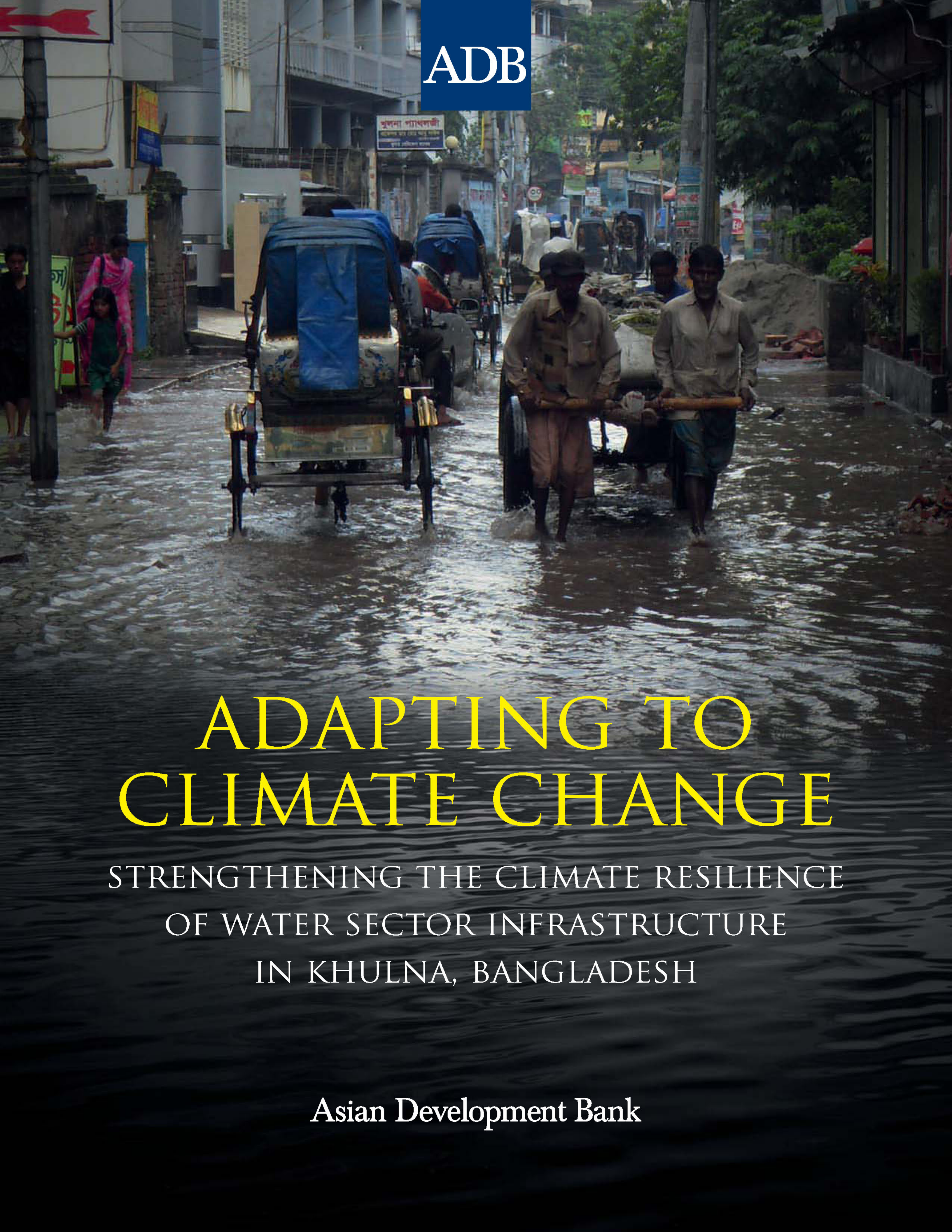

ADAPTING TO CLIMATE CHANGE

STRENGTHENING THE CLIMATE RESILIENCE
OF WATER SECTOR INFRASTRUCTURE
IN KHULNA, BANGLADESH

Asian Development Bank

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Acknowledgments

This report was developed from the findings of policy and advisory technical assistance (TA) to the People's Republic of Bangladesh for Strengthening the Resilience of the Water Sector in Khulna to Climate Change. The report was written by Norio Saito, senior urban development specialist, Urban Development and Water Division, South Asia Department, Asian Development Bank (ADB), who also supervised the TA. Consultants' reports for the TA were prepared by a team of experts from Alterra, Netherlands, and the Institute of Water Modelling (IWM), Bangladesh. The team included Pavel Kabat, team leader; Fulco Ludwig; Hendrikus Ter Maat; Eelco Van Beek; and Adri Verwey from Alterra and Deltares. Sharif Uzzaman Choudhury, deputy team leader; Khurshed Alam; A. K. Enamul Haque; Md. Manirul Haque; Mir Mostafa Kamal; David M. Khan; Md. Sohel Masud; Khondker Neaz Rahman; Mizanur Rahman; S. M. Mahbubur Rahman; Nasima Safa; and Asif M. Zaman from IWM were also involved.

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Abbreviations

ADB	–	Asian Development Bank
DOE	–	Department of Environment
GPS	–	global positioning system
IPCC	–	Intergovernmental Panel on Climate Change
IWM	–	Institute of Water Modelling
JICA	–	Japan International Cooperation Agency
KCC	–	Khulna City Corporation
KWASA	–	Khulna Water Supply and Sewerage Authority
TA	–	technical assistance

Weights and Measurements

cm	–	centimeter
L	–	liter
m^3	–	cubic meter
mg	–	milligram
mm	–	millimeter
ppt	–	part per thousand
s	–	second

Currency unit – taka (Tk)
Tk1.00 = $0.014286
$1.00 = Tk70.0

Introduction

Background

Bangladesh has a high probability of being heavily affected by climate change because of its vast, low-lying areas along the Ganges–Brahmaputra–Meghna Delta, as well as its large population, high population density, inadequate infrastructure, low level of social development, lack of institutional capacity, and high dependence on natural resources. Although the country has made steady progress in terms of social and economic development and poverty alleviation over the past several decades, Bangladesh—as a whole and, in particular, its poorer communities—could suffer soon and tremendously from such effects. Strengthening resilience to climate change is therefore central to the agenda for development and poverty reduction in Bangladesh.

The impacts of climate change will be severe in Bangladesh's urban areas, where drainage is already a serious problem. Sewers frequently back up during the rainy season of May through October, which would be further aggravated by higher, more intense rainfall associated with climate change. In addition, rising sea levels could delay discharge from the drainage system in low-lying areas, and flooding by contaminated wastewater could cause serious health risks.

Another challenge in urban areas is the provision of safe water. The increasing prevalence of droughts is affecting surface water and shallow tube wells, and the situation may further deteriorate. In coastal zones, salinity intrusion from rising sea levels may affect the availability of fresh surface and groundwater. As such, improving urban drainage and implementing water and sanitation programs in areas vulnerable to climate change are among the priority actions identified in the Bangladesh Climate Change Strategy and Action Plan.[1]

With this background, in consultation with the Government of Bangladesh, the Asian Development Bank (ADB) undertook a study to assess the impacts of climate change on urban infrastructure in Bangladesh, particularly water supply and drainage systems, and to identify adaptation options to strengthen its climate resilience.[2] Khulna, the third-largest city in Bangladesh with a population of about 1 million,[3] was selected for the study. ADB had identified two planned projects there: a project for improving the urban drainage system, and another for developing a surface water supply system.

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[1] Government of Bangladesh. 2009. *Bangladesh Climate Change Strategy and Action Plan*. Dhaka.

[2] ADB. 2008. *Technical Assistance to People's Republic of Bangladesh for Strengthening the Resilience of the Water Sector in Khulna to Climate Change*. Manila.

[3] This figure is based on the 2001 census result of 770,000 population and the expected rate of urban population increase from 2001 to 2010. According to the data provided by the Khulna City Corporation (KCC), the population was about 1.4 million in 2007.

The objective of the study is to (i) propose appropriate adaptation options to be incorporated into the design of future ADB-financed projects, with a view to strengthening resilience of the water sector in Khulna to climate change; and (ii) enhance ADB's understanding of climate-related risks in urban infrastructure and the cost-effectiveness of adaptation options. The study area for the water supply system covers the southwest region of Bangladesh, while that for the urban drainage system comprises the area under the Khulna City Corporation (KCC), which is about 45 square kilometers (km^2), consisting of 31 wards.

Overview of Khulna

Khulna is located in southwest Bangladesh (Figure 1), where the consequences of climate change are expected to be particularly severe due to its geographical location. As a deltaic plain, the land is flat and poorly drained. The whole city area is only about 2.5 meters above the mean sea level, with the minimum and maximum altitudes between 0.45 meter and 5.4 meters. The city's land-use pattern has been substantially influenced by the flow of the Bhairab and Rupsha rivers. According to a land-use survey undertaken for the preparation of the Khulna Master Plan, about 80% of the KCC area in 1999 is classified as "built-up," with 51% for residential use, followed by 15% for mixed use, and 8% for industrial use.[4] Khulna's low topography is clearly an obstacle to the development of a proper land-use structure.

The average annual rainfall in Khulna during 2004–2009 was 1,924 millimeters (mm), and more than 90% of the annual rainfall occurs between May and October. The highest average maximum temperature of 33°C and above is usually recorded during March and May, and the lowest average minimum temperature of about 15°C is usually recorded in December and January. Bangladesh is often severely hit by tropical cyclones, and Khulna is no exception. Tropical cyclones in 1988, 2002, and 2007 made landfall near Khulna. The cyclone Sidr, which hit Bangladesh's southwestern coast in November 2007, killed about 3,400 people and fully damaged 1,714 km of roads, according to government statistics.[5] The total damage was estimated at $1.7 billion. Storm surges are higher in Bangladesh because the Bay of Bengal narrows toward the north, and in recent years, general cyclonic activity in the Bay of Bengal has become more frequent (footnote 1).

Salinity levels near Khulna have increased in the last several years as well, as seen from the data obtained by the Department of Environment (DOE) in Figure 2. Rising sea levels and prolonged dry weather are expected to increase these levels even more. Salinity intrusion from the Bay of Bengal into the river system around Khulna is influenced by the surface water hydrology prevailing around the city; tidal flow from the bay has daily, seasonal, and annual variations. Moreover, salinity originally started to rise after the commencement of the Farakka Barrage operation in India in 1975,[6] which significantly reduced the flow of the Gorai River, a distributary of the Ganges River and a major source of freshwater to the rivers surrounding Khulna.

Besides the Bhairab and Rupsha rivers, a few other rivers are of relevance to Khulna. Among those, the Madhumati River is of particular interest because of its potential as a source of raw water. This river carries little salinity (within acceptable limits) except for a few days per year and is essentially

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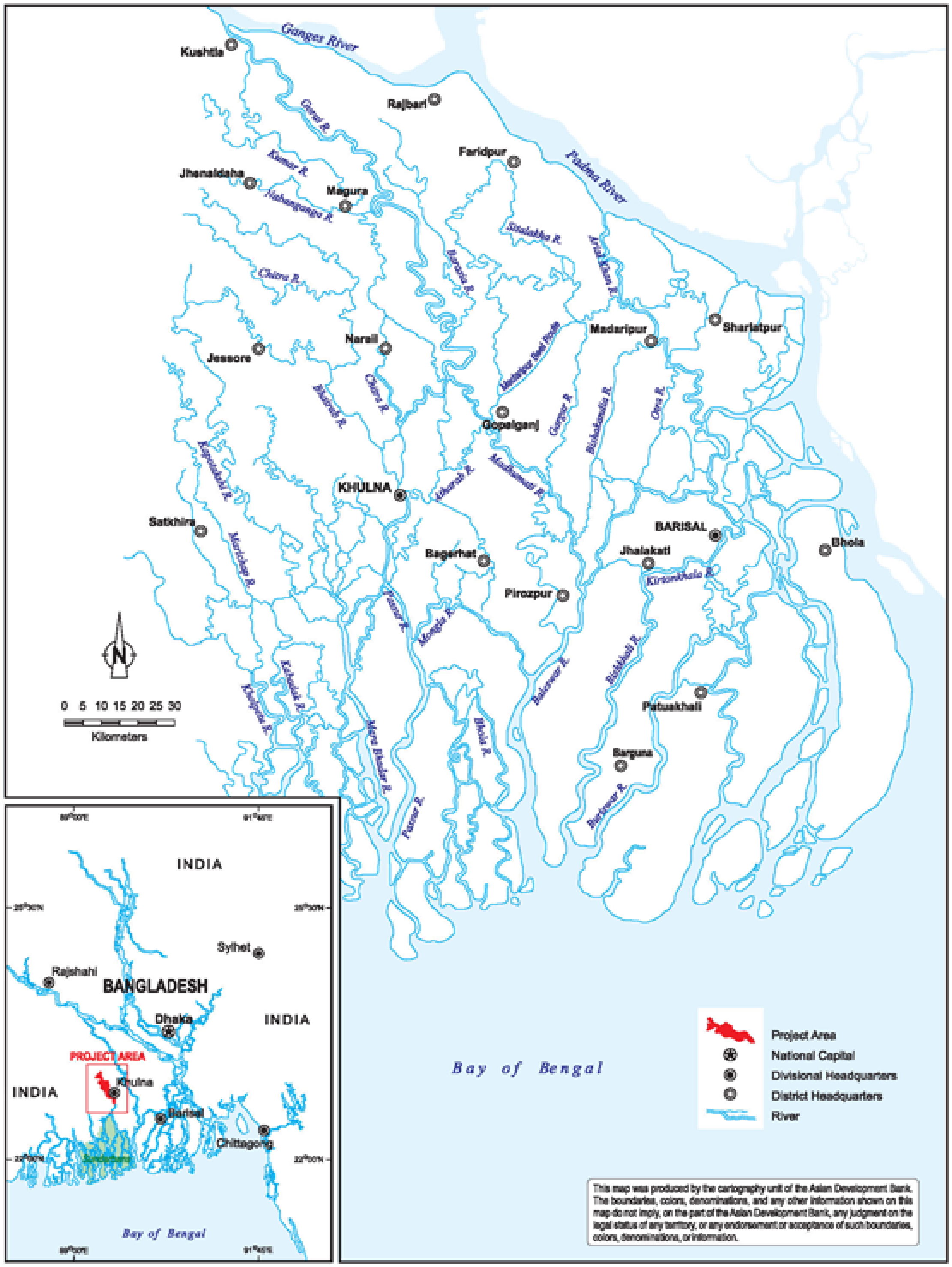
[4] Khulna Development Authority. 2002. *Structure Plan, Master Plan, and Detailed Area Plan for Khulna City 2001–2020*. Khulna.

