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Environment and Sustainable Development

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Building Local Resilience to Disaster Risk

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1 2 3 4 18 17 16 15

ISBN (paper): 978-1-4648-0710-7
ISBN (electronic): 978-1-4648-0712-1
DOI: 10.1596/978-1-4648-0710-7

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Cover design: Debra Naylor, Naylor Design, Inc.

Library of Congress Cataloging-in-Publication data has been requested.

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Foreword

Urban flooding from intense rainfall is a recurring phenomenon that adversely affects life and livelihoods in Dhaka, the capital and largest city of Bangladesh. Rapid and indiscriminate urbanization has aggravated the problem, contributing to the gradual filling up of low-lying flood plains, rivers, canals, and other water bodies that used to drain or retain water during heavy rainfall events. The floods of 1998, 2004, and 2007 battered the city, affecting communications, livelihoods, and service facilities for many days. The fringe areas, slums, and shanties—where many of the city's poor reside—suffered more.

In the coming decades, the effects of climate change may further aggravate Dhaka's flood vulnerability. Projections by the Intergovernmental Panel on Climate Change (IPCC) and the World Meteorological Organization suggest more erratic monsoon rainfall in the Ganges, Brahmaputra, and Meghna Basin and an increase in the frequency and intensity of climate extremes in the 21st century. Adapting to the increased risks of severe rainfall events, along with the other climate change impacts, is essential for the development of Greater Dhaka.

Adaptation will require climate-smart policies and investments to make Greater Dhaka more resilient to the effects of climate change, including loss of property, habitat, and infrastructure. To formulate effective adaptation, the residents of Greater Dhaka and the Government of Bangladesh, as well as development partners, need a better understanding of the potential damage related to climate change and the cost of adapting to extreme rainfall events.

The World Bank, the Institute of Water Modelling, Development Policy Group, Bangladesh University of Engineering and Technology (BUET), and BRAC University, in consultation with the Dhaka Water Supply and Sewerage Authority, have conducted a study on the potential intensification of urban flooding in the Greater Dhaka area in a changing climate. The study sheds light on the potential damage from extreme weather events and adaptation costs.

Earlier analytical work on climate-proofing Dhaka's infrastructure has been confined mainly to case studies, with relatively limited sets of locations, impacts, and adaptation measures. This study fills that critical knowledge gap by providing itemized estimates of the incremental costs of infrastructure adaptation out to the year 2050. The study is of prime importance, as it identifies vulnerable populations and infrastructure, quantifies outstanding deficits in addressing current climate-related risks, and estimates the adaptation cost of avoiding further damage due to climate change. It is my hope that these estimates will serve as a pragmatic tool for Bangladesh's decision-makers to develop location-specific adaptation plans for the Greater Dhaka area.

Johannes C. M. Zutt
Bangladesh Country Director
The World Bank

Acknowledgments

We would like to express our sincere appreciation to the many people whose dedicated work contributed to the creation of this book. We are particularly grateful to Masahiro Sugiyama, assistant professor at the University of Tokyo, Policy Alternatives Research Institute, who provided us critical data on the expected increase in the extreme 24-hour precipitation increase factor for Dhaka in 2050.

We appreciate the support provided by experts at the Institute of Water Modelling, Water Resources Planning division, throughout various stages of the hydrological modeling study. We would like to mention S. R. Prodhan, water sector specialist; David M. Khan, senior specialist; Imtiaz A. Taher, drainage modeling expert; Ismat A. Parvin, associate specialist; Md. Atikul Islam, junior specialist; and junior engineers Md. Feroz Islam, Nabila F. Tasneem, Sadbir Rahman, Johor K. Munni, and Shadman S. Protik.

The book benefited from the valuable suggestions and insights provided by numerous experts in Bangladesh. At the Bangladesh University of Engineering and Technology (BUET), Department of Urban and Regional Planning, we would like to note the contributions of Shakil Akther, professor and head; Ishrat Islam, professor (and director, Center for Regional Development Studies); and Gulshan Ara Parvin, former associate professor (and former post-doctoral fellow, Graduate School of Global Environmental Studies, Kyoto University). At the Bangladesh Water Development Board (BWDB), we would like to thank Choudhury Nazmul Alam, superintending engineer; Amirul Hossain, executive engineer; and K. M. Nurul Islam, superintending engineer. At the Dhaka Water Supply and Sewerage Authority (DWASA), we would like to mention Kyaw Sha Ching, superintending engineer and project director and A. K. M. Shahid Uddin, superintending engineer. At Dhaka University, Department of Geography and Environment, we would like to thank professors A. Q. M. Mahbub and Nurul Islam Nazem. We also extend our thanks to Akhter H. Choudhury, professor, Khulna University, Urban and Rural Planning Discipline division; Md. Moinul Islam, town planner, Narayanganj City Corporation; Md. Taibur Rahman, senior assistant chief, Bangladesh Planning Commission; and Khurshid Zabin Hossain Taufique, director, town planning, RAJUK.

In addition to those mentioned above, we extend our thanks to the experts who participated in the study's three stakeholder conferences convened at the

World Bank Dhaka Office. We would also like to thank the participants of the study's two Focus Group Discussions, held at the World Bank Dhaka Office and BRAC University.

At the World Bank, we are grateful for the contributions of Johannes C. M. Zutt, Bangladesh country director; Ellen A. Goldstein, former Bangladesh country director; Michael Toman, research manager, DECEE; Kseniya Lvovsky, practice manager, GENDR; Herbert Acquay, former practice manager, GENDR; Bernice K. Van Bronkhorst, practice manager, GSURR; Maria Sarraf, lead environmental specialist, GENDR; Lia C. Sieghart, program leader, SACBN; Mehrin A. Mahbub, communications officer, SAREC; Cecilia Belita, senior program assistant, GWADR; Sayeeda S. Tauhid, former senior monitoring and evaluation specialist; and Omar Farook, former operations analyst.

Finally, we gratefully acknowledge the financial support provided by the Bangladesh Climate Change Resilience Fund (BCCRF). In April 2012, the BCCRF Management Committee endorsed this study, requested by the Government of Bangladesh, as a priority research project. The BCCRF is a multidonor trust fund supported by the governments of the United Kingdom, Denmark, Sweden, Switzerland, Australia, the United States, and the European Union.

Note of Appreciation

As it often happens, there are people without whose dedicated work the creation of this book would not have been possible. We would like foremost to mention S. M. Mahabubur Rahman, director, Water Resources Planning Division, Institute of Water Modelling, Bangladesh, who played a vital role in designing the study and ensuring the quality of the hydrological modeling, thus providing a solid foundation on which the other components of the analytic work were developed. We also express our sincere appreciation to Kazi Habib Ullah, executive engineer, Dhaka Water Supply and Sewerage Authority, and Md. Liakath Ali, climate change and environmental adviser, UK Department for International Development, Bangladesh, for providing technical guidance throughout the study.

At the World Bank, our sincere gratitude goes to Norma Adams, consultant editor, whose linguistic skills and creativity enabled us to produce this book from its underlying multidisciplinary technical reports. Our special thanks go to Polly Means, who worked tirelessly to prepare the graphics presented in this book. We also extend special thanks to Shahpar Selim, environmental specialist, for her support at various stages of the study. As a native Bangladeshi, she had knowledge of Dhaka that was essential to building multisectoral cooperation and the participatory process for implementing the study. We are especially grateful to Angie Harney, program assistant, SACBD, for meticulously planning the study workshops and Focus Group Discussions. Finally, special thanks go to B. Elaine Wylie, program assistant, DECEE, and Angie Harney for their support with contract-related logistics.

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Executive Summary

Dhaka, the capital of Bangladesh and one of the world's rapidly growing megacities, is an urban hotspot for climate risks. Nearly every year, the city experiences urban flooding and waterlogging following intense rainfall during the rainy season. The city's poorer inhabitants are usually among the most vulnerable since large, densely populated conglomerations of slums and shanties are located in areas of unplanned and unregulated development.

A major concern is that, in a changing climate, Dhaka's flooding situation may worsen dramatically into disasters. Projections by the Intergovernmental Panel on Climate Change (IPCC) suggest heavier, more erratic rainfall in the Ganges, Brahmaputra, and Meghna (GBM) Basin during the monsoon season. Also, warmer ocean-surface temperatures and rising sea levels will likely mean more intense cyclones in the future. *Thus, adaptation to the challenges posed by climate change in this rapidly growing megacity is critical.*

Against this backdrop, the World Bank, in collaboration with experts from Bangladesh, has undertaken analytical work to provide Dhaka's local planners an effective approach to mitigate the damage risk of rainfall-induced urban flooding in a changing climate. Funded by the Bangladesh Climate Change Resilience Fund (BCCRF), this study was launched in 2012. Its specific objectives were to evaluate the Greater Dhaka area's local capacity to address urban flooding in the current climate, assess the impacts of climate change on location-specific inundation for various scenarios, and identify adaptation measures for each of the city's areas to address the threat of climate change–related impacts.

The general physical setting for the study is a 1,528 km^2 area in north-central Bangladesh that corresponds to RAJUK's (Rajdhani Unnayan Kartripakkha—the Capital Development Authority of Bangladesh) Dhaka Metropolitan Development Plan (DMDP). It consists of the Dhaka metropolitan area, the Dhaka-Narayanganj-Demra (DND) area, and the townships of Narayanganj, Savar, Gazipur, and Tongi. For the latter three townships, detailed data on drainage infrastructure, which are required for location-specific mapping of inundation depth and duration, were lacking. Therefore, the detailed study area of 345 km^2 was limited to the Dhaka metropolitan area, the DND area, and Narayanganj township. The Dhaka metropolitan area consists of two parts: Eastern Dhaka (121 km^2) and Western Dhaka (143 km^2). Western Dhaka, in turn, is divided into four areas: Old Dhaka, Central Dhaka, Kallyanpur, and Goranchatbari.

The study comprises four main activities: (a) hydrological modeling and development of adaptation measures, (b) spatial ranking of flood vulnerability, (c) evaluation of expected damage from flooding, and (d) estimation of adaptation costs. The overall objectives and scope of the hydrological modeling exercise were to assess climate change impacts on location-specific waterlogging for various scenarios, focusing on the inundation depth and duration caused by extreme precipitation events for the standard IPCC AR4 high-emissions, fossil-fuel intensive (A1FI) scenario in 2050. The baseline (without climate change scenario) selected for the modeling exercise was the September 2004 extreme rainfall event (341 mm in 24 hours), which caused one of the heaviest urban flooding damages in recent history.

The study's hydrological modeling component adopted a three-step approach to account for the effects of river flows on flooding in the Greater Dhaka area. Because Dhaka is located on the lower reaches of the Ganges-Brahmaputra Delta and surrounded by six rivers and canals, flooding in the study area is also affected by flows in the Brahmaputra (Jamuna) River and its distributaries in north-central Bangladesh. Thus, the first modeling step simulated basin-level flows from the Brahmaputra River in the GBM system since they strongly influence monsoon-season river flows and water levels in the Greater Dhaka area. In the second step, the effects of climate change on the regional rivers were simulated. Finally, in the third step, detailed modeling of the drainage system in and around Dhaka city was simulated. Although river levels affect the drainage system within the city area, this study centered on the worst-case scenario in which river levels are high and all sluice gates are closed; that is, there is no gravity drainage out of the city, and the drainage system depends primarily on the performance efficiency of drainage pumps, which is often the case during intense rainfall. For Western Dhaka—Old Dhaka, Central Dhaka, Kallyanpur, and Goranchatbari—the impacts of climate change on river flooding were not considered in the analyses as this main part of the city is protected by flood embankments on all sides.

In order to conduct the hydrological modeling, local engineers were consulted to understand the functioning of each existing drainage system in the detailed study area. In accordance with recommendations received from the experts, all future scenarios assumed that all improvements to Dhaka's drainage infrastructure—both planned and proposed by the relevant drainage-system authorities—would be implemented. These included improvements covered in RAJUK's Detailed Area Plan (DAP), the Sewerage Master Plan of the Dhaka Water Supply and Sewerage Authority (DWASA), and Narayanganj City Corporation's Concept Vision Plan. Previous recommendations on improving drainage-system performance were included in the modeling of future scenarios for Eastern Dhaka, Central Dhaka, the DND area, Kallyanpur, and Narayanganj. Modeling assumptions also included recommendations of Jurutera Perunding Zaaba Sdn. Bhd. (Malaysia), Farhat Consulting Engineers and Architects Limited, and SARM Associates Limited; the Institute of Water Modelling (IWM); and the Institute of Water and Flood Management (IWFM).

Based on the hydrological modeling simulations, structural measures beyond current planned improvements were developed to address the current and climate change adaptation deficits. In order to identify interventions to close the existing gap in drainage capacity, flood modeling simulations were repeated, using alternative pump capacities and diameters of drainage pipes, until the resulting flood maps met pre-set acceptable flooding criteria for inundation depth and duration. These criteria, agreed on by the local experts and other stakeholders, were based on the level of standing water that the local people in each of the modeled zones have learned to cope with over the years as a usual occurrence during the flood season (between 4 and 8 inches).

To provide a more complete picture of how the various areas of Dhaka may be affected, the study conducted a detailed vulnerability impact assessment, taking into account all non-flood factors that, when combined with flooding, may exacerbate the impact. Inundation of even the same depth and duration can have significantly different impacts on the population and infrastructure, depending on an affected area's physical, social, economic, and institutional characteristics. Drawing on the hydrological modeling data, along with information generated from a climate disaster resilience index (CDRI) analysis for Dhaka conducted for this assessment, the study developed a flood vulnerability index (FVI) that ranked the population and infrastructure of the city's major areas and wards, according to their relative exposure, susceptibility, and resilience. It is expected that the resulting ward-level analysis, which identified Dhaka's 20 most vulnerable wards/regions, will provide local policymakers a useful roadmap for future planning to minimize the effects of climate change.

Since flooding in an urban area like Dhaka can lead to widespread damage resulting from submersion of buildings and property, as well as livelihood disruption among the flood-affected population, the study assessed the extent of flood damage for the major affected sectors of the economy, as well as overall potential economic damage. Given the uncertainty surrounding the magnitude and timing of climate change risk, this study considered the following alternative cases. Based on alternative future scenarios, it evaluated the direct and indirect economic damage to the local population from a severe (100-year, return-period) event occurring in 2050; a probability-weighted damage of different return-period rainfall events occurring in 2050; and an estimate of total cumulative damage between 2014 and 2050, using random assignment of 1-year to 100-year storms for each year.

Results of the hydrological modeling exercise were used to quantify the economic damage—effects on the urban-built environment and infrastructure, human health, and family assets—caused by flooding of the Greater Dhaka detailed study area. The likely increase in damage due to climate change was also separately assessed. Both depth and duration of inundation were analyzed to estimate the extent of flood damage. The study not only assessed readily quantifiable damage; wherever possible, it assigned monetary values to intangible damages, based on analysis of losses gleaned from comparison with similar ones that are more easily quantified. Sector-wise cumulative damage was also examined using random assignment of various return-period, extreme rainfall events.

Finally, the adaptation costs of the proposed structural measures were estimated for each modeled zone. These cost estimates were divided into two components: (a) additional investments required to meet the current adaptation deficit without climate change and (b) further measures required to meet the 2050 climate change deficit. To estimate the costs of the various recommended measures, a number of assumptions were made, some of which were supplied by DWASA officials. Numerous practitioners were consulted, including officials and engineers of DWASA, the Bangladesh Water Development Board (BWDB), the Public Works Department (PWD), IWM, World Bank, and Dhaka North and South City Corporations (DNCC and DSCC), as well as contractors, suppliers, businessmen, and independent consultants. In addition, several field visits were undertaken to physically inspect the situation around Dhaka city.

The study also explored non-structural flood-mitigation measures and how key institutional, technical, and financial challenges to their implementation can be effectively addressed. The recommended conveyance-centric structural approach to flood mitigation—featuring mainly pipes, *khals* (canals), and pumps—appears appropriate, given Dhaka's land scarcity, growing population density, and other prevailing socioeconomic, environmental, and geophysical conditions. However, implementing these structural adaptation measures in isolation cannot be expected to eliminate the flood-damage risk entirely. Therefore, the study explored an array of urgently needed non-structural flood-mitigation measures, including an improved approach to solid waste management and maintenance of the conveyance system, which are designed to complement the structural measures. In addition, it considered alternative ways to shave peak stormwater flow, including delaying, diverting, or detaining runoff.

The study's key findings highlight the importance of implementing the additional investments recommended by the hydrological modeling exercise to close the current adaptation deficit and secure the significant damage savings that would result. The cost of meeting Dhaka's current adaptation deficit, even without climate change, would total Tk. 2.7 billion, equivalent to just 0.35 percent of the government's annual development budget expenditure for 2014–15. Of this amount, Central Dhaka would comprise the largest investment, at about Tk. 1.4 billion. The added cost of closing the climate change gap would require the other Tk. 1.3 billion. Implementing the recommended additional investments can result in significant damage savings for Dhaka, given that the expected damage from flooding would be quite significant for the city overall. For example, if an extreme rainfall event like that of 2004 were to occur in 2050, then, without investment to address the current adaptation deficit, the increased damage caused by climate change would amount to Tk. 2.0 billion; however, it would be reduced significantly (to Tk. 0.9 billion) by investing to close the current adaptation gap. Such savings in damage of Tk. 1.1 billion in just one year reveal how quickly the investment of Tk. 2.7 billion in current adaptation deficit can be paid back.

The estimates presented in this study should be considered conservative. Climate science predicts that extreme rainfall events will become more frequent over time, suggesting that Dhaka may experience a number of intense rainfall events between now and 2050. Thus, the expected damage from a single storm (which is a proxy for the benefit of adaptation), as presented above, must be considered conservative. In the absence of information on the current condition of all drainage pipes, this study's hydrological modeling exercise has assumed that pipes, khals, and box-culverts will perform according to their designated capacity and that stormwater will reach them without undue difficulty. But given Dhaka's current reality, these assumptions are somewhat optimistic. Accounting for the added expenditures needed to achieve a flood-free Dhaka—including urgently needed non-conveyance flood mitigation measures—would raise the total cost of adaptation substantially.

That said, this analytical work will assist Bangladesh's policymakers to develop effective adaptation to urban flooding in Dhaka and improve the city's capacities against the impacts of climate change and variability. Equipped with a menu of investment options (the implementation of which would require project-specific, cost-benefit analysis) designed to close the current adaptation deficit and further climate-proof urban infrastructure, local decision-makers will be able to formulate more effective strategies, prioritize interventions, and sequence activities as resources permit. In light of the uncertainties about the magnitude and timing of climate change–related risks, it may be wise to start by addressing the current adaptation deficit that the city's residents are already facing. Closing the current adaptation gap will provide policymakers a solid foundation on which to develop additional measures to mitigate climate risks.

Abbreviations

AD	adaptation (to climate change)
AI	additional investments
A1FI	IPPC scenario with future based on fossil fuel–intensive development
BBS	Bangladesh Bureau of Statistics
BCCRF	Bangladesh Climate Change Resilience Fund
BMD	Bangladesh Meteorological Department
BSCIC	Bangladesh Small and Cottage Industries Corporation
BUET	Bangladesh University of Engineering and Technology
BWDB	Bangladesh Water Development Board
B1	IPPC scenario with future based on a high level of environmental and social consciousness combined with a globally coherent approach to a more sustainable development
CBO	community-based organization
CC	climate change
CCA	climate change adaptation
CDRI	Climate Disaster Resilience Index
CER	certified emission reduction
DALY	Disability-Adjusted Life Year
DAP	Detailed Area Plan
DCC	Dhaka City Corporation
DEM	Digital Elevation Model
DGHS	Directorate General of Health Services
DMDP	Dhaka Metropolitan Development Plan
DNCC	Dhaka North City Corporation
DND	Dhaka-Narayanganj-Demra
DRR	disaster risk reduction
DSCC	Dhaka South City Corporation
DWASA	Dhaka Water Supply and Sewerage Authority
EWS	economically weaker sections

FGD	Focus Group Discussion
FVI	Flood Vulnerability Index
GBM	Ganges-Brahmaputra-Meghna (river system)
GCM	General Circulation Model
GHG	greenhouse gas
GIS	Geographic Information System
HIG	high-income groups
IPCC	Intergovernmental Panel on Climate Change
IUCN	International Union for Conservation of Nature
IWFM	Institute of Water and Flood Management
IWM	Institute of Water Modelling
JICA	Japan International Cooperation Agency
LGED	Local Government Engineering Department
MIG	middle-income groups
NAM	Nedbør-afstrømnings (Rainfall-Runoff) Model
NCC	Narayanganj City Corporation
NCRHD	North Central Region Hydrodynamic (model)
NGO	nongovernmental organization
NIMBY	“not in my back yard”
PI	planned improvements
PWD	Public Works Department
RAJUK	Rajdhani Unnayan Kartripakkha (Capital Development Authority of Bangladesh)
SREX	Special Report on Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation (by IPCC)
UNESCO	United Nations Educational, Scientific and Cultural Organization

Units of Measure

cm	centimeter
ft^3/s	cubic foot per second
ha	hectare
K°	degree Kelvin
km	kilometer
km^2	square kilometer
kVA	kilovolt-ampere
m	meter

m^3	cubic meter
m^3/s	cubic meter per second
mm	millimeter

Currency Equivalents

currency unit = Bangladesh Taka (Tk.)
Tk. 78 = US$1

CHAPTER 1

Introduction

Overview

Dhaka, the capital of Bangladesh and one of the world's rapidly growing megacities, is an urban hotspot for climate risks. Located in central Bangladesh on the lower reaches of the Ganges-Brahmaputra Delta, the city faces the recurring phenomena of urban flooding and waterlogging following intense rainfall nearly every year. As a low-elevation city with a tropical monsoon climate, Dhaka has a long history of river flooding as a natural hazard. Recent major floods have been worse in terms of depth and extent of inundation and duration, especially in fringe areas, where many of the city's poor reside. Rapid, unplanned urbanization and the gradual filling up of low-lying flood plains, rivers, canals, and other water bodies traditionally used to drain or retain water during rainfall have exacerbated the problem. A growing concern is that, in a changing climate, characterized by heavier and more erratic rainfall in the Ganges-Brahmaputra-Meghna (GBM) Basin during the monsoon season, the situation may worsen.

Dhaka's average annual rainfall is about 2,000 mm, most of it occurring during the summer monsoon. The rivers surrounding the city are distributaries of the Brahmaputra River. Thus, the water level of the Brahmaputra and rainfall and runoff from the entire Brahmaputra Basin influence the process of river floods in and around the city. The entire drainage system is also influenced by water levels of the Ganges and Meghna rivers. At present, the western part of Dhaka is protected against river floods that formerly resulted from overflow of the Turag, Buriganga, and Balu rivers. However, the western part of the city is now vulnerable to urban flooding resulting from the combined effects of poor drainage of rainfall inside the city's western (polder) area, inadequate drainage capacity of pump stations, and high water levels of the outfall rivers. The eastern side of the city suffers from river floods, though plans have been developed to build an embankment along the Balu and Lakhya rivers and develop the eastern polder with a number of drainage pumps. When the western polder was completed after the 1988 flood, southeastern Dhaka was a rural setting free from river and urban (drainage congestion) flooding. But rapid industrialization and illegal encroachment along drainage channels in recent years have made this area highly vulnerable to urban flooding (box 1.1).

Dhaka has a long history of regular inundation during the monsoon season. Documented incidence of river flooding can be traced back to 1787–88, when floodwaters following heavy monsoons submerged city streets to a depth that required boats for moving around (Hunter 1877). River floods again devastated the city in 1833–34 and 1870. In the past century, the floods of 1954, 1955, 1962, 1966, 1974, 1987, 1988, 1998, and 2004 were of major significance in terms of lost lives and property (Haque 2010; Nishat et al. 2000; Rahman 2006). Today, urban flooding from intense rainfall in the western and southern parts of the metropolis and river floods in the eastern part are recurring phenomena.

Box 1.1 Clarification of Key Concepts

Throughout this book, unless otherwise noted, the following definitions apply:

- *River flooding* refers to the inundation that occurs when excessive runoff from upstream catchments leads to the river channel's capacity being exceeded, resulting in water spilling over the bank; thus, the floodplain is flooded by water spilling over from the river channel.
- *Urban flooding* refers to the inundation that occurs after heavy-rainfall events, which causes runoff to exceed the capacity of the local drainage system. As a result, water remains stagnant in the built-up area for extended periods. This type of flooding is also known as rain flooding or waterlogging; however, these terms can also apply to a rural setting.
- *Waterlogging*. See *urban flooding* definition.
- *Return period* estimates the time interval between two hydrological events of the same size or intensity. It is a statistical measure of the average recurrence interval over a long period and is the inverse of the probability that the event will be exceeded in a single year. For example, the chances of 10-year, 20-year, and 30-year rainfall amounts occurring in any given year are 10, 5, and 3.3 percent, respectively, regardless of when the last similar event happened. Thus, a 10-year, return-period flood is 10 times more likely to occur, compared to a 100-year, return period event, which has a 1 percent probability. The amount of rainfall, expressed as depth (mm), increases with the return period, meaning that a 100-year rainfall event will be comparatively larger than a 20-year or 30-year event.

  For design purposes, choice of return period depends on multiple factors, such as size of the drainage area, risk of failure, importance of at-risk structures, and decision-makers' desired level of risk aversion. Shorter return periods tend to be based on observed data, where available, while longer ones are estimated from a statistical distribution. For urban areas susceptible to river flooding, the return period of urban flooding depends on the return period for both the rainfall event and water levels of the peripheral rivers. Thus, for unprotected areas, the return period of urban flooding is a joint probability function related to frequency of rainfall events and high river stages. Other factors that contribute to the return period of urban flooding events (e.g., land-cover changes and condition of drainage

box continues next page

Box 1.1 Clarification of Key Concepts *(continued)*

channels), for which it is difficult to assign probability distributions, are usually kept constant for a given modeling scenario.

- *Adaptation* refers to any activity undertaken to reduce or completely remove potential harm from climate change. It can be "planned" via a deliberate policy decision or "reactive," after the change has happened.
- *Adaptation benefits* are avoided damage costs or accrued benefits following the implementation of adaptation measures.
- *Adaptation deficit* refers to the gap between the current and desired or targeted practice/performance. For example, if an urban drainage system designed to prevent flooding of streets from 100 mm rainfall in six hours can only achieve that when 70 mm falls in six hours, then it has an adaptation deficit of 30 mm in six hours. Before considering climate change adaptation, the adaptation deficit should be addressed; otherwise, the costs (and potentially the benefits) of measures to adapt to climate change will be overestimated.
- *Detention pond* refers to a temporary water body that "detains" or delays the flood peak by storing some stormwater runoff for a certain period. This helps prevent the rest of the drainage system from being overwhelmed by particularly large rainfall events. Water is removed from the detention pond by a pipe/culvert at the bottom of the pond (lowest point). When there is no rainfall over extended periods of time, the pond area remains dry and can be used for other purposes (e.g., agriculture or sports field).
- *Retention pond* refers to a permanent water body that "retains" stormwater. During rainfall events, the water level increases up to a certain height, after which it is controlled by a pump or outlet structure.

Impact of Recent Major Floods

In the past few decades, both river and urban flooding have seriously impacted Dhaka in terms of floodwater inundation and duration, especially in fringe areas, mainly affecting slum dwellers. Residents suffered from health-related problems as a result of consuming contaminated drinking water. In addition, communications, livelihoods, and service facilities were severely affected for days.[1,2]

The 1988 flood inundated about 85 percent of Dhaka (water depths were in a range of 0.3–4.5 m), isolating the city from the rest of the country for about two weeks. Water supplies were severely affected; and road, rail, air transport, and telecommunications were disrupted. A decade later, about 56 percent of Dhaka was inundated by the 1998 flood, which was unprecedented in terms of duration and damage. Most of the city's eastern portion suffered from river flooding, and 23 percent of its western part was affected by urban flooding (Hasnat 2006). Nearly 80 percent of the city was inundated at water depths of 0.3–3.0 m, which lasted about 10 weeks. Some two-thirds of city residents suffered damage to assets, and daily wage earners (e.g., rickshaw pullers and vendors) suffered direct loss of income. In all, some three-fifths of residents were affected (Hasnat 2006). Rising water levels of the Buriganga, Turag, Balu, and Lakhya rivers affected the eastern and southeastern portions of the city (Hossain, Azam, and Serajuddin 2006). In central areas, poor discharge capacity of drainage *khals* (open channels) increased the extent and duration of flooding. Some 66 km of khals and 80 km of stormwater drains were damaged (Huq and Alam 2003). At Narinda, the retention tank overflowed, affecting its only pumping station. The estimated cost of rehabilitating the water supply system was about Tk. 127 million (Huq and Alam 2003).

In terms of river levels, the 2004 flood was of shorter duration than the 1988 and 1998 events; however, water took longer to drain from Dhaka city areas and extreme rainfall in September made the situation worse. The flood wreaked havoc on major portions of the city's population. More than 5 million people—two-fifths of city residents—were affected. Out of the city's 22 *thanas* (subdistricts), 18 were inundated. The eastern portion of the city was hardest hit. Gulshan, Banani, Baridhara, and Nikunja experienced prolonged inundation, while the Motijheel commercial area, including Arambagh and Gopibagh, was underwater for a few days as a result of drainage congestion. Water pipelines stretching over a few hundred kilometers and many ponds were submerged. The sewerage system broke down, which resulted in contaminated drinking water, in turn, posing a serious threat to public health.

The August 2007 flood exceeded the duration of the 1988 and 2004 events; however, the magnitude of peak flow above the danger mark for all rivers surrounding Greater Dhaka was less than 1988, 1998, and 2004 levels. Flooding of the Buriganga River receded within 24 hours, but lasted more than 20 days for other major rivers and canals. Eastern Dhaka was especially hard hit due to the absence of a flood-protection embankment, with boats serving as the only means of transport. Sections of major roads and bridges were washed away, and numerous drowning deaths were reported. Thousands of stranded residents lacked access to safe drinking water. Hospitals were overwhelmed with patients suffering from water-borne illnesses, including more than 90,000 cases of diarrhea within a single week. Most patients were residents of the more severely inundated, low-lying areas.

In July 2009, heavy monsoon rains battered the capital city. The national weather office reported more than 333 mm of precipitation within a 12-hour period; more than 290 mm fell within six hours, setting a 60-year record. Downed power lines resulted in at least nine deaths and numerous injuries. Rickshaw pullers struggled to carry passengers through knee-to-waist-deep water. Bus and ferry services were disrupted and major thoroughfares were submerged for hours, leaving thousands of stranded residents. In more vulnerable, low-lying areas, many families were trapped in their flooded homes, and slum dwellers suffered the most. Production was suspended at most industrial units in the southeastern area of Dhaka-Narayanganj-Demra (DND). Businesses and schools were forced to close, and trading on the stock market was delayed.

Waterlogging and Drainage System Capacity

The risk of waterlogging in Dhaka is particularly high during the monsoon season (June–September), when 70 percent of annual rainfall occurs (Zaman 2014). Traditionally, Dhaka's river system and interconnected canals or khals formed the city's lifeline. The network of myriad surrounding rivers includes the Tongi Khal to the north, the Balu and Lakhya to the east, the Dhaleswari to the south, and the Buriganga, Bangshai, and Turag to the west. In earlier centuries, the city had dozens of natural khals, which served as arteries for navigation routes within the greater metropolis. Many of these have since disappeared, owing mainly to unplanned urban development, encroachment, dumping of solid waste, poor system maintenance, and lack of coordination between government agencies (Shajahan and Nilufar 2013).

