the future of the climate change regime. The first program to be included in the SCF would pilot national-level actions for enhancing climate resilience in a few highly vulnerable countries.	Terrestrial ecosystems, disaster risk reduction, education and training, food security, agriculture, forestry and fisheries, health, oceans and coastal areas, population and human settlements, tourism, water	Multilateral banks
Water Financing Partnership Facility	The facility offers technical assistance and loans in three key areas: rural water, urban water, and basin water. The funding in water management projects will promote integrated water resource management and healthy rivers.	Water	Asian Development Bank

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Assessing the Costs of Climate Change and Adaptation in South Asia

With a population of 1.43 billion people, one-third of whom live in poverty, the South Asia developing member countries (DMCs) of the Asian Development Bank (ADB) face the challenge of achieving and sustaining rapid economic growth to reduce poverty and attain other Millennium Development Goals in an era of accentuated risks posed by global climate change. Economic losses in key sectors, such as agriculture, energy, transport, health, water, coastal and marine, and tourism, are expected to be significant, rendering growth targets harder to achieve. This report synthesizes the results of country and sector studies on the economic costs and benefits of unilateral and regional actions on climate change in ADB's six South Asia DMCs, namely Bangladesh, Bhutan, India, the Maldives, Nepal, and Sri Lanka. The study takes into account the different scenarios and impacts projected across vulnerable sectors and estimates the total economic loss throughout the 21st century and amount of funding required for adaptation measures to avert such potential losses. It is envisioned to strengthen decision-making capacities and improve understanding of the economics of climate change for the countries in South Asia.

About the Asian Development Bank

ADB's vision is an Asia and Pacific region free of poverty. Its mission is to help its developing member countries reduce poverty and improve the quality of life of their people. Despite the region's many successes, it remains home to approximately two-thirds of the world's poor: 1.6 billion people who live on less than $2 a day, with 733 million struggling on less than $1.25 a day. ADB is committed to reducing poverty through inclusive economic growth, environmentally sustainable growth, and regional integration.

Based in Manila, ADB is owned by 67 members, including 48 from the region. Its main instruments for helping its developing member countries are policy dialogue, loans, equity investments, guarantees, grants, and technical assistance.

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