[5] Government of Bangladesh. 2008. *Cyclone Sidr in Bangladesh: Damage, Loss, and Needs Assessment for Disaster Recovery and Reconstruction*. Dhaka.

[6] Farraka Barrage is a barrage (dam) across the Ganges River, located in the Indian state of West Bengal. The barrage was built to divert the Ganges River water into the Hooghly River during the dry season.

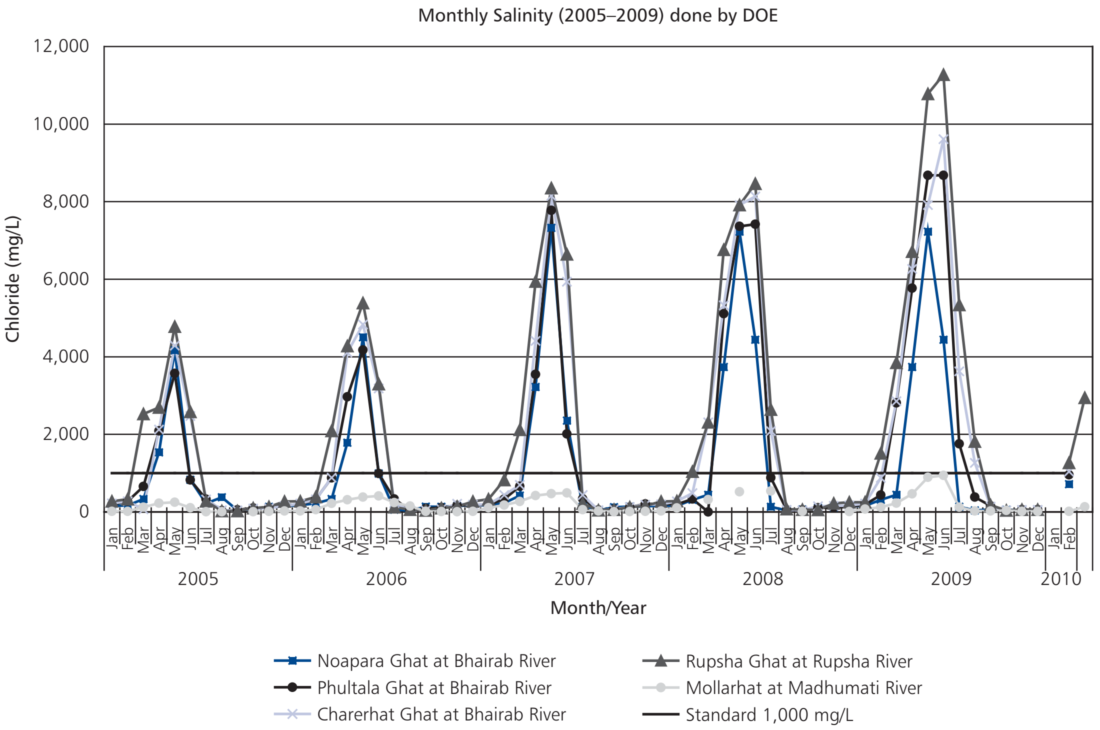
Figure 1 River System of Southwest Bangladesh



Note: Boundaries are not necessarily authoritative.

Source: ADB.

Figure 2 **Salinity Concentration in Rivers in and around Khulna**



DOE = Department of Environment, mg/L = milligrams per liter.

Source: JICA. 2010. Feasibility Study for the Khulna Water Supply Improvement Project in the People's Republic of Bangladesh. Tokyo.

free from pollution. Another important river in the area is the Arial Khan River, a distributary of the Padma River that provides water to the Madaripur Beel Route, which meets the Madhumati River at Gopalganj.

The present water supply for Khulna is mainly from groundwater sources drawn from both deep and shallow tube wells. To cope with current insufficient supply and increasing demand, the Khulna Water Supply and Sewerage Authority (KWASA) plans to construct a new treatment plant using surface water, with assistance from ADB and the Japan International Cooperation Agency (JICA).[7]

Khulna currently suffers from recurring and worsening urban flooding (i.e., waterlogging), which can be exacerbated by increased rainfall and rising sea levels caused by climate change. The City Region Development Project, which includes Khulna's drainage system improvement as a subproject, was approved by ADB in November 2010.[8]

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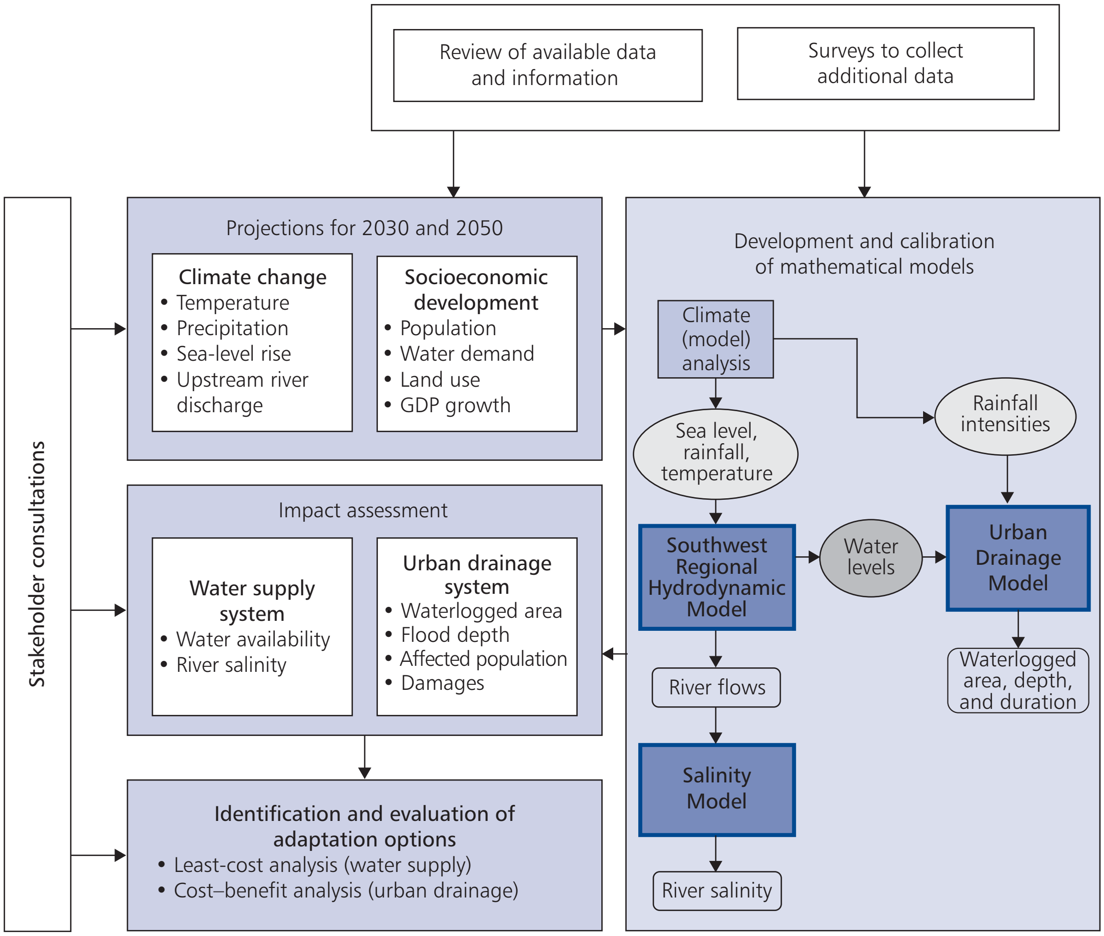
[7] Khulna Water Supply Project is being processed in ADB at the time of report writing.

[8] ADB. 2010. *Report and Recommendation of the President to the Board of Directors: Proposed Loan and Technical Assistance Grants to the People's Republic of Bangladesh for the City Region Development Project*. Manila.

Study Approach and Methodology

To assess climate change risks and impacts for Khulna, the study (i) made climate change projections for Khulna for 2030 and 2050; (ii) developed socioeconomic development scenarios for Khulna for 2030 and 2050; (iii) developed and calibrated three mathematical models; (iv) ran the models for 2030 and 2050, using the climate and socioeconomic changes projected; (v) assessed impacts through geographic information system mapping; and (vi) identified and analyzed adaptation options. A flow diagram showing this approach and work flow is in Figure 3.

Figure 3 **Flow Diagram of the Study**



GDP = gross domestic product.

Source: Adapted from ADB.

Climate Change Projection

Climate

Two greenhouse gas emission scenarios, A2 and B1, from the Special Report on Emissions Scenarios by the Intergovernmental Panel on Climate Change (IPCC) were used because they represent the high and low brackets of the estimated global temperature increases under the report story lines.[9] A2 is the business-as-usual scenario, a very heterogeneous, market-led world, with high population growth, slow economic development, and slow technological change. B1, however, is the sustainable development scenario, a convergent world with rapid changes in economic structures toward a service and information economy, with resulting lower greenhouse gas emissions.

Table 1 **Summary Features of Climate Projections for Khulna**

Scenario	A2	B1
Temperature	The average monthly temperature rise by 2050 varies from +0.5°C in October to +1.7°C in January and February.	The average monthly temperature rise by 2050 varies from +0.5°C in June, July, and August to +1.5°C in February and April.
Rainfall	The annual rainfall increases by about 5.0% by 2050 (1,860 mm per year) from the reference period.[a]	The annual rainfall increases by about 9.3% by 2050 (1,739 mm per year) from the reference period.[b]
Seasonal rainfall	Increase in July–September by 4.6% and a decrease in December–February by 26.3%	Increase in July–September by 10.5% and a decrease in December–February by 46.2%.[c]
Rainfall intensity	50 mm or more rainfall in 6 hours increases from 4.20 times per year to 5.90 times per year in 2050.	50 mm or more rainfall in 6 hours marginally increases from 4.20 times per year to 4.25 times per year in 2050.

C = Celsius, mm = millimeter.

[a] The value is compared with 1,769 mm, the average annual rainfall from 2001 to 2020 projected in the model under the A2 scenario, and thus is different from the observed value (1,924 mm from 2004 to 2009) in the past. The observed value is higher than the projected value. The historical observed average between 1985 and 2009 is 1,887 mm.

[b] The value is compared with 1,591 mm, the average annual rainfall from 2001 to 2020 projected in the model under the B1 scenario, a much lower figure than the observed value.

[c] A higher degree of increase and decrease under the B1 scenario in comparison to that under the A2 scenario is different from what one normally expects. Due to the interannual and decadal variability and chaotic nature of atmospheric process, individual model runs can result in different changes in rainfall. Therefore, these differences are considered within the margin of error and do not necessarily mean that there will be higher variation under the B1 scenario.

Source: Adapted from ADB.

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[9] The scenarios in the Special Report on Emissions Scenarios are grouped into four scenario families (i.e., A1, A2, B1, and B2) that explore alternative development pathways, covering a wide range of demographic, economic, and technological driving forces and resulting greenhouse gas emissions. A1 assumes a world of very rapid economic growth; a global population that peaks in the mid-21st century; and swift introduction of new, more efficient technologies. B2 details a world with intermediate population and economic growth, emphasizing local solutions to economic, social, and environmental sustainability. IPCC. 2007. *The Fourth Assessment Report*. www.ipcc.ch/#

Statistical downscaling was then undertaken from a Global Climate Model (ECHAM5/MPI-OM)[10] to a finer resolution (0.5° x 0.5°), mainly because of the time available for the study. The model outputs were bias-corrected for rainfall and temperature.[11] The findings are outlined in Table 1.