The surviving khals, generally in poor condition, continue to serve as the city's primary drainage system.[3] Having to rely on this outdated system means that many urban residents—mainly those in the city's middle- and lower-class areas—face prolonged inundation after even an hour of normal rainfall. Also, many low-lying areas that previously functioned as rainwater retention ponds are being filled for industrial and residential use, further impeding drainage in many parts of the city. As urban expansion continues, the city's remaining open spaces and low-lying areas face more intense pressure from private land developers. If urgent measures are not taken to protect these vulnerable lands from further encroachment, the situation will likely worsen (Jahan 2014a).

Dhaka's aging drainage infrastructure (e.g., drainage pipes in Old Dhaka and pumps in the DND area) heightens the population's vulnerability to the disaster risks from waterlogging. The situation is exacerbated by the increased paving of surfaces with impervious materials and a failure to implement activities that reduce flood risk. Waterlogging puts city dwellers and family assets, the urban-built environment, and vital public infrastructure at risk; in turn, industry and trade are harmed, and daily wage earners and temporary workers lose employment and income (Roy 2014).

Megacity in a Changing Climate

Dhaka has witnessed tremendous population growth in the past century and is now among the world's largest and fastest growing cities, with an estimated 34,000 people per km^2. In 1980, the Greater Dhaka area (1,528 km^2) entered the ranks of megacity, with a total population of 6.6 million; by 2011, that number had more than doubled, crossing the 14 million mark (BBS 2012). During 1985–95, its population growth rate averaged 5 percent a year, much higher than for other South Asian megacities. Today, approximately 13 percent of Bangladesh's population—a staggering 22 million people—call Greater Dhaka their home. The United Nations projects that, by 2025, Dhaka will become the world's fifth largest city, surpassed only by Tokyo, New Delhi, Mumbai, and São Paolo (UN 2010). According to the Institute of Water

Modelling (IWM 2012), Greater Dhaka's population will have climbed to 29 million by 2035.

Much of Dhaka's current population growth is related to rural-to-urban migration. Since the founding of Bangladesh in 1971, Dhaka has drawn job seekers. As the process of industrialization got under way and service sectors became active, job opportunities were created in and around the capital city. The annual flow of migrants includes many poor farmers; since the farming sector cannot accommodate the younger generation entering the job market, many have had to move to the cities and towns to find work. Natural disasters (e.g., river bank erosion) have also contributed to the movement of rural people to Dhaka and other major cities.

Urban Flood Vulnerability and Disaster Risk

The effects of climate change, including intensified rainfall and greater frequency of extreme weather events, coupled with unplanned, rapid urbanization extending into the floodplains, are expected to aggravate Dhaka's vulnerability to flooding (UNFCCC 2008; World Bank 2010; WWF 2009). The climate of South Asia is changing: the frequency of heavy-rainfall events is increasing, while light-rainfall events are decreasing (IPCC 2013). In the coming decades, all climate models and scenarios are predicting an increase in South Asia's average and extreme rainfall during the summer monsoon (IPCC 2014). Regarding seasonality, climate model agreement is high on an earlier onset and later retreat and thus longer duration of the summer monsoon. For tropical cyclones making landfall in South Asia, model agreement indicates that rainfall will likely be more extreme near the centers of such systems (IPCC 2013). On the whole, scientific evidence to date predicts high flood risk for low-lying areas in Bangladesh in a changing climate; and Dhaka has been identified as one of the top Asian cities in terms of population exposure to flooding by the 2070s (Hanson et al. 2011; IPCC 2014).

Without adequate protection, Dhaka's residents, particularly slum dwellers, will be continuously exposed to the risks of both river and urban flooding in a changing climate. Thus, policymakers must take targeted steps to better manage Dhaka's flood infrastructure and integrate climate risks into local planning to strengthen the city's climate-disaster resilience and adaptive capacity.

Building a Sound Strategy for Local Action

Preparing for the unfolding impacts of climate-related changes—sociodemographic, environmental, economic, and political—is a daunting task. It requires that Dhaka's policymakers, like those in other megacities of South Asia's low-lying deltas, understand how climate change is anticipated to affect natural hazards that lead to flooding in the cities. Given that the timing and magnitude of climate change impacts, though uncertain, show a trend, policymakers also have an urgent need to better understand how non-climate factors (e.g., inadequate drainage capacity and unplanned urban development in upstream catchments) have contributed to the severity of recent floods.

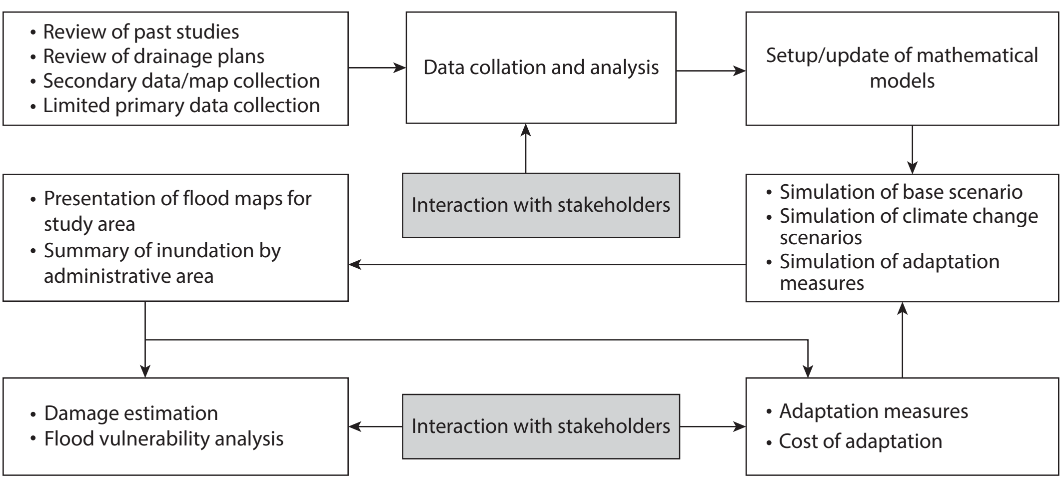
Study Purpose and Approach

This study's overall aim is to provide local decision-makers an effective planning approach for minimizing the damage risk of rainfall-induced urban flooding in Dhaka in a changing climate (box 1.1). Specific objectives are to assess the vulnerability of the Greater Dhaka area to urban flooding and waterlogging, estimate probable economic damage due to climate change, develop structural adaptation measures, evaluate the reduction in economic damage resulting from implementing these measures, and estimate their cost. The list of location-specific interventions and their costing, in turn, can help the city's local planners to meet their goals of minimizing the total expected disaster costs and the cost of risk-reduction measures. Equipped with a menu of options designed to close the current adaptation deficit and further climate-proof urban infrastructure, it is expected that local decision-makers will better evaluate their choices and develop effective strategies that prioritize and sequence activities as resources permit.

The study comprises four main activities: (a) hydrological modeling and development of adaptation measures, (b) spatial ranking of flood vulnerability, (c) evaluating expected damage from flooding, and (d) estimating adaptation costs (figure 1.1).

The overall objectives and scope of the hydrological modeling exercise were to assess climate change impacts on location-specific waterlogging for various scenarios, focusing on the inundation depth and duration caused by extreme precipitation events for the high-emissions, fossil-fuel intensive (A1FI) scenario in 2050. The baseline selected for the modeling exercise was the September 2004 extreme rainfall event (341 mm in 24 hours), which caused one of the heaviest urban flooding damages in recent history. In order to approximate the

Figure 1.1 Overview of Study Approach



Source: Adapted from Zaman 2014.

Box 1.2 Expected Increase Factor in Extreme 24-hour Precipitation for Dhaka in 2050

In a changing climate, it is expected that Dhaka will experience a 16 percent increase in extreme 24-hour precipitation by 2050, compared to the 2004 baseline for this study. The statistical downscaling used in Sugiyama (2012) estimated a 16 percent increase factor in extreme 24-hour precipitation for Dhaka in 2050 for the high-emissions, fossil-fuel intensive (A1FI) scenario. To develop the estimates, the methods of Allen and Ingram (2002) and Pall, Allen, and Stone (2007) were used.

The study started with the 12 climate models used for the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC). However, since precipitation extremes increase at different rates by climate model, it was not possible to make a definite conclusion about future precipitation extremes based solely on climate models. For this reason, the study drew on the physical basis that relates change in precipitation extremes with moisture availability in the atmosphere (e.g., Allen and Ingram 2002; Trenberth et al. 2003), and set the fractional change of precipitation extremes to change in precipitable water (i.e., the amount of water in a column of air that could fall as precipitation) at 9 percent per K° for Dhaka.

The uncertainty range for estimates of precipitation extremes may be set at 3–28 percent per K°, based on the full range of the model-based statistics.

Sources: Allen and Ingram 2002; IPCC 2013; Pall, Allen, and Stone 2007; Sugiyama 2012; Trenberth et al. 2003.

future (2050) climate and minimize biases in precipitation estimated from climate models, the study used pattern scaling, a form of statistical downscaling, to convert low-resolution, General Circulation Model (GCM) outputs to regional and city scale (Sugiyama 2012) (box 1.2).[4]

For hydrological modeling, local engineers were consulted to understand the functioning of each existing drainage system in the detailed study area. In accordance with recommendations received from the experts, all future scenarios assumed that all improvements to Dhaka's drainage infrastructure—both planned and proposed by the relevant drainage-system authorities—would be implemented. In order to identify interventions to close the remaining gap in the existing drainage capacity, flood modeling simulations were conducted with different pump capacities and diameters of drainage pipes until resulting flood maps met pre-set acceptable flooding criteria for inundation depth and duration for each modeled zone. Based on these simulations, structural measures beyond current planned improvements were developed to address the current and climate change adaptation deficits.

Drawing on this hydrological modeling data, along with information generated from a Climate Disaster Resilience Index (CDRI) analysis for Dhaka (Jahan 2014b),[5] the study then developed a flood vulnerability index (FVI) that ranked the population and infrastructure of Dhaka's major areas and wards, according to their relative exposure, susceptibility, and resilience. Next, it evaluated the direct and indirect economic damage to the local population from a 100-year return-period rainfall event in 2050, a probability-weighted damage of different return-period rainfall events occurring in 2050, and cumulative damage between 2014 and 2050, using random assignment of various return-period extreme rainfall events.

Finally, the adaptation costs of the proposed structural measures were estimated for each modeled zone in the detailed study area. The costs of their implementation were assessed against the 2004 baseline (100-year, return-period) extreme rainfall event. These cost estimates were divided into two components: (a) additional investments required to meet the current adaptation deficit without climate change and (b) further measures required to meet the 2050 climate change deficit. The cost estimates should be considered indicative since the extent of expected climate change remains uncertain and the process of change, as viewed from a planning perspective, is slow (Huq 2014).

To estimate the costs of the various recommended measures, a number of assumptions were made, some of which were supplied by DWASA officials. Numerous practitioners were consulted, including officials and engineers from DWASA, the Bangladesh Water Development Board (BWDB), the Public Works Department (PWD), the Institute of Water Modelling (IWM), the World Bank, and Dhaka North and South City Corporations (DNCC and DSCC), as well as contractors, suppliers, businessmen, and independent consultants. In addition, several field visits were undertaken to physically inspect the situation around Dhaka city (appendix A).

Launched in 2012 and conducted over two-and-one-half years, the study was funded by the Bangladesh Climate Change Resilience Fund (BCCRF), a coordinated financing mechanism of the Government of Bangladesh, development partners, and the World Bank, with additional technical support provided by the IWM. Since the project outset, consultative workshops were convened annually, and two Focus Group Discussions (FGDs) were held.

The consultative workshops presented study objectives and methods (June 2012); shared preliminary findings on climate change impacts (April 2013); and discussed study results on Dhaka's flood vulnerability, adaptive capacity, and adaptation costs (August 2014). At the first FGD, held in May 2013, experts recommended location-specific, structural adaptation measures, taking into account preliminary findings on climate change impacts. At the second one, held in August 2014, stakeholders agreed on a strategy to mitigate flooding in built-up areas, including ways to reduce peak surface runoff during extreme rainfall events, remove blockage from drainage channels and sewerage pipes, and reduce flood duration in low-lying areas. In addition, meetings and discussions have been held at various stages of the project with drainage system engineers at the DWASA, BWDB, Narayanganj City Corporation (NCC), and IWM.

The study also reviewed a range of secondary sources. Previous recommendations on improving drainage-system performance were included in the modeling of future scenarios for Eastern Dhaka (Halcrow Bangladesh Limited 2006), Central Dhaka (RAJUK 2008), the DND area (BWDB 2010), and Kallyanpur

(IWM 2011). The study also reiterated recommendations from IWFM (2005, 2008) and UGIIP (2006). RAJUK's Detailed Area Plan (RAJUK 2010) and drainage and stormwater master plans (IWM 2006; DWASA 2014) were reviewed, as were earlier studies on drainage-system criteria (JICA 1987, 1990) and flood protection of Western Dhaka (Louis Berger International 1991).

Defining the Detailed Study Area

The general physical setting for this study is a 1,528 km^2 area in north-central Bangladesh that corresponds to RAJUK's Dhaka Metropolitan Development Plan (DMDP). It consists of the Dhaka metropolitan area, the DND area, and the townships of Narayanganj, Savar, Gazipur, and Tongi. For the latter three townships, detailed data on drainage infrastructure, which is required for location-specific mapping of inundation depth and duration, was lacking. Therefore, the detailed study area of 345 km^2 was limited to the Dhaka metropolitan area, the DND area, and Narayanganj township. The Dhaka metropolitan area consists of two parts: Eastern Dhaka (121 km^2) and Western Dhaka (143 km^2). Western Dhaka, in turn, is divided into four areas: Old Dhaka, Central Dhaka, Kallyanpur, and Goranchatbari. The DND area covers 59 km^2, while Narayanganj township is a 22 km^2 area.

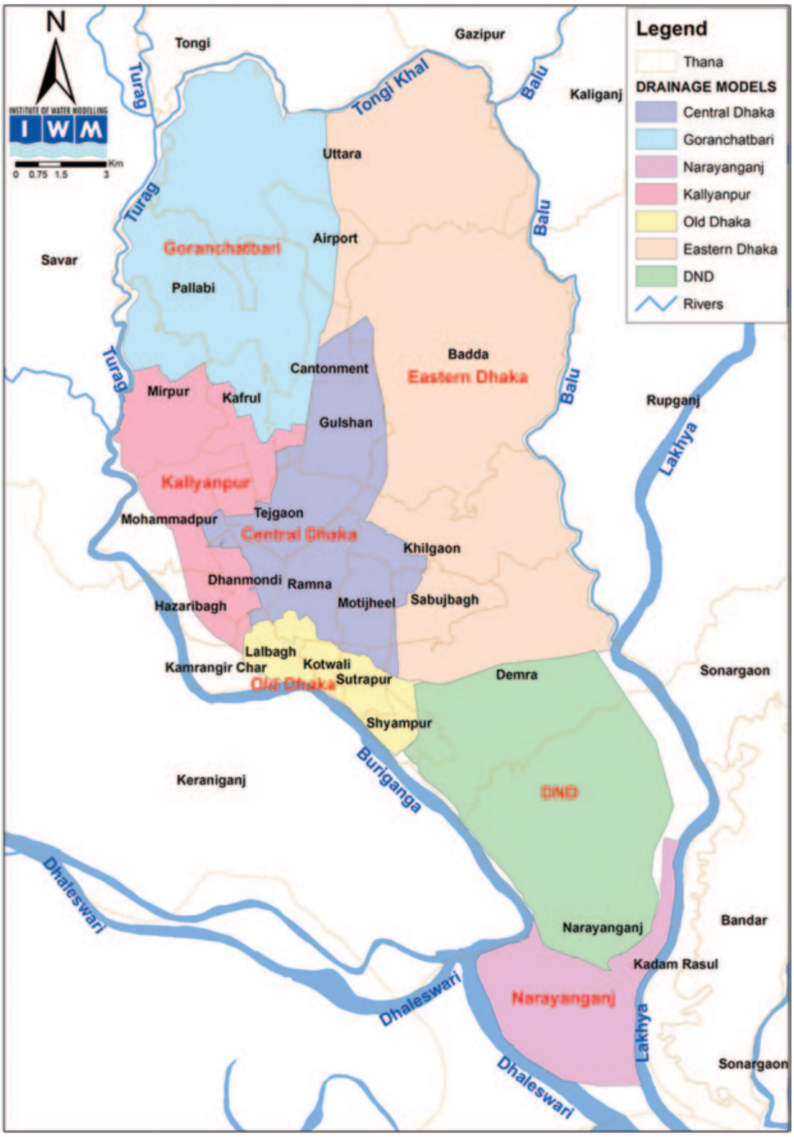
Key Features of Modeled Zones

Based on the drainage system, the detailed study area was divided into seven models (map 1.1). Each model is briefly described below, while more detailed descriptions are provided in chapter 3.

Old Dhaka. A historic area south of Central Dhaka, the Old Dhaka model spans about 12 km^2. The area is bounded by Border Guard Bangladesh and Dhaka University campus to the north, Dhaka flood wall and embankment to the west and southwest, and Atish Dipankar-Jatrabari-Mawa Road in the east and southeast. Control structures, known as sluice gates, allow for stormwater to drain into the river; however, they mostly remain closed during the monsoon season due to the high river-water levels, functioning only when the river-water level drops below the ponded water in front of the sluice gate. Old Dhaka was one of the worst-affected areas during the extreme rainfall events of 2004 and 2009. In 2004, about half of the area's wastewater contributed to the volume to be drained. Since then, operation and maintenance of the sluices have improved. Even so, recurrent waterlogging persists in low-lying parts of the area.

Central Dhaka. Situated in the center of the detailed study area, Central Dhaka is bounded by Goranchatbari to the north, Eastern Dhaka to the east, Old Dhaka to the south, and Kallyanpur to the west. Mainly flat terrain covers about 39 km^2, including low-lying areas near Khilgaon, Bashabo, and Kamlapur. Two major river embankments—Western Flood Protection Embankment and Pragati Sharani—protect Central Dhaka from river flooding. Population growth is rapid in such high-density areas as Shantinagar and Malibagh. The area also has pockets

Map 1.1 Detailed Study Area, Showing Seven Drainage Models



Source: IWM 2014.

that are relatively sparsely populated (e.g., Ramna and Gulistan). By 2050, it is anticipated that more than half of all land will be zoned for urban residential and mixed use. Central Dhaka has three major lakes, which serve as retention ponds. All three are connected to the Balu River via the Begunbari Khal. Sluice gates control the lakes' flow to the khal.

Kallyanpur. This densely populated area of about 28 km^2 is situated at the western edge of Dhaka along the banks of the Turag River. Kallyanpur shares adjoining borders with Goranchatbari to the north, Central Dhaka to the east, and Old Dhaka to the south. The Western Embankment along the left bank of the Turag River protects the area from river flooding. The area's several sluice gates, located along the embankment, remain closed during the monsoon season. Its stormwater is pumped from the Kallyanpur Retention Pond, located in the northwest part of the drainage system. Kallyanpur is a key contributor to Dhaka's economy, featuring a variety of manufacturing and processing factories; commercial activities; and offices, clinics, and schools. By 2050, more than three-fifths of land will have been zoned for either residential use or the transportation network.

Goranchatbari. Spanning nearly 64 km^2 in northwestern Dhaka, Goranchatbari shares borders with the adjoining areas of Eastern Dhaka to the east, Central Dhaka to the southeast, and Kallyanpur to the south. The Western Embankment—from the Tongi Rail Station to Kellarmor on the city's west side—protects the area from flooding of the Turag River. The drainage system is predominantly natural. Khals carry stormwater to the Goranchatbari Pumping Station, where it is pumped to the Turag River. In the northeast, stormwater drains to the Tongi Khal through sluice gates. The area varies widely socioeconomically. In planned, densely populated areas, most residents are engaged in commerce. In unplanned, moderately populated areas, residents work mainly in manufacturing and industrial-related activities. Many women in unplanned areas work in garment and apparel factories.

Eastern Dhaka. This 121 km^2 area features a mix of urban and rural landscapes interspersed with numerous wetlands and khals. It is bounded to the north by the Tongi Khal; the Balu River to the east; Demra Road to the south, which forms a boundary with the DND area; and Pragati Sharani to the west, which protects Western Dhaka from river flooding. Land use in Eastern Dhaka is dedicated mainly to agriculture and residential use. Khals are the main component of the drainage system. Outfalls of the khals are mainly to the Balu River; however, some also discharge into Tongi Khal. A road bypass likely to be completed by 2025 will function as embankment along the right bank of the Balu River and Tongi Khal and protect Eastern Dhaka from river flooding.

DND (Dhaka-Narayanganj-Demra). The DND is a 59 km^2 area in southeast Dhaka originally developed as an irrigation project by the BWDB in 1962. The area is bounded by the Dhaka-Demra-Chittagong Road to the north, the Lakhya River to the east, Narayanganj township to the south, and the Buriganga River to the west. Flood embankments along the Lakhya and Buriganga rivers prevent river flooding. The land is crisscrossed by numerous khals. In the past, the DND area was relatively free of flooding; however, recent haphazard urbanization, as well as encroachments on drainage channels, has resulted in waterlogging during the monsoon season. The 2004 flood inundated 70 percent of the area, highlighting the urgent need for drainage system improvements.

Narayanganj. Situated at the southern edge of Dhaka, Narayanganj is one of Bangladesh's oldest and largest inland ports. The township spans about

22 km^2. The Lakhya and Dhaleswari rivers form respective natural boundaries on the east and west sides. These rivers meet near Munshiganj and continue as the Dhaleswari River until merging with the Meghna River, which eventually flows into the Bay of Bengal. To the north, the Narayanganj Highway separates Narayanganj from the DND area. The Narayanganj-Munshiganj Highway functions as an embankment that protects some of the western portion from flooding of the Dhaleswari River. The drainage system comprises covered street drains considered as box-culverts, a piped network, khals, and large ponds. Most residents are slum dwellers employed as industrial laborers and porters. A small portion of the population is engaged in agriculture.

Hydrological Features

The hydrological setting of the detailed study area consists of climate, river network, topography, and land cover (box 1.3). The tropical monsoon climate comprises four hydrological seasons: pre-monsoon (April–May), monsoon (June–September), post-monsoon (October–December), and dry season (January–March). Most river and urban flooding problems occur during the monsoon season. Annual average rainfall is about 2,000 mm. At the start of the monsoon and post-monsoon seasons, cyclones with strong winds hit Bangladesh, sometimes causing heavy rainfall in Dhaka city with subsequent urban flooding.

An intricate river network surrounds the detailed study area. To the north, Tongi Khal (15 km long) is connected to the Turag River at its upstream and to the Balu River at its downstream. The Turag River (75 km long) is connected at its downstream to the Buriganga River, which, in turn is connected to Dhaleswari

Box 1.3 Topography of Dhaka at a Glance

Dhaka is situated at the southern tip of the Madhupur Tract, a Pleistocene terrace 1–10 m above the adjacent floodplains. The areas surrounding the city are mostly flat alluvial plain formed during the Holocene age or in recent time. The city is encircled by six rivers and canals. The Turag, Buriganga, and Dhaleswari rivers are located on the western side, while the Balu and Lakhya rivers are situated to the east. Tongi Khal, a manmade canal, connects the Turag and Balu rivers to complete the encirclement.

The city's central area or spine is the highest part, with land sloping to the west, east, and south directions. The high-elevated part continues on the northern side, dividing the city into three major blocks from a flood management perspective. A peripheral dyke, completed after the 1988 flood, forms the western polder, protecting western Dhaka. The eastern side remains unprotected from river flooding, which may occur due to spillage of floodwater from the Balu and Lakhya rivers. The southern part—a low-lying floodplain that was polderized by raising the Dhaka-Narayanganj and Dhaka-Demra roads and connecting Demra and Narayanganj with a flood embankment—is now known as the Dhaka-Narayanganj-Demra (DND) Polder.

River at its downstream. The Balu River (30 km) is connected to the Lakhya River at its downstream. The Lakhya River (120 km long) is connected to the Dhaleswari River at its downstream. These rivers are primarily distributaries of the Brahmaputra River.

The topography of the detailed study area is a flat alluvial plain with irregular contour lines and numerous khals that subdivide the land. About 55 percent of the land is at an elevation of 6–8 m PWD, with just 15 percent above 8 m PWD. The area is dominated by a 5–8 m deep layer of cohesive soils of clay and plastic silt with poor permeability, which overlay a sand layer. Depending on the location of built-up areas, the soil's poor permeability has consequences for urban flooding.

Structure of the Book

This book is divided into two major parts: study methods (part 1) and results (part 2). Part 1 is organized into four chapters. Chapter 2, which will be of interest to hydrologists, presents the conceptual framework for the hydrological modeling study and the method and processes used to model future scenarios. Chapter 3, of interest to local planners as well as hydrologists, presents the seven model setups for the detailed study area. The following two chapters will be of interest to economists and risk-assessment experts. Chapter 4 describes the method used to assess the modeled areas' relative vulnerability to urban flooding, while chapter 5 explains the method used to estimate their economic damage. Part 2, also organized into four chapters, is designed mainly for Dhaka's local policymakers. Chapter 6 provides the study results for each of the seven modeled areas, while chapter 7 summarizes the overall study results for Dhaka city. Chapter 8 turns to the secondary flood-mitigation measures that can complement the recommended conveyance-centric solutions. Finally, chapter 9 suggests a way forward.

Notes

1. In the 2007 flood, more than 90,000 people in Dhaka city alone were affected by diarrhea.
2. Nishat et al. (2000) provides a detailed study of the various adverse impacts of the 1998 flood.
3. Seventeen of Dhaka's 43 natural canals no longer exist. Recently, however, the Dhaka Water Supply and Sewerage Authority (DWASA) has brought the remaining 26 under its control. Rehabilitation is currently under way for 19 of these—11 under the second phase of the government's Removal of Water-Logging Project and 8 under the World Bank–funded Dhaka Water Supply and Sanitation Project.
4. Sugiyama (2012) constitutes voluntary work conducted by the author. The views expressed in this report are solely those of the author and do not reflect the views of the author's present or former institutional affiliations. The report describes an extension of an earlier study conducted in 2008. Since then, the climate science community has made significant strides in further developing the pattern-scaling technique, which

the report uses extensively. For a summary of recent scientific development, interested readers should consult IPCC (2013, section 12.4.2).

5. The CDRI analysis is based on a planning tool developed under the Climate and Disaster Resilience Initiative of Kyoto University (Joerin and Shaw 2011). To measure climate-disaster resilience, the CDRI considers five dimensions (physical, social, economic, institutional, and natural), each of which has five parameters; these, in turn, have five variables each, for a total of 125 variables (Jahan 2014b).

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PART 1

Methods

CHAPTER 2

Hydrological Modeling

Introduction

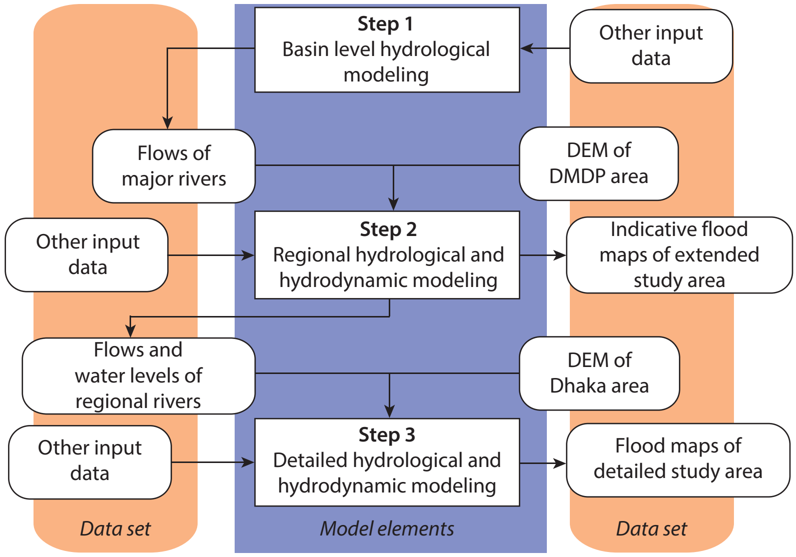
Estimating the impact of an extreme rainfall event on the magnitude and duration of flooding requires hydrological modeling. Hydrological models attempt to represent the processes by which various forms of precipitation or rainfall are converted into runoff or overland flow of water, which then drains or flows through depressions or channels into water courses. Depending on the modeling objective, this representation is done over various time and spatial scales. This chapter is divided into three sections. The first one describes the conceptual framework for the hydrological modeling exercise, including the required three levels of modeling. The second reviews the rainfall analyses undertaken, while the third provides a general overview of the process used to model future scenarios for the detailed study area.

Modeling Framework

As mentioned in chapter 1, Dhaka is located on the lower reaches of the Ganges-Brahmaputra Delta, surrounded by six rivers and canals. In addition, flooding in the study area of Greater Dhaka is affected by flows in the Brahmaputra (Jamuna) River and its distributaries in north-central Bangladesh. Since the study needed to assess flooding changes in the Dhaka Metropolitan Development Plan (DMDP) area, which is mainly influenced by river flooding, a three-step modeling approach was adopted (figure 2.1).

In the first step, basin-level hydrological modeling simulated flows from the Brahmaputra River in the Ganges-Brahmaputra-Meghna (GBM) system since they strongly influence monsoon-season river flows and water levels in the extended study area. In the second step, the effects of climate change on the regional rivers were simulated. Finally, in the third step, detailed modeling of the drainage system in and around Dhaka city was simulated. Although river levels affect the drainage system within the city area, the focus of this study was the worst-case scenario, meaning that river levels are high and all sluice gates are closed; that is, there is no gravity drainage out of the city and the drainage system is primarily dependent on

Figure 2.1 Conceptual Framework for the Modeling Exercise



Source: Zaman 2014.
Note: DEM = Digital Elevation Model; DMDP = Dhaka Metropolitan Development Plan.

the performance efficiency of drainage pumps. Thus, changes in river levels due to climate change were not considered in the analyses of the detailed study area.[1]

Basin-level model output was used to create boundary conditions for region-level hydrological and hydrodynamic modeling. As input, the region-level step simulated flows from the basin-level modeling, along with data from the Digital Elevation Models (DEMs) of RAJUK's DMDP area and climate and river-network information. Region-level model outputs were river flows and water levels of key rivers in north-central Bangladesh. This simulated data was used to generate indicative flood maps for the DMDP area. Outputs from region-level simulations were used as boundary conditions for modeling the detailed study area. The urban-area modeling step involved a more detailed level of hydrological and hydrodynamic modeling of the urban drainage system and catchments. Model outputs were stormwater flows and flood levels, which were used to generate location-specific depth-and-duration maps. The subsections below provide more detailed descriptions of the three modeling levels.

Basin-Level Modeling

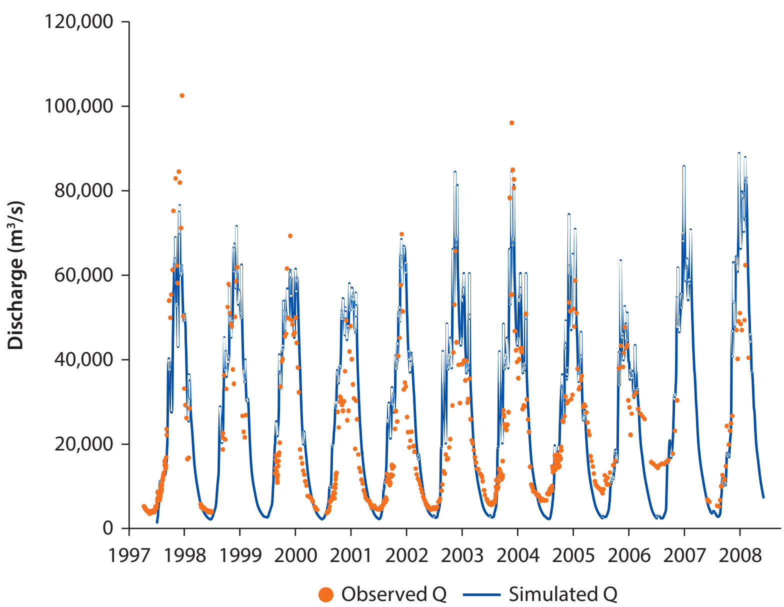
The basin-level model for the GBM system developed by the Institute of Water Modelling (IWM) was used to estimate future flow changes of the Brahmaputra (Jamuna) River due to climate change. This model was selected because it had already been calibrated and validated for large flood events and had been used for several climate change studies (e.g., IWM and CCC 2008). This is a water mass-balance model that runs at a daily time-step, based on the MIKE Basin software package (Nishat and Rahman 2009).

The model was used to simulate daily river flows for the base period and future monsoon river flows of the Brahmaputra (Jamuna) River with climate change–adjusted catchment rainfall and temperature series and without climate change. The selected base period was 1998–2008, which covers extreme, normal, and less than normal monsoon flows. The catchment rainfall and temperature series for climate change were based on the estimates of Masahiro Sugiyama for the Brahmaputra Basin (Sugiyama 2012). Monsoon-season flows of the Brahmaputra River were simulated for future (2050) low- and high-emissions scenarios. Selection of the year 2050 was considered appropriate in terms of deriving a clear climate signal and being close enough to be relevant for today's planners and decision-makers.

Modeling input obtained from the IWM included meteorological (e.g., rainfall, evapotranspiration, and temperature), river-channel (e.g., alignment, catchment area, and distributary channels), and catchment-properties (e.g., runoff coefficient, baseflow parameters, and snowmelt characteristics) data. The 543,467 km^2 Brahmaputra Basin was modeled with a total of 34 catchments, including 4 snowmelt ones. The Nedbør-afstrømnings (Rainfall-Runoff) Model (NAM) was used to represent the hydrological processes. The 1998–2008 base simulation period was calibrated at Bahadurabad Station. Figure 2.2 shows that agreement between the simulated and observed flows was good for some years and poor for others.

The model performance was measured using the Nash Sutcliffe Coefficient (E) for each year and monsoon season (June–September). Whole-year performance

Figure 2.2 Basin Model Calibration Plot



Source: Zaman 2014.

varied from 0.85 in 1999 to 0.05 in 2001. The model performed better (0.76) when only monsoon-season flows were considered. Based on the calibration results, the model performance was deemed acceptable for the purposes of the extended study area.

In keeping with the objective of assessing changes in monsoon flows, key assumptions were made for future basin scenarios. It was considered that flooding of the Greater Dhaka area would be dominated by flows from the Brahmaputra (Jamuna) River. The water levels of the Ganges and the Meghna were not considered important as they only influence the outflow boundary condition. It may be of some importance when the peaks of the major rivers coincide, as happened in 1988, and drainage from upstream rivers is impeded. It was assumed that future land use and land cover would not change dramatically (i.e., catchment runoff coefficients would be similar).[2] It was further assumed that future basin water losses through evapotranspiration would not differ significantly in the monsoon season. Additional assumptions were that peak monsoon flows would be minimally affected by the building of future dams, hydrological regimes would not be significantly altered by water demands, a lumped calculated method would be used to model snowmelt, and snowmelt modeling procedures would include glacier contribution to runoff.

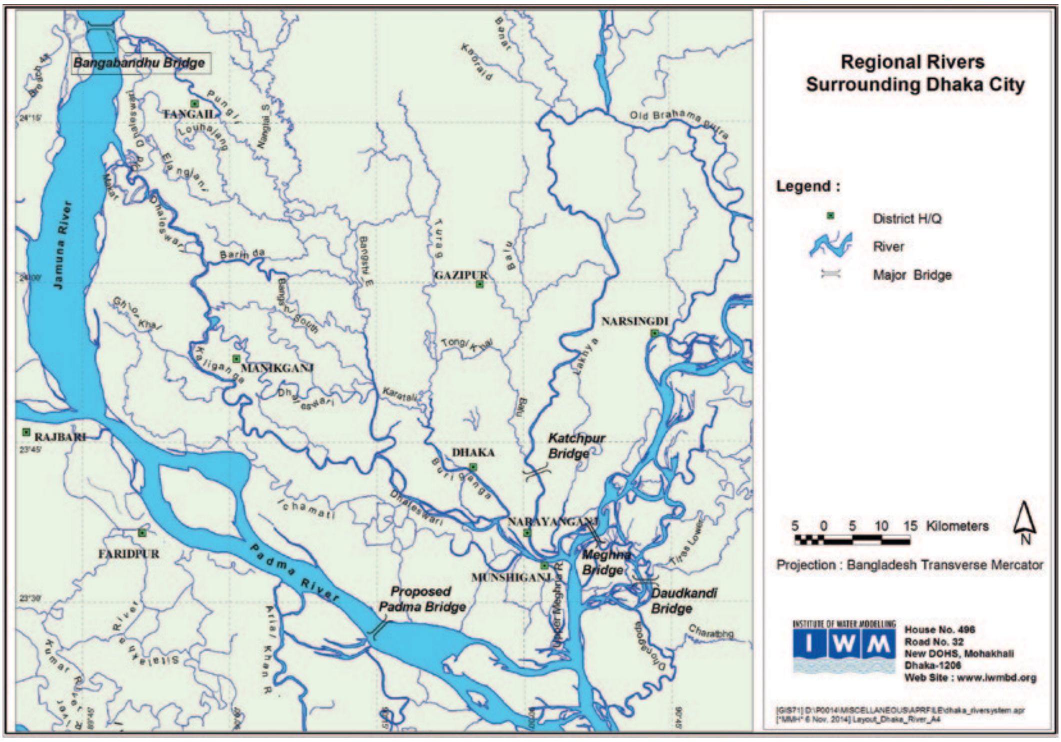
Region-Level Modeling

To model the Greater Dhaka region, the study used IWM's North Central Region Hydrodynamic (NCRHD) model to simulate monsoon seasonal flows and water levels of the river network in the extended study area (map 2.1). Developed in 1991, the NCRHD model has been validated for 14 hydrological years (up to 2005–06). It is linked to MIKE 11 RR, a lumped conceptual rainfall-runoff model that generates flows from catchments. Surface runoff generated from rainfall is estimated for each catchment. The flows are then used as an input to a hydrodynamic model that simulates the flow of water through drainage channels and surrounding rivers of Dhaka city. The hydrodynamic model also simulates the operation of infrastructure at the end of the drainage system.

For this study, the NCRHD model was used to simulate daily flood flows and water levels for the base year (2004 monsoon).[3] Then, using adjusted catchment rainfall series for climate change based on Masahiro Sugiyama's estimates for catchments in the north-central region (Sugiyama 2012) and adjusted flows from Chilmari (Jamuna River), the NCRHD model was used to simulate future (2050 monsoon season) river flows and water levels for the A1FI scenario.[4] Based on the simulated maximum water levels, flood depths were calculated and mapped using GIS for each scenario. The NCRHD model covers a 14,223 km^2 area divided into 20 catchments. The total length of rivers and khals is about 3,006 km. Calibration and validation of the model are based on available observed discharge and water-level data.

The detailed input data required for hydrodynamic modeling, already available at IWM, included meteorological (e.g., rainfall and evapotranspiration), river-water level and discharge, and hydraulic structures data, as well as information on

Map 2.1 Regional Rivers Surrounding Dhaka City

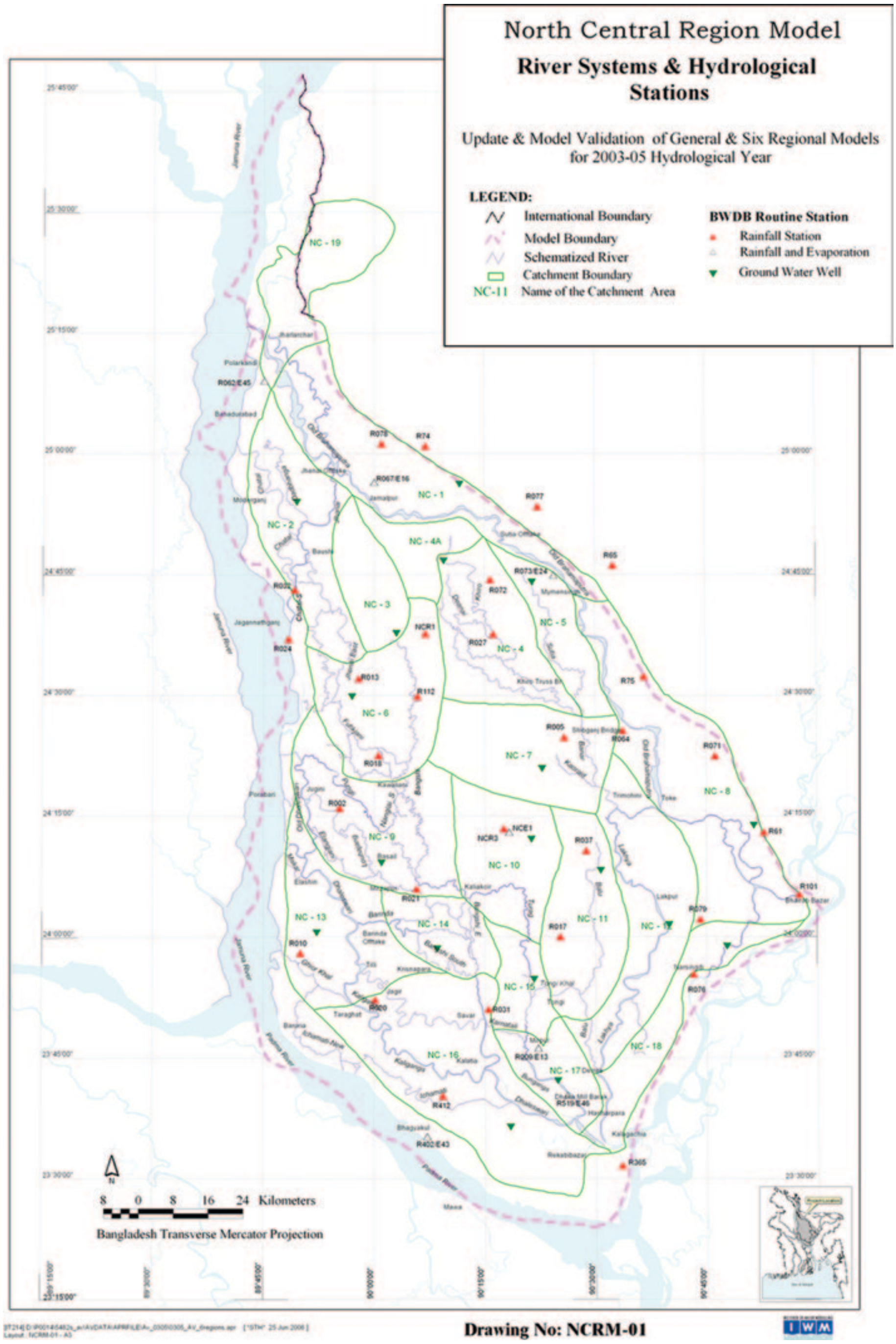


Source: IWM 2014.

river channels (e.g., alignment, slope, width, bank, and bed friction) and catchment properties (e.g., runoff coefficient and baseflow parameters). Daily-point rainfall data from manual rain gauges at 31 rainfall stations maintained by Bangladesh Water Development Board (BWDB) in north-central Bangladesh was used to calculate the mean area rainfall for each catchment in the region (map 2.2). Pan evaporation data was collected from 6 evaporation stations maintained by BWDB.[5] Observed river-water level data were available at 41 stations in the north-central area; water-level, time-series data were also required for model calibration and validation. Similarly, river discharge data was required as both an input into the hydrodynamic model and for model calibration and validation. For the base scenario, measured discharge data were collected from BWDB stations.[6]

The rainfall-runoff model comprises 20 subcatchments—19 in Bangladesh and 1 in India—which drain into the Old Brahmaputra River. The rainfall-runoff model receives precipitation and evaporation from 31 and 6 stations, respectively, within the areas where measurements are available. The NAM model usually uses abstraction data processed by the Water Resources Planning Organisation, based on the census of the National Minor Irrigation Development Project.

Map 2.2 River System and Hydrological Stations of the North Central Region Hydrodynamic Model



Source: IWM 2006.

Land-Use and Land-Level Data

Analysis of 2004 and future land-cover data was based on RAJUK's Detailed Area Plan (DAP) in GIS format and IWM's projected population data (IWM 2012). Land levels were a key input for flood mapping of the extended and detailed study areas. The study used an existing DEM available from IWM, based on topographic sheets from the Survey of Bangladesh (Government of Bangladesh 1979) and past IWM surveys. For future changes in terrain, the DEM was adjusted according to a relationship between population density and land levels in proposed built-up areas in the DAP (e.g., urban residential, institutional, and mixed use) (Jahan 2014) (table 2.1).[7] Land levels for other land-use zones in the original DEM (e.g., rural settlements, open spaces, water bodies, flood flows, and agriculture) remained unchanged. Thana-wise population projections were obtained from the Dhaka City Water Supply Master Plan (IWM 2012).

Boundary Conditions

The model boundaries comprised 10 upstream and 6 downstream locations. The change in upstream flows were simulated in the GBM Basin model and used as input in the boundary condition at Chilmari Station. From the basin model simulations, it was observed that the monsoon flows increased due to climate change for the A1FI emissions scenario in 2050.

Other considerations included wastewater inflows, sea-level rise, and subsidence. It was found that wastewater flows during the monsoon are negligible compared to high river flows; thus, the NCRHD model did not consider them. Potential changes in sea-level rise can affect river-water levels around Dhaka during the monsoon season due to possible backwater effects from the Padma and Meghna rivers. Based on a review of the Special Report on Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation (SREX) by the Intergovernmental Panel on Climate Change (IPCC 2012), it was determined that the effect of sea-level rise in the study area by 2050 would be negligible.[8] The study also reviewed subsidence rates for Dhaka

Table 2.1 Relationship between Population Density and Land Levels

Density (thousand people/km^2)	*Land level (m PWD)*
50 and above	7.5
45–50	7.5
40–45	7.0
35–40	7.0
30–35	6.5
25–30	6.5
20–25	6.0
15–20	5.5
10–15	5.0
Less than 10	4.5

Source: Jahan 2014.
Note: PWD = Public Works Department.

using secondary sources, notably Alam (1996) and Hoque and Alam (1997). The former study gave a rate of 0.65 mm per year, while the latter reported 1.88 mm a year. Using the higher rate, this study calculated that total subsidence by 2050 would be less than 10 cm, which was considered negligible.

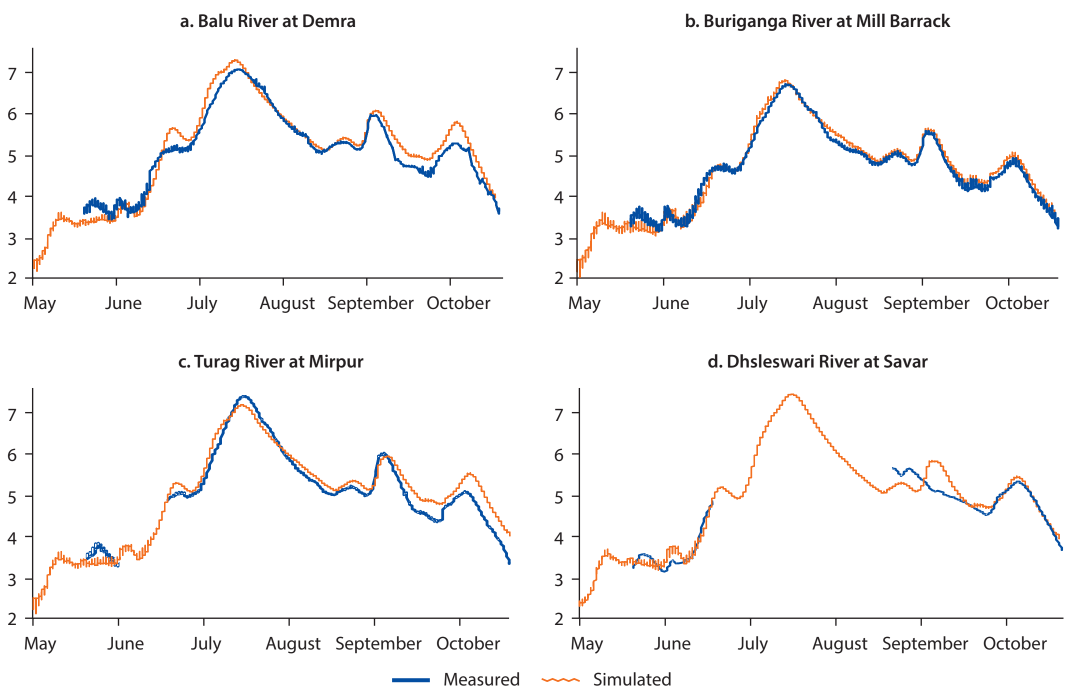
Model Calibration and Validation

The model was calibrated based on a comparison of simulated and observed data at 34 locations where measured water level and discharge data were available. The calibrated model was validated against known events without changing model parameters. From the comparison plots, it was evident that the model-generated water levels matched reasonably well with the observed data (figure 2.3). Therefore, the model was considered suitable for application runs to study climate change scenarios.

Key Assumptions

Key model assumptions were that land use and land cover would change in accordance with the DAP, land levels in built-up areas would increase as population densities increased, and land levels for other land-use categories (e.g., rural settlements, water bodies, and agriculture) would not increase. These assumptions were confirmed through various workshops and stakeholder consultations.

Figure 2.3 Comparison of Simulated and Measured Water Levels (m PWD) at Selected BWDB Stations, 2004



Source: Zaman 2014.
Note: BWDB = Bangladesh Water Development Board; PWD = Public Works Department.

Furthermore, they assumed that the DAP would be implemented and enforced, which would prevent changes in land uses that could lead to land-level changes. It was also assumed that water losses through evapotranspiration would not differ significantly in the future, no major changes in the river network would occur in the future, and water demands would not significantly alter the hydrological regime in the monsoon.

Urban-Area Modeling

For modeling of the detailed study area, two types of models were used: MIKE 11 and MIKE Urban. MIKE 11 is a one-dimensional model that estimates water flows and levels by solving non-linear, one-dimensional Saint Venant equations that mathematically describe the motion of fluids. This model can also simulate the performance of various drainage structures, such as pipes, *khals* (open channels), box-culverts, bridges, pumps, and sluice gates. MIKE Urban is a coupled one- and two-dimensional model that links the capabilities of MIKE 11 in a GIS framework so that DEMs can be used to simulate the flow of water on the ground surface. Chapter 3 provides details on the modeling requirements.

Rainfall Analyses

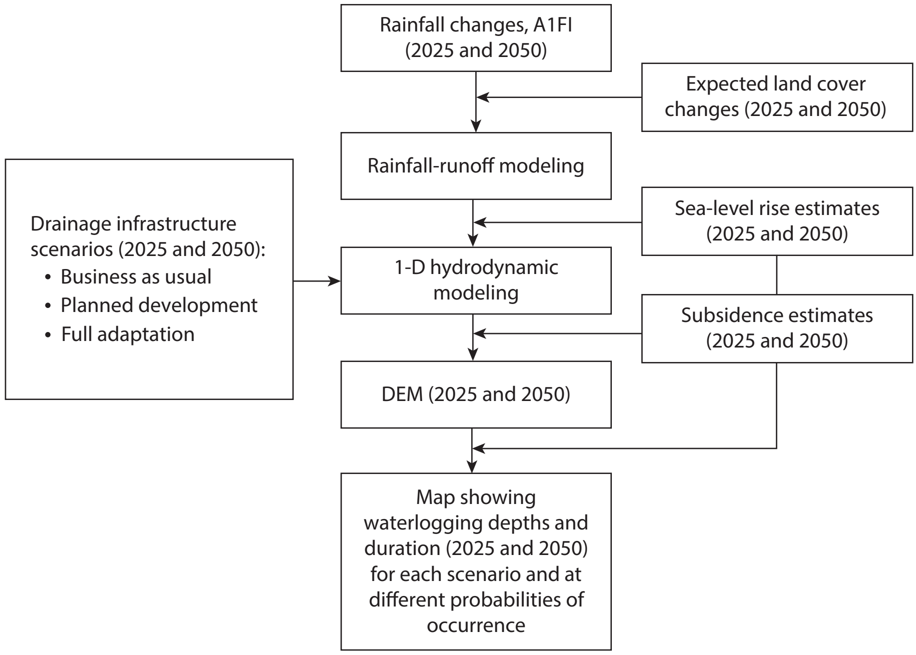
The study reviewed previous research that investigated trends and changes in rainfall frequencies in and around Dhaka City for various time periods. It then analyzed and compared historical rainfall data from the BWDB and the Bangladesh Meteorological Department (BMD). Results of these rainfall analyses, along with a review of frequency analyses done by JICA (2000), are presented in appendix B, while appendix C summarizes the findings from previous research.

Process for Modeling Future Scenarios

Figure 2.4 shows the general process used to model future scenarios in the detailed study area. Design rainfall events were adjusted by climate change factors for A1FI future scenarios (box 1.2). These were inputted into the MIKE Urban A rainfall-runoff model with calculated changes in catchment impervious area due to the densification driven by population growth. Next, the resulting simulated stormwater runoff was inputted into the one-dimensional hydrodynamic model, along with planned changes in the drainage infrastructure (e.g., increased pump capacity and re-sectioning of khals). The one-dimensional model provided estimates of water levels at various points for each time-step.

For the areas modeled with MIKE 11, the data on peak-water level was brought into GIS format and analyzed with reference to the DEM of the model area to produce flood maps. Changes in land levels due to land filling or local subsidence were represented by changing the DEM accordingly. For the areas modeled with MIKE Urban, the flooding process was done automatically due to its one- and two-dimensional coupling. That is, when pipes and khals overflow,

Figure 2.4 Process for Modeling the Detailed Study Area



Source: Zaman 2014.
Note: A1FI = Intergovernmental Panel on Climate Change scenario with future based on fossil fuel–intensive development; DEM = Digital Elevation Model.

the water is spread across the DEM; after the peak runoff passes, the water follows the natural slope of the DEM to re-enter the drainage system. As a result, MIKE Urban outputs a time series of inundation maps.

Simulations of 2050 Scenarios

The models described above were used to simulate various future scenarios, whose outputs were flood depth-and-duration maps. As mentioned in chapter 1, the 100-year, extreme rainfall event that occurred in September 2004 (341 mm in 24 hours) was taken as the baseline to simulate future scenarios in 2050. The selection of this baseline event was based on simulations and analyses that showed a clear trend of increasing frequency of intense rainfall events. The underlying assumption was that such extreme events will become more frequent due to climate change processes. Also, most of the available datasets coincided at that time. These included land-use data from the DAP, infrastructure data from existing IWM models, and DEM data.

The effects of the 2004 event were simulated for five future scenarios (table 2.2). For all scenarios, detailed drainage models incorporated projected population growth and densities, planned DAP land-use changes, estimated land-level changes, and planned drainage improvements. The resultant flooding patterns in the future scenarios were compared to specified acceptable flooding criteria. These were set through consultations with experts and relevant stakeholders in Bangladesh, taking into consideration that residents of Dhaka, where flooding is a recurrent phenomenon, have become accustomed to even ankle-deep water, and the vertical accuracy of the current DEM does not allow one to go below 0.10 m. The criteria set were that, in the peak flood situation, 90 percent of each administrative area should have less than 0.25 m flood depth—with the exception of Central Dhaka, where the threshold was set at 0.10 m—and the duration of inundation should be less than 12 hours.

Modeling Assumptions: Planned Improvements

Development of the five future scenarios described in table 2.2 assumed that all improvements to Dhaka's drainage infrastructure—both planned and proposed by the relevant drainage-system authorities—would be implemented. These included improvements covered in RAJUK's DAP (RAJUK 2010), DWASA's Sewerage Master Plan, and Narayanganj City Corporation's Concept Vision Plan. Previous recommendations on improving drainage-system performance were included in the modeling of future scenarios for Eastern Dhaka (Halcrow Bangladesh Limited 2006), Central Dhaka (RAJUK 2008), the DND area (BWDB 2010), Kallyanpur (IWM 2011), and Narayanganj (UGIIP 2006). Modeling assumptions also included recommendations of DWASA (2014), IWM (2006), and IWFM (2005, 2008).

Table 2.2 Model Simulations for the Detailed Study Area

Scenario	*Data sources/remarks*
Base run, 2004 100-year return-period storm; 1 in 10-, 20-, and 30-year events	DAP's land-cover, land-use, and topography data; IWM's drainage infrastructure data and Dhaka DEM.
2050 SE[a] + PI[b] + rain events with no CC[c]	DAP's proposed land-cover and land-use data; changes in land levels due to expansion of built-up areas.
2050 SE[a] + PI[b] + CC[c]	Drainage improvements based on published reports and discussions with relevant agencies.
	A1FI climate change factors were derived from Sugiyama (2012) for increased rainfall (based on statistical downscaling of GCM results) and
	NCRHD model simulations for changes in peripheral river-water levels.
2050 SE[a] + PI[b] + AI[d] + rain events with no CC[c]	Additional investments to meet the flooding criteria set through consultations: 90% of administrative area has less than 0.25 m flood depth (0.10 m for Central Dhaka) and duration of less than 12 hours.
2050 SE[a] +PI[b] + AI[d] + CC[c]	
2050 SE[a] + PI[b] + AI[d] + CC[c] + AD[e]	Design parameters of adaptation measures based on consultations with relevant stakeholders and experts.

Note: SE = socioeconomic changes; PI = planned improvements; AI = additional investments; CC = climate change; AD = adaptation to climate change; DAP = Detailed Area Plan.

a. Socioeconomic changes refer to changes in land use and DEMs.

b. Planned improvements refer to drainage-system improvements by relevant agencies.

c. Climate change refers to the effects of the IPCC's A1FI scenario (i.e., future based on fossil fuel–intensive development) applied to the design storm events and river levels.

d. Additional investments refer to improvements to address the current climate adaptation deficit without climate change to meet the acceptable flooding criteria set for the extreme rainfall event.

e. Adaptation refers to the adaptation measures modeled to mitigate the impacts of climate change to satisfy the acceptable level of flooding in each administrative area.

Computing Flood Damage in a Changing Climate

The computations for estimating flood damage and adaptation costs were based on the estimates of extent, depth, and duration of flooding, as described above. The avoided damage from adaptation was based on the 100-year, return-period flood occurring in 2050. Because of the likelihood that such extreme events may become more frequent in the future due to climate change processes, the study also examined the flood damage that would result if the 100-year, return-period storm were to hit with greater frequency (i.e., once every 50, 33, or 20 years).

Notes

1. All three levels of modeling were undertaken by the Institute of Water Modelling (IWM).
2. It was beyond the scope of this study to assess how land use and land cover may change in the basin area with and without climate change.
3. The year 2004 was chosen as the base year as key datasets for drainage modeling were available for this flood year.
4. The A1FI scenario was chosen since it provides an upper bound for the possible effects of climate change.
5. Potential evapotranspiration data from direct measurements were not available. Pan evaporation expresses the volume of water that evaporates from a standard evaporation pan over a given period of time. This is the most widely used method by hydrologists for calculating actual evaporation rates of large water bodies.
6. IWM and BWDB are the main sources of river discharge data in the north-central region of Bangladesh.
7. Prior experience suggests that the conversion into built-up areas involves land filling.
8. The SREX report indicates that sea-level rise above 2 m by 2100 would be implausible and that "an estimate of 0.8 m by 2100 that included increased ice dynamics was considered most plausible" (IPCC 2012, p. 179).

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CHAPTER 3

Detailed Area Modeling

Introduction

The detailed study area was divided into seven areas for modeling: Old Dhaka, Central Dhaka, Kallyanpur, Goranchatbari, Eastern Dhaka, DND, and Narayanganj. Map 3.1 shows the model boundaries, respective areas modeled, and types of models used. Deciding on which model to apply depended on the drainage-system features of each area. For example, in Eastern Dhaka and the DND area, where khals constitute the primary drainage system, MIKE 11 was used to assess future river flood situations. In Western Dhaka and Central Dhaka, where the primary drainage system consists of pipes and khals, MIKE Urban was used to predict urban flood problems.

Modeling Setup

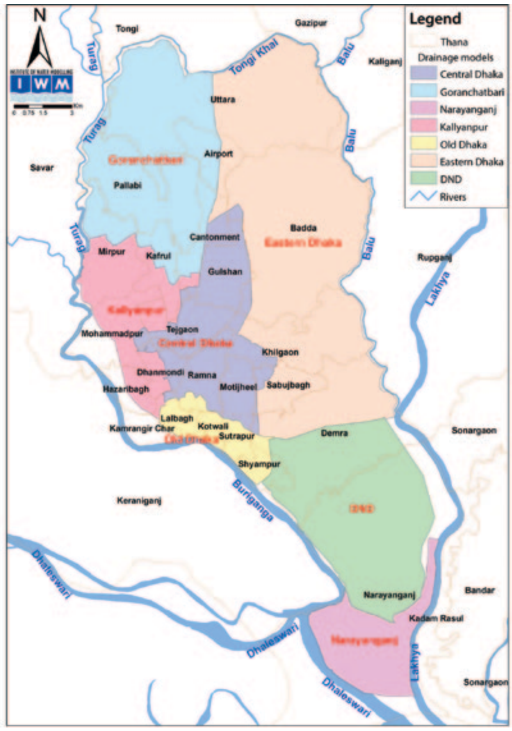
Data Requirements and Sources

To provide location-specific depth and duration of inundation, model analyses required detailed spatial and temporal resolution data. This included detailed information on topography, meteorology, drainage infrastructure,[1] land cover, and population density. Topographical data included a Digital Elevation Model (DEM) (25 m^2 grid) prepared by the Institute of Water Modelling (IWM), using information from their various projects, as well as the Survey of Bangladesh (Government of Bangladesh 1979). Meteorological data included historical daily rainfall provided by the Bangladesh Water Development Board (BWDB) and historical three-hourly rainfall provided by the Bangladesh Meteorological Department (BMD). Sedimentation measurements for drainage pipes and box-culverts were estimated by IWM via field inspections and discussions with Dhaka Water Supply and Sewerage Authority (DWASA) engineers. The Demographic Census of Bangladesh for 2001 and 2011, conducted by the Bangladesh Bureau of Statistics (BBS), provided the source for estimating population density (table 3.1).