These results are, however, based on the outcomes of a single Global Climate Model. Other models indicate similar changes, but there are still considerable uncertainties about the possible change in rainfall in Bangladesh.

Sea-Level Rise

As for the rising sea levels, two different levels (i.e., plausible high and plausible low) were used in the different model runs, due to high uncertainty of the levels. The plausible-low scenarios, 10 centimeters (cm) in 2030 and 20 cm in 2050, are about midrange in the IPCC scenarios. The plausible-high scenarios, 25 cm in 2030 and 40 cm in 2050, assume significant melting of land ice. This is in line with the findings of recent new models and research, which indicate that the contribution of melting land ice to rising sea levels may be substantially more than what IPCC projected (footnote 9).

River Discharge

Another important factor is the intake discharge of the Gorai and Arial Khan rivers from the Ganges and Padma rivers, respectively. As it was not possible in the study to develop a hydrological model for the complete Ganges and Brahmaputra basins to determine future discharge rates, the output of the same Global Climate Model (ECHAM5/MPI-OM) on the runoff changes of the Ganges and Brahmaputra basins was used. Under both the A2 and B1 scenarios, the intake discharge of the Gorai and Arial Khan rivers is reduced in 2030 and 2050 during most of each year, except in October (i.e., the end of the rainy season) when the discharge is increased.

Socioeconomic Scenario Development

For the study, numerous assumptions were made regarding Khulna's socioeconomic scenarios in 2030 and 2050. Socioeconomic surveys, various census data, literature reviews, and discussions with relevant agencies and experts were the basis of scenario development. Key parameters are shown in Table 2.

Hydraulic Models Development

Three mathematical models were developed and/or calibrated to assess the impacts of climate change for the study. The roles of these models—the Southwest Regional Hydrodynamic Model, Salinity Model, and Urban Drainage Model—are shown in Figure 4, and the main features of each model are given in Table 3.

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[10] The model was sponsored by the Max Planck Institute for Meteorology, Germany.

[11] The Urban Drainage Model requires rainfall data with a time resolution of 3 hours, while the statistical downscaling undertaken provides only daily rainfall data, too coarse for the analysis. Therefore, probability distribution functions were derived from (i) the observed precipitation figures from 2003 to 2008 that report rainfall every 3 hours, and (ii) the outputs from the Global Climate Model with a time resolution of 6 hours. A bias-correction factor, given by dividing one probability distribution function with the other, was used to correct the future rainfall. Details of the bias correction are found in ADB. 2010. *Strengthening the Resilience of the Water Sector in Khulna to Climate Change*. Consultant's report. Manila (TA 7197-BAN), p. 5, Annex C.

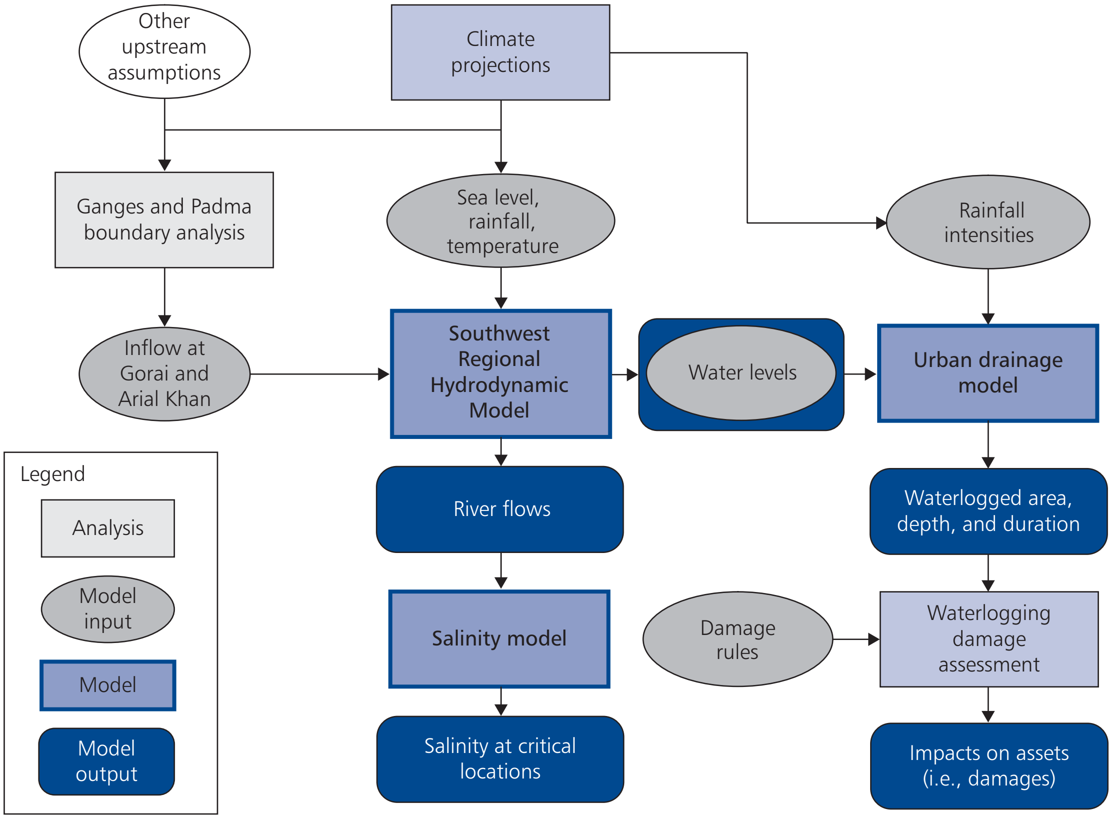
Table 2 Key Parameters for Socioeconomic Development

Parameter	Assumption	Remarks
Population in KCC area	2% growth per year: (i) 976,000 in 2010; (ii) 1,450,000 in 2030; and (iii) 2,155,000 in 2050	Population distribution among the 31 wards was assumed to be maintained.
Water demand	Per capita domestic demand of 120 liters per day in 2030 and 150 liters per day in 2050	100% of the population in the KCC area will be served by the proposed water supply system.
GDP growth rate	6.2% per year	The national average rate of growth between 2001 and 2009 was 6.2%.
Urban development	Proportion of impervious areas (weighted average): (i) 17.7% in 2010, (ii) 29.0% in 2030, and (iii) 38.7% in 2050	For each subcatchment area, a change in the proportion between pervious and impervious areas was projected.

GDP = gross domestic product, KCC = Khulna City Corporation.

Source: Adapted from ADB.

Figure 4 Model Framework



Source: Adapted from ADB.

Table 3 **Features of the Three Mathematical Models**

Model Name	Features	Models Used	Remarks
Southwest Regional Hydrodynamic Model	Provides water level, discharge, and depth of rivers in southwest Bangladesh.	MIKE 11[a]	Originally developed by IWM and calibrated under the TA.
Salinity Model	Provides salinity levels of rivers in southwest Bangladesh by using outputs from the Southwest Regional Hydrodynamic Model.	MIKE 11	Originally developed by IWM and calibrated under the TA.
Urban Drainage Model	Provides water level, discharge, and depth of drainage systems in the KCC area.	MIKE Urban[b]	Newly developed under the TA. It is a nested model inside the Southwest Regional Hydrodynamic Model, which enables the accounting of the complex tidal system of southwest Bangladesh.

IWM = Institute of Water Modelling, KCC = Khulna City Corporation, TA = technical assistance.

[a] Mike 11 is a software program that could simulate flow and water level, water quality, and sediment transport in rivers. Mike 11 is a one-dimensional model.

[b] Mike Urban is a geographic information system-based urban water modeling software.

Source: Adapted from ADB.

After calibration, simulation results satisfactorily reproduced observed data in the field. Figure 5 shows simulation results of the Southwest Regional Hydrodynamic Model, and Figures 6 and 7 show simulation results of the Salinity Model against observations. Simulated salinity values in 2009 in Figure 7 are higher than those measured by DOE but are in line with measurements taken by KWASA.

Scenarios Examined under the Study

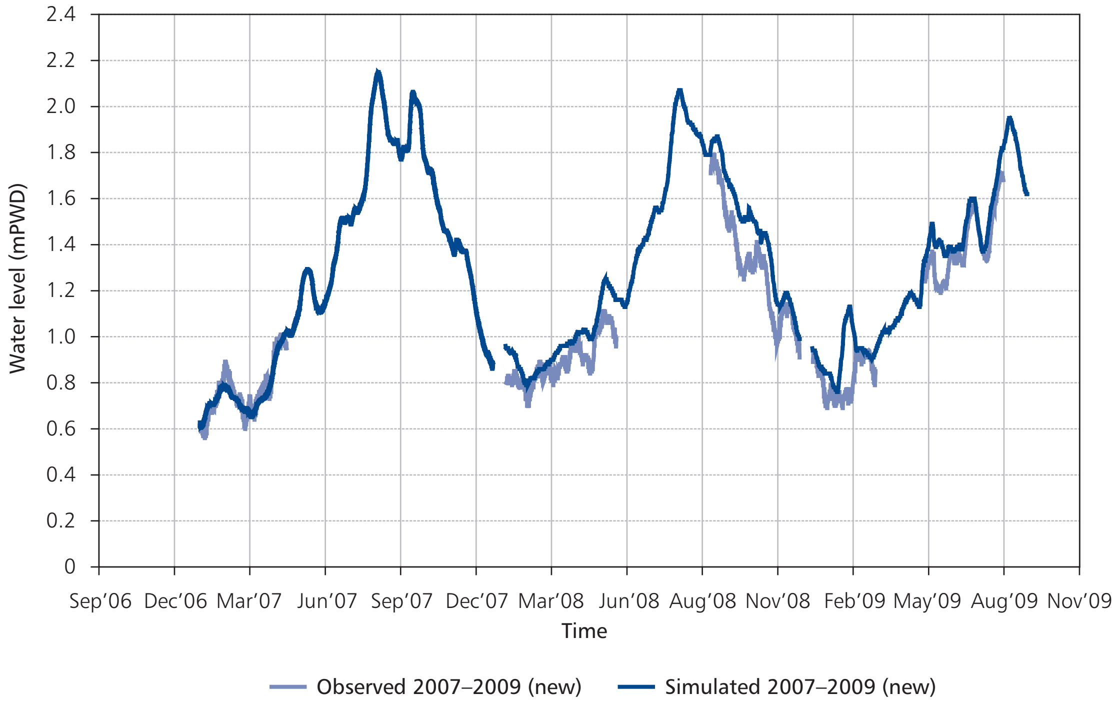
A combination of climate and rising sea level scenarios was used to assess the impacts of climate change on Khulna's water infrastructure (Table 4). "Run 1" was the base case, as this did not assume climate change in the future. Most of the results presented in the following chapters are for Runs 3a and 5a, as these runs provided noticeable changes that require adaptation measures to climate-related risks. Results of other scenarios are presented in the consultants' reports (footnote 11).

Damage Assessment

Households, economic enterprises (i.e., commercial, industrial, and manufacturing), urban infrastructure, and agriculture in Khulna are likely to be affected by waterlogging. The socioeconomic survey collected information on damages incurred by households of climate-related events, such as floods, salinity intrusion, and cyclones.

First, damages to households were examined, which could be traced in terms of loss of income and employment for informal sectors, loss in terms of sickness and suffering, and damages to assets including trees. The Urban Drainage Model was used to trace the waterlogging to the date of the

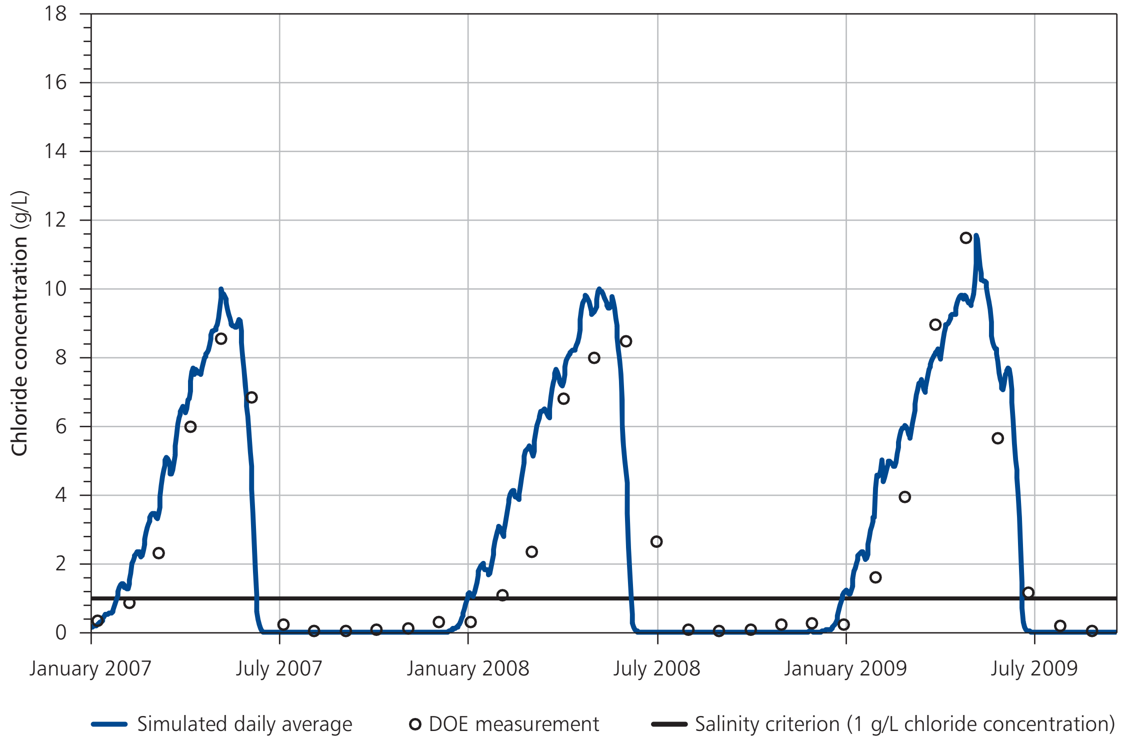
Figure 5 **Comparison of Simulated and Observed Moving Average Water Levels in Khulna**



mPWD = meter in Public Works Department datum. mPWD = mean sea level + 0.46 meter.