Map 3.1 Model Boundaries of Detailed Study Area

Model name	*Model area (km²)*	*Model type*
Old Dhaka	12	MIKE urban
Central Dhaka	39	MIKE urban
Kallyanpur	28	MIKE urban
Goranchatbari	64	MIKE urban
Eastern Dhaka	121	MIKE 11
DND	59	MIKE 11
Narayanganj	22	MIKE urban, MIKE 11

Total area modeled: 345 km²



Source: IWM 2014.

Table 3.1 Summary of Data Requirements and Availability

Data type	*Source*
Topography (DEM)	IWM, Survey of Bangladesh
Meteorological information	BMD and BWDB
Drainage infrastructure	DWASA
Land cover	BUET and RAJUK
River stage	BWDB
River flow	BWDB
River sections, slope, and alignments	IWM
Population density	BBS

Note: BBS = Bangladesh Bureau of Statistics; BMD = Bangladesh Meteorological Department; BUET = Bangladesh University of Engineering and Technology; BWDB = Bangladesh Water Development Board; DEM = Digital Elevation Model; DWASA = Dhaka Water Supply and Sewerage Authority; IWM = Institute of Water Modelling; RAJUK = Rajdhani Unnayan Kartripakkha (Capital Development Authority of Bangladesh).

Design of Base Model and Future Scenarios

Each base model was calibrated against a schematic inundation map of Dhaka city for the year 2004 (IWFM 2005). For this purpose, temporally concentrated rainfall data was required; thus, the BMD three-hourly rainfall data was used. Design rainfall patterns were made by segregating one-day rainfall data from JICA (2000) into six hourly rainfalls following the pattern recommended by JICA (1987). To simulate the 2050 A1FI emissions scenario for Dhaka, the design rainfalls were adjusted using the 16 percent increase factor in extreme 24-hour precipitation estimated by Sugiyama (2012) (box 1.2). Appendix B provides further details.

MIKE Urban A, a lumped hydrological model that uses the time-area method, was selected as the most appropriate method to represent generation of runoff from local rainfall. MIKE Urban A uses various parameters to control the amount of surface runoff. These include size of the contributing (impervious) area, initial loss (wetting and filling of local depressions/storages), and reduction factor (for evapotranspiration and imperfect imperviousness). The average daily evaporation in Dhaka for the month of September was estimated at 4 mm per day (based on a rate of 118 mm per month). Total rainfall within the simulation period (eight-day event of September 2004) was 660.5 mm. The percentage of evaporation thus computed was 5 percent of total rainfall (32/660.5). It was assumed that another 5 percent of rainfall is lost due to evapotranspiration and depression storage (not contributing to runoff). Therefore, a value of 0.9 was used as the reduction factor (table 3.2).

Estimation of Impervious Area

The 2004 and proposed land-cover information was based on Detailed Area Plan (DAP) data. Based on the various types of land cover identified in each catchment, the percentages of pervious and impervious area were estimated for the detailed study area, using typical values in the field (i.e., the actual percent values corresponding to a particular land cover) (table 3.3). For example, for residential land use, DND (a low-density area), Central Dhaka (a medium-density area), and Old Dhaka (a high-density area) have impervious areas of 17 percent, 38 percent, and 70 percent or higher, respectively.[2]

For example, in the residential-use category, the percentage of impervious area in low-density areas varies from 18 percent to 34 percent as the population density increases from 10,000 people per km^2 to 20,000 per km^2. In high-density areas, the percentage of impervious area varies from 60 percent to 70 percent as the population density increases from 40,000 people per km^2 to 50,000 per km^2 (table 3.3). In this way, the relationship captures the time dimension for future (2050) scenarios.

Modeling Steps

Each model setup included hydrological and hydraulic models. The first step was to develop the hydrological model. Input data, including catchment properties

Table 3.2 Typical Parameters and Values for MIKE Urban Model A

Parameter	*Value used*
Impervious area (%)	70
Time of concentration (minutes)	120
Initial loss (mm)	10
Reduction factor	0.9
Time area curve no.	Varies with catchment shape

Table 3.3 Impervious Percentage for Various Land Uses

	Population density (thousand people/km²)								
	10	*15*	*20*	*25*	*30*	*35*	*40*	*45*	*50*
	Low density			*Moderate density*			*High density*		
DAP land type	*Impervious area by land type (%)*								
Agriculture	0	1	1	1	1	1	1	1	1
Circulation network	2	3	4	4	5	6	6	7	7
Commercial activity	19	27	35	44	50	56	63	68	73
Community service	21	30	39	48	55	62	69	74	80
Diplomatic	9	14	18	22	25	28	31	34	36
Education and research	11	16	21	26	30	34	38	41	44
Governmental services	9	14	18	22	25	28	31	34	36
Manufacturing and processing activity	15	22	28	35	40	45	50	54	58
Mixed use	21	30	39	48	55	62	69	74	80
Recreational facilities	4	5	7	9	10	11	13	14	15
Residential	18	26	34	42	48	54	60	65	70
Restricted area	2	3	4	4	5	6	6	7	7
Service activity	9	14	18	22	25	28	31	34	36
Transport and communication	8	11	14	18	20	23	25	27	29
Vacant land	2	3	4	4	5	6	6	7	7
Water body not connected to drains	0	1	1	1	1	1	1	1	1
Water body connected to drains	100	100	100	100	100	100	100	100	100

Source: Jahan 2014.
Note: DAP = Detailed Area Plan.

and available climate information, were used to simulate surface runoff. These data, along with a DEM of the study area and information on the drainage network, sedimentation depth, and pump discharge, were used as inputs in the detailed-area hydraulic models to generate time-series inundation data. These simulated data, in turn, were used to generate location-specific flood maps and an inundation depth and duration table.

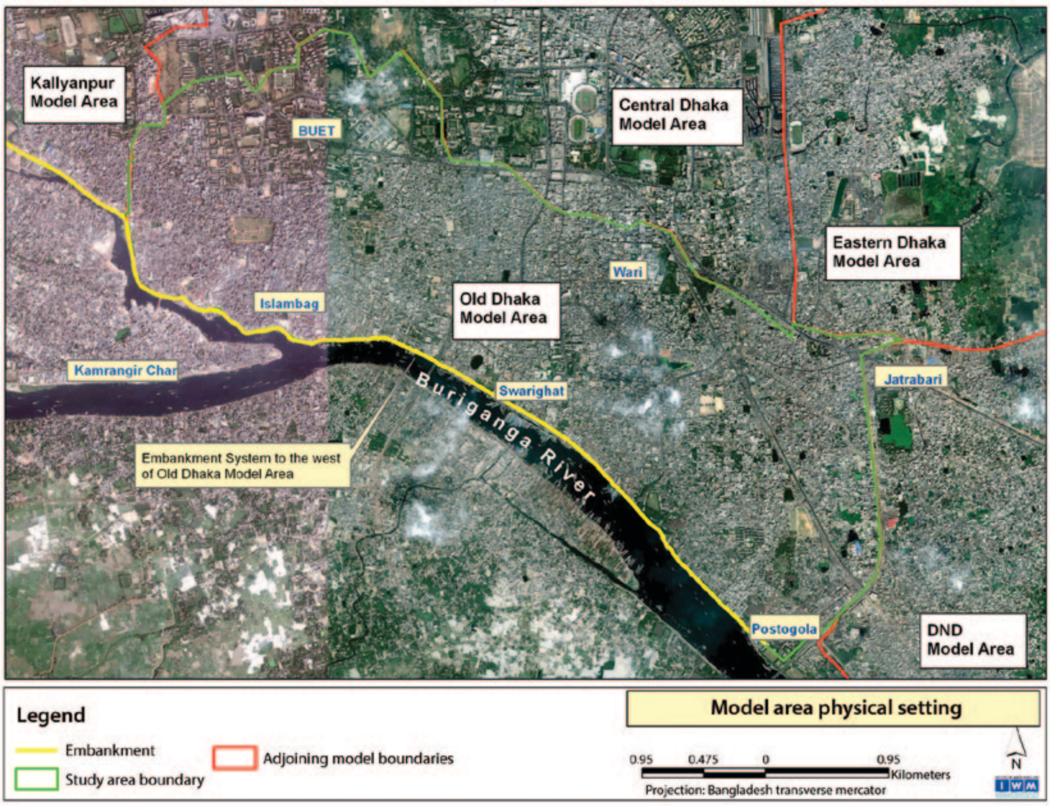
Old Dhaka Model Setup

The model selected for Old Dhaka was MIKE Urban, and the area modeled covered about 12 km^2. The Old Dhaka area is protected by embankments along the western boundary. The stormwater networks drain into the Buriganga River through control structures (sluice gates) and Dholaikhal Pump Station. Embankments in the west (Western Flood Protection Embankment) protect Old Dhaka from river flooding (map 3.2).

Future Scenario: Socioeconomic Changes

In 2011, Old Dhaka had an estimated population of some 1.1 million, with an extremely high density of about 94,000 people per km^2. Data from the census for 2001 and 2011 was linearly interpolated to estimate the 2004 base-scenario density (92,305 per km^2). Using the 2011 census data, future changes

Map 3.2 Physical Setting of Old Dhaka Model with Adjoining Boundaries



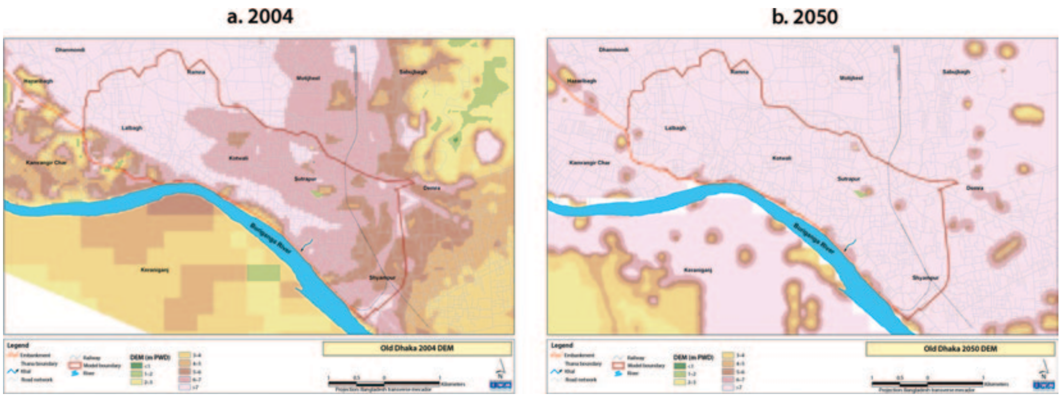
Source: IWM 2014.

in population densities up to 2050 were projected for Old Dhaka thanas (129,435 per km^2 in 2050) (IWM 2012).

Only 23 percent of the study area is below 6 m in elevation, including some low-lying areas below 5 m in elevation along the banks of the Buriganga River. The total area above 8 m in elevation accounts for 18 percent of the study area. Another 59 percent is in a range of 6–8 m in elevation. The study area also features a few small water bodies. For flood modeling, the DEM grid provided by IWM was used for the 2004 base model; for future scenarios, it was adjusted based on projected population densities and DAP-proposed land uses, as described in chapter 2 (map 3.3).

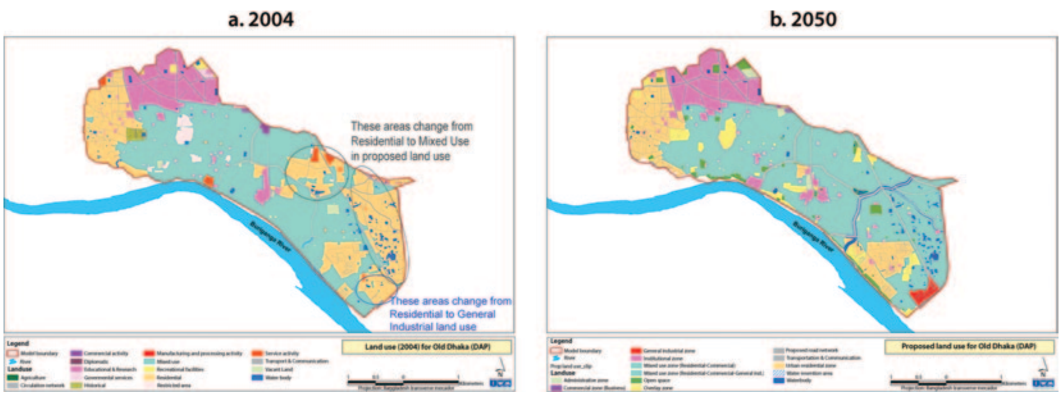
In 2004, about 94 percent of the study area was dedicated mainly to four uses: mixed use (48 percent), residential use (26 percent), education and research (11 percent), and transportation network (9 percent). The remaining 6 percent was used for government services and commercial activities, restricted and historical zones, water bodies, and scant vacant land. By 2050, pronounced changes in land-use patterns are expected for residential areas in the east and southeast, where respective plans include mixed use and dedicated industrial use. For example,

Map 3.3 Change in Land Elevation over the Study Period, Old Dhaka Model



Source: IWM 2014.

Map 3.4 Changes in Proposed Land Use over the Study Period, Old Dhaka Model



Source: IWM 2014.

some residential areas near Wari and Mirhazaribag have been declared mixed-use zones, and area near Shyampur has been declared a general industrial, instead of a residential, zone (map 3.4).

Drainage System: Base Scenario and Planned Improvements

Pipe networks dominate Old Dhaka's drainage system. For the 2004 base scenario, the system includes some 24 km of stormwater pipes and 3.64 km of box-culverts and open intake canal of Dholaikhal Pump Station. For future scenarios, planned improvements include another 6 km of pipe networks, along with rehabilitated and diverted pipes. All pipes and box-culverts were assumed to drain into the Buriganga River (map 3.5, photo 3.1).

Other Parameters and Features

The area's only permanent pumping station, at Dholaikhal, has a 22.4 m^3/s capacity, with three pumps (each with a 7.47 m^3/s capacity). Since installation,

Map 3.5 Planned Drainage System Improvements for Old Dhaka

Source: IWM 2014.

only two of the three pumps have been run simultaneously, with the third kept on stand-by (photo 3.2). But during the 2004 flood, only one pump was operational, and 22 temporary pumps (each with a 0.14 m^3/s capacity) were installed at various locations. These pumps were also considered for future scenarios. For permanent pumps, an efficiency level of 80 percent was considered, while 75 percent was considered for temporary pumps. As flood-control structures, the six sluice gates were included in the base model. For all scenarios, these gates were kept closed, as the high anticipated river-water level would block natural drainage, depicting the worst possible scenario for urban flooding.

For the 2004 base scenario, the model was divided into 262 subcatchments. These were delineated according to the distribution of drainage networks and land terrain. For future scenarios, some of the subcatchments were split further due to installation of new drainage pipes, resulting in a total of 275 subcatchments (table 3.4).

Sedimentation depth was estimated by IWM via field inspections and discussions with DWASA engineers. For pipes, sedimentation depth was estimated as 20 percent of pipe diameter and, for box-culverts, as 33 percent of section height (table 3.4).

The 2004 base model included 50 percent contribution of wastewater to the drainage system. A study that compared wastewater and runoff contribution for the 2004 base case concluded that the ratio between peak runoff (from the 1-in-30-year event, with a peak intensity of 93 mm per hour) and the wastewater rate was less than 1 percent for 255 out of the 262 subcatchments. For the other 7, the ratio was within 5 percent. The study also calculated the ratio of total accumulated

Photo 3.1 Site investigation to measure sediment depth in box-culvert

Credit: © Asif Zaman / World Bank. Used with permission. Further permission required for reuse.

wastewater volume to total accumulated runoff (from the 1-in-30-year design storm, at 211 mm per day). It was seen that 247 out of 262 subcatchments had a ratio below 20 percent, suggesting that wastewater flow has a minimal effect on flooding. Thus, wastewater was not included in the 2050 scenarios (table 3.4).

Key Assumptions

The following key assumptions were made for the 2050 simulations for the Old Dhaka model:

- All stormwater from the model area drains out to the Buriganga River through the drainage networks.

Photo 3.2 Drainage pumps at Dholaikhal Pump Station, Old Dhaka

Credit: © Asif Zaman / World Bank. Used with permission. Further permission required for reuse.

Table 3.4 Development Baseline: Key Assumptions Comparison between 2004 and 2050, Old Dhaka Model

Parameter or key feature	*2004*	*2050*
Population density (persons/km^2, weighted average)	92,305	129,435[a]
Land level (m PWD, average)	7.24	7.68
Subcatchments (number)	262	275
Imperviousness (%, weighted average)	71	76
Time of concentration (minutes, weighted average)	88.26	86.53
Initial loss (m)	0.01	0.01
Reduction factor	0.9	0.9
Total length of pipes, box-culverts, and khals (km)	27.77	33.88
Wastewater (% of total domestic load)	50	0
Sedimentation (%)		
Pipes (diameter)	20	20
Box-culverts (section height)	33	33
Ponding area (km^2)	0.011	0.011
Pumps (number)		
Permanent	3	3
Temporary	22	22
Total pump capacity (m^3/s)	25.48	25.48
Working efficiency of pumps (%)		
Permanent	80	80
Temporary	75	75
Sluice gates (number)	6	6

a. This projected value is based on past trends; densification is presently continuing, but at a comparatively lower rate.

- All sluice gates/regulators remain closed during the monsoon season; that is, there is no natural gravity drainage to the river (worst-case flooding).
- Embankments in the west protect the area from river flooding.[3]
- Operating efficiency of permanent pumps at Dholaikhal Station is considered as 80 percent; temporary pumps are considered to have 75 percent efficiency.
- Sediment depth remains 20 percent of the diameter of drainage pipes and 33 percent of the section height of box-culverts.
- Initial water level at Dholaikhal is considered as 4 m Public Works Department (PWD).
- In 2004–12, significant changes were made in the drainage system of BUET and in Islambag areas. In other areas, the drainage system remains almost the same, except for construction of some new drainage lines and a few rehabilitation works. DWASA has no major plans for improving Old Dhaka's drainage system.
- Wastewater will not contribute to the stormwater drainage system in the future as a result of DWASA's implementation of the Sewerage Master Plan for Dhaka (DWASA 2012).

Boundary Conditions

For all scenarios, the water level of the Dohlaikhal Pump Station (4 m PWD) was used as an initial boundary condition. For future scenarios, initial boundary conditions also included discharge data from the Central Dhaka model. None of the scenarios used the water level of the Buriganga River as an external boundary condition because all six flood control structures (sluice gates) are expected to remain closed during the peak of the monsoon season.

Central Dhaka Model Setup

The MIKE Urban platform was selected for Central Dhaka, and the area modeled covered about 39.2 km^2 located in the center of the detailed study area. The model area has four adjoining models: Goranchatbari to the north, Eastern Dhaka to the east, Old Dhaka to the south, and Kallyanpur to the west (map 3.6). Several wide roads serve as transportation arteries in more densely populated areas, such as Malibag and Shantinagar, while narrow roads are common in areas of relatively low-population density, such as Ramna and Gulistan. Embankments in the west and east (Western Flood Protection Embankment and Pragati Sharani, respectively) protect Central Dhaka from river flooding.

Future Scenario: Socioeconomic Changes

Central Dhaka has a rapidly growing population, whose overall density is projected to reach about 95,000 per km^2 by 2050—58,000 per km^2 more than in 2011 (IWM 2012). Population densities above 60,000 per km^2 are projected for all but two thanas (Cantonment and Demra).

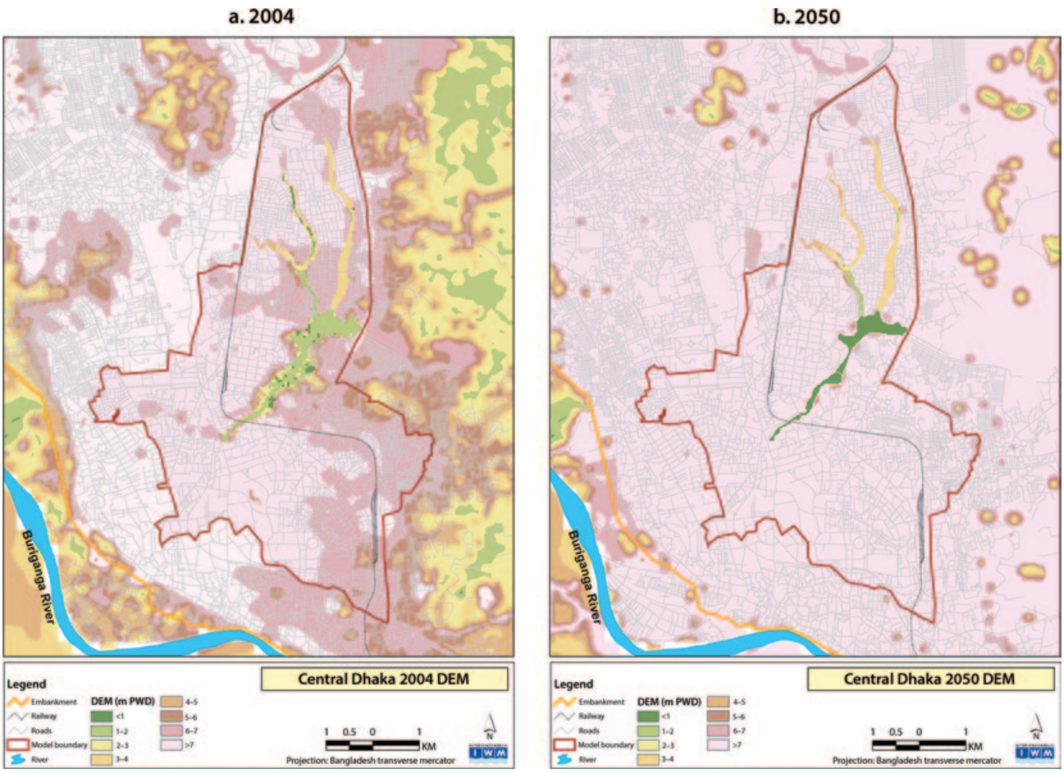
For three-fourths of the area, land elevation is in a range of 6.5–8.0 m PWD; another 13 percent is above 8.5 m PWD, and the other 12 percent—with the exception of three lakes—is below 6.5 m PWD (2004 figures). A uniform land level above 7 m PWD is expected to have been achieved by 2050 (map 3.7).

Map 3.6 Physical Setting of Central Dhaka Model with Adjoining Boundaries

Source: IWM 2014.

A substantial portion of land has been zoned for either urban residential (40.17 percent) or mixed use (12.32 percent); by 2050, these two categories will still account for more than half of all land use (map 3.8). New developments will be more pronounced in eastern areas, and southeastern residential areas near Motijheel will be re-zoned for mixed use. By 2050, impervious land will have reached 82 percent. Preservation of the area's three lakes—located at Hatir Jheel, Gulshan, and Banai—is expected. All three serve as retention ponds, with a total ponding area of 1.91 km^2. The lakes are connected to the Balu River via the

Map 3.7 Change in Land Elevation over the Study Period, Central Dhaka Model



Source: IWM 2014.

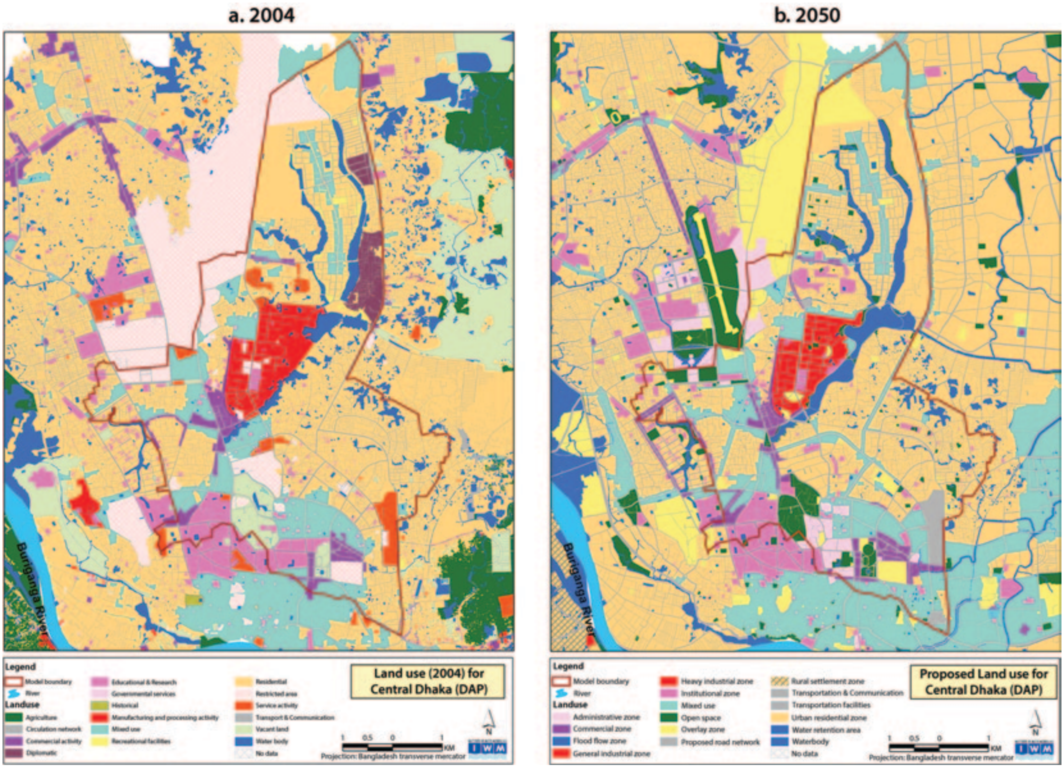
Begunbari Khal. Sluice gates and drainage pumps at the Rampura Bridge control the lakes' flow to the khal.

Drainage System: Base Scenario and Planned Improvements

Central Dhaka's drainage system consists of pipes, box-culverts, and khals (map 3.9). The 2004 base scenario includes about 104.3 km of stormwater pipes, 9.7 km of box-culverts, and 10 km of open canals. Additional drainage pipeline (1,500 mm diameter) has been recently laid along Gulshan Lake to protect it from wastewater pollution; 34 km^2 at the center of the area drains to Hatir Jheel, while the rest drains to Manda Khal. The area has two temporary pump stations, Rampura and Maniknagar, whose respective pump capacities are 4.5 m^3/s and 2.5 m^3/s (photo 3.3).

In 2004, the total length of the drainage network was about 124 km, with a total pump capacity of 7 m^3/s. Future scenarios assumed a total drainage-network length of 139 km, with a total pump capacity of 25–40 m^3/s at Rampura and 15 m^3/s at Maniknagar. The start-and-stop levels for permanent pumps were considered as 5.25 m and 5.0 m, respectively.[4] Future scenarios assumed efficiency levels of 90 percent for permanent pumps (table 3.5).

Map 3.8 Changes in Proposed Land Use over the Study Period, Central Dhaka Model



Source: IWM 2014.

Other Parameters and Features

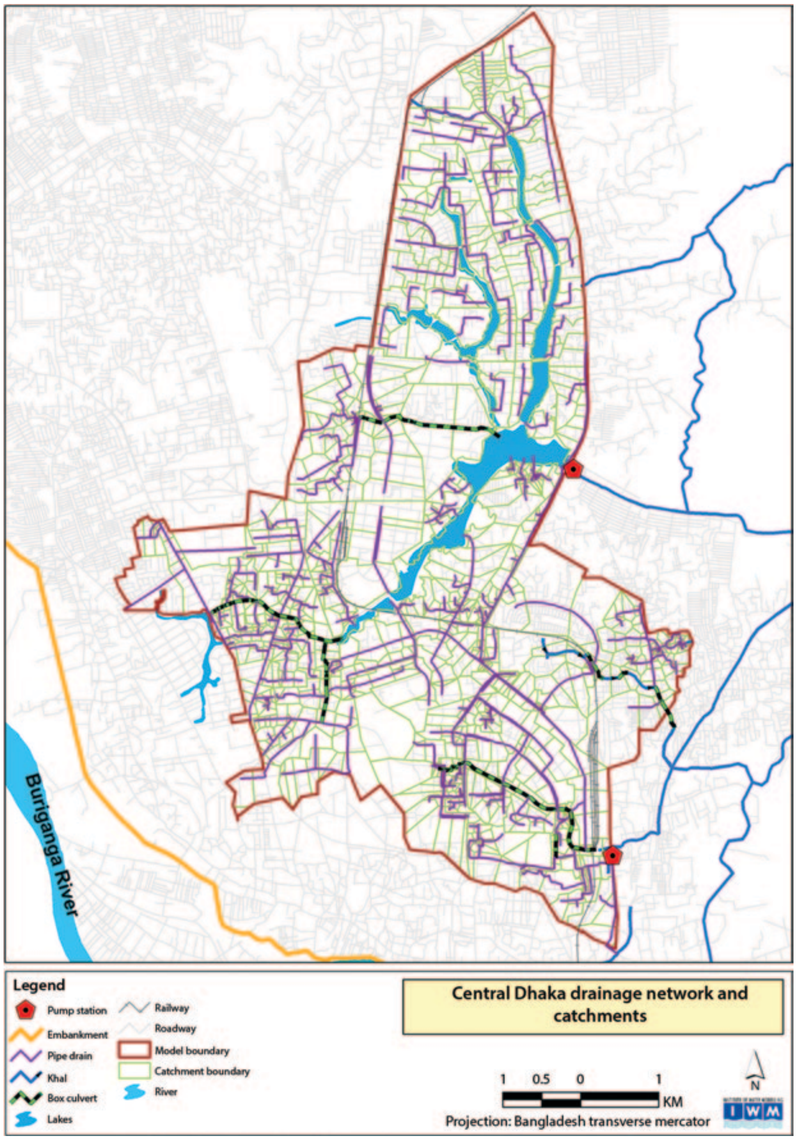
The 2004 model area was divided into 315 subcatchments, delineated according to the distribution of drainage networks and land terrain (table 3.5). In future scenarios, the impervious area of subcatchments will increase from 10–96 percent (2004) to 14–99 percent (2050). The Hatir Jheel cross-section will be implemented in accordance with the RAJUK proposal (RAJUK 2008). Sedimentation depth was estimated by IWM via field inspections and discussions with DWASA engineers. For pipes, sedimentation depth was estimated as 20 percent of pipe diameter and, for box-culverts, as 20 percent of the section height (table 3.5). All scenarios assumed that wastewater flow is insignificant compared to the runoff volume generated by the extreme rainfall events being simulated.

Key Assumptions

The following key assumptions were made for the 2050 simulations for the Central Dhaka model:

- All stormwater is pumped out to the Begunbari and Manda Khals (open channels of the Eastern Dhaka model), and eventually falls to the Balu River.

Map 3.9 Planned Drainage System Improvements, Central Dhaka



Source: IWM 2014.

- A portion of the runoff from ward 75 drains to Dholaikhal in the Old Dhaka model.
- All sluice gates, located at Rampura, Kamalapur, and Bashabo, remain closed during the monsoon season; this means there is no gravity drainage to the river, depicting the worst case of urban flooding.
- Embankments in the west and east protect the area from river flooding.
- The two temporary pump stations at Rampura and Maniknagar will become permanent pump stations with a total capacity of 40 m^3/s; permanent pumps will have a 90-percent operating efficiency.