Source: ADB.

Figure 6 **Comparison of 2007–2009 Measured and Simulated Salinity Levels at Labanchara**

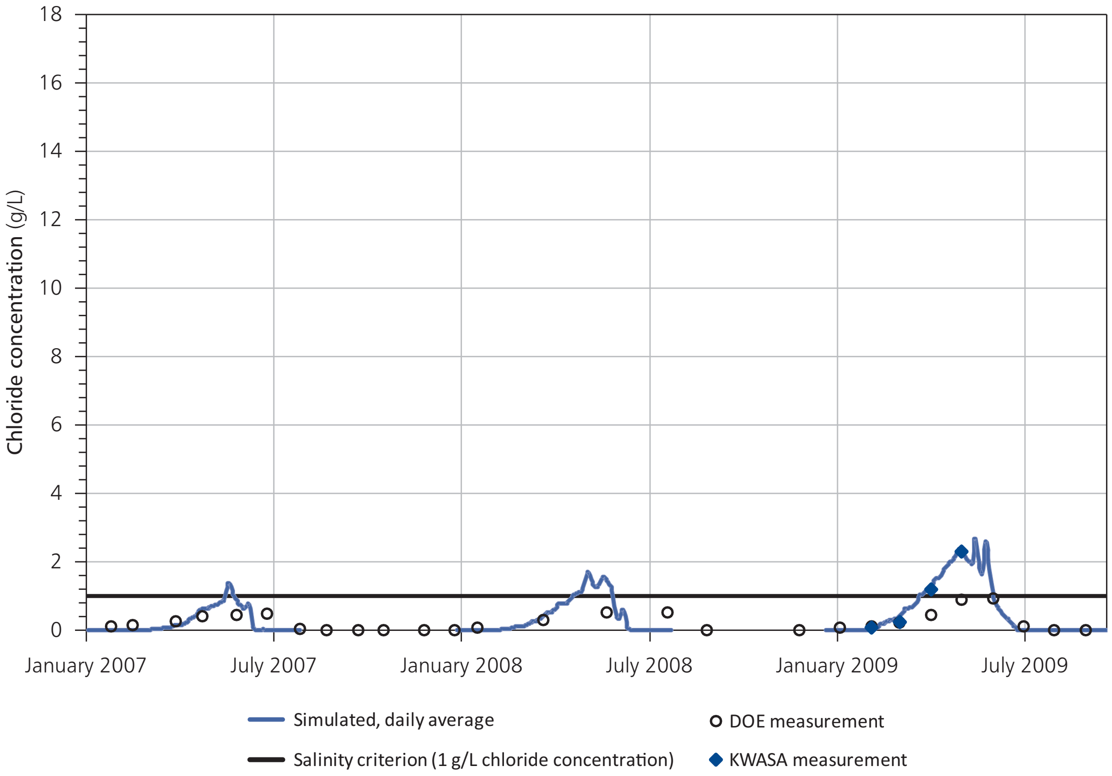


DOE = Department of Environment, g/L = gram per liter.

Note: Measurement dates for 2009 DOE data were not available, so points shown are on the 15th of each month.

Source: ADB.

Figure 7 **Comparison of 2007–2009 Measured and Simulated Salinity Levels at Mollarhat**



DOE = Department of Environment, g/L = gram per liter, KWASA = Khulna Water Supply and Sewerage Authority.

Note: Measurement dates for 2009 DOE data were not available, so points shown are on the 15th of each month.

Source: ADB.

Table 4 **Scenarios Used for the Study**

Simulation Run	Period		Climate Scenarios			Rising Sea-Level Scenarios		
	2030	2050	Base	A2	B1	Base	Plausible Low	Plausible High
1			√			√		
2a	√			√			10 cm	
3a	√			√				25 cm
4a		√		√			20 cm	
5a		√		√				40 cm
6a	√				√		10 cm	
7a	√				√			25 cm
8a		√			√		20 cm	
9a		√			√			40 cm

cm = centimeter.

Source: Adapted from ADB.

climate-related events for the location of the households. Unfortunately, household survey data did not report the exact geographic information system-based locations of the households, so it was not easy to estimate the damage function.[12] In the absence of such information, the average depth of waterlogging for the ward was used to estimate a damage function. This substitution of average waterlogging depth or duration with individual household damages significantly reduced the degrees of freedom during estimation. Regression equations, therefore, did not provide any statistically significant relationship between the damage and depth of waterlogging

As a result, the following steps were used to arrive at an average damage estimate:

Based on sample household reports on damages (by year) and annual income, the percent of damages in terms of annual income for the sample households was estimated.

The calibrated Urban Drainage Model was used to estimate the average depth of waterlogging in each ward for the years reported in the household samples, and the sample damage data were used to estimate the corresponding average damage as a percent of household income.

Based on estimated waterlogging depth derived from the Urban Drainage Model, estimated damage, and estimated affected households (in percent), a damage function was developed.[13] The slope coefficient was calculated for Khulna.

It was observed that the waterlogging depth was most relevant to the damages, and that the duration of waterlogging did not significantly increase financial damages to the households.

Damages to other sectors of Khulna's economy due to climate change were also required for the analysis of avoided damages (i.e., benefits) from strengthening the climate resilience of the urban drainage infrastructure. To assess this, focus group discussions were held in the affected areas with representatives from industries, manufacturing firms, government agencies, and local hospitals. One of the objectives was to assess the points on a damage function in terms of percent of output per year with different levels of waterlogging.[14] Based on these discussions, damage functions for various economic sectors (i.e., industry, manufacturing, commercial enterprises, agriculture, and public roads) were projected with hypothetical estimates of damages at different waterlogging levels.

However, the method used to estimate the damage functions was limited in its accuracy of the estimates. First, the actual damage data at the household level could not be collated with the waterlogging depth, as mentioned previously. Second, the damage function for other economic sectors was estimated from information obtained through the focus group discussions, so these damages were merely perceived damages. In the actual cost–benefit analysis, these damages were found to be much higher than damages at the household level (Table 11).

There is a possibility that other damages than those for households were overestimated, while they might have been able to capture some indirect costs such as loss of industrial production. Some costs associated with flooding, such as time costs from traffic disruptions, were not considered. Moreover, damage functions will change over time. Economic growth puts more assets at risk in absolute terms, but greater flexibility is obtained for climate variability. Building structures will

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[12] Damage = f (depth of waterlogging, duration of waterlogging).

[13] $Y = a X$, where Y is the percent of damage (in terms of annual income) and X is the depth of waterlogging.

[14] Damage was estimated in terms of (i) value of assets for industry, manufacturing, and commercial enterprises; (ii) yields for agriculture; and (iii) physical damage for public roads.

be more resilient, and buildings will be constructed on a higher plinth level to reduce damages. Therefore, there are significant uncertainties in the damage costs used in the study; thus, it needs to be viewed as an initial attempt at estimating the damage costs.

Other Issues

Land subsidence could have a significant impact on waterlogging in Khulna, as on the low-lying areas affected by tidal movements. It could have the same impact as rising sea levels. The Dhaka University Earth Observatory, in collaboration with Lamont-Doherty Earth Observatory, Columbia University, New York, installed six continuous geodetic global positioning system (GPS) stations in Bangladesh in 2003, including one at Khulna University. These GPS stations were installed to monitor the three-dimensional motion of the earth's crust to study crustal dynamics and earthquake hazards in Bangladesh. The vertical component of the GPS time-series plots demonstrate that the Bengal Basin as a whole is subsiding, including Khulna. Although the GPS station at Khulna has a data gap due to poor maintenance, the results from collected data show that Khulna is subsiding at a rate of 9.55 mm per year. Since the data were not verified during the study, land subsidence was not considered in assessing impacts of climate change. However, if this rate—which is quite significant—proves to be valid, future waterlogging in Khulna could be even more serious than that described in the following sections.

Estimating Impacts on the Proposed Surface Water Supply System

The impacts of climate change on Khulna's water supply were assessed in terms of changes in (i) dependable river flow (i.e., water availability) from January to June when the water flow is less, and (ii) maximum salinity levels and duration of river chloride levels above 600 milligrams per liter (mg/L) and 1,000 mg/L.[15] These impacts were estimated at Haridaspur, Mollarhat, upstream of Phultala, Phultala, Daulatpur, and Labanchara (Figure 8).

Impacts on Water Availability

During the dry season, the river flows in southwest Bangladesh are highly dependent on upstream inflows (from the Ganges and Padma rivers) and on local inflows from groundwater. In Figure 9 and Table 5, 95% dependable flows from January to June at the locations of interest are shown for the base and two reference cases, Runs 3a and 5a.[16] For all locations, there was a marginal decrease in dependable river flows in Run 3a (i.e., the year 2030) and Run 5a (i.e., the year 2050) compared to Run 1 (i.e., the base case). The decrease in all locations was less than 9% of the 95% dependable flows in Run 1.

The proposed intake flow rate for water supply was estimated by the Japan International Cooperation Agency (JICA) to be 1.27 cubic meter per second (m^3/s) in 2020 and 2.93 m^3/s in 2030.[17] In this study, the 2050 intake rate was estimated to be 4.71 m^3/s. All three of these intake rates are well below the 95% dependable flows at all candidate intake locations in the climate change scenarios. At Mollarhat, the proposed intake location, the intake requirements are 4% in 2030 and 6% in 2050 of the 95% dependable flows.

Increased groundwater abstractions and direct river water withdrawals upstream of these six locations were not considered in this study. Therefore, these 95% dependable flow estimates for 2030 and 2050 should be considered optimistic. Nevertheless, it would be reasonable to conclude that climate change in 2030 and 2050 would not significantly affect the water availability of the proposed surface water supply system.

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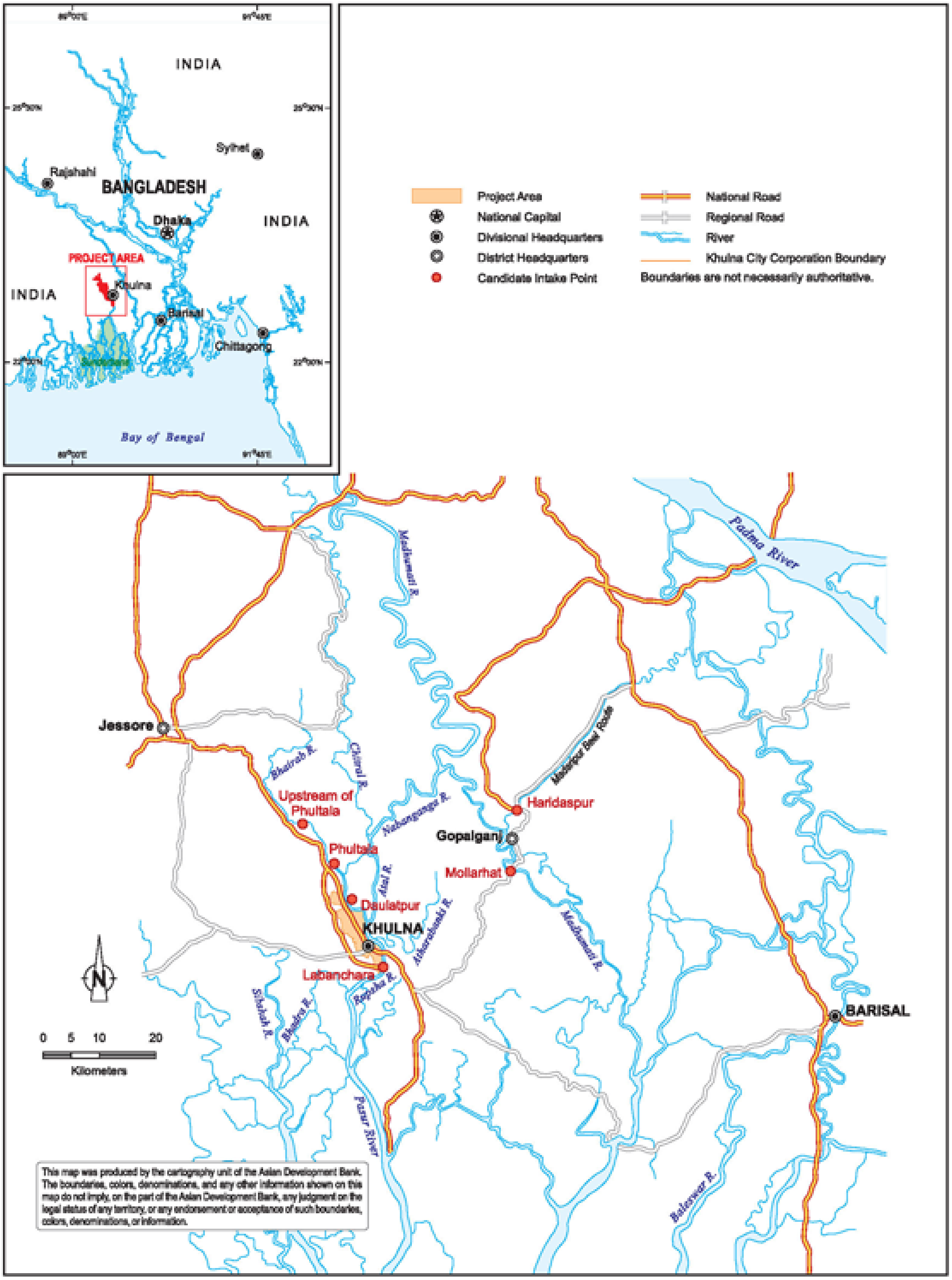
[15] National drinking water quality standards in Bangladesh under the Environment Conservation Rules (1997) require a maximum chloride concentration of 600 milligrams per liter (mg/L) (0.6 part per thousand [ppt]), while the maximum allowable concentration is 1,000 mg/L (1.0 ppt) in coastal areas, including Khulna.

[16] A 95% dependable flow is the level of flow that is expected to be ensured for 95% of the time.

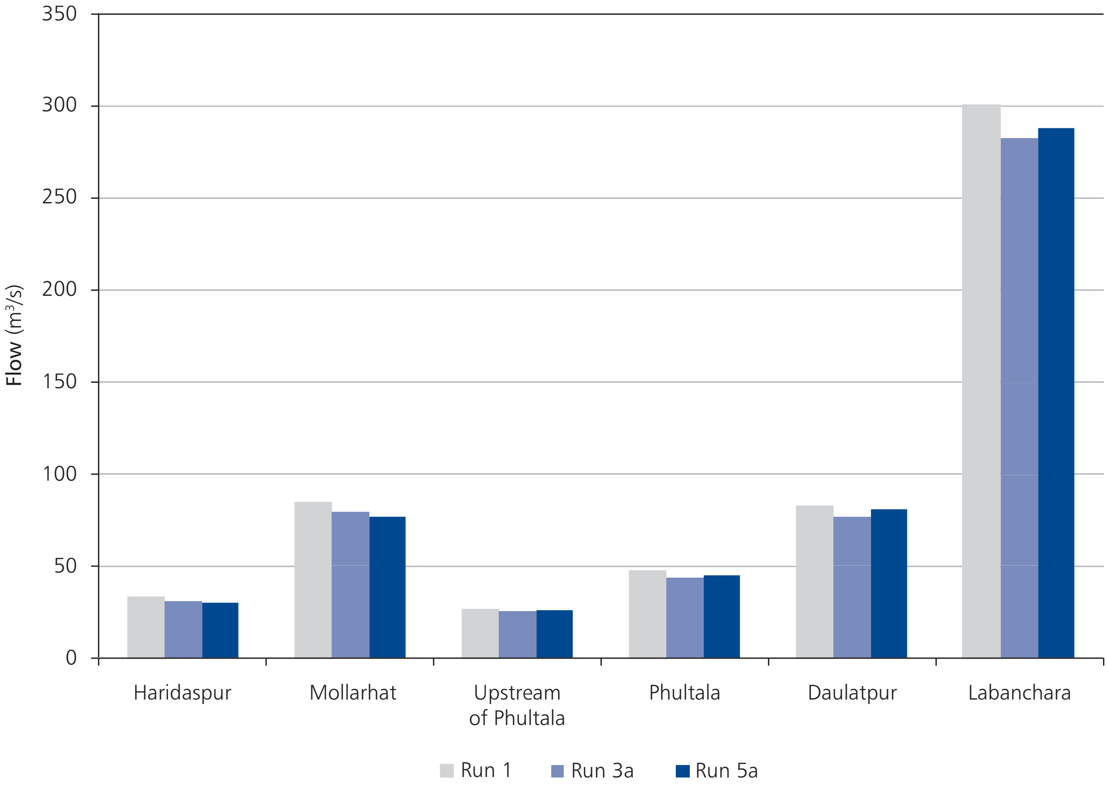
[17] JICA. 2010. *Feasibility Study for the Khulna Water Supply Improvement Project in the People's Republic of Bangladesh*. Tokyo.

Figure 8 Locations of River Salinity and Water Availability Analysis



Source: ADB.

Figure 9 **95% Dependable Flow in Base and Reference Scenarios**



m^3/s = cubic meter per second.

Source: ADB.

Impacts on River Salinity

The impacts of climate change on maximum river salinity levels at the six locations of interest are shown in Table 5. A clear, rising trend in salinity is evident in 2030 and 2050 due to climate change. At all locations, the maximum salinity exceeds 1,000 mg/L in terms of chloride concentration.[18]

Figure 10 presents a probability plot of the number of days that the salinity is exceeded at Mollarhat for the five scenarios. The y-axis is the number of days in a year that the maximum daily chloride level exceeds 1,000 mg/L. The x-axis is the probability of the number of days that the river has high salinity in any given year for each scenario based on 20-year simulations. For Run 1, the salinity profile crosses the x-axis at around 33% (i.e., high salinity is likely to occur in about 1 of 3 years with current conditions). This means that there is a 33% chance that the salinity at Mollarhat will exceed the 1.0 mg/L limit for at least 1 day in any given year for the base conditions.

At the other end of the plot for Run 1, there is a 5% chance (i.e., about 1 in 20 years) that the number of high salinity days at Mollarhat will be 55 or higher. In Run 3a (i.e., 2030 climate change under the A2 scenario with high sea-level rise), the number of high salinity days is similar, with the same exceedance probability. In 2050, the duration increases to 75 days, with a 5% exceedance probability.

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[18] The Salinity Model provides, as its output, the salinity level in terms of salinity concentration. This was converted into the chloride concentration on the condition that the chloride concentration would be about 55% of the total salinity. Although this rate is an internationally accepted rate for seawater, there is uncertainty if this conversion is appropriate for brackish and turbid water.

Table 5 Projected 95% Dependable Flow and Salinity Levels

Intake Source Point			Haridaspur	Mollarhat	Upstream of Phultala	Phultala	Daulatpur	Labanchara
Indicator	Modeled 95% dependable flow (m³/s)	Base	33	84	26	48	83	301
		Run 3a	31	80	25	44	77	283
		Run 5a	30	77	26	45	81	288
		Run 7a	31	80	25	44	77	283
		Run 9a	30	78	26	44	80	286
	Maximum salinity level (mg/L chloride concentration)	Base	0.9	1.8	5.9	7.8	10.1	11.6
		Run 3a	1.0	2.1	7.0	8.7	10.6	11.7
		Run 5a	1.5	3.0	7.0	8.7	10.6	11.7
		Run 7a	1.1	2.3	7.0	8.3	10.3	11.6
		Run 9a	1.6	3.0	7.0	8.7	10.6	11.7
	No. of days in a year river salinity is higher than 600 mg/L chloride	Base	0	59	126	145	161	175
		Run 3a	6	62	128	145	162	176
		Run 5a	16	89	128	149	163	176
		Run 7a	7	65	132	152	162	175
		Run 9a	25	86	142	155	163	175
	No. of days in a year river salinity is higher than 1,000 mg/L chloride	Base	0	41	114	134	153	168
		Run 3a	0	42	125	135	153	171
		Run 5a	2	65	128	137	154	172
		Run 7a	0	43	127	139	154	169
		Run 9a	4	70	126	140	155	170

m³/s = cubic meter per second, mg/L = milligram per liter.

Notes: 3a = 2030, scenario A2, high sea-level rise; 5a = 2050, scenario A2, high sea-level rise; 7a = 2030, scenario B1, high sea-level rise; 9a = 2050, scenario B1, high sea-level rise. Durations are for 15% exceedance probability (i.e., there is a 15% chance that this duration can be exceeded in any year). Another way to view this is that this duration of salinity can occur once in around every 7 years.

Source: ADB.

Adaptation Options

Due to increased river salinity levels and longer durations of river salinity, the number of days that river water is unsuitable for drinking purposes will increase with climate change. Thus, one core option is to increase the impounding reservoir size so that it can provide an alternative supply for a longer period.[19] Another core option is to move the intake point further upstream where the salinity level in the climate change scenario is similar to that in the base case at the original intake point. These two types of core adaptation options have been selected based on practicality and cost-effectiveness. Although salty river water could also be diluted with groundwater, this core option was not examined closely due to lack of data on groundwater availability and safe yields. Two additional measures, which could be core options, are also worth noting but were excluded

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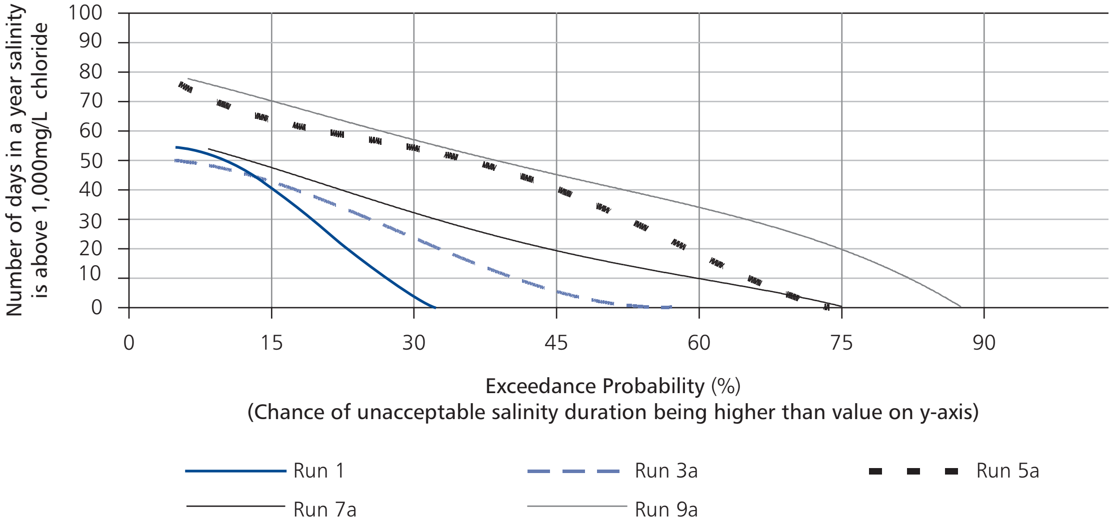
[19] This report uses the term “core” and “add-on” adaptation options. Core options refer to major measures that directly and largely solve the main issues, while add-on options entail additional measures that do not solve the main issues fully but will be useful in addressing them. Further, the idea of an impounding reservoir is to store river water when the water meets chloride concentration standards and to use it when the river water is too salty.

Figure 10 **Change in Mollarhat Salinity Duration Curves due to Climate Change**



mg/L = milligram per liter.

Source: ADB.

in this study: (i) separating water supply lines in two parts, one for drinking and cooking purposes with higher price tags per liter, and one for other uses; and (ii) supplying bottled water during high salinity periods instead of expanding the reservoir size. These could reduce the investment cost substantially, while additional management costs would be incurred. Social acceptability would need to be carefully assessed before further consideration of these measures.

JICA, in its feasibility study, identified eight intake points, including Daulatpur, Haridaspur, Labanchara, Mollarhat, and Phultala, which were also analyzed under this study (footnote 17). It preliminarily estimated the total investment, operation, and maintenance costs required for each core option, and concluded that locating the intake near Khulna—at Daulatpur, Labanchara, or Phultala—would not be feasible because of the large impounding reservoir required and unavailability of suitable land. Desalination was also considered but rejected because it is too expensive for Khulna's socioeconomic condition. Therefore, the study was focused on the Madhumati River side, with a proposed intake point at Mollarhat as it was closer to Khulna and would lead to cost savings.

Under the A2 scenario with a high sea-level rise (corresponding to Run 5a), the size of impounding reservoir needs to be increased by 12 million m^3 by 2050.[20] On the other hand, moving the intake upstream by 4 km from Mollarhat would also cancel out the effects of climate change.