Photo 3.3 Pumping floodwater out of Hathir Jheel using temporary pumps, Central Dhaka

Credit: © Asif Zaman / World Bank. Used with permission. Further permission required for reuse.

Table 3.5 Development Baseline: Key Assumptions Comparison between 2004 and 2050, Central Dhaka Model

Parameter or key feature	*2004*	*2050*
Population density (persons/km^2, weighted average)	33,160	95,160
Land level (m PWD, average)	7.03	7.54
Subcatchments (number)	315	315
Imperviousness (%, weighted average)	68	82
Time of concentration (minutes, weighted average)	24	22
Initial loss (m)	0.01	0.01
Reduction factor	0.9	0.9
Total length of pipes, box-culverts, and khals (km)	124	139
Sedimentation (%)		
Pipes (diameter)	20	20
Box-culverts (section height)	20	20
Ponding area (km^2)	1.91	1.91
Pump stations (number)		
Permanent	0	2
Temporary	2	0
Total pump capacity (m^3/s)	7	40
Working efficiency of pumps (%)		
Permanent	n.a.	90
Temporary	60	n.a.
Sluice gates (number)	3	3

Note: n.a. = not applicable.

- Sediment depth remains 20 percent of the diameter of the drainage pipes and 20 percent of the section height of box-culverts.
- Wastewater volume will be insignificant compared to runoff volume and will not enter the drainage system.
- The initial water level at Hatir Jheel, Banani Lake, and Gulshan Lake is considered as 5 m PWD.

Boundary Conditions

Outside river-water levels were not used as external boundary conditions since they do not influence flooding, given that sluice gates remain closed for all scenarios. An inflow boundary was used at the upstream end of the Panthapath Box-Culvert to represent the contribution from a small portion of ward 49 from the Kallyanpur model.

Kallyanpur System Model Setup

The MIKE Urban platform was selected for the Kallyanpur system model, which covered about 27.8 km^2. Kallyanpur is a densely populated, urban area on the west side of Dhaka City, situated along the Turag River. The river's Western Embankment (left bank) protects Kallyanpur from river flooding. The model area is adjoined by three models: Goranchatbari to the north, Central Dhaka to the east, and Old Dhaka to the south (map 3.10).

Future Scenario: Socioeconomic Changes

A key contributor to Dhaka's economy, Kallyanpur has steadily increasing population densities in both high-density (e.g., Lalbagh) and low-density (e.g., Cantonment) thanas. The area's overall population density is projected to reach 92,946 per km^2 by 2050, nearly twice the 2011 level (IWM 2012).

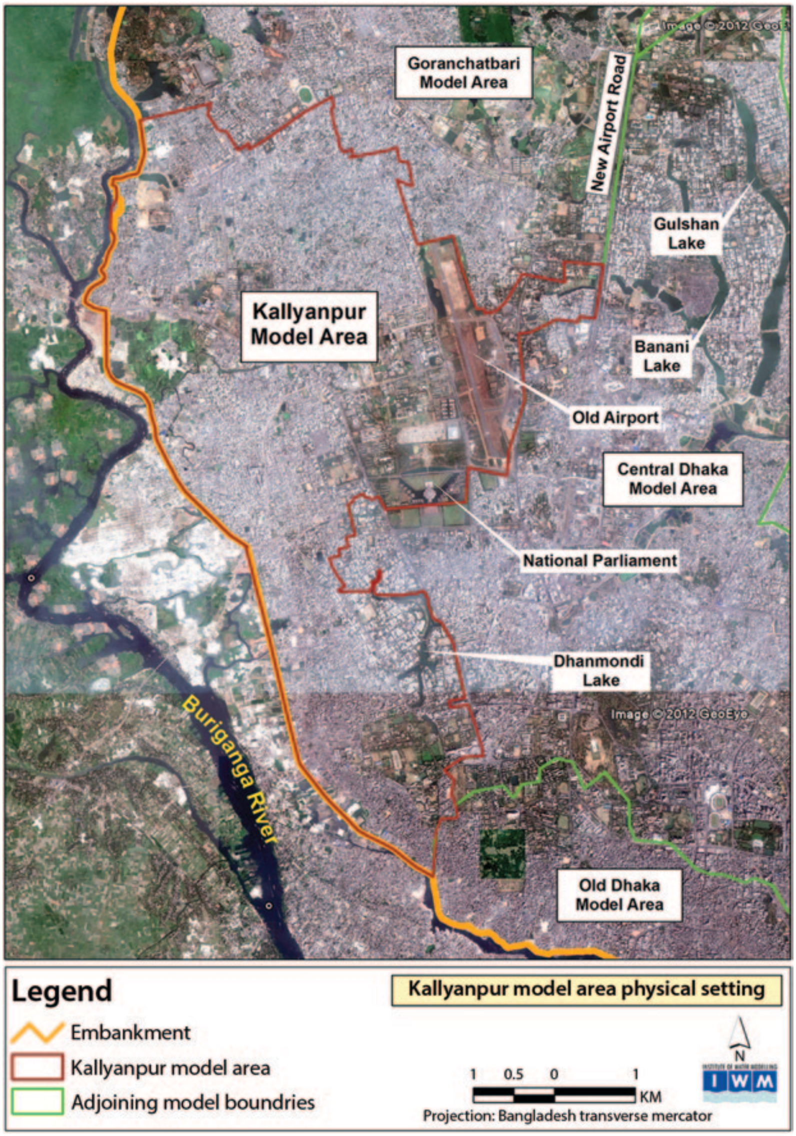
The Kallyanpur system model features generally flat terrain, consisting mainly of low-lying areas along the Western Embankment. In 2004, about 93 percent of the area was above 6 m PWD in elevation. By 2050, it is expected that all land below 6 m PWD will have reached a uniform level above 7.96 m PWD on average, with only designated water bodies remaining in low-lying areas (map 3.11).

In 2004, the following categories comprised about 90 percent of land use: residential, manufacturing and processing activity, restricted area (Old Airport and Peelkhana Cantonment), transportation network, education and research, and water bodies. By 2050, more than three-fifths of land will have been zoned for either residential use or the transportation network. Vacant land and water bodies are expected to increase, mainly replacing restricted and agricultural areas. Catchment impervious areas are projected to grow by 15 percent (from 51 percent in 2004 to 66 percent in 2050) (map 3.12).

Drainage System: Base Scenario and Planned Improvements

The Kallyanpur system model's drainage system consists mainly of pipes, box-culverts, khals, and lakes. The main khals are Ramchandrapur, Katasur, and

Map 3.10 Physical Setting of Kallyanpur System Model with Adjoining Boundaries

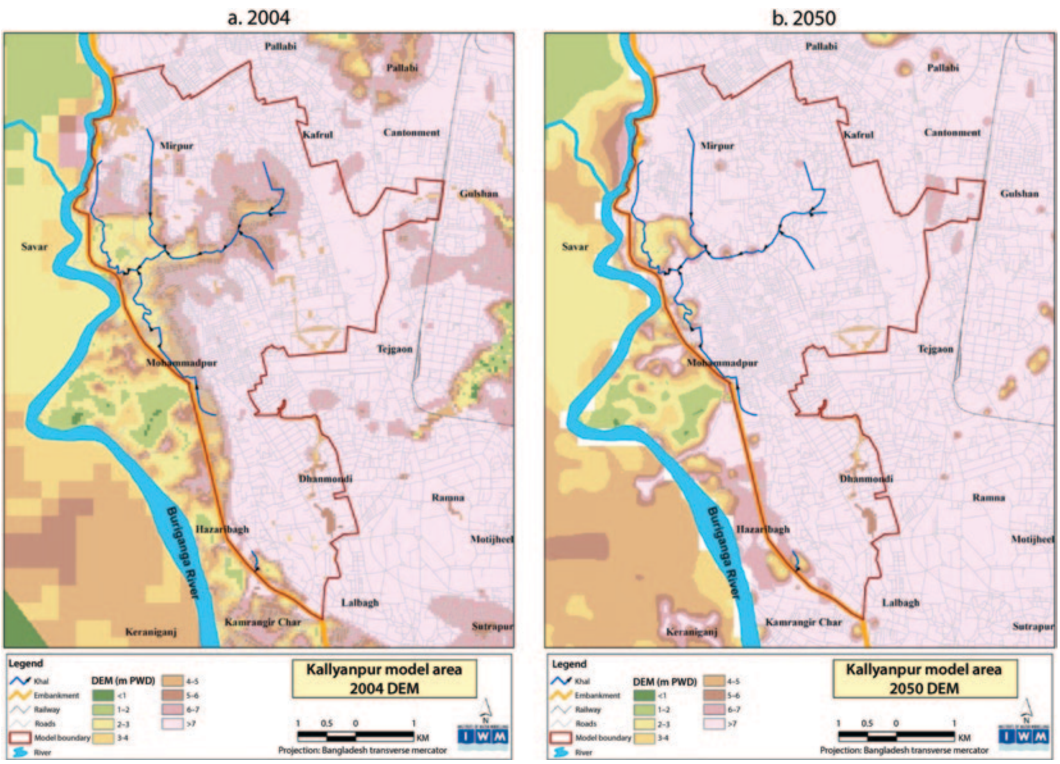


Source: IWM 2014.

various branches of Kallyanpur in the northern part of system. Most of the drains and khals carry stormwater to the Kallyanpur Retention Pond, a one-km^2 (100 ha) area located in the northwest part of the system (photo 3.4).[5] Stormwater is pumped from the pond to the Turag River via the Western Embankment.

For 2004, the system model setup included about 55.5 km of stormwater pipes, drains, and khals (map 3.13). The main features were a permanent pump station at Kallyanpur with a 10 m^3/s capacity and 80 percent efficiency and four temporary pump stations (one located at Rayerbazar and one near Sikder

Map 3.11 Change in Land Elevation over the Study Period, Kallyanpur System Model



Source: IWM 2014.

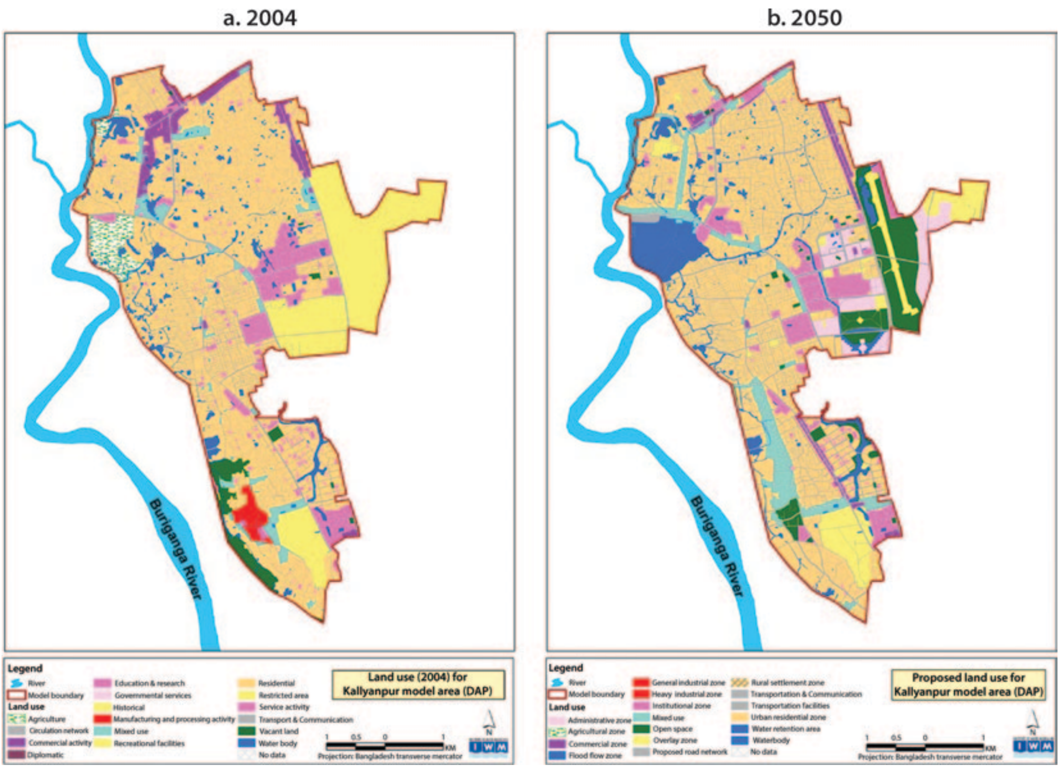
Medical College with respective capacities of 0.14 m^3/s and 0.56 m^3/s and two in Hazaribag, each with a 0.35 m^3/s capacity), all of which had a working efficiency of 60 percent (map 3.13, photo 3.5).

For 2050, recent capacity improvements at Kallyanpur Pump Station (to 20 m^3/s) were incorporated into the drainage model. Efficiency levels were considered as 80 percent for permanent pumps and 60 percent for temporary pumps. The drainage system also included new pipes, for a total length of about 75 km, and some changes to khal cross-sections. The number of subcatchments increased to 374, 38 more than in 2004 (table 3.6).

Other Parameters and Features

Sedimentation depth was estimated by IWM via field inspections and discussions with DWASA engineers. For pipes, sedimentation depth was estimated as 20 percent of pipe diameter (table 3.6). For the 2004 base scenario, it was assumed that 100 percent of domestic wastewater load enters the stormwater drainage system. However, for all future scenarios, it was assumed that wastewater flow is separate from the stormwater system, as proposed by the Dhaka Sewerage Master Plan (DWASA 2012).

Map 3.12 Changes in Proposed Land Use over the Study Period, Kallyanpur System Model



Source: IWM 2014.

Photo 3.4 Kallyanpur Retention Pond in the dry season

Credit: © Subhendu Roy / World Bank. Used with permission. Further permission required for reuse.

Map 3.13 Kallyanpur System Model Drainage Network and Subcatchments, 2004

Source: IWM 2014.

Key Assumptions

The following key assumptions were made for the 2050 simulations for the Kallyanpur system model:

- All sluice gates, which are located along the Western Embankment, remain closed for all scenarios, depicting the worst possible urban flood situations.
- The Western Flood Embankment protects the area from river flooding.
- Operating efficiency is 80 percent for permanent pumps at Kallyanpur Station and 60 percent for temporary pumps.
- Sediment depth remains 20 percent of the diameter of drainage pipes.
- Wastewater volume is insignificant compared to the runoff volume generated by the extreme rainfall events simulated as a result of DWASA's implementation of the Sewerage Master Plan for Dhaka (DWASA 2012); thus,

Photo 3.5 Outlet of temporary drainage pumps on the Western Embankment near Rayerbazar, Kallyanpur system

Credit: © Asif Zaman / World Bank. Used with permission. Further permission required for reuse.

Table 3.6 Development Baseline: Key Assumptions Comparison between 2004 and 2050, Kallyanpur System Model

Parameter or key feature	*2004*	*2050*
Population density (persons/km^2, weighted average)	40,509	92,946
Land level (m PWD, average)	7.26	7.97
Subcatchments (number)	336	374
Imperviousness (%, weighted average)	51	66
Time of concentration (minutes, weighted average)	37	35
Initial loss (m)	0.01	0.01
Reduction factor	0.9	0.9
Total length of pipes, box-culverts, and khals (km)	55.51	74.94
Wastewater (% of total domestic load)	100	0
Sedimentation for pipes (diameter) (%)	20	20
Ponding area (km^2)	1	1
Pump stations (number)		
Permanent	1	1
Temporary	4	4
Total pump capacity (m^3/s)	11.4	21.4
Working efficiency of pumps (percent)		
Permanent	80	80
Temporary	60	60
Sluice gates (number)	5	5

wastewater will not contribute to the stormwater drainage system in the future.
- The initial water level for Kallyanpur Retention Pond is considered as 4 m PWD.

Boundary Conditions

The water levels of outside rivers were not used as external boundaries because they have no influence on flooding, given that all sluice gates remain closed for all scenarios. A small part of ward 49 drains to Panthapath Box-Culvert, which is used as an inflow boundary for the Central Dhaka model.

Goranchatbari System Model Setup

The MIKE Urban platform was selected for the Goranchatbari system model, and the area modeled spans about 63.8 km^2 in northwestern Dhaka. The drainage system model area shares borders with the adjoining areas of Eastern Dhaka to the east, Central Dhaka to the southeast, and Kallyanpur to the south. The Western Embankment—from the Tongi Rail Station to Kellarmor on the city's west side—protects the area from flooding of the Turag River (map 3.14).

Future Scenario: Socioeconomic Changes

Goranchatbari has a steadily increasing population density, which is projected to reach about 92,000 people per km^2 by 2050, nearly three-and-one-half times the 2011 density (IWM 2012). The area varies widely socioeconomically. Most residents in planned, densely populated urban areas are engaged in commerce, while those in moderately populated, unplanned areas are involved in manufacturing and industrial-related activities; many women in unplanned areas work in garment and apparel factories.

Goranchatbari lies on a flat alluvial plain. In 2004, approximately three-fifths of the total study area was above 6 m PWD, while about one-fifth was above 8 m PWD. Two-fifths was in a range of 6–8 m PWD. The northwestern part of the study area comprises quite low-lying areas, including the Goranchatbari Retention Pond, situated along the left bank of the Turag River. Many low-lying areas have been raised and are being developed for urban residential use. By 2050, all land below 6 m PWD will have been raised to a uniform level above 7 m PWD, with an average level of 7.68 m PWD (map 3.15). Only designated water bodies will remain in low-lying areas. By 2050, it is expected that 66 percent of the study area will be impervious, compared to 51 percent in 2004.

In 2004, the vast majority of the study area (about 91 percent) was dedicated to four land-use categories: residential (40.11 percent), vacant land (21.53 percent), restricted area (15.17 percent), and water bodies (14.44 percent). The remaining areas functioned as transportation network, agricultural and educational areas, and recreational zones, with a small portion designated as a mixed-use zone; few areas were zoned for commercial, manufacturing and processing, and service activities (map 3.16).

Map 3.14 Physical Setting of Goranchatbari System Model with Adjoining Boundaries

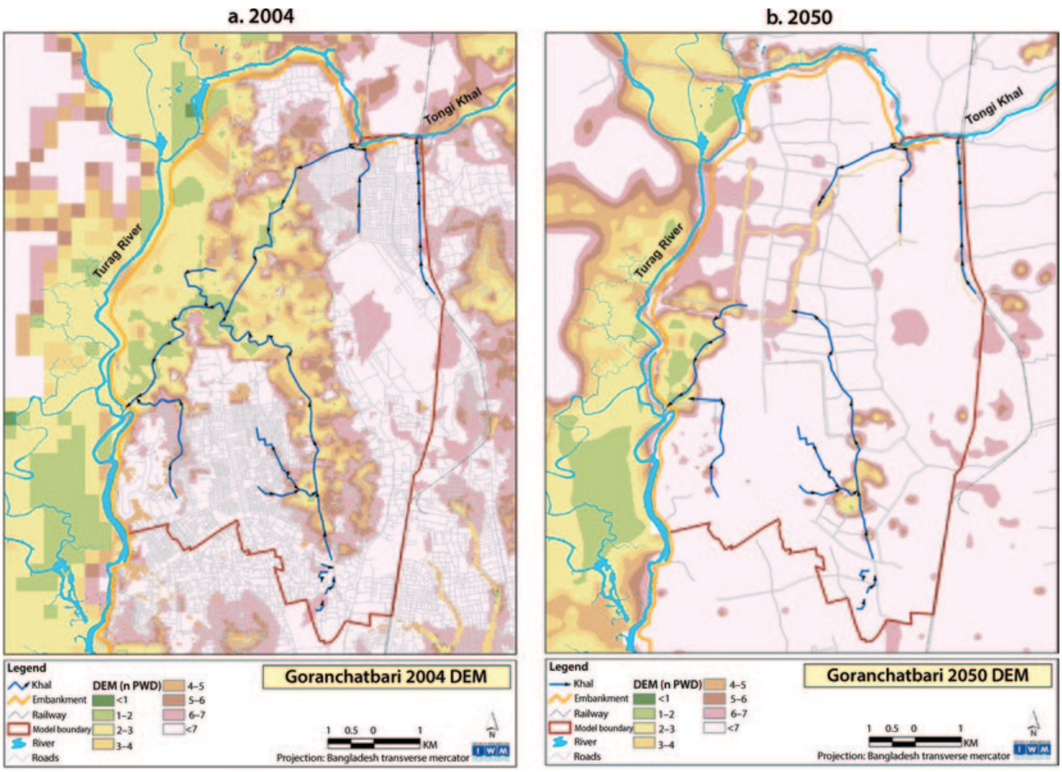
Source: IWM 2014.

By 2050, nearly 59 percent of the land will be zoned for urban residential use, while the transportation network will cover more than 7 percent. Vacant land and water bodies are expected to increase, primarily at the expense of restricted and agricultural areas (map 3.16).

Drainage System: Base Scenario and Planned Improvements

Goranchatbari has a predominantly natural drainage system, featuring khals that carry stormwater to the Goranchatbari Pump Station, where it is pumped

Map 3.15 Change in Land Elevation over the Study Period, Goranchatbari System Model



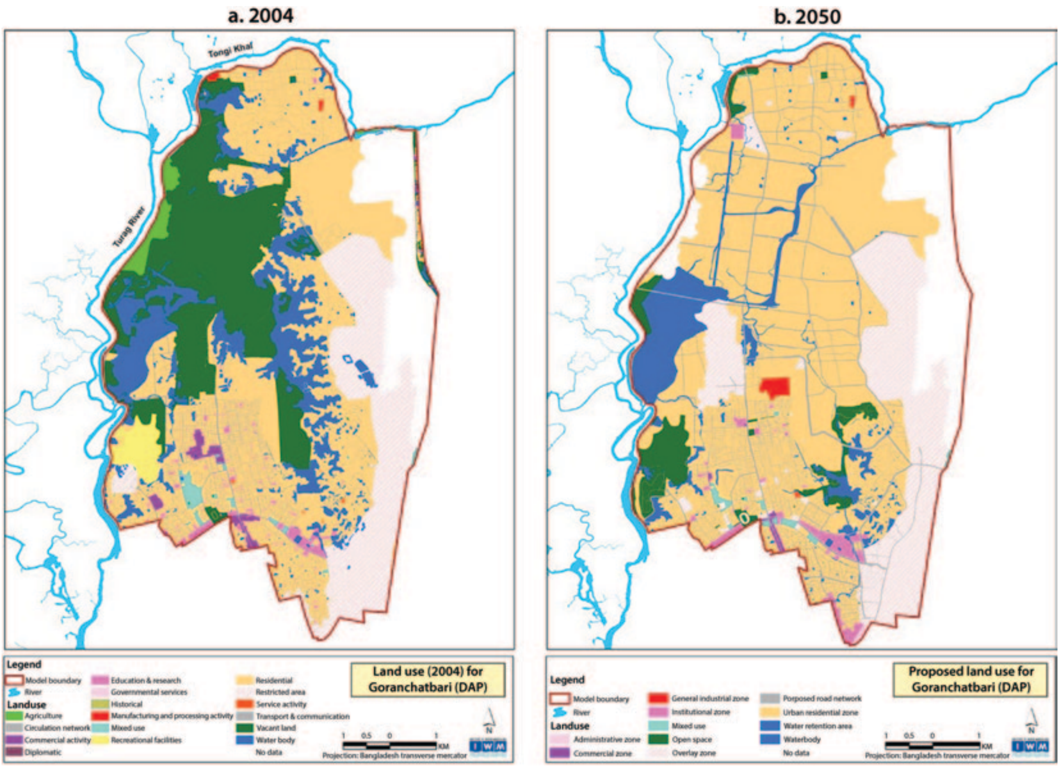
Source: IWM 2014.

to the Turag River via the Western Embankment. In 2004, the 2.43 km^2 retention pond area had a total pump capacity of 22 m^3/s, consisting of three pumps, each with a 7.33 m^3/s capacity. Based on observation of the pump logbook at the site, all pumps were run simultaneously during various extreme events. Currently, construction is under way to double the station's total pumping capacity to 44 m^3/s, with the addition of three pumps of equal capacity. Start-and-stop levels were considered as 4 m and 3.5 m PWD, respectively (IWFM 2005). For both 2004 and future scenarios, all pumps were considered to have an efficiency level of 85 percent.

In the northeastern part of the study area, some stormwater also drained to Tongi Khal through sluice gates. For all model simulations, these gates were kept closed due to high river levels, representing the worst possible case for urban flooding. The 2004 base scenario included about 44.6 km of drainage khals and storm sewers (map 3.17). The model area was divided into 134 subcatchments, which were delineated according to the distribution of drainage networks and land terrain.

By 2050, subcatchments will be split further due to the addition of drainage pipes or changes in land terrain, resulting in a total of 244 subcatchments,

Map 3.16 Changes in Proposed Land Use over the Study Period, Goranchatbari System Model



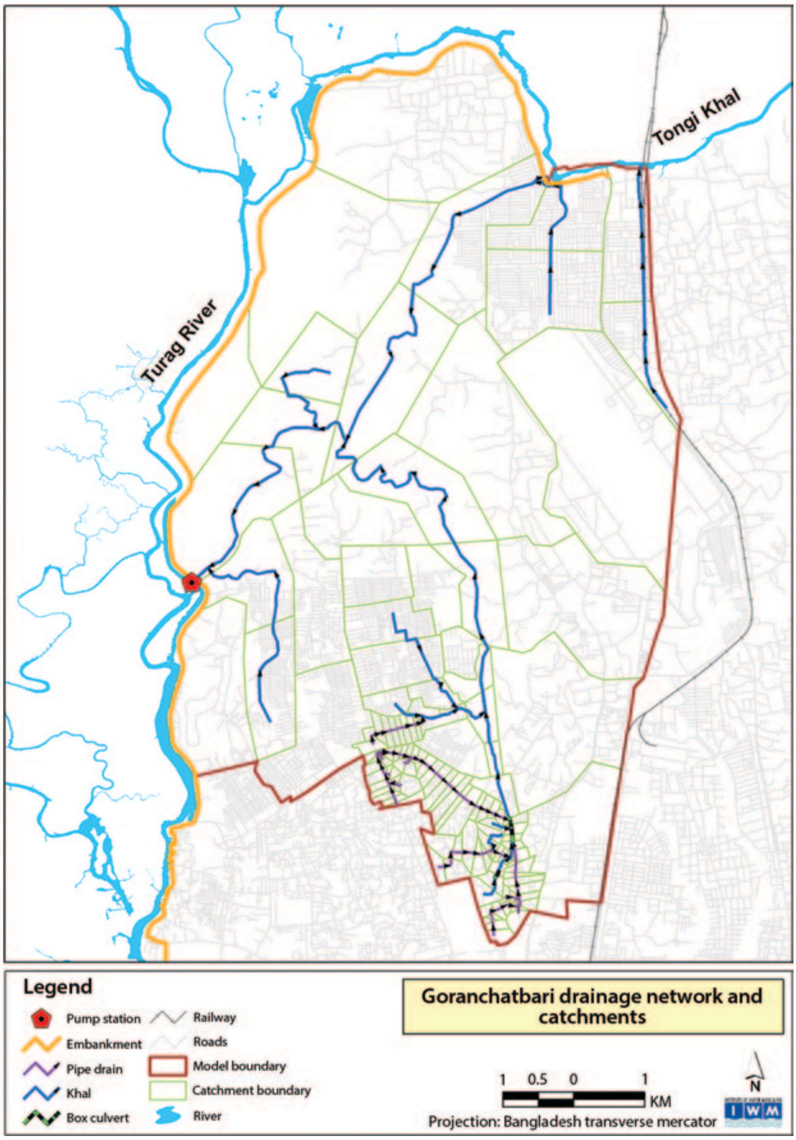
Source: IWM 2014.

110 more than in 2004. An additional 21.8 km of pipe networks were included as planned improvements, based on reports from DWASA and RAJUK, giving a total length of approximately 66 km. All pipes and canals were assumed to drain into the Turag River via the Goranchatbari Pump Station and Tongi Khal through sluice gates. The current capacity improvements at the Goranchatbari Pump Station were incorporated into the drainage model (table 3.7).

Other Parameters and Features

Because the Goranchatbari study area consists of a relatively new storm-sewer network, it was assumed that sedimentation in those pipes is not prominent; thus, all pipes were considered free of sediment for all scenarios (table 3.7). For the 2004 model setup, it was assumed that 100 percent of domestic wastewater load enters the stormwater drainage system. However, for all future scenarios, it was assumed that wastewater flow is separate from the stormwater system, as proposed by the Dhaka Sewerage Master Plan (DWASA 2012), and thus will not contribute to the drainage system (photo 3.6).

Map 3.17 Goranchatbari System Model Drainage Network and Subcatchments, 2004



Source: IWM 2014.

Key Assumptions

The following key assumptions were made for the 2050 model simulations for the Goranchatbari system:

- There are no water inflows into the Goranchatbari area from other drainage areas.
- All stormwater drains out to the Turag River and Tongi Khal through the drainage networks.

Table 3.7 Development Baseline: Key Assumptions Comparison between 2004 and 2050, Goranchatbari System Model

Parameter or key feature	*2004*	*2050*
Population density (persons/km^2, weighted average)	20,066	88,776
Land level (m PWD, average)	6.19	7.68
Subcatchments (number)	134	244
Imperviousness (%, weighted average)	42	62
Time of concentration (minutes, weighted average)	85	68
Initial loss (m)	0.01	0.01
Reduction factor	0.9	0.9
Total length of pipes, box-culverts, and khals (km)	44.6	66.4
Wastewater (% of total domestic load)	100	0
Sedimentation for pipes (diameter) (%)	0	0
Ponding area (km^2)	2.43	2.43
Pumps (number)		
Permanent	3	6
Temporary	0	0
Total pump capacity (m^3/s)	22	44
Working efficiency of pumps (%)		
Permanent	85	90
Sluice gates (number)	4	4

Photo 3.6 Water inlet after garbage filtering at Goranchatbari Pump Station

- All sluice gates remain closed during the monsoon season.
- The Western Embankment protects the area from river flooding.
- The operating efficiency of permanent pumps at the Goranchatbari Station is 90 percent (compared to 85 percent in the 2004 setup).
- Sedimentation in drainage pipes is minimal to none.
- Wastewater volume is insignificant compared to runoff volume.
- Initial water level at Goranchatbari Retention Pond is 4 m PWD.

Boundary Conditions

No upstream boundaries were used since there are no external inflows into the Goranchatbari system. For the downstream external boundary, the river water level was not used since it will not influence flooding, given that sluice gates remain closed for all model scenarios. The water level of the Goranchatbari Pump Station, 4 m PWD, was used as the initial condition for all scenarios.