The above two core options were also evaluated preliminarily from economic, social, and environmental viewpoints, and the summary is provided in Table 6. A least-cost analysis was

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[20] The following formula was used: Impounding Reservoir Size = Intake Flow Requirement × Duration of High Salinity × 10% Adjustment Factor for Evaporation Losses. A calculation was made for 24 additional days (65 days in 2050 minus 41 days in the base case) when the salinity is above 1.0 mg/L chloride concentration in 2050. Based on the domestic water demand of 150 liters per capita per day; 10% additional demand for nondomestic water; a population of 2,155,000; water use at the water treatment plant (5%); and leaks in the system (18%), the intake flow requirement of 456,000 m^3 per day was used. Evaporation rates will increase in the future due to temperature increases, although this issue was not analyzed in depth in the study.

Table 6 **Evaluation of Adaptation Options**

Adaptation Options	Economic	Social	Environmental
Option 1. Relocate the intake point upstream by 4 kilometers from Mollarhat by 2050.	Investment cost—$8.39 million O&M cost—$24,000 per year	16 households affected, no resettlement	Construction impacts (noise, vibration)
Option 2. With an intake point at Mollarhat, increase the reservoir size by 12 million m^3 by 2050.	Investment cost—$29.04 million O&M cost—$28,000 per year	More than 20 households affected, including resettlement	Construction impacts (noise, vibration)

m^3 = cubic meter, O&M = operations and maintenance.

Source: Adapted from ADB.

conducted, as the objectives (i.e., benefits) of the adaptation options were the same—providing 100% of the population in the KCC area with an adequate amount of water that satisfies drinking water quality standards.[21] However, the table shows that option 1, relocating the intake point upstream by 4 km from Mollarhat, will cost less and is socially more acceptable.

In addition to the core options, add-on options were also examined. The add-on options are designed not only to improve the social acceptability of the intervention but also to make the core options more effective and robust against climate change. Reduced water leaks and better water demand management were identified as effective add-on options that may reduce the overall cost of the project in the long term.

Gorai River Dredging

The Gorai River, an important source of freshwater in southwest Bangladesh, collects water from the Ganges River. For the last 20 years, the dry season flows (i.e., December–April) have been decreasing, and it is reported that the Gorai River is recurrently disconnected from the Ganges River during the driest months as a consequence of heavy sedimentation at the Gorai River intake. Reduced freshwater flow to the Gorai River is a major cause of increasing salinity in the area, including Khulna. In this context, the Government of Bangladesh has decided to commence the Goral River Restoration Project, with an estimated cost of about $1.7 billion. The main component of the project is to implement capital dredging for 2 years followed by 8 years of maintenance dredging. As the project could have significant positive impacts on salinity concentrations in rivers, its impacts were also assessed in the study.

Assuming that a constant inflow of 60 m^3/s would be available at the Gorai River intake during the dry season, an analysis was conducted for both the A2 and B1 scenarios.[22] The number of days in a year when chloride concentrations exceed 1,000 mg/L in Mollarhat would be reduced to zero in Run 3a in the worst case (from 55 days without the dredging), and to 4 days in Run 5a in

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[21] If no adaptation options are undertaken, the quality or quantity—or both—of the water supply will not meet design standards. Incremental benefits of the adaptation options, which are to provide water that satisfies both quality and quantity to the entire population of KCC, are difficult to quantify in monetary terms and are beyond the scope of the study. The argument made in the study implicitly assumes that the benefits of implementing adaptation options are higher than their costs.

[22] 60 m^3/s was the observed average dry season flow in the Gorai River intake during the previous dredging project in 1999.

the worst case (from 75 days without the dredging).[23] There would be co-benefits to the project as well, including increased freshwater supply for agriculture, industry, and other uses; enhanced navigability of rivers; and ecosystem restoration.

Despite its sizeable benefits, however, the reliability and effectiveness of the project needs careful consideration. Previously, the government implemented a dredging project and reopened the Gorai River intake in 1999, but the effect did not last long due to a lack of sufficient maintenance dredging. The urgency of water supply improvement in Khulna cannot afford to wait to see if the Goral River Restoration Project will be fully implemented and if the sustainability of its effects can be ensured.

Proposed Investment Project

After the overall findings of this technical assistance (footnote 2) were presented to stakeholders, further studies were undertaken to propose an appropriate project design. First, shifting the water intake upstream by 4 km from Mollarhat would be a challenging option, though cost-effective and socially more acceptable according to a preliminary result presented earlier in this report. Unfortunately, the relocation of the intake would place it in a different administrative division requiring excellent coordination, which is challenging and time-consuming in Bangladesh. In light of this, further analyses were undertaken by JICA to minimize the required size of the impounding reservoir (footnote 17).

The JICA study team initially estimated, through a simplified statistic analysis based on DOE's monthly chloride concentration monitoring record, that an impounding reservoir for storing 45 days of water demand (5.4 million m^3) would be required with an area of 60 hectares in 2025 to cope with the salinity increase, with an estimated cost of $65 million.[24] This output harmonizes well with the simulation result of 42 days a year in 2030 under Run 3a.

Then, to minimize the required land for the impounding reservoir, introduction of a developed management system was considered. Under this system, the river water quality is continuously monitored, and the water in the impounding reservoir is mixed with the river water every day to satisfy the water quality standard of 1,000 mg/L chloride concentration. For example, in case the chloride concentration of the river water is 1,900 mg/L and that of the impounding reservoir water is 50 mg/L, these waters would be mixed in a 1:1 ratio to make the chloride concentration of the mixed water less than 1,000 mg/L (in this case, 975 mg/L).

Due to the uncertainty of future salinity levels, the proposed investment project will adopt an adaptive management: it aims to acquire 16 hectares of land, which is large enough to cope with the expected salinity increase up to about 2025. However, the impounding reservoir to be built initially will have the capacity of 0.77 million m^3 with an area of 10 hectares. This would result in significant investment savings.[25] The size of the reservoir is expected to be adequate to provide freshwater for about 23 days per year if the river water exceeds the chloride concentration standards to the extent observed in 2010. The impounding reservoir will be expanded as and when the salinity levels actually rise in the future.

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[23] Instead of using the exceedance probability, the worst case in 20 years (from 2020 to 2040 and 2040 to 2060) was considered. This is the equivalent of 5% exceedance probability.

[24] According to the DOE record and JICA's water quality monitoring, the chloride concentration in Mollarhat exceeded the threshold of 1,000 mg/l for the first time in 2010 for 15 days.

[25] JICA requested ADB not to disclose the estimated cost due to its possible influence on the bidding.

Regarding salinity levels in southwest Bangladesh, it is debatable to what extent the salinity is being caused by climate change, and to what extent it is being caused by other factors (e.g., natural sedimentation in the Gorai River intake or reduced flow from the Ganges River). If the increased salinity is caused by climate change, based on the monitoring result that salinity was not a problem in Mollarhat up to 2008,[26] the whole cost of the impounding reservoir may be regarded as an adaptation cost. On the other hand, if the increased salinity is a natural phenomenon or caused by anthropogenic interventions, only a portion of the cost of the impounding reservoir can be considered adaptation costs. In either case, constructing the reservoir with a size currently proposed would be an intermediate solution only. Incremental costs, which could be wholly regarded as costs of adaptation, would likely be required to expand the size of the reservoir.

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[26] In data obtained by KWASA, the chloride concentration exceeded 1,000 mg/L for the first time in 2009.

Estimating Impacts on the Current and Proposed Urban Drainage System

Waterlogging is expected to become more serious with climate change due to increased rainfall intensity and increased outfall water levels caused by rising sea levels. In assessing the impacts, 1-in-5- and 1-in-10-year flood events were considered.[27]

Impacts on the Current Urban Drainage System

First, impacts on Khulna's drainage conditions were assessed by assuming future socioeconomic development and no improvement in the drainage system (Table 7). The waterlogged area with damaging water depths (i.e., higher than 30 centimeters [cm]) increases from 29% to 34% for 2030 (Run 3a) and to 54% for 2050 (Run 5a) for a 1-in-10-year flood event. Figure 11 shows the projected waterlogged area for the 1-in-10-year flood event in 2050. Due to climate change, a 1-in-10-year flood event for the base condition is close to a 1-in-5-year event in 2030, and a 1-in-10-year flood event for 2030 becomes a 1-in-5-year event in 2050. The average water depth in the area of damaging floods (i.e., F1 and above) increases from 41 cm in the base case to

Table 7 **Waterlogged Area in Khulna with Climate Change** (%)

Scenarios	FF (0–10 cm)	F0 (11–30 cm)	F1 (31–60 cm)	F2 (61–90 cm)	F3 (91 cm and above)	Damaging Water Depth (F1 + F2 + F3)
Base 1-in-10-year flood event	64	7	26	3	0	29
Base 1-in-5-year flood event	81	7	11	1	0	11
2030 1-in-10-year flood event	60	7	28	5	0	34
2030 1-in-5-year flood event	71	8	19	2	0	21
2050 1-in-10-year flood event	42	3	23	28	3	54
2050 1-in-5-year flood event	58	10	28	4	0	32

cm = centimeter.

Note: The table assumes an A2 scenario and high sea-level rise.

Source: ADB.

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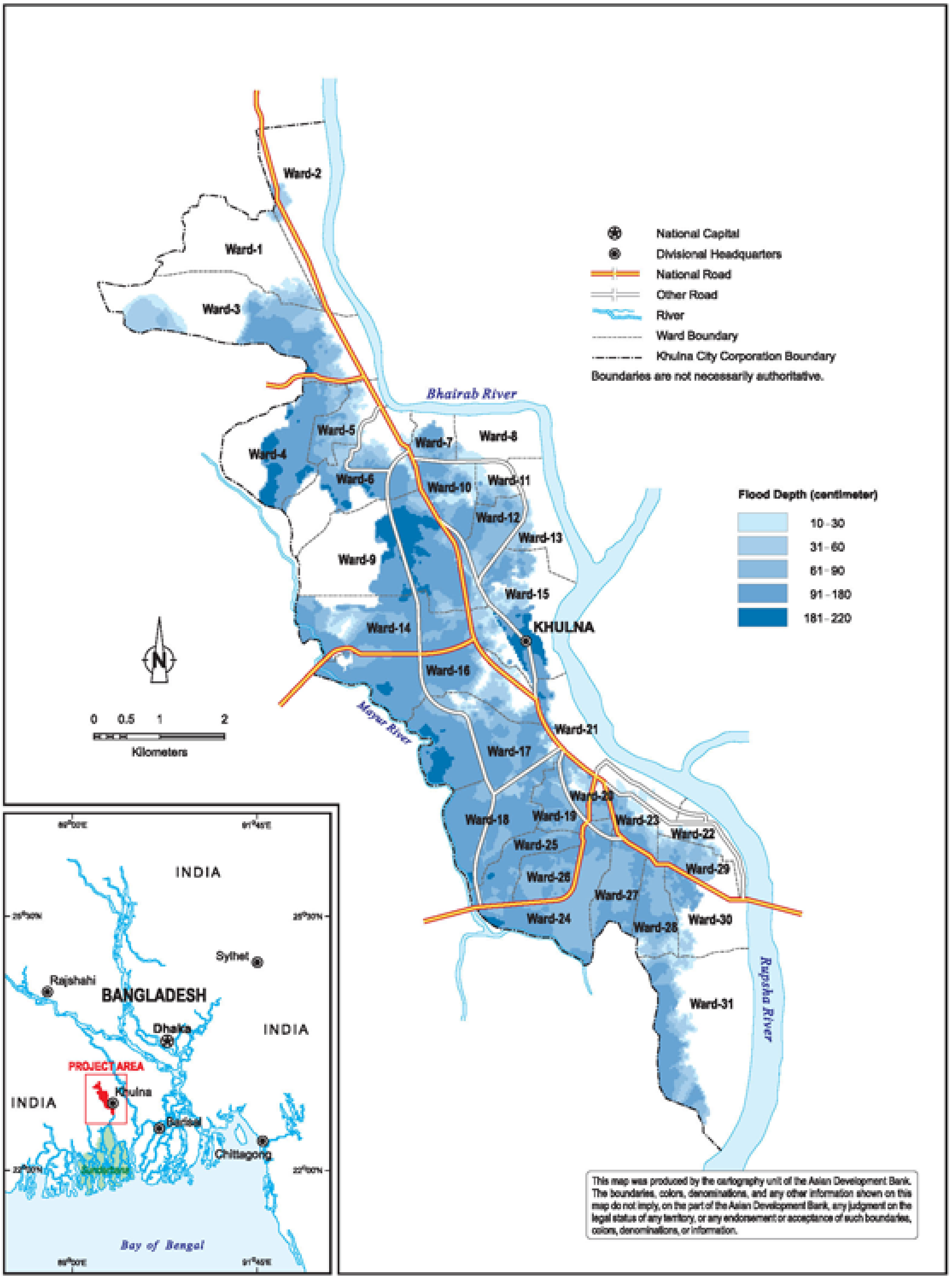
[27] Normally, rainfall frequency is considered to assess flood events. However, flood depth frequency analysis was performed in this study, as Khulna's drainage system is also affected by tidal flow at the outfall. A separate statistical analysis would have been required for outfall water level condition, and the combination could have made the return period calculation more complex.