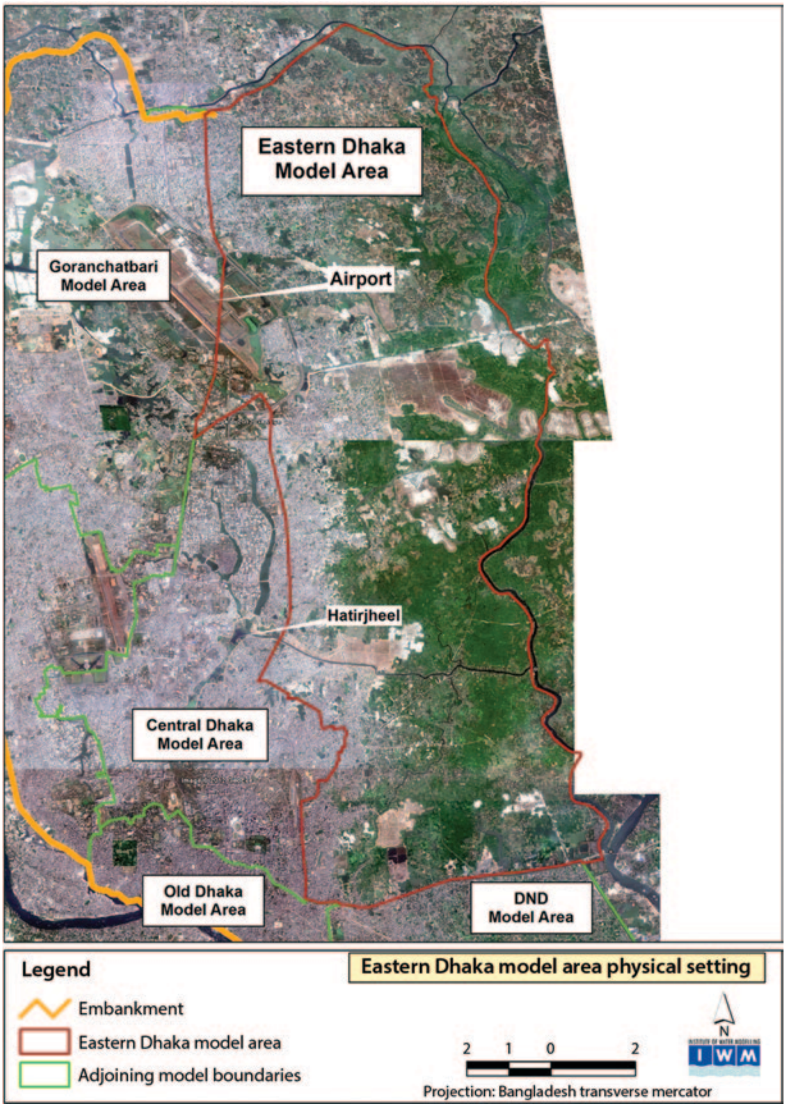
Eastern Dhaka Model Setup

The MIKE 11 platform was selected for the Eastern Dhaka model. This part of the city still remains unprotected from river flooding caused by overflow of the Balu and Lakhya rivers. Natural khals that fall into these two rivers comprise Eastern Dhaka's primary drainage system. The 121 km^2 area modeled features a mix of urban and rural landscapes interspersed with numerous wetlands and khals (photo 3.7). It is bounded by Tongi Khal to the north, the Balu River to the east,

Photo 3.7 Tin-shed house built on stilts in low-lying area of Khilgaon, Eastern Dhaka

Credit: © Asif Zaman / World Bank. Used with permission. Further permission required for reuse.

Map 3.18 Physical Setting of Eastern Dhaka Model with Adjoining Boundaries



Source: IWM 2014.

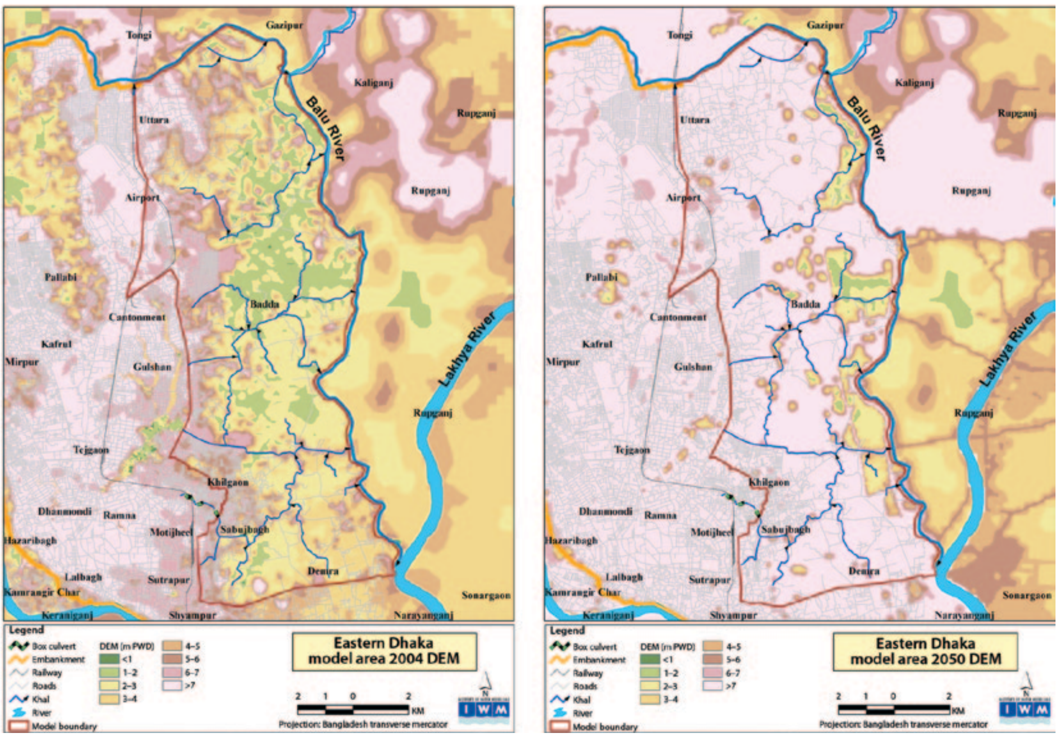
Demra Road to the south (which forms a boundary with the DND area), and Pragati Sarani—the high ridge that passes through the central part of the city—to the west. This western boundary forms the Eastern Embankment, and protects Western Dhaka from river flooding (map 3.18).

Future Scenario: Socioeconomic Changes

Eastern Dhaka has a steadily rising population density, estimated at about 17,000 people per km^2 in 2011. By 2050, it is expected to reach nearly 81,000 people per km^2 (IWM 2012).

Map 3.19 Change in Land Elevation over the Study Period, Eastern Dhaka Model

a. 2004 b. 2050



Source: IWM 2014.

Eastern Dhaka's land elevation is mainly within a 2–5 m PWD range, reaching up to 12 m PWD and as low as 0 m PWD near the Balu River. The development of low-lying areas for urban residential use is under way. Owing to land filling to accommodate increasing urbanization and population, all lower-elevation areas are expected to be raised up to 7 m PWD by 2050, with only designated water bodies remaining as low-lying areas. Impervious land is expected to reach about 71 percent by 2050, up from 19 percent in 2004 (map 3.19).

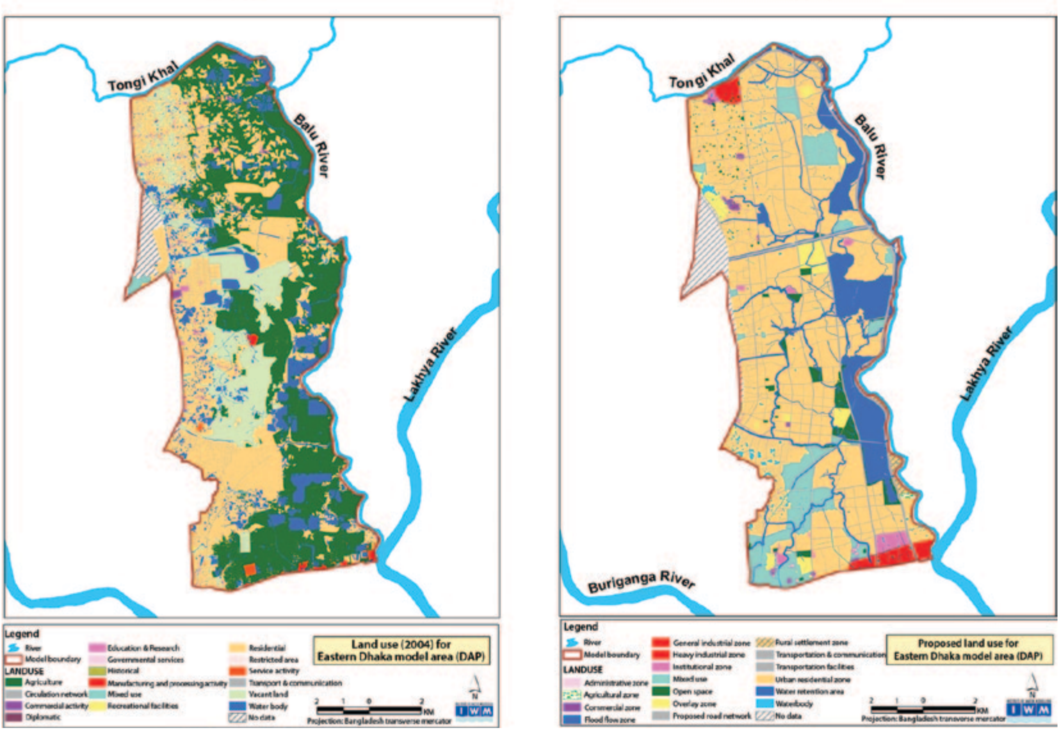
Major land-use categories in 2004 consisted of agriculture (34.4 percent) and residential use (34.2 percent), followed by vacant land (14.0 percent) and water bodies (13.2 percent) (RAJUK 2010). By 2050, the residential category is expected to account for 58.28 percent of land use, and residential/commercial mixed use area will comprise 8.11 percent. The water retention area will cover 11.99 percent, while the proposed road network will comprise 8.53 percent (map 3.20).

Drainage System: Base Scenario and Planned Improvements

Khals are the main component of Eastern Dhaka's drainage system. Major khals are Babur, Barail, Begunbari, Manda, Mangakhali, Satarkul, and Senoti.

Map 3.20 Changes in Proposed Land Use over the Study Period, Eastern Dhaka Model

a. 2004 b. 2050



Source: IWM 2014.

The Senoti Khal receives drainage water from Dhaka International Airport and the Nikunja residential area via sluice gates, while the Begunbari and Manda khals receive drainage water from Central Dhaka through sluice gates/pumps at Rampura and Maniknagar, respectively. The outfalls of the khals are mainly the Balu River; however, some also discharge into Tongi Khal. A bypass expected to be completed by 2025 will function as an embankment along the right bank of the Balu River and Tongi Khal. A dedicated sewerage system is planned for Eastern Dhaka under DWASA's 2012 Sewerage Master Plan (DWASA 2012).

Eastern Dhaka is divided into three large subcatchments (map 3.21). In the 2004 model setup, the total river and khal length was 164 km. The existing cross-section data for the khals was collected from the 2004 IWM survey and DWASA drawings. The Balu River is the main outfall for these khals. Some khals also discharge into Tongi Khal.

The Eastern Dhaka Bypass, expected to be completed by 2025, is designed to serve as an embankment along the right side of the Balu River and Tongi Khal. The parameters for the project's regulators and pump stations to control urban drainage congestion and river flooding have been adopted from a separate 2006

Map 3.21 Eastern Dhaka Drainage Network and Subcatchments, 2004

Source: IWM 2014.

modeling study conducted by Halcrow Bangladesh Limited. It is expected that all of the khals are to be resectioned as the design cross-section, according to Halcrow Bangladesh Limited (2006).

Other Parameters and Features

For future scenarios, it was assumed that the full cross-section, as conceived by Halcrow Bangladesh Limited (2006), will be available for conveying stormwater. It was also assumed that the dedicated sewerage system planned for the study area under DWASA's Sewerage Master Plan means that wastewater will not contribute to the drainage system in the future (table 3.8).

Table 3.8 Development Baseline: Key Assumptions Comparison between 2004 and 2050, Eastern Dhaka Model

Parameter or key feature	*2004*	*2050*
Population density (persons/km^2, weighted average)	12,523	73,516
Land level (m PWD, average)	3.4	7.45
Subcatchments (number)	3	3
Imperviousness (percent, weighted average)	19	71
Time of concentration (minutes, weighted average)	1,200	1,200
Initial loss (m)	0.01	0.01
Reduction factor	0.6	0.8
Total length of pipes, box-culverts, and khals (km)	157	157
Wastewater (% of total domestic load)	100	0
Pump stations (number)		
Permanent	0	3
Temporary	0	0
Total pump capacity (m^3/s)	0	245
Sluice gates (number)	0	6

Key Assumptions

The following key assumptions were made for the 2050 model simulations for Eastern Dhaka:

- All stormwater drains out to the Balu River and Tongi Khal through the drainage networks.
- The Eastern Dhaka Bypass Project will be completed.
- The proposed seven regulators and three pump stations will be operational.
- All stormwater drains out to the Balu River and Tongi Khal through the drainage networks.
- Initial loss and the reduction factor remain the same in the future.
- All sluice gates remain closed during the monsoon season.
- All khals will be resectioned as the design cross-sections provided by Halcrow Bangladesh Limited (2006).
- Retention ponds and water bodies identified in the DAP will be preserved; thus, catchment areas will not change in the future.
- The contribution of wastewater volume to the drainage system is insignificant compared to runoff volume.

Boundary Conditions

The Eastern Dhaka model has 4 river and 18 khal boundary conditions. In the 2004 model setup, the average monsoon water-level values were used at the river boundaries. Zero discharge was used as the upstream boundary for the khals, except for those receiving water from the Western Dhaka side (i.e., Begunbari and Manda khals). The boundary flows for these khals were obtained from the Central Dhaka model.

Table 3.9 shows the distribution of runoff contributions from the three catchments among the khals.

Table 3.9 Runoff Contribution into Khals, Eastern Dhaka Model

Catchment compartment (number)	*Contributing area (km²)*	*Khal (name)*
1	3.19	Tongi_K
1	2.65	AD3
1	22.70	Senoti
1	10.50	AD8
1	1.00	AD1
1	6.45	Babur
1	2.53	AD4
2	10.03	Satarkul_Barail
2	6.90	Shahzadpur
2	8.41	Mangakhali_Upper
2	1.85	Batara
2	3.11	Mangakhali_Lower
2	2.92	Meruler
2	7.91	Barail
3	0.97	CD9
3	1.57	Banabil
3	2.30	Gazaria
3	15.88	Manda
3	10.01	Joaira
3	5.41	Kajla
3	2.73	Khilgaon_Bashabo
3	37.34	Begunbari

Model Calibration

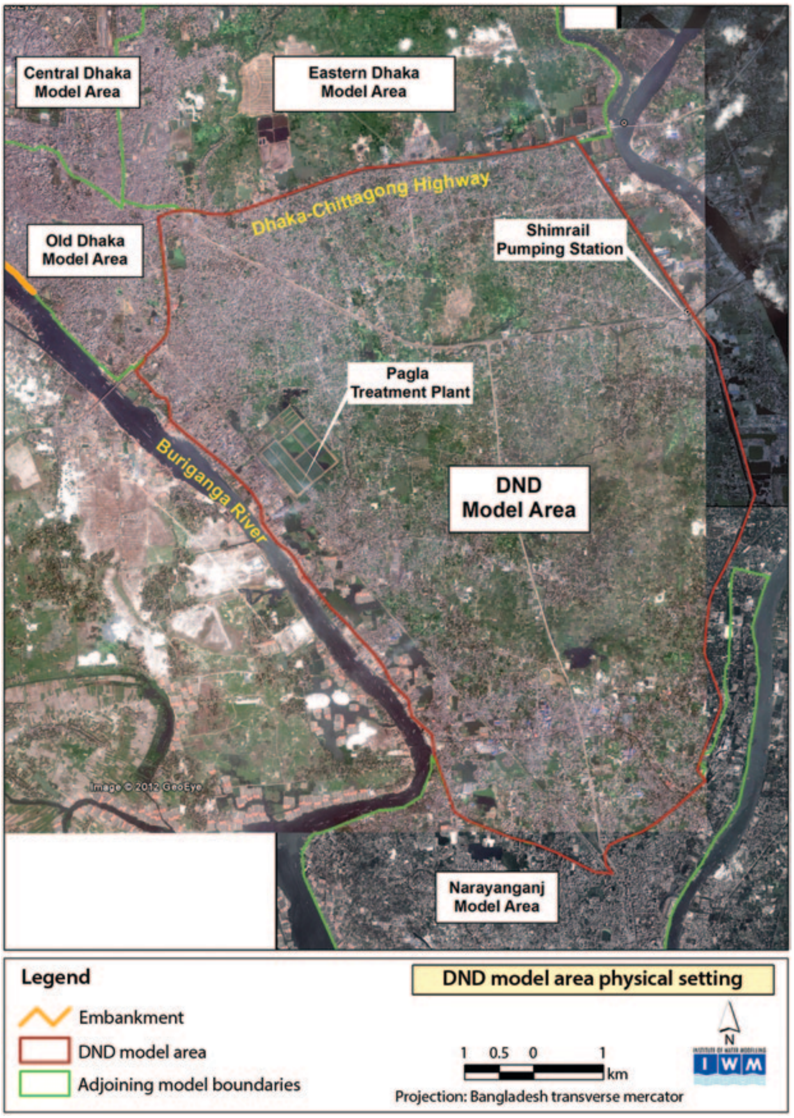
The original model of Eastern Dhaka was developed by IWM by truncating the NCRHD model and including the internal khal system as calibrated at Demra. Figure 2.3 (chapter 2) shows the comparison plots of the simulated and observed water levels.

The internal khal system has no other water level or discharge data; thus, more detailed calibration is not possible. The results for Demra indicate that the model performance is sufficiently sound for the modeling objective.

DND Model Setup

The MIKE 11 platform was selected for the Dhaka-Narayanganj-Demra (DND) model. This 59 km^2 area, located in southeast Dhaka, is subdivided by numerous khals. The area is bounded by the Dhaka-Chittagong Highway to the north, the Lakhya River to the east, Narayanganj township to the south, and the Buriganga River to the west (map 3.22). Flood embankments along the Lakhya and Buriganga rivers prevent fluvial flooding. In the past, DND land was of comparatively low value and relatively free of urban flooding and waterlogging. Today, however, waterlogging is a common occurrence during the monsoon season,

Map 3.22 Physical Setting of DND Model with Adjoining Boundaries



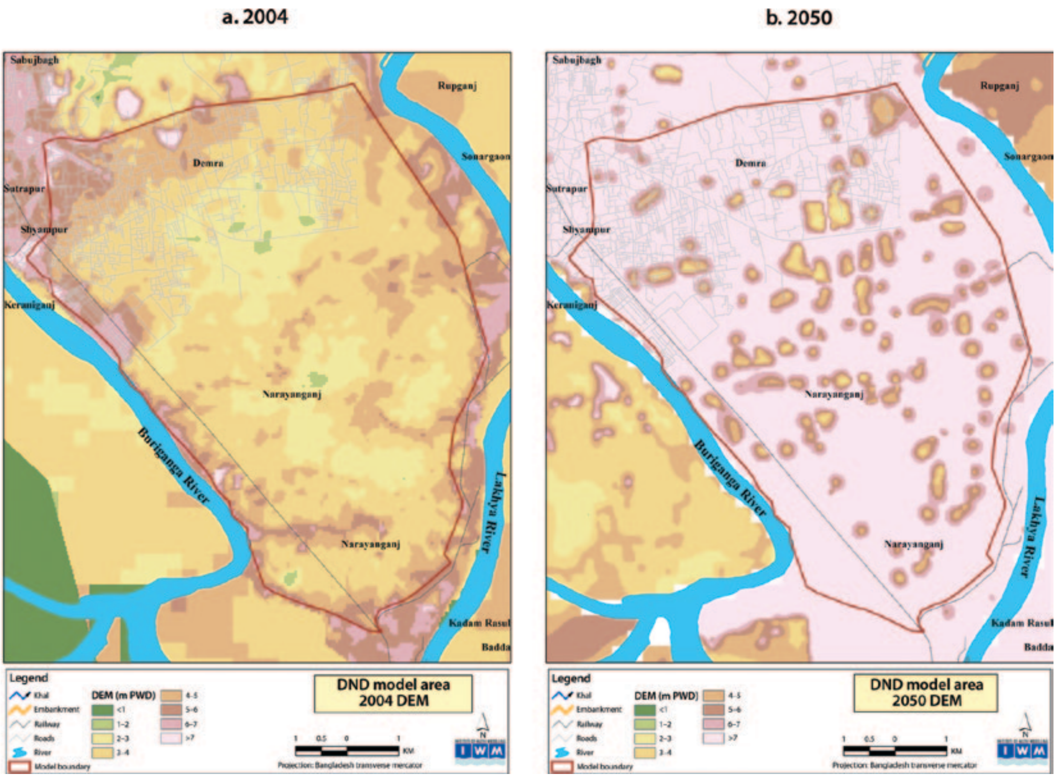
Source: IWM 2014.

owing to accelerated unplanned development and encroachment on drainage channels, despite embargos (RAJUK 2010).

Future Scenario: Socioeconomic Changes

The next few decades will witness a nearly fivefold increase in the DND area's population density, which is projected to reach 65,144 per km^2 by 2050. Among the area's four thanas, Shyampur and Demra are expected to exhibit the highest and lowest densities, respectively (IWM 2012).

Map 3.23 Change in Land Elevation over the Study Period, DND Model



Source: IWM 2014.

About half of the DND's land is at an elevation of 3–5 m PWD; another one-fifth is above 5 m PWD, and the remainder is in a range of 1.5–3 m PWD. By 2050, it is expected that most land will be raised above 7 m PWD (map 3.23). Land levels of proposed water bodies, open lands, recreational areas, flood-flow zones, and canals/khals in the DAP will not change in the future.

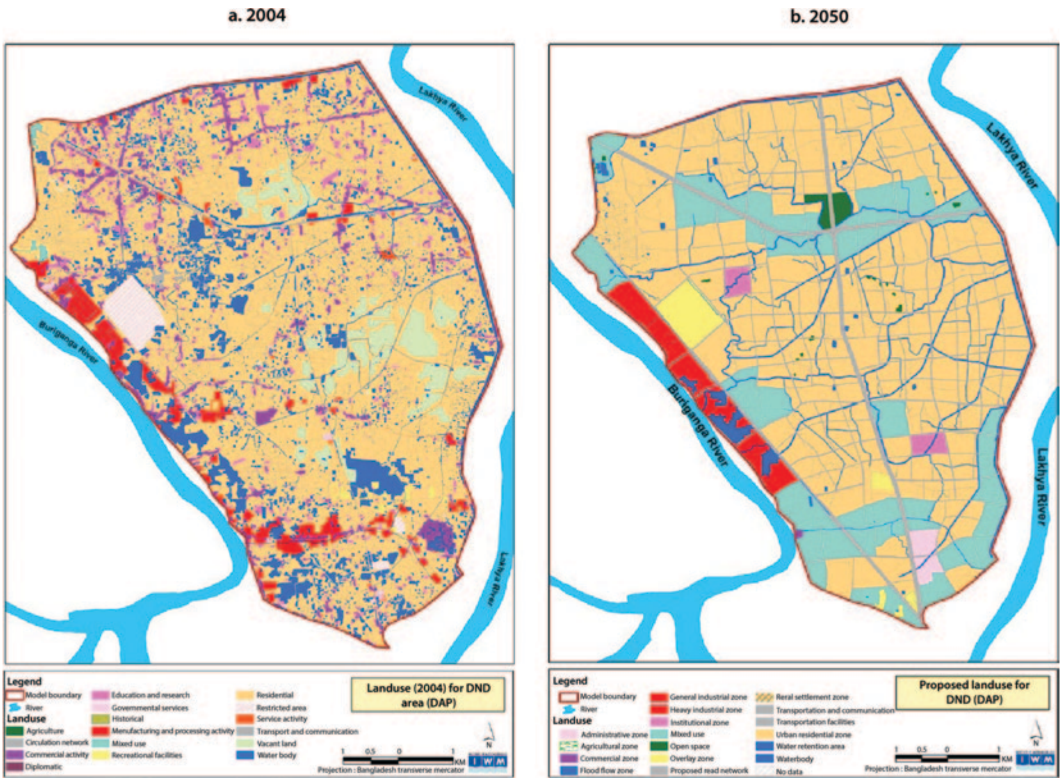
Haphazard urban development without adherence to standards has resulted in waterlogging during the monsoon season, often for prolonged periods. The flood risk is exacerbated by the poor permeability of soils, characterized by plastic silts and clay on a sand overlay. The percentage of impervious land will rise sharply in the future, significantly increasing runoff volume.

In 2004, about 64 percent of the DND area was zoned for residential use. By 2050, this percentage will decrease by about 7 percent, owing to the proposed increase in mixed-use areas. Other proposed land-use changes include an increase in road network and a reduction in free-flow zones (e.g., water bodies and water-retention areas) (map 3.24).

Drainage System: Base Scenario and Planned Improvements

The drainage system includes some 85 km of khals, which carry both stormwater and wastewater toward Shimrail Pump Station, where water is pumped out into

Map 3.24 Changes in Proposed Land Use over the Study Period, DND Model



Source: IWM 2014.

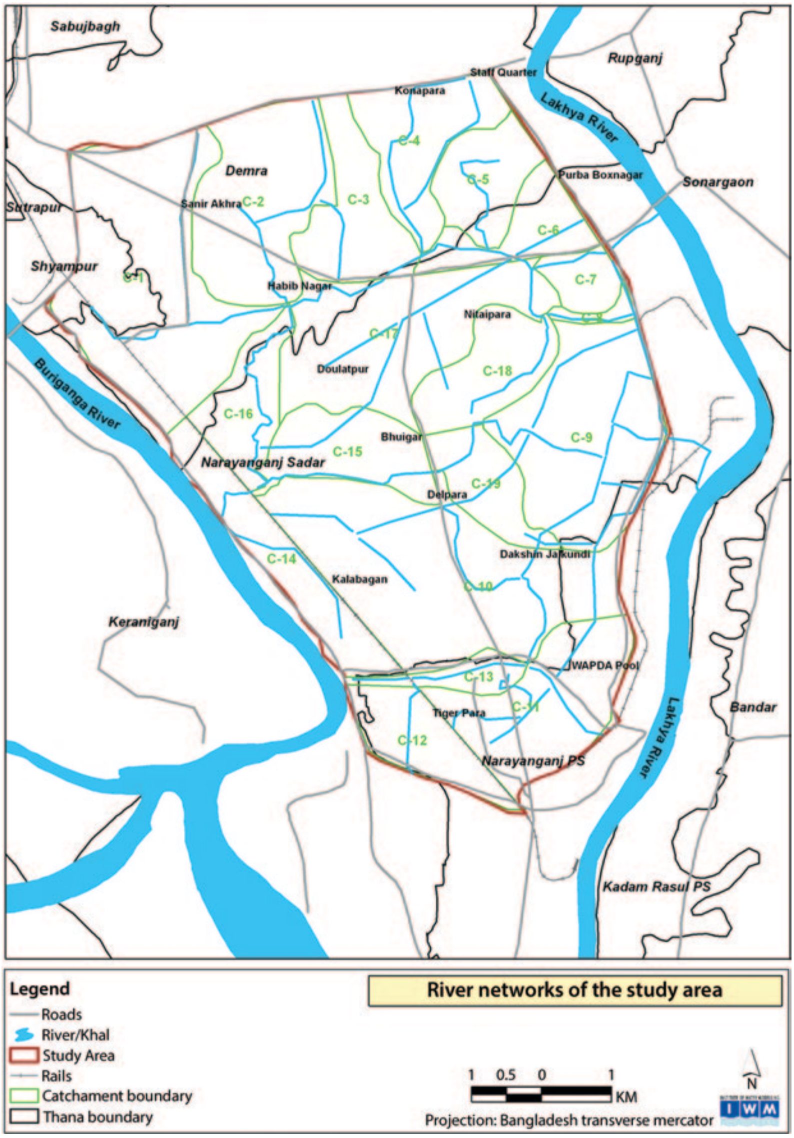
the Lakhya River. Major khals include MDC-02 (15–20 m width, running from Shyampur to Shimrail Pump Station), Pagla (15 m width, running from west to east in the middle of DND), and MDC-01 (10–15 m width, running from south DND toward Shimrail Pump Station).

The area has 19 subcatchments (map 3.25). The 2004 urban flood inundated 70 percent of the area, highlighting the urgent need for drainage system improvements. Planned drainage improvements include design of cross-sections for khals to increase conveyance capacity and installation of new pump stations at Shimrail, Adamjinagar, Pagla, and Fatulla (BWDB 2010) (table 3.10). In addition, separate drainage and sewerage systems will be developed under DWASA's 2012 Sewerage Master Plan.

Other Parameters and Features

For the 2004 model setup, historical khal cross-sections from the BWDB feasibility study were used (BWDB 2010). The proposed cross-sections from the same study were used for the planned improvements. Additional conveyance losses due to sedimentation were not taken into consideration. The estimated 2004 wastewater inflows into the drainage system were based on population estimates and per capita water consumption. Given BWDB's plans to implement separate

Map 3.25 DND Drainage Network and Subcatchments, 2004



Source: IWM 2014.

drainage and sewerage systems, wastewater flow into the drainage system was not considered for future scenarios.

Key Assumptions

The following key assumptions were made for the 2050 DND model simulations:

- There are no stormwater inflows into the DND area.
- Highways do not act as drainage barriers due to structures allowing water to flow under the roads.

Table 3.10 Development Baseline: Key Assumptions Comparison between 2004 and 2050, DND Model

Parameter or key feature	*2004*	*2050*
Imperviousness (%)	39–92	62–96
Time of concentration (minutes)	2,170	2,170
Initial loss (mm)	6	6
Reduction factor	0.9	0.9
Time area curve (no.)	1	1
Total length of khal (km)	85	85
Pump stations (number)	1	4
Total pump capacity (m^3/s)	14.51	74.69

Planned drainage pumps

Station location	*Number of pumps*	*Pump capacity (m^3/s)*	*Start-and-stop levels (m, PWD)*
Shimrail	7	38.41	2.5, 2
Adamjinagar	5	30.21	2.5, 2
Pagla	9	2.82	2.6, 2.5
Fatulla	10	3.25	2.6, 2.5

Note: DND = Dhaka-Narayanganj-Demra; PWD = Public Works Department.

- Four permanent pump stations and resectioning of khals, as proposed in the BWDB feasibility study, will be implemented (BWDB 2010).
- Wastewater does not contribute to the drainage system.
- Land levels of the proposed wetland/pond/flood-flow zone in the DAP remain at 2004 levels.
- All pumps have an 80-percent operating efficiency.

Boundary Conditions

The DND model area is bounded by embankments. Upstream of all khals is a dead end; therefore, the MIKE 11 one-dimensional model considers the discharge at all upstream boundaries of the drainage khals as zero. Because a canal downstream of Shimrail Pump Station connects the inside khals with Lakhya River, pump discharge at Shimrail Pump Station is the only boundary used for the 2004 simulations (photo 3.8). Although other drainage pumps are used in the DND area, these were considered as insignificant and their operational data for 2004 were not available.