Figure 11 Waterlogging Map for a 1-in-10-Year Return Period Flood in 2050 (Under the A2 Scenario and High Sea-Level Rise)



Source: ADB.

49 cm in 2030 and 63 cm in 2050 under the 1-in-10-year flood event. The population exposed to damaging floods increases from 24% in the base case to 41% in 2030 and 58% in 2050.

Proposed Improvements to the Urban Drainage System and Impacts of Climate Change on the Improved System

Khulna's existing drainage system is insufficient even without any climate change in the future. Therefore, it was necessary to assume that the drainage system will be improved to an acceptable level with current climate conditions.[28] As there is no common design standard for urban drainage systems in Bangladesh, the design standard under the study was set so that the improvement makes 80% of each ward free from damaging floods (i.e., flood depths of 30 cm or less). Costs for the improvement, comprising such measures as new construction of drains, river dredging, and re-excavation of drains with lining, were estimated to be $7.0 million for a 1-in-5-year return period and $10.7 million for a 1-in-10-year return period. This cost takes into account only primary channel improvement.

Table 8 shows how the waterlogging conditions change in 2030 and 2050 under Runs 3a and 5a with 1-in-5- and 1-in-10-year flood events. It demonstrates that with improvement of the drainage

Table 8 **Waterlogged City Area, with Climate Change** (%)

Design Event	Measures	FF (0–10 cm)	F0 (11–30 cm)	F1 (31–60 cm)	F2 (61–90 cm)	F3 (91 cm and above)	Damaging Water Depth (F1 + F2 + F3)
Base 1-in-5 year flood event	No improvement	81	7	11	1	0	11
	With improvement	92	6	2	0	0	2
Base 1-in-10 year flood event	No improvement	64	7	26	3	0	29
	With improvement	87	5	8	0	0	8
2030 1-in-5 year flood event	No improvement	71	8	19	2	0	21
	With improvement	83	8	8	0	0	8
2030 1-in-10 year flood event	No improvement	60	7	28	5	0	33
	With improvement	79	7	13	1	0	14
2050 1-in-5-year flood event	No improvement	58	10	28	4	0	32
	With improvement	68	10	21	1	0	22
2050 1-in-10 year flood event	No improvement	42	3	23	28	3	54
	With improvement	64	8	22	7	0	29

cm = centimeter.

Note: The table assumes an A2 scenario and high sea-level rise.

Source: Adapted from ADB.

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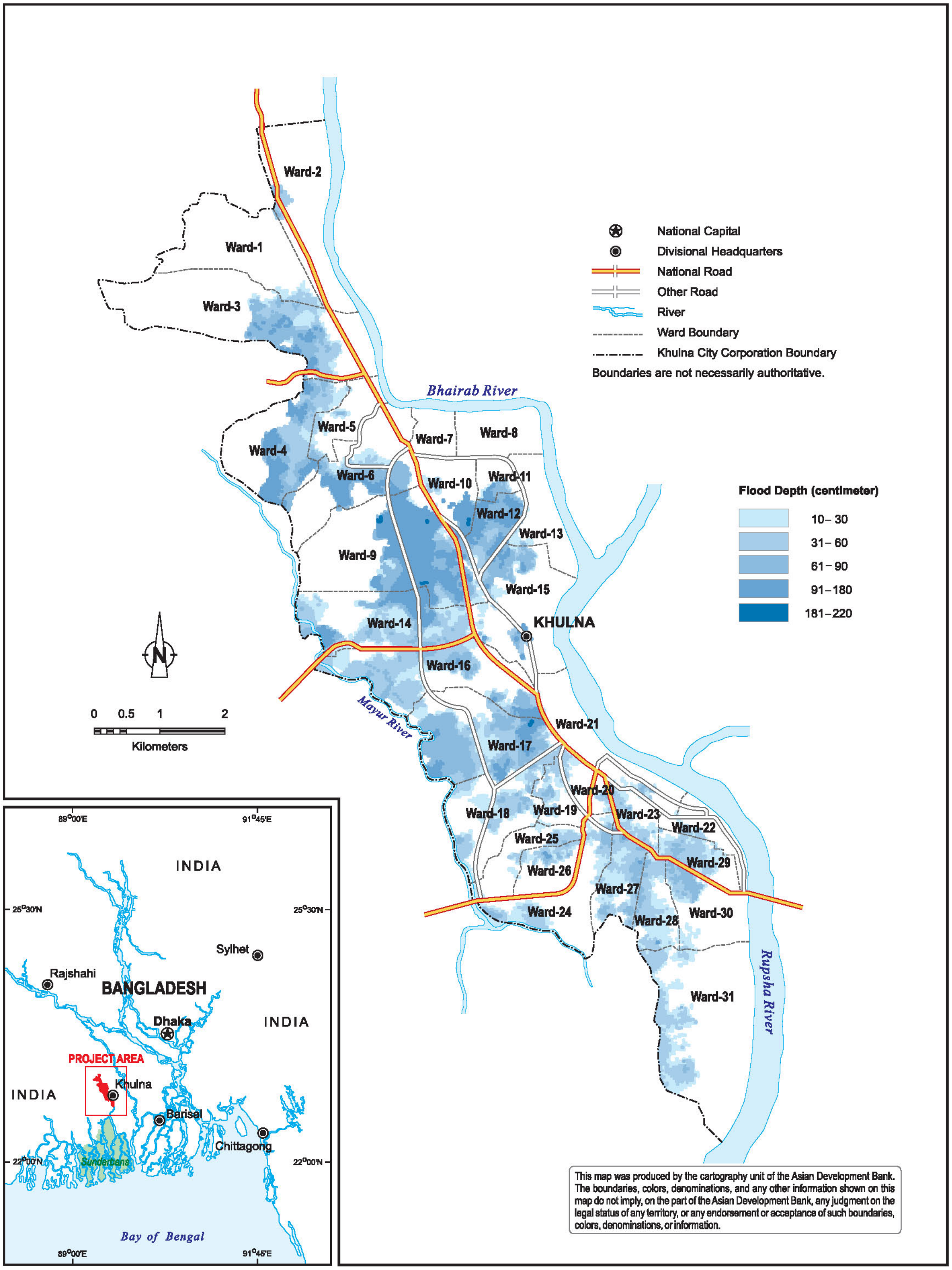
[28] This is termed as "adaptation deficit," which indicates that countries are underprepared for current climate conditions, much less for climate change. The second use of the term conveys that poor countries have less capacity to adapt to change, whether induced by climate change or other factors, because of their lower stage of development. Details are provided in World Bank. 2010. *The Economics of Adaptation to Climate Change: A Synthesis Report. Final consultation draft.* Washington, DC.

Figure 12 **Waterlogging Map for a 1-in-10-Year Return Period Flood in 2050 with Improvement (Under the A2 Scenario and High Sea-Level Rise)**



Source: ADB.

system, the waterlogged area is reduced from 33% to 14% in 2030, and from 54% to 29% in 2050 in a 1-in-10-year flood event. In addition, the average flood depth in the areas of damaging floods is reduced from 63 cm to 47 cm, and the population affected by damaging floods falls from 58% to 30% in 2050 for a 10-year return period flood. Figure 12 shows the extent of flooding in 2050 under the 1-in-10-year return period with the proposed improvement.

However, both in 2030 and 2050, the design criteria of making 80% of each ward flood-free cannot be met. Therefore, additional measures (i.e., adaptation measures) are required to protect Khulna from waterlogging.

Adaptation Options

Adaptation options were designed for Runs 3a and 5a. As in the case of water supply, two types of adaptation options were considered. The core adaptation options contained engineering measures, such as additional river dredging, re-excavation of drains with lining, sluice gate improvement, and widening of drains, to address Khulna's waterlogging problem in 2030 and 2050 and to ensure that 80% of each ward remains free from damaging floods.

Table 9 shows how the waterlogging conditions are reduced with the adaptation measures, and improved waterlogging conditions with the adaptation options are presented in Figure 13. The average waterlogging depth is reduced to 40 cm, and the population exposed to floods falls to 13% in 2050 with a 1-in-10-year flood event. These figures are still higher than 33 cm and 6% for the improved drainage system under the current climate, implying the need for add-on options.

Add-on options identified include good solid waste management to ensure functionality of the drainage system, strict implementation of building codes and land-use planning, awareness and

Table 9 **Waterlogged City Area, with Climate Change** (%)

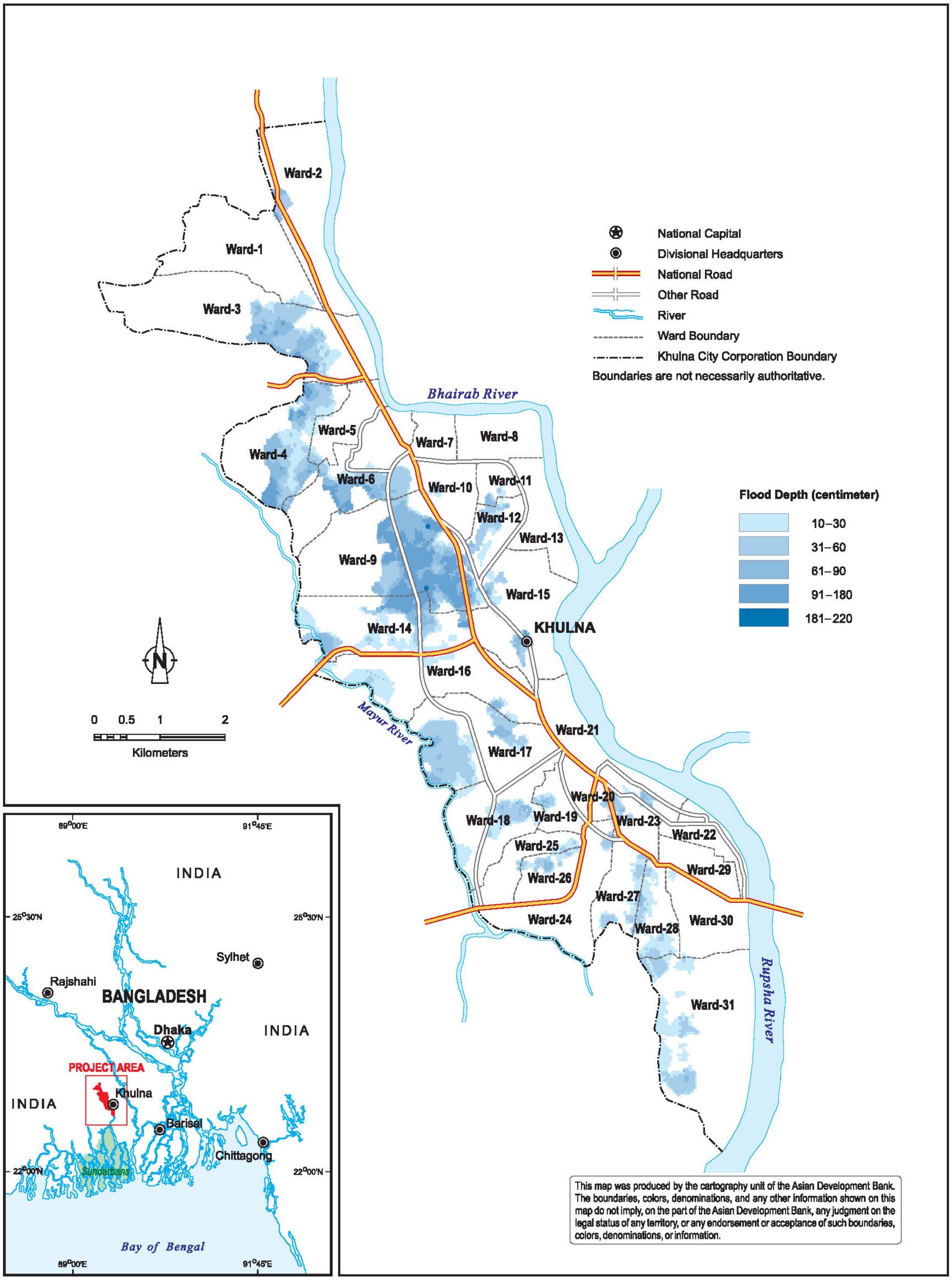
Design Event	Measures	FF (0–10 cm)	F0 (11–30 cm)	F1 (31–60 cm)	F2 (61–90 cm)	F3 (91 cm and above)	Damaging Water Depth (F1 + F2 + F3)
2030, 1-in-5 year flood event	No improvement	71	8	19	2	0	21
	Improvement	83	8	8	0	0	8
	Improvement and adaptation measures	86	7	7	0	0	7
2030, 1-in-10 year flood event	No improvement	60	7	28	5	0	33
	Improvement	79	7	13	1	0	14
	Improvement and adaptation measures	82	7	10	1	0	11
2050, 1-in-5-year flood event	No improvement	58	10	28	4	0	32
	Improvement	68	10	21	1	0	22
	Improvement and adaptation measures	80	10	10	0	0	10
2050, 1-in-10 year flood event	No improvement	42	3	23	28	3	54
	Improvement	64	8	22	7	0	29
	Improvement and adaptation measures	80	6	11	3	0	14

cm = centimeter.

Note: The table assumes an A2 scenario and high sea-level rise.

Source: Adapted from ADB.

Figure 13 **Waterlogging Map for a 1-in-10-Year Return Period Flood in 2050 with Improvement and Adaptation (Under the A2 Scenario and High Sea-Level Rise)**



This map was produced by the cartography unit of the Asian Development Bank. The boundaries, colors, denominations, and any other information shown on this map do not imply, on the part of the Asian Development Bank, any judgment on the legal status of any territory, or any endorsement or acceptance of such boundaries, colors, denominations, or information.

Source: ADB.

education campaigns, and improved prediction and early warning systems, which all contribute to alleviating the flood damage. These options are consistent with the adaptation measures in the context of managing floods provided in the IPCC report (footnote 9) that involve (i) protection against predicted climate change (e.g., structural measures and ensuring functionality of the drainage system); (ii) accommodation to improve resilience (e.g., building codes and improved prediction and early warning systems); and (iii) retreat to reduce exposure (e.g., land-use planning). Regular maintenance dredging should also be stressed to ensure the conveyance capacity of the drainage network.

It was found that improvements required for the base case were sufficient to address drainage problems for Runs 6a and 8a (i.e., scenario B2 with low sea-level rise). Thus, no adaptation measures were considered for these scenarios.

An evaluation was undertaken for the adaptation measures shown in Table 9. A summary of the cost of the adaptation measures is provided in Table 10. A cost–benefit analysis was also conducted, as the benefits (i.e., damage costs avoided) of the adaptation measures were different. Damage costs under different scenarios are provided in Table 11.

Using a 40-year cash flow (from 2010 to 2050) and a 10% discount rate,[29] the benefit to cost ratio is 2.89 for a 5-year return period and 4.97 for a 10-year return period. The economic internal rate of return is high at 34.2% for a 5-year return period and 111.0% for a 10-year return period.[30] These figures, however, should be considered indicative only, as significant uncertainties are involved in estimating both costs and benefits, as previously described.

Table 10 Cost of Drainage System Improvements for Different Scenarios

Design Event	5-Year Return Period				10-Year Return Period			
	Investment Cost		O&M Cost per Year		Investment Cost		O&M Cost per Year	
	(Tk million)	($ million)	(Tk million)	($ million)	(Tk million)	($ million)	(Tk million)	($ million)
Base Improvement	493.0	7.0			751.0	10.7		
2030 Adaptation	64.0	0.9	24.4	0.3	39.0	0.6	15.0	0.2
2050 Adaptation	1,312.0	18.7	100.5	1.4	1,167.0	16.7	89.4	1.3

O&M = operations and maintenance.

Notes:

1. Adaptation investment cost for climate change is on top of drainage system improvement costs. Adaptation measures ensure that 80% of each ward is free from damaging floods.
2. Similarly, the adaptation O&M cost is on top of annual costs without climate change.

Source: ADB.

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[29] A discount rate of 10% is used for all development projects of Bangladesh by the Planning Commission.

[30] The cost–benefit analysis did not take into account the costs required for the improvement regardless of climate change and associated benefits derived from the improvement. In other words, only the benefits and costs pertaining to the adaptation measures were considered. For simplicity, investment for adaptation measures required for 2030 and 2050 was assumed to be made in 2010 and 2030, respectively.

Table 11 **Damage Costs and Adaptation Benefits** (Tk million)

1-in-10 Year Return Period Flood Event	Average Waterlogging Depth (cm)	Household	Industry	Manufacturing	Commercial and Others	Agriculture	Roads	Total
Base case damage	41	5	33	14	564	3	535	1,155
Base case damage with improvement	33	1	6	3	109	1	165	285
Damage in 2050 with climate change	63	48	13,745	30,665	59,548	21	4,651	108,679
Damage in 2050 with climate change and improvement	47	25	4,964	11,075	21,507	7	1,680	39,259
Damage in 2050 with climate change, improvement, and adaptation measures	40	10	2,157	4,813	9,345	3	730	17,059
Damage in 2030 with climate change	49	17	2,300	2,374	13,266	11	1,494	19,461
Damage in 2030 with climate change and improvement	41	6	623	643	3,593	3	405	5,272
Damage in 2030 with climate change, improvement, and adaptation measures	39	3	435	449	2,506	2	282	3,677
Benefits (reduced damages) of base improvement	(8)	4	27	11	455	3	371	870
Benefits (reduced damages) of adaptation measures for 2030	(1)	2	188	194	1,087	1	122	1,595
Benefits (reduced damages) of adaptation measures for 2050	(7)	15	2,807	6,263	12,162	4	950	22,201

cm = centimeter.

Notes: The scenario assumes A2 and high sea-level rise. Those in parenthesis are negative figures.

Source: Adapted from ADB.

Proposed Investment Project

Two separate studies were carried out for the required improvement of the urban drainage system in Khulna.[31] As the secondary system was not analyzed in this study, the recommendations of these two studies were taken into account to estimate the cost. The base case improvement (referred to as "unified improvement") without considering climate change is expected to cost $25.6 million, including improvement of secondary channels, rehabilitation of outlet structures, protection of link channels, dredging and re-excavation, removal of encroachment, and development of recreational facilities for other rivers. This is more than double the cost of base improvement shown in Table 10. If the unified improvement is implemented, the waterlogged area in the city would be reduced as shown in Table 12. Adaptation requirements to satisfy the design standard for 2030 and 2050 also cost much less, as the unified improvement includes some of the adaptation measures originally proposed. Costs would be $0.4 million for 2030 and $12 million for 2050.

The City Region Development Project, which includes Khulna's drainage system improvement as a subproject, is expected to build upon the findings of this study and propose an appropriate level of investment to strengthen the climate resilience of the urban drainage system in Khulna.

Table 12 **Waterlogged Area in Khulna with Unified Improvement** (%)

Scenario	Design Event	Measures	FF (0–10 cm)	F0 (11–30 cm)	F1 (31–60 cm)	F2 (61–90 cm)	F3 (91 cm and above)	Damaging Floods (F1 + F2 + F3)
Base	1–10 year	Unified improvement	89	5	6	0	0	6
2030	1–10 year	Unified improvement	90	4	6	0	0	6
		Unified improvement + adaptation	90	5	5	0	0	5
2050	1–10 year	Unified improvement	76	7	16	1	0	17
		Unified improvement + adaptation	82	6	11	1	0	12

cm = centimeter.

Note: The scenario assumes A2 and high sea-level rise.

Source: Adapted from ADB.

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[31] ADB. 2010. *Technical Assistance to the People's Republic of Bangladesh for Preparing the City Region Development Project.* Consultant's report. Manila; and ADB. 2009. *Cities Development Initiative for Asia Support to Khulna City Corporation*. Consultant's report. Manila.

Limitations and Conclusions

Limitations

The study adopted a similar approach as the preceding studies, particularly those undertaken by ADB, JICA, and the World Bank for Asian coastal megacities.[32] Based on the downscaled climate variables, hydrological models were used to simulate flooding, and damages caused by the flooding were estimated. Then, adaptation options to alleviate the flooding and its damages were identified and evaluated. This study also included an impact assessment of the proposed water supply system.

Limitations of this study, therefore, are similar to those in the preceding studies. Numerous assumptions about the socioeconomic development of Khulna in 2030 and 2050 were made. Greenhouse gas emissions in the future and resulting climate change, particularly on a localized scale as needed for this study, are highly uncertain. Further, only one Global Climate Model was used for statistical downscaling. Although rising sea levels have significant impacts both on water supply systems and urban drainage systems, the research on the likely levels is evolving. Also, the three hydraulic models used in this study, while well calibrated using the existing data and reproducing past events fairly accurately, also have some degrees of error. Lastly, as discussed earlier, the damage costs of flooding were derived with inadequate background data and socioeconomic surveys. Details of uncertainties, in terms of climate, growth, and technology, are well described in other studies (footnote 28). Thus, these uncertainties and errors need to be considered in interpreting the results of the study.

While these uncertainties could be reduced by further analysis of climate downscaling, results of evolving research on rising sea levels, further calibration of models with more data collection, fine-tuning of socioeconomic development scenarios, and more studies on the relationship between flood levels and associated damages in each sector, they cannot be totally eliminated. Uncertainty will remain in considering 20 or 40 years from the present, and decisions should be taken toward strengthening the climate resilience of infrastructure in parallel with the efforts for narrowing the range of and quantifying uncertainties. Therefore, some thoughts are given below as to the possible criteria used for decision making, although the analysis is only qualitative and preliminary.

First, investment decisions can be made now if benefits are expected even under the current climate. This would apply to the drainage system improvement in Khulna, as it is currently facing an adaptation deficit, and the improvement would be a cost-effective method of adaptation. In other words, focus should be placed on no-regret or low-regret options, which are effective and robust under different climate scenarios. All of the add-on options fall under this category.

Second, investment may be delayed if incremental investment will not result in a significant cost increase. Third, investment may be delayed if the investment can be made in the short term. The impounding reservoir for the water supply system (Proposed Investment Project, p. 20) may satisfy these conditions, as the second reservoir may be constructed close to the first reservoir within a

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[32] World Bank, ADB, and JICA. 2010. *Climate Risks and Adaptation in Asian Coastal Megacities: A Synthesis Report*. Washington, DC.

short period of time. Moreover, a huge reservoir is unlikely to be necessary under the current climate (the first criterion). However, it would be sensible to acquire the land for the second reservoir well in advance, as the land acquisition could be time-consuming. In addition, the monitoring of water quality needs to be continued to see if the chloride concentration increases as projected, and some margin of safety should be added to deal with uncertainty.

On the other hand, construction of small drains will probably not satisfy the second criterion, as widening or newly constructing these drains would cost as much as the initial investment. Constructing small drains in an incremental manner would not be feasible, as acquiring the land inside of urban areas would be challenging. Therefore, if the land is available and appropriate from an engineering viewpoint, the investment for improvement of drains could be made earlier.

Conclusions

The study shows that climate change is likely to exert impacts on Khulna’s water supply system. The system could be made more climate-resilient by relocating the water intake point further upstream or by increasing the size of the impounding reservoir. Further consideration has concluded that the impounding reservoir is a feasible option. While it would not be possible to clearly delineate the adaptation costs, climate change would require the construction of an impounding reservoir, which will need to be expanded in the future.

Climate change will also likely aggravate Khulna’s waterlogging by increasing the area, duration, and depths of the floods. The climate resilience of the urban drainage system could be strengthened by increasing the conveyance capacity of the drains and outfall capacities of several outlet structures. Moreover, as the current drainage system is inadequate even under existing conditions, improvement of the drainage system would be a robust strategy and is urgently required. Adaptation costs, to protect 80% of the area in each ward from flood damages in a 1-in-10-year return period, were estimated to be $12 million–$17 million, on top of the base investment required under the existing conditions. The cost–benefit analysis, albeit preliminary, has proved that the adaptation measures are economically justified.

The study has also proven that the use of future climate scenarios and well-developed mathematical models provides the extent of impacts on the infrastructure quantitatively, leading to the identification and evaluation of specific adaptation interventions. These specifics are required to design a project for strengthening climate resilience. It is worth noting, however, that many other factors could significantly influence future impacts, such as changes in development patterns and water use upstream, land-use change, and population and economic growth. The planned Gorai River dredging is one example showing how an intervention could affect the proposed infrastructure development. Focus should not be placed too much on climate change alone; other changes that could have far-reaching impacts on the sustainability of water sector infrastructure should not be overlooked.

The study was initiated partly because ADB’s support for infrastructure investment was already planned in Khulna. Therefore, feasibility studies of investment projects were being undertaken prior to or in parallel with this study. Preliminary project designs were tested against the climate risks identified in the study, and adaptation options were identified and evaluated, albeit preliminarily. Then, further analyses were conducted under the feasibility studies to incorporate the study findings, including the adaptation options, into the final project designs. One lesson learned is that the study on climate-proofing, or strengthening the climate resilience of infrastructure, in a specific location will be most effective and efficient if it is implemented in tandem with the project design work.

Adapting to Climate Change: Strengthening the Climate Resilience of Water Sector Infrastructure in Khulna, Bangladesh

Climate change and the resulting rise in sea level would affect water sector infrastructure, such as surface water supply and urban drainage systems. The climate resilience of such infrastructure should then be made more climate-resilient to optimize its expected benefits. This publication provides a specific example of assessing the impacts of climate change on the water sector infrastructure in Khulna, Bangladesh, by developing the climate change and socioeconomic development scenarios for 2030 and 2050, and running mathematical models to obtain the level of salinity in river water—where the proposed intake for water supply is located—and the extent of waterlogging in the city. The study then identifies and makes a financial evaluation on adaptation options to cope with the impacts. While various uncertainties still remain, the proposed investments would be made more climate-resilient by incorporating adaptation options into the project design.

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