Model Calibration

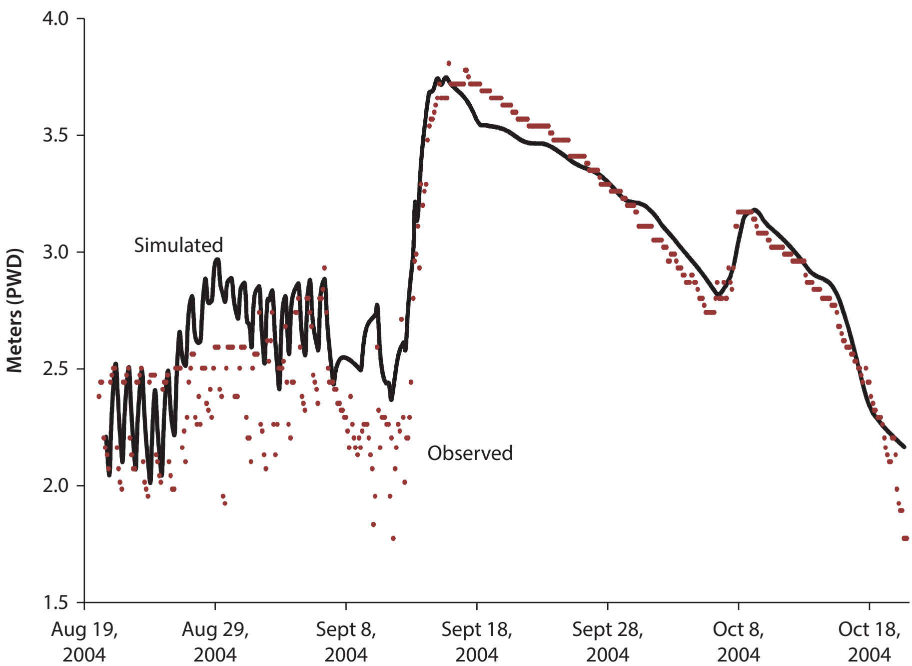
The model was calibrated for the 2004 period. Figure 3.1 shows the comparison plots of simulated and observed water levels at Shimrail Pump Station.

Comparison of water levels indicated that the model performance was acceptable for the modeling objective, especially during peak monsoon period.

Photo 3.8 Intake pipes of drainage pumps at Shimrail Pump Station, DND system

Credit: © Asif Zaman / World Bank. Used with permission. Further permission required for reuse.

Figure 3.1 Comparison of Simulated and Observed Water Levels at Shimrail Pump Station



Source: Zaman 2014.

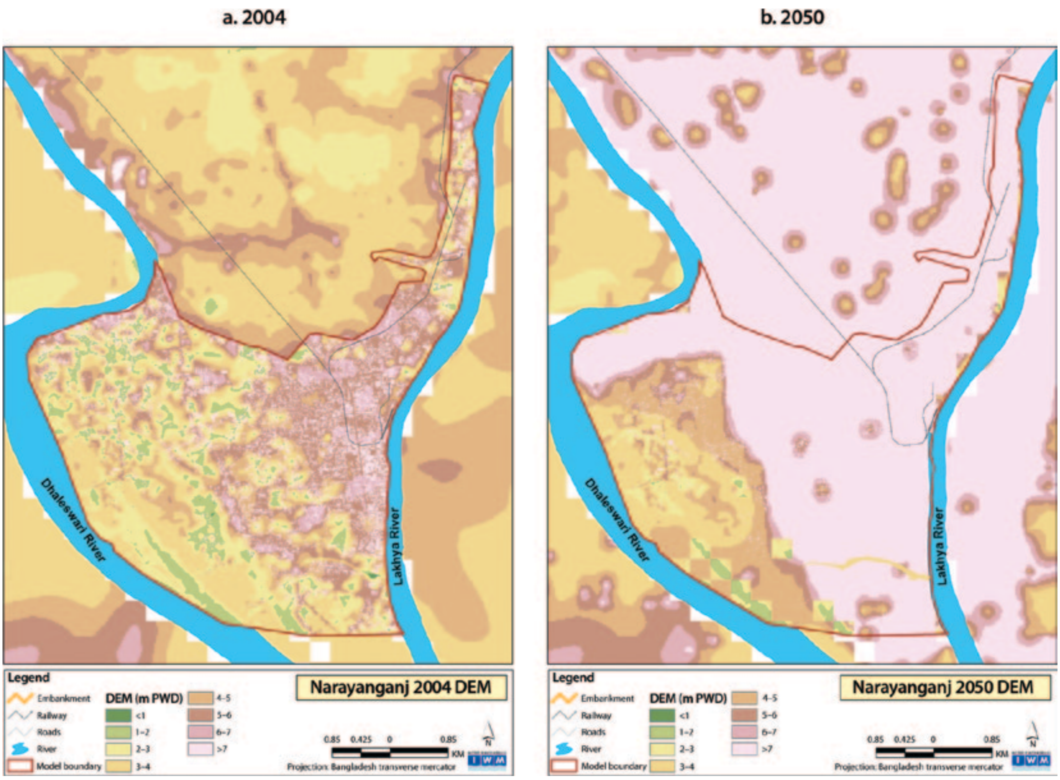
Narayanganj Model Setup

The model setup for Narayanganj used both the MIKE Urban and MIKE 11 platforms, spanning 12.5 km^2 and 9.8 km^2, respectively, for a total coverage of 22.3 km^2. Situated at the southern edge of Dhaka, the township of Narayanganj is one of Bangladesh's oldest and largest inland ports. The Lakhya and Dhaleswari rivers form respective natural boundaries on the east and west sides of the study area (map 3.26). These rivers meet near Munshiganj and continue as the

Map 3.26 Physical Setting of Narayanganj Model with Adjoining Boundaries

Source: IWM 2014.

Map 3.27 Change in Land Elevation over the Study Period, Narayanganj Model



Source: IWM 2014.

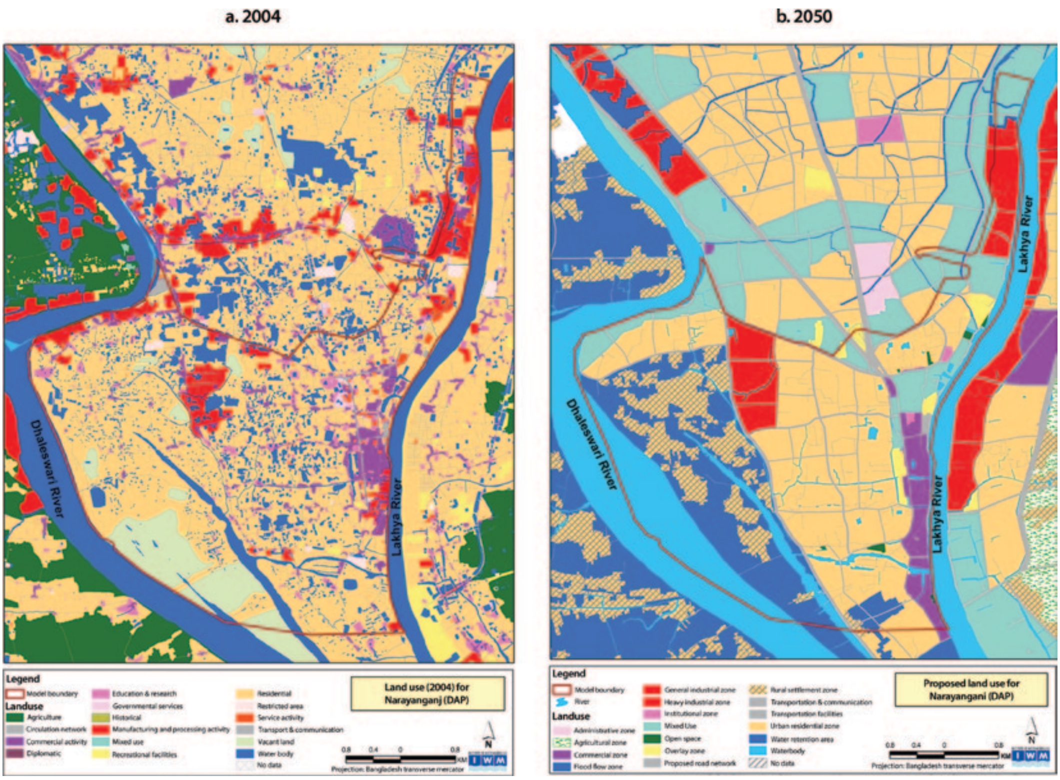
Dhaleswari River until merging with the Meghna River, which eventually flows into the Bay of Bengal. To the north, the Narayanganj Highway separates Narayanganj from the DND area. The Narayanganj-Munshiganj Highway functions as an embankment that protects some of the western portion of the area from flooding by the Dhaleswari River. About 12 km^2 suffers mainly from urban flooding, while the other 10 km^2 is affected by river flooding.

Future Scenario: Socioeconomic Changes

Narayanganj features both densely and sparsely populated areas at varying land elevations. The overall population density, estimated at 94,000 per km^2 in 2011, is steadily increasing and will likely reach 129,000 per km^2 by 2050 (IWM 2012). Owing to shortage of space for construction, multistoried buildings are on the increase in the core area.

Land elevation averages about 6.4 m PWD in built-up areas and 4.9 m PWD in outlying ones. Planned land-use changes include development of some residential areas into mixed-use zones and protection of major canals and large ponds. It is expected that low-lying areas and small ponds will be filled and converted into urban residential zones. By 2050, the land will be raised to an average elevation of 7.54 m PWD (map 3.27).

Map 3.28 Changes in Proposed Land Use over the Study Period, Narayanganj Model



Source: IWM 2014.

In 2004, the vast majority of land area in Narayanganj was zoned for residential use, manufacturing and processing activities, and commercial use, as well as education and research and vacant land. The remaining land was classified as government services, restricted, and service activity areas (map 3.28).

By 2050, changes in land-use patterns will be pronounced, particularly in the western portion of the study area, which is considered a flood-flow zone (map 3.28). For example, some residential zones alongside the Lakhya River near Gonje Ali Khal and B. B. Road and near Hariharpar by the Buriganga River are planned for mixed commercial and residential use.

Drainage System: Base Scenario and Planned Improvements

The drainage system of Narayanganj comprises covered street drains considered as box-culverts, a piped network, khals, and large ponds. A rail line and Bangabandhu Road divide the system into two parts, which drain eastward to the Lakhya River and westward to the Dhaleswari River. Several khals—Baburail, Boalia, and Gonje Ali—convey excess water to these rivers, and some large ponds serve as retention ponds. The flow from these water bodies to the river is unregulated and works as gravity drainage. Because most of the area is at a high elevation, there are no sluice gates at drainage outfalls (photo 3.9).

Photo 3.9 Drainage outfalls to Lakhya River in Narayanganj township at end of RK Mitra Road, eastern area (above) and end of BK Road, southeastern area (below)

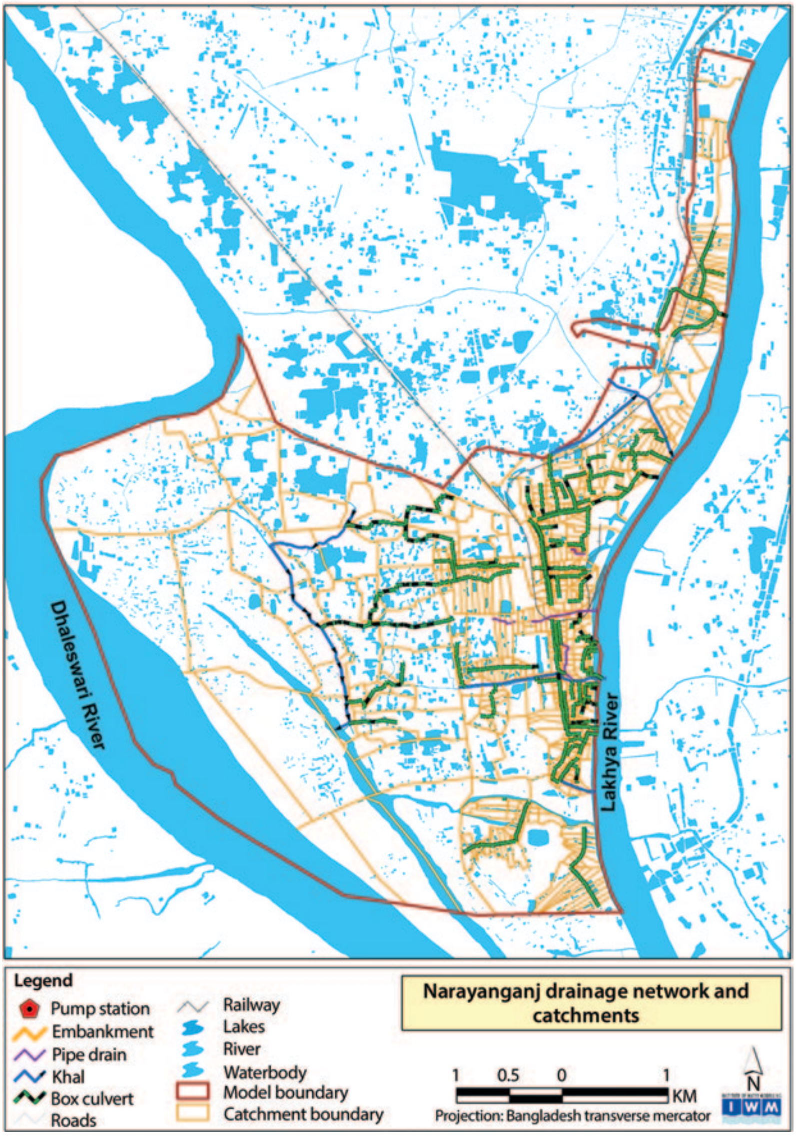
Credit: © Asif Zaman / World Bank. Used with permission. Further permission required for reuse.

The 2004 base scenario included about 1.7 km of stormwater pipes, 40 km of box-culverts, and 4.6 km of open canals. An additional 930 m of covered street drains (box-culverts) will be laid near the Bangladesh Small and Cottage Industries Corporation (BSCIC) area to drain excess rainfall runoff to the BSCIC Khal (map 3.29).

Other Parameters and Features

The modeled area was divided into 547 subcatchments, delineated according to the distribution of drainage networks and land terrain. No sediment depth was considered in the simulations since, according to officials of the Narayanganj City Corporation (NCC), siltation is minimal since most networks are relatively new and regular cleaning and maintenance are observed. The 2004 model setup included 100 percent of total generated wastewater since no dedicated disposal system had been implemented at that time. Given that DWASA's 2012 Sewerage Master Plan includes a dedicated sewerage system for the study area (DWASA 2012), it was assumed that no wastewater will contribute to the drainage system for future scenarios (table 3.11).

Map 3.29 Drainage System of Narayanganj, 2004



Source: IWM 2014.

Key Assumptions

The following key assumptions were made for the 2050 model simulations for Narayanganj:

- Stormwater drains from part of Narayanganj township to Lakhya River through several outlets along the river bank and, from the other part, to Dhaleswari River through several canals.
- The railway track functions as drainage boundary.

Table 3.11 Development Baseline: Key Assumptions Comparison between 2004 and 2050, Narayanganj Model

Parameter or key feature	*2004*	*2050*
Population density (persons/km^2, weighted average)	92,000	129,000
Land level (m PWD, average)	7.03	7.54
Subcatchments (number)	547	547
Imperviousness (%, weighted average)	26	55
Time of concentration (minutes, weighted average)	32	28
Initial loss (m)	0.01	0.01
Reduction factor	0.9	0.9
Total length of pipes, box-culverts, and khals (km)	42.8	43.6
Wastewater (percent of total domestic load)	100	0
Sedimentation of pipes (%)	0	0
Ponding area (km^2)	2.11	2.11
Pumps (number)	0	0

Note: PWD = Public Works Department.

- The drainage system is based on gravity; thus, there are no pumps or sluice gates.
- All of the network consists of box-culverts/covered drains, and no sedimentation is considered as the network is relatively new.
- The building footprints are elevated to represent actual flood-flow path.
- A network will be constructed along the road near the Panir Tanki area to convey stormwater to the nearest canal, which currently drains to low land being filled, causing drainage congestion in that area.

Boundary Conditions

Because there are no sluice gates at the outfalls, the water levels of the Shitalakhya and Dhaleswari rivers govern the drainage system. Therefore, the boundary conditions were considered as river water levels at the outfalls, which were extracted using the NCRHD model.

A local channel situated in the southern part of the Narayanganj model area connects the Shitalakhya and Dhaleswari rivers. The water level governs the direction of flow of that channel and subsequently the drainage system of the southern part of the modeled area.

Notes

1. Because insufficient data were available on the drainage infrastructure of Savar, Gazipur, and Tongi, rigorous urban-flood modeling could not be undertaken for these townships; thus, they were omitted from the detailed area study.
2. The typical imperviousness values were estimated from analyses of aerial images and Geographic Information System datasets of existing land uses in various parts of Dhaka with different population densities. The imperviousness of a water body that does not contribute to stormwater runoff into the drainage system is considered quite low. However, the imperviousness is quite high for a water body that acts like a

retention pond, meaning that all rainfall on the water-body area contributes to the drainage system flow (i.e., linked to outfalls via sluice gates or pumps).

3. These embankments have been designed for 100-year, return period events; they have never been overtopped in the past, and the modeling exercise assumed this will still hold true in the future.
4. Start-and-stop levels for additional improvements were considered as 4.25 m and 4.0 m, respectively.
5. The Kallyanpur Retention Pond area is threatened by encroachers.

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CHAPTER 4

Vulnerability Assessment

Introduction

The hydrological modeling method, discussed in chapters 2 and 3, enables the estimation and assessment of the depth, duration, and extent of flooding in Dhaka due to extreme weather events, along with the additional flooding that may arise from the effects of climate change (Zaman 2014). While hydrological modeling results provide valuable information on the depth, extent, and duration of flooding due to extreme rainfall events, they do not offer a complete picture of how the various areas of Dhaka may be affected. The impact of inundation of even the same depth and duration on the population and infrastructure will differ significantly, depending on an affected area's vulnerability, determined by its physical, social, economic, and institutional characteristics. Therefore, estimating overall vulnerability requires a more detailed vulnerability impact assessment, taking into account all other factors that, when combined with flooding, may exacerbate that impact. This study conducted a flood vulnerability assessment to recognize what appropriate actions can be taken to reduce vulnerability before possible harm is realized (Roy 2014).

Key Concepts and Approach

In the scientific literature, the concept of vulnerability analysis covers a variety of dimensions, including natural, physical, social, economic, and institutional vulnerability. But the relative emphasis on these sectors of vulnerability can differ, depending on the nature of the cause that increases vulnerability. In the context of flood vulnerability, it is important to understand what can be used to define it. For the purposes of this study, the approach adopted by the United Nations Educational, Scientific and Cultural Organization (UNESCO) for assessing flood vulnerability was followed (UNESCO 2012). This approach focuses not only on factors that aggravate vulnerability, but also on those that can help us understand the best ways to reduce it. According to this approach, vulnerability is considered as the extent of harm that can be expected under certain conditions of exposure, susceptibility, and resilience. The first two factors heighten vulnerability while the third lessens it.

Exposure

In this analysis, exposure is defined as the predisposition of a system to be disrupted by a flooding event due to its location (UNESCO 2012). The exposure arises from what elements (e.g., people, property, goods and other infrastructure) are present at the location that may be impacted by floods that may occur. To capture this aspect, the indicators for this component must include physical aspects that take into account the exposure of elements at risk and also the general characteristics of the flood. In terms of the physical dimension, examples of vulnerability exposure include topography, geology, and proximity to river. Other examples include population density and population below the poverty line (social dimension), land use and percent urbanized area (economic dimension), and types of vegetation and degraded land (environmental dimension).

Susceptibility

Susceptibility is generally defined as the elements exposed within the system, which influence the probabilities of being harmed at times of hazardous floods (UNESCO 2012). For evaluating susceptibility, it is important to examine physical aspects at the location, as well as social and economic factors among the population at risk. The focus here is not only on the advance preparation that exists in the area to face the flood risk but also on awareness and preparedness of people regarding the risk they live with. It also includes the presence of institutions, mechanisms, and systems that can minimize the impact caused during the floods. Examples of susceptibility include dams and storage capacity and roads (physical dimension), warning systems and evacuation routes (social dimension), unemployment and inequality (economic dimension), and nature reservations and human health (environmental dimension).

Resilience

Resilience refers to the capacity of a system to endure any perturbation, like floods, maintaining significant levels of efficiency in its social, economic, environmental, and physical components (UNESCO 2012). Resilience to flood damage must be considered both during and after floods. The social, economic, and institutional factors in the location can determine how quickly the affected area can recover from the flood impact. Examples of resilience include building codes (physical dimension), literary rates and public awareness (social dimension), investment in counter-measures and flood insurance (economic dimension), and flood recovery time (environmental dimension).

Development and Application of the FVI

Capturing these aspects of exposure, susceptibility, and resilience requires appropriate indicators that account for the various dimensions involved. To develop a composite Flood Vulnerability Index (FVI) based on these dimensions, this study modified the Climate Disaster Resilience Index (CDRI), a planning tool developed by the Climate and Disaster Resilience Initiative of Kyoto University (Joerin and Shaw 2011) (box 4.1).[1]

The CDRI is a widely used indicator for examining the vulnerability of an area facing the effects arising out of climate change. Because this study focused on flood vulnerability only and not vulnerability from all natural disasters, only the four CDRI dimensions that contribute to flood vulnerability (physical, social, economic, and institutional) were used; the fifth CDRI dimension (natural) was replaced with a flood dimension. Each CDRI dimension used has five parameters, which, in turn, have five variables each. The selected parameters and variables adequately reflect those likely to be most affected by the effects of climate change. The flood dimension has two parameters, each of which is defined by one variable (table 4.1).

These vulnerability indicators can provide additional information for setting more precise and quantitative targets for vulnerability reduction and facilitate analysis of the relative conditions in the flood-affected area. Identifying areas with high flood vulnerability can guide the decision-making process toward helping societies deal with floods in a better way. In short, FVI is a powerful tool that policymakers can utilize to prioritize investments and make the decision-making process more transparent.

Box 4.1 CDRI: Assessing Adaptive Capacity at the Local Level

Traditional frameworks for assessing local-level adaptive capacity have focused mainly on asset-oriented approaches. While useful in understanding a system's capacity to cope with and adapt to changing environments, such approaches overlook the processes and functions that can enhance its adaptive capacity. Dhaka City Corporations (DCCs) are divided into numerous wards that vary significantly in terms of physical features, land development levels, land-use patterns, socioeconomic features, and exposure to various types of hazards. These differences underscore the need for a multidimensional approach that considers micro-level variations in the city's adaptive capacity to climate change. The Climate Disaster Resilience Index (CDRI) is a useful tool for filling this gap.

To compute Dhaka's CDRI, a micro-level analysis was conducted for this study (Jahan 2014). The CDRI's 125 variables (five dimensions × five parameters × five variables) were used to develop a survey questionnaire to assess the local situations of wards and thanas in the seven drainage zones of the detailed study area. Respondents used a five-point rating scale (from lowest to highest) to assess the status of each variable. In addition, they were asked to assign weights to the variables and parameters to reflect the relevance of the indicators to their local situations. Using data collected from the questionnaires, a weighted-mean-index method was used to compute the scores for each parameter. The resulting CDRI is the simple average of the indexes for the five dimensions (physical, social, economic, institutional, and natural). The index ranges from 1 to 5, with higher CDRI values equal to higher preparedness to cope with climate change and disasters.

Source: Jahan 2014.

Table 4.1 Indicators Used to Develop the Flood Vulnerability Index

Dimension	*Parameters*	*Variables*
Physical	Electricity	Access, availability, supply capacity, dependence on external supply, and alternative capacity
	Water	Access, availability, supply capacity, dependence on external supply, and alternative capacity
	Sanitation and solid-waste disposal	Access to sanitation, toilets, waste collection, waste treatment, and recycling
	Road accessibility	Percentage of land transportation network, paved roads, accessibility during flooding, status of interruption after intense rainfall, and roadside-covered drain
	Housing and land use	Building code, buildings with nonpermanent structure, buildings above waterlogging, ownership, and population living close to polluted industries
Social	Population	Population growth, population under 14 years of age and above 64 years old, population of informal settlers, and population density
	Health	Population suffering from waterborne/vectorborne diseases, population suffering from waterborne diseases after a disaster, access to primary health facilities, capacity of health facilities during a disaster, and disaster preparedness
	Education and awareness	Literacy rate, population's awareness of disasters, availability of public-awareness programs/disaster drills, Internet access, and functionality of schools after disaster
	Social capital	Population's participation in community activities and clubs, acceptance level of community leader (in ward), ability of communities to build consensus and participate in city's decision-making process (level of democracy), and mixing and interlinking of social class
	Community preparedness during a disaster	Preparedness (logistics, materials, and management), provision of shelter for affected people, support from NGOs/CBOs, population evacuating voluntarily, and population participating in relief works
Economic	Income	Population below poverty line, number of income sources per household, income derived from informal sector, income disparity, and percentage of households with reduced income due to a disaster
	Employment	Formal sector: percentage unemployed labor, unemployed youth, employed women, employees who come from outside the city, and child labor in city
	Household assets	Households with television, mobile phone, motorized vehicle, non-motorized vehicle, and basic furniture
	Finance and savings	Availability of credit facility to prevent disaster, credit access, credit access for urban poor, household savings practice, and household's insured properties
	Budget and subsidy	City's annual budget for DRR and CCA, availability of subsidies/incentives for residents to rebuild houses, alternative livelihood, and health care after a disaster
Institutional	Mainstreaming of disaster risk reduction (DRR) and climate change adaptation (CCA)	Mainstreaming of DRR and CCA in city development plans, housing and transport policies; ability (manpower) and technical capacity to produce development plans, extent of community participation in development-plan preparation process, and implementation of disaster management plan
	Effectiveness of city's crisis management framework	Existence of disaster management plan, existence and effectiveness of an emergency team during a disaster: leadership, availability of evacuation centers, efficiency of trained emergency workers during a disaster, and existence of alternative decision-making personnel

table continues next page

Table 4.1 Indicators Used to Develop the Flood Vulnerability Index *(continued)*

Dimension	*Parameters*	*Variables*
	Knowledge dissemination and management	Effectiveness to learn from previous disasters, availability of disaster-training programs for emergency workers, existence of disaster-awareness programs for communities, capacity (e.g., books and leaflets) to disseminate disaster awareness-raising and education programs, and extent of community satisfaction with disaster awareness programs
	Institutional collaboration with other organizations and stakeholders during a disaster	City's dependence on external institutions/support, collaboration and interconnectedness with neighboring cities, city's cooperation (support) with central municipal department for emergency management, cooperation of city's ward officials for emergency management, and city's institutional collaboration with NGOs and private organizations
	Good governance	Effectiveness of early warning systems, accountability and transparency of city government, implementation of building codes, existence of disaster drills, promptness of city body to disseminate emergency information during a disaster to communities, and capability of city body to lead recovery process
Flooding[a]	Extent	Area flooded >0.25 m (percentage)
	Duration	Duration of flood >0.25 m (hours)

Source: Adapted from Jahan 2014.
a. For the flood dimension, depth of inundation was not used as a separate parameter since depth varies widely in a flooded area and average flood depth is highly correlated with the flood duration parameter.

Data Collection and FVI Calculation

For the four dimensions of the CDRI, data were collected using a survey questionnaire and secondary sources for each ward and some outlying areas of the detailed study area (Jahan 2014). The survey was conducted among planners involved in the 2009 preparation of the Detailed Area Plan (DAP) for the Dhaka metropolitan area. The planners belonged to various consultancy firms, each of which was responsible for preparing the plan of a particular area of the city. Data on some variables, especially related to physical and social aspects, were also collected from such secondary sources as the 2011 population census and DAP reports.

Each dimension's respective five parameters could take vulnerability values ranging from 0 (indicating high vulnerability) to 5 (indicating low vulnerability). For the flood dimension, data was obtained from the results generated by the hydrological modeling exercise (Zaman 2014). This information was available for five future scenarios based on alternative assumptions. The flood dimension's two parameters were measured in percentages and hours, respectively. But unlike the CDRI parameter values, higher values indicated greater vulnerability.

Since the parameters used in the four CDRI dimensions and flood dimension differed in units of measure, they first had to be normalized—they were assigned values ranging from 0 (indicating high vulnerability) to 1 (indicating low vulnerability)—before being combined into one FVI. For the four dimensions of the CDRI, the normalized value Y_{ij} for parameter i in ward j was calculated using the following formula:

$$Y_{ij} = \frac{(X_{ij} - Min\ X_{ij})}{(Max\ X_{ij} - Min\ X_{ij})}, \tag{4.1}$$

where X_{ij} represents indicator i for ward j.

For the normalization, another formula was needed for the flood parameters because a higher value in those parameters indicated greater vulnerability. Thus, to ensure normalization with assigned values between 0 and 1, with 0 indicating high vulnerability and 1 indicating low vulnerability, the following formula was used:

$$Y_{ij} = \frac{(Max\ X_{ij} - X_{ij})}{(Max\ X_{ij} - Min\ X_{ij})}, \tag{4.2}$$

where X_{ij} represents indicator i for ward j.

For each ward in the detailed study area, the vulnerability indexes in each of the five dimensions were separately determined based on data from each ward for the normalized values of the chosen parameters. Thus, $\bar{Y}_{jk}$, the vulnerability index of dimension k in ward j, was computed as the weighted sum of all the normalized values of the parameters included in dimension k for that ward, expressed as follows:

$$\bar{Y}_{jk} = \sum_{i=1}^{N} w_i Y_{ijk}, \tag{4.3}$$

where w_i is the weight for indicator i, and N is the number of indicators in the index of type k. The weights were assigned based on the variability of each indicator among all wards in Dhaka since a greater variability poses higher risk.[2] To ensure that the weights added up to 1, they were defined as follows:

$$w_i = k\sqrt{Var(Y_i)} \quad where \quad k = \frac{1}{\sum_{i=1}^{N} \sqrt{Var(Y_i)}}, \tag{4.4}$$

where $Var(Y_i)$ is the variance of indicator i normalized values among all of Dhaka's wards.

Finally, the composite FVI was computed as a weighted average by combining the indexes developed for each of the five dimensions. Separate *FVIj* for ward j is created for each of the five flooding scenarios as follows:

$$FVI_i = \sum_{k=1}^{5} w_k \bar{Y}_{jk}, \tag{4.5}$$

where w_k represents the weight for dimension k.

The FVI computation is done under two alternative assumptions about the importance of flooding parameter in the composite FVI index. The first assumes equal weight for each of the five dimensions and thus $w_k = 0.2$ for all five dimensions. Under the second assumption, the weight of the combined four CDRI dimensions is considered the same as the weight for the flood dimension. Since all CDRI dimensions are given the same weights, $w_k = 0.125$ for each of those four dimensions and $w_k = 0.5$ for the flood dimension. The second assumption thus assigns a much greater weightage to flooding effects. In all, 10 FVIs are generated for each study area, one for each of the five scenarios under the two alternative assumptions about the importance of flooding in the FVI.

Finally, the comparison of vulnerability is done at two area levels: (a) a broad, aggregated study-area level by comparing the FVI among the specific study areas and (b) a ward-wise FVI to compare the relative vulnerability among the various wards in Dhaka.[3] The ward-wise comparison allows development of vulnerability ranking to determine a list of Dhaka's most vulnerable wards.

Notes

1. This study drew specifically on the CDRI analysis conducted by Sarwar Jahan for Dhaka (Jahan 2014). To develop the FVI, the study used a portion of the data collected in that study, along with data generated by the hydrological modeling exercise (Zaman 2014).
2. A greater variability of data means a greater uncertainty, and uncertainty directly correlates with risk. For example, if two areas have the same average rainfall but different variance in rainfall, then the area with the higher variance is likely to be more vulnerable as the range of rainfall will be much wider. Thus, the risk being faced by the area with higher vulnerability is likely to be higher. The index created is trying to capture that.
3. The vulnerability comparison excludes the Narayanganj area for lack of complete detailed data and difficulty in matching of the areas between CDRI rankings and flooding data.

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CHAPTER 5

Estimating Flood Damage

Introduction

Results of the hydrological modeling exercise were also used to quantify the economic damage—effects on the urban-built environment and infrastructure, human health, and family assets—caused by flooding of the Greater Dhaka detailed study area in the current climate.[1] The likely increase in damage due to climate change was also separately assessed. Both depth and duration of inundation were analyzed to estimate the extent of flood damage. The study assessed not only property damage, income loss, and other readily quantifiable damages; wherever possible, it assigned monetary values to intangible damages, based on analysis of losses gleaned from comparison with similar ones that are more easily quantified (Roy 2014).

Alternative Cases and Assumptions for Future Scenarios

The analysis centered on the likely economic damage that may occur in 2050 and cumulatively between 2014 and 2050. For each of the five future scenarios covered in the hydrological modeling exercise (table 2.2), three cases were computed, as follows:

- The damage resulting from a 100-year return-period storm occurring in 2050. This is the most severe weather event used in the hydrological modeling exercise; thus, the estimate provides an upper limit of the annual damage that may occur in 2050.
- A weighted average estimate of damage, based on the probability of each return-period storm from 1 year to 100 years occurring in 2050. The probability of each return-period event is given by $1/N$, where N equals the return period.
- The cumulative damage between 2014 and 2050, based on random assignment of 1-year to 100-year storms during each year. This estimate helps to determine the expected total damage between 2014 and 2050, using the probability of each outcome.

The increased precipitation likely to result from climate change effects has already been factored into the hydrological modeling exercise by incorporating the 16 percent expected increase in precipitation from the pattern-scaling exercise by Sugiyama (2012) (box 1.2). In a changing climate, the frequency of heavy-rainfall events in South Asia is also increasing (IPCC 2013). In order to account for the increased frequency of more severe storms in estimating economic damage, a sensitivity analysis was conducted under three assumptions:

- Low increased frequency. The 100-year, return-period storm (1 percent probability), would occur once every 50 years (2 percent probability).
- Medium increased frequency. The 100-year, return-period storm (1 percent probability) would occur once every 33 years (3.3 percent probability).
- High increased frequency. The 100-year, return-period storm (1 percent probability) would occur once every 20 years (5 percent probability).

Data to Project Future Outcomes

The analysis extrapolated Dhaka's predicted population growth between 2014 and 2050 based on past decadal growth rates adjusted for likely future changes.[2] Expected changes in housing characteristics, roads, and other physical infrastructure were estimated based on existing plans. To assess the damage in real terms, all economic data were based on 2013 prices, thus ignoring any inflation that could occur by 2050. Any increase in per capita income in 2014–50 was excluded to compensate for the need to discount future damage.[3] It was assumed that excluding inflation and increased per capita income would obviate the need for converting future damage estimates into present values using a discount factor based on time preference for money. This approach was adopted because of the inherent controversy over the choice of a discount rate in environmental economics when examining outcomes long into the future; even catastrophic outcomes show negligible effects when discounted over a long time horizon, and the estimates included here are looking into outcomes well into the future.[4]

Direct and Indirect Damage

Direct damage is primarily concerned with the economic loss resulting from damage to physical capital. The main determinant is depth of inundation; however, the degree of damage can also increase with flood duration of a given depth. Thus, any analysis of direct damage must start with depth of flooding and then be adjusted upward using duration of flooding. Damaged physical capital comprises both private and public resources. Damaged private resources commonly include residential, commercial, and industrial buildings and property; industrial factories also face damage to machinery and inventory. Other private-property losses include damage to transport vehicles and telecommunication and electric infrastructure. Common examples of publicly-owned damaged resources are roads, rails, ports, water and sewerage facilities, hospitals, and government-owned buildings and property.

Indirect damage is mainly concerned with loss of income due to the inability of residents, businesses, and industries to carry out their daily economic activities. The main determinant is duration of flooding above a certain depth, which can lead to disruption of day-to-day activities over a period of time. Most economic losses occur during the flooding, but some may continue after the water recedes. The direct damage of public and private resources may prolong the total or partial loss of earning capacity, even after floodwaters recede. Indirect damage also results from direct damage to roads and communication infrastructure, which leads to future disruption of economic activity. Indirect damage to public health arises from added health-care costs and the effects of increased morbidity on livelihoods.

It has been found that a water depth level of 0–0.1 m produces little or no damage. In all of the affected areas, people have learned to adapt to such levels of flooding as a common annual occurrence. With the exception of Central Dhaka, a water depth level of 0.1–0.25 m produces slight damage in a few areas. Again, such flooding tends to be perceived as an annual feature during the rainy season. However, with water depths above 0.25 m, some level of economic damage is unavoidable. The extent of direct damage depends mainly on the flooding depth. At a water depth range of 0.25–0.75 m, the extent of damage is low for all areas. At 0.75–1.50 m, all areas experience moderate damage. Above 1.50 m, damage is extensive in all areas and continues to rise the longer flooding persists.

To examine the damage resulting from duration of flooding, the study analyzed the extent of flooding above 0.25 m for up to 10 days. The selection of 10 days as the cut-off was based on the finding that floodwater recedes from most areas of Dhaka within that period, even in the worst case (i.e., A1FI scenario for the 100-year, return-period storm). Indirect damage depends mainly on how long flooding exceeds the critical 0.25 m depth level; however, it may be exacerbated by higher levels of inundation since indirect damage may arise as the result of loss of physical capital and other resources resulting from direct damage from a given water depth.

Key Sectors

The sectors most affected by the economic damage from flooding are residential (buildings and property), commerce and industry, health care, roads and railways, and public transport. The subsections below describe how the direct and indirect damages were assessed for these sectors.

Residential Buildings

Repair and clean-up costs were used to estimate the direct damage to residential buildings. The study analysis was based on Dhaka's categorization of building structures (*jhupri*, *kutchha*, *semi-pucca*, and *pucca*) and floor space.[5] Pucca structures were further divided into three broad housing categories: economically weaker sections (EWS), middle-income groups (MIG), and high-income groups (HIG). For multi-storied buildings, it was assumed that damage would be limited to the first floor.[6] Based on past experience, the housing composition for 2050 was assessed. It was assumed that building upgrades would result in a large reduction of jhupri and kutchha structures and a gradual transformation of a percentage of semi-pucca buildings into pucca structures. It was further assumed that the average jhupri, kutchha, or semi-pucca structure is a one-story building, while the average pucca structure consists of two (EWS), three (MIG), or four (HIG) stories (table 5.1).

Repair Costs

The calculation of repair costs was based on building construction costs and the percentage of construction cost needed for repair (2013 figures). For jhupri, kutchha, semi-pucca, and pucca buildings, repair costs were estimated at 50, 25, 12, and 6 percent, respectively, of building construction costs. For EWS, MIG, and HIG structures, building construction costs per square meter of floor area were estimated at Tk. 8,000, 9,300, and 12,800, respectively.[7] The average costs of jhupri, kutchha, and semi-pucca houses were estimated at Tk. 50,000, 90,000, and, 150,000, respectively.

Determining the percentage of buildings incurring repair costs was based on damage factors developed using flooding depth and duration for each ward in Dhaka. It was assumed that any inundation greater than 0.25 m depth lasting more than one day would cause a minimum-threshold,[8] proportional damage requiring repair that varies by building type. The minimum-damage threshold for EWS, MIG, and HIG housing differs because of the nature of the building and quality of construction materials used (table 5.1). It was also assumed that any building submerged for 10 days or longer at an inundation depth greater than 1.5 m would always require repair. The proportion of buildings needing repair decreases linearly for fewer days of inundation. For depth ranges of 0.1–0.25 m, 0.25–0.75 m, and 0.75–1.5 m, the damage proportions were 25, 50,

Table 5.1 Residential Housing Data to Estimate Direct Damage

Building type	*Floor area, average (m²)*	*Stories, average (no.)*	*First floor area (%)*[a]	*Building cost for all floors (million Tk.)*	*Repair costs per building (million Tk.)*[b]	*Minimum-damage threshold (%)*	*Clean-up costs per building (million Tk.)*[b]
Jhupri	Not used	1	100	0.05	0.025	33	0.0005
Kutchha	Not used	1	100	0.09	0.022	20	0.0005
Semi-pucca	Not used	1	100	0.14	0.017	10	0.0005
Pucca:							
EWS	25	2	50	0.40	0.012	5	0.001
MIG	75	3	33	2.09	0.042	5	0.002
HIG	150	4	25	7.68	0.115	5	0.004

Source: World Bank 2010.
Note: EWS = economically weaker sections; HIG = high-income groups; MIG = middle-income groups.
a. This estimate is based on the average number of floors for each building type.
b. 2013 figures.

and 75 percent, respectively, of the proportion for a depth greater than 1.5 m. Since the depth of inundation continues to change as water recedes from a given area, the proportion of damaged building requiring repair (R_f) in an area is the maximum proportion found from the inundation duration for the four depths over a 10-day period, expressed as follows:

$$R_f = M_t + \text{MAX}\ (D1 * 0.25, D2 * 0.5, D3 * 0.75, D4 * 1) * \{(1 - M_t/10)\}, \quad (5.1)$$

where M_t represents the minimum threshold per building type, and $D1$, $D2$, $D3$, and $D4$ equal the number of days at inundation depths of 0.1–0.25 m, 0.25–0.75 m, 0.75–1.5 m, and greater than 1.5 m, respectively.

Clean-Up Costs

The analysis assumed that all inundated buildings not requiring repair would incur clean-up costs. Based on field surveys, the main clean-up components were identified as whitewash, fixed inventories, and labor. Their total costs were estimated at Tk. 500 for jhupri, kutchha, and semi-pucca structures and Tk. 1,000, 2,000, and 4,000, respectively, for EWS, MIG, and HIG buildings. For each building category, the total damage to the residential building (D_{RB}) can be expressed by the following equation:

$$D_{RB} = HH * I * P * S * [(C_b * R_f * D_h) + 1 - R_f) * C_c], \quad (5.2)$$

where HH equals the total number of households in the affected area by category, I equals the percentage of area inundated in the affected area, P is the percentage of composition of various categories, S is the proportion of households on the first floor, C_b equals building construction costs, R_f is the proportion of damaged buildings requiring repair costs, D_h is the damage factor of a building needing repair (assumed at 0.06), and C_C equals clean-up cost. Finally, total costs are extrapolated to 2050 based on the predicted housing structures for that year.

Residential Property

Sudden and prolonged flooding causes extensive damage to residential property. Submerged vehicles owned by households, situated in ground-floor garages, comprise the largest component of such direct damage. Other household property, including appliances, electronics, and furniture, can be damaged to varying degrees, especially if they are difficult to move to upper floors. The direct correlation between household income and value of household property makes it possible to estimate damage to residential property based on household income for each ward in Dhaka. The analysis extrapolated household-income data to 2050 using an average GDP growth of 4 percent per capita over the period. For the middle three household-income groups, the midpoint in each income range was used as the average income for that group. For the lowest and highest income groups, which are characterized by skewed income distribution, income data was

Table 5.2 Household Income Distribution and Affected Property
Percent

	Monthly income group (thousand Tk.)				
Household factor	*<5*	*5–10*	*10–15*	*15–20*	*>20*
Savings rate	5	10	15	20	25
Proportion on first floor	100	50	33	33	25

Source: World Bank 2010.

derived location-wise to determine the number of households in each income category (table 5.2) (BBS 2011).

The value of the property owned depends on the savings accumulated in each income category over a five-year period, with annual savings rate differing by income category. The property-damage factor is based on the depth and duration of flooding. For household property submerged 10 or more days at an inundation depth greater than 1.5 m, with proportional decrease for fewer days of inundation, the assumed maximum damage is 33 percent. For depth ranges of 0.25–0.75 m and 0.75–1.5 m, the corresponding maximum damages are 20 percent and 25 percent, respectively. The property damage factor (D_P) can be expressed as follows:

$$D_P = \text{MAX}\ (D3 * .033, D2 * 0.025, D1 * 0.02), \tag{5.3}$$

where $D3$, $D2$, and $D1$ represent the number of days of inundation at depths of more than 1.5 m, 0.75–1.5 m, and 0.25–0.75 m, respectively.

For each income group, residential property damage (D_{RP}) is expressed as follows:

$$D_{RP} = HH * Y * C * S * D_P * I, \tag{5.4}$$

where HH represents the total number of households in each income category in the affected area, Y equals the average income in a household income group in 2050, C equals the savings rate in an income group for five years, S represents the proportion of total households located on the first floor, D_P is the property damage factor, and I is the percentage of area inundated in the affected area.

Commerce and Industry

As mentioned above, both commercial and industrial sectors face direct damage to buildings and property (e.g., inventory); industry also faces direct damage to machinery. In the absence of data identifying business hubs, it was not possible to assess damage to business interruptions. A damage factor was developed, based on the average depth, duration, and extent of flooding in the affected area. The damage factor was applied to the value of the affected holdings to assess such damage, expressed as follows:

$$D_{XP} = V * D_C, \tag{5.5}$$

where D_{XP} represents the direct damage, V equals the total value of the holding, and D_C is the holding's property damage factor. The analysis assumed that 50 percent of commercial establishments will be damaged since flooding affects only the first floor. For industries, fixed capital is used to estimate the value of buildings and machinery (BBS 2003).

Because ward-wise distribution of commercial and industrial data was unavailable, the average extent of flooding for the 10 days under various depths for the whole of Dhaka was used to develop the damage factor. The analysis assumed the extent of damage for depth ranges of 0.25–0.75 m, 0.75–1.5 m, and > 1.5 m as 3, 6, and 9 percent of the value of the holdings, respectively. Thus,

$$D_C = [0.03 * (F_L - F_M - F_H) + 0.06 * (F_M - F_H) + 0.09 * F_H], \qquad (5.6)$$

where D_C represents the property damage factor and F_L, F_M, and F_H represent the average proportion of flooding in the Dhaka area over the 10 days for the three depths in increasing order.

The damage to property was assessed as the difference in the daily value added for the number of days a business is affected. The number of lost days of business was based on the extent of average flooding and its duration. This indirect damage (D_{XF}) is expressed as follows (box 5.1):

$$D_{XF} = N * D_T, \qquad (5.7)$$

where N equals the value added per day and D_T represents the number of lost days. In turn, the number of lost days is expressed as follows:

$$D_T = [0.5 * (F_L - F_M - F_H) + 0.67 * (F_M - F_H) + F_H]/100 * 10, \qquad (5.8)$$

where F_L, F_M, and F_H represent the average extent of flooding in the Dhaka area over the 10 days for the three depths in increasing order.

Health Care

Increased cases of diarrhea and dengue fever constitute most of the economic losses from flooding suffered in the health-care sector. This analysis assumed that, with increased prosperity, current rates of these diseases will likely decline, but that economic impacts will be higher because of the increased value of life. These two factors were assumed to offset each other; thus, the current damage valuation was used as the future estimates between 2014 and 2050. The effect of changes caused in the future scenarios was based on the percentage of area flooded. Current damage was used as the baseline, including only planned improvements.

Health damage costs were computed using data on the incidence and mortality from diarrhea and dengue fever.[9] Productivity loss from morbidity and loss of productive life from mortality were assessed using Disability Adjusted Life Years (DALYs) data (WHO 2009).[10] Since urban areas like Dhaka witness about

Box 5.1 Calculating Indirect Damage from Income Loss

The disruption caused by urban flooding results in income loss not only for Dhaka residents, but also for daily migrant workers who commute to the Dhaka area for their livelihood. To estimate the indirect damage from income loss, this analysis extrapolated the population of Dhaka and the number of migrant workers to each year between 2014 and 2050, using an estimated annual population growth rate of 3 percent.

For Dhaka residents, income loss was based on household income data since all workers in a household are likely to face similar impact from flooding. The computation was limited to workers in the unorganized sector since (a) most workers in the organized sector are paid on a monthly basis and thus are unaffected by daily disruptions and (b) most of the loss for those affected is captured in the loss in value added under the commerce and industry portion of the analysis.

The analysis assumed that all workers in the top monthly income bracket (> Tk. 20,000) are in the organized sector and all workers in the lowest monthly income bracket (< Tk. 5,000) are in the unorganized sector. For the middle three brackets (Tk. 15,000–20,000, Tk. 10,000–15,000, and Tk. 5,000–10,000 per month), 10, 50, and 90 percent, respectively, were assumed to work in the unorganized sector. Income loss was computed based on lost work days multiplied by the average income in each category.

The analysis further assumed that 25 percent of migrant workers are in the unorganized sector. Since these workers tend to have lower skills, it was assumed that they earn an average of 33 percent less than the average urban worker in Dhaka. Income loss was computed based on lost work days, developed using the average flooding for the whole of Dhaka and its duration.

For each income group, income loss (D_I) is expressed as $D_I = I * D_T$, where I equals the income per day in each income category and D_T equals the number of lost work days due to flooding in each ward for Dhaka residents and the average for the Dhaka area overall for migrant workers.

Source: Roy 2014.

one-quarter of the overall average for the entire country, the DALY estimates were lowered to 25 percent of the overall average for Bangladesh.

Roads and Railway

Flooding directly damages roads and railways and also causes indirect damage through disruption of economic activity. For the purposes of this analysis, only the direct damage was estimated, based on repair costs. Depth of flooding was a major factor in estimating the extent of road damage. Repair costs were estimated based on the per-meter of inundation approach used by Kok (2001). Accordingly, damage factors of 0.1, 0.225, and 0.4, respectively, were used for water depths of 0.25–0.75 m, 0.75–1.5 m, and > 1.5 m. The maximum extent of inundation in the Dhaka area over the 10 days of flooding under each depth was used to determine the length of damaged roads (L_D), expressed as follows:

$$L_D = L_T * [A_H * 0.4 + (A_M - A_H) * 0.225 + (A_L - A_M - A_H) * 0.1], \qquad (5.9)$$

where L_T equals the total length of roads and A_L, A_M, and A_H represent the maximum proportions of flooded area over the 10 days under the three respective flood depths in increasing order.

The average cost of road repair was assessed at Tk. 24 million per km, based on World Bank estimates (World Bank 2010). For the final analysis, the average road lengths were extrapolated to 2050, and the road repair cost from flooding was then obtained by multiplying the length of damaged roads by the per-kilometer road repair cost.

Similarly, property damage for railways was estimated based on the length of track in each ward of Dhaka. An average rail repair cost of Tk. 240 million per km was based on World Bank estimates.[11]

Other Surface Transport

The analysis covered the direct damage from flooding to public-transport vehicles, including buses, taxis, auto-rickshaws, and goods vehicles. The estimated number of public-transport vehicles in 2050 was extrapolated from current data for such vehicles. Their damage repair costs were obtained using sample surveys from auto-repair shops. The average estimated cost of repairs was in a range of Tk. 10,000–30,000, based on depth of water submersion and vehicular type. To determine the proportion of vehicles damaged, assumptions were made by depth category, as follows: > 1.5 m, 50 percent of vehicles; 0.75–1.5 m, 33 percent of vehicles; and 0.25–0.75 m, 25 percent of vehicles. Thus, the transport damage factor (T_P) can be expressed as follows:

$$T_P = [0.25 * (F_L - F_M - F_H) + 0.33 * (F_M - F_H) + 0.5 * F_H]/100, \qquad (5.10)$$

where F_L, F_M, and F_H represent the average extent of flooding in the Dhaka area over the 10 days for the three respective depths in increasing order.

Notes

1. Damage estimates are based mainly on the Dhaka Municipal Corporation area (both North and South) owing to the availability of detailed data on its population and physical assets.
2. Details are available at http://www.prb.org/Publications/Articles/2001/UrbanizationTakesonNewDimensions inAsiasPopulationGiants.aspx.
3. In computing damage, current income/output data was used. In 2050, income/output will certainly be higher (current annual GDP growth in Bangladesh exceeds 6 percent). One reason for discounting future values is to account for a higher future income level in the economy. Since no discounting of future values was done, the income/output data was not extrapolated with estimated growth rates from the present to 2050.

Thus, instead of trying to separately estimate GDP growth and likely discounting factors (an exercise difficult to do with accuracy) an assumption was made that the two will counterbalance each other.

4. More information is available at http://csc.noaa.gov/archived/coastal/economics/discounting.htm.
5. *Jhupri* structures are temporary houses made of such removable materials as grass, thatch, bamboo, and wood. *Kutcha* houses have walls and roofs made of unburnt brick, bamboo, mud, reed, thatch, or loosely packed stones. *Semi-pucca* houses have fixed walls made of pucca materials (see below), with non-pucca materials used for roofing. *Pucca* houses have walls and roofs made of such materials as burnt bricks, stones (packed with lime or cement), cement concrete, timber, and ekra. More information is available at http://mospi.nic.in/Mospi_New/upload/statistical_year_book_2011/SECTOR-4-SERVICE%20SECTOR/CH-28-HOUSING/HOUSING-WRITEUP.pdf.
6. The 2011 population census was used to estimate the number of houses in each building category. For the pucca subcategories, data was extrapolated from a similar study conducted for Calcutta (Kolkata), which used Google Earth data to separate the composition of city residential buildings into EWS, MIG, and HIG.
7. These figures are based on the ACC Help Home Building Calculator (https://www.acchelp.in/cost-calculators.asp).
8. For Central Dhaka, a threshold of 0.1 m was used.
9. Data was provided by the Director for Disease Control, Directorate General of Health Services (DGHS), Ministry of Health and Family Welfare, Mohakhali, Dhaka.
10. The estimates for Southeast Asia were applied to Bangladesh as a whole.
11. Details are available at http://www.chinaafricarealstory.com/2010/08/real-cost-of-chinese-railway.html.

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PART 2

Results

CHAPTER 6

Assessment of Dhaka's Modeled Zones

Introduction

Having estimated the regional impacts of climate change, land development, and land-use changes, the impact of urban (as well as river) flooding on the Dhaka detailed study area can be investigated. This chapter is organized into seven major sections corresponding to this study's modeled drainage zones. Each section begins by estimating the location-specific inundation depth and duration for 100-year, return-period rainfall with and without climate change. The flood vulnerability indices of constituent wards are then presented, taking into account each ward's physical, social, economic, and institutional characteristics, together with the inundation depths and duration of the alternative scenarios considered for hydrological modeling with different weights assigned to flooding (chapter 4). Next, the expected damage and loss from flooding are provided. Finally, the estimated costs of addressing the current adaptation deficit and climate change adaptation are presented and compared with the benefits of making these investments.

Old Dhaka Results

Hydrological Modeling Output

The study generated maps simulating the inundation depth and duration of urban flooding for the historic 100-year, return-period rainfall event of 2004 and alternative scenarios for 2050 for a similar rainfall event with and without climate change. For 2050, alternative scenarios were simulated using flood criteria of 0.1 m and 0.25 m.

The maps generated for the 100-year rainfall event in 2050 show that, with improvements already planned, even without climate change, the extent of shallow flooding (0.1–0.25 m depth) is significantly greater than in 2004. Some deeper pockets of waterlogging (>0.75 m depth) persist, and flooding duration

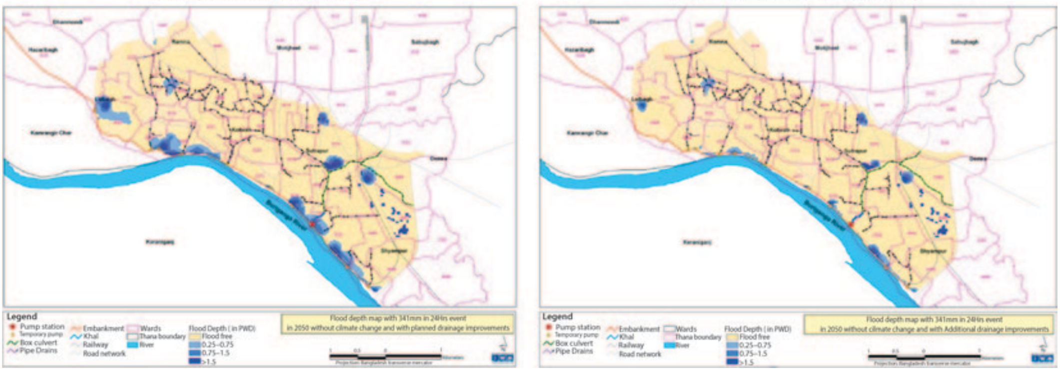
Table 6.1 Comparison of Flooding Results with 0.1 m Flood Criteria, Old Dhaka Model

Extreme storm (341 mm/24 hour)	*Maximum flooded area (km²)* Flood free (0–0.1 m)	*0.1–0.25 m*	*0.25–0.75 m*	*0.75–1.5 m*	*>1.5 m*	*Average duration above 0.1 m depth (hours to recede)*
2004 (actual storm)	7.8	1.2	2.0	0.5	0.3	19.2
2050 (SE + PI)	3.7	7.0	0.6	0.3	0.2	20.6

Source: Zaman 2014.
Note: SE = socioeconomic changes; PI = planned improvements.

Map 6.1 Extreme Rainfall Scenarios in 2050 with 0.25 m Flood Criteria, Old Dhaka

a. PI (341 mm/24 hour) **b. PI + AI (341 mm/24 hour)**



Source: IWM 2014.
Note: PI = planned improvements; AI = additional investments.

increases slightly (table 6.1). The changes in depth and duration are attributable to increases in land elevation and imperviousness.

Achieving an inundation-free Old Dhaka, especially the deep pockets, will be a difficult task from a practical perspective. Since Old Dhaka residents have adopted various strategies for coping with periodic episodes of modest flooding, the flood criteria for 0.1 m depth appeared too stringent, as pointed out by local experts. As a planning goal, it was later agreed that flood criteria up to a depth of 0.25 m would be acceptable, and this was the inundation depth later used to simulate scenarios for rainfall extremes (341 mm per 24 hours) in 2050. The maps generated showed that there is an adaptation deficit (map 6.1), meaning that the infrastructure in place or the improvements already planned are insufficient to cope with such extreme events. Thus, even without climate change, additional investments (AI) in the drainage system would be needed to meet acceptable criteria: 90 percent of administrative areas with a maximum flood depth less than 0.25 m and duration less than 12 hours. Table 6.2 compares the simulated results for the extreme rainfall event in 2050 with planned improvements (PI) only, as well as with the incorporation of AI required to meet the current adaptation deficit.

The AI required to meet the current adaptation deficit included increasing the capacity of temporary pumps located along the flood embankment. To remove

Table 6.2 Comparison of 2050 Flooding Results with 0.25 m Flood Criteria, Old Dhaka Model

Extreme storm in 2050 (without climate change)	*Maximum flooded area (km²)*				*Average duration above 0.25 m depth (hours to recede)*
	Flood free (0–0.25 m)	*0.25–0.75 m*	*0.75–1.5 m*	*>1.5 m*	
Future SE + PI (341 mm/24 hour)	10.6	0.6	0.3	0.2	5
Future SE + PI + AI (341 mm/24 hour)	11.3	0.2	0.1	0.1	1

Source: Zaman 2014.
Note: SE = socioeconomic changes; PI = planned improvements; AI = additional investments.

floodwater faster, all three pumps at the Dholaikhal Station were operated simultaneously in the model. It was assumed that sedimentation would be removed from key box-culverts (Debdulai and Dholaikhal) and that khals would be protected from encroachment and solid waste.

Specifically, the analysis identified the following measures to address the current adaptation deficit:

- At Shahid Nagar—Increase pump capacity from 0.7 m^3/s to 1.82 m^3/s.
- At Swarighat—Increase pump capacity from 0.14 m^3/s to 1.12 m^3/s.
- At Islambag—Increase pump capacity from 1.26 m^3/s to 3.08 m^3/s.
- Near Islambag—Increase pump capacity from 0.28 m^3/s to 1.26 m^3/s.
- Near Farashganj—Increase pump capacity from 0.28 m^3/s to 0.56 m^3/s.
- Near Faridabad—Increase pump capacity from 0.14 m^3/s to 1.12 m^3/s.
- At Postogola—Increase pump capacity from 0.28 m^3/s to 0.84 m^3/s.
- At Postogola—Install additional pumps of 0.42 m^3/s capacity.
- At Islambag—Install additional pumps of 0.98 m^3/s capacity.
- At Imamganj—Install additional pumps of 0.56 m^3/s capacity.
- At Dholaikhal—Operate all three pumps together for extreme rainfall events.
- At Debdulai—Remove sediment from the box-culvert (2.5 m × 2.8 m): total length = 2,385 m; total volume of sediment to be cleaned = 5,500 m^3 (assuming sedimentation depth is 33 percent of culvert height).
- At Dholaikhal—Remove sediment from the box-culvert (3.8 m × 4.0 m): total length = 940 m; total volume of sediment to be cleaned = 4,700 m^3 (assuming sedimentation depth is 33 percent of culvert height).

These measures were first designed based on an understanding of the drainage-system behavior and then simulated in the drainage model. This process was repeated until the acceptable flooding criteria were met in all administrative areas. The results highlight how AI significantly reduces the extent and duration of flooding.

Simulation with climate change increased the extent and duration of flooding (table 6.3). Several localities experienced more than 0.25 m inundation over 12 hours; thus, further adaptation measures were required.

Table 6.3 2050 Rainfall Event in a Changing Climate, Old Dhaka

Extreme storm in 2050	*Maximum flooded area (km²)* Flood free (0–0.25 m)	*0.25–0.75 m*	*0.75–1.5 m*	*>1.5 m*	*Average duration above 0.25 m depth (hours to recede)*
Future SE + PI (341 mm/24 hour)	10.6	0.6	0.3	0.2	5
Future SE + PI + CC (396 mm/24 hour)	9.8	1.4	0.3	0.2	6
Future SE + PI + AI (341 mm/24 hour)	11.3	0.2	0.1	0.1	1
Future SE + PI + AI + CC (396 mm/24 hour)	11.0	0.3	0.2	0.2	2
Future SE + PI + AI + CC + AD (396 mm/24 hour)	11.3	0.2	0.1	0.1	1

Source: Zaman 2014.
Note: SE = socioeconomic changes; PI = planned improvements; CC = climate change; AI = additional investments; AD = adaptation to climate change.

Once again, alternative measures—increasing the capacity of existing pumps, adding pumps, and removing sediment from drainage pipes—were designed, and their likely impacts were simulated in the flood model. The process was repeated until the acceptable flooding criteria were met. Further adaptation measures required to cope with climate change were identified as follows:

- At Shahid Nagar—Increase pump capacity from 1.82 m³/s to 2.24 m³/s.
- At Swarighat—Increase pump capacity from 1.12 m³/s to 1.26 m³/s.
- At Imamganj—Increase pump capacity from 0.56 m³/s to 1.26 m³/s.
- Near Farashganj—Increase pump capacity from 0.56 m³/s to 1.68 m³/s.
- Near Faridabad—Increase pump capacity from 1.12 m³/s to 1.54 m³/s.
- At Postogola—Increase pump capacity from 0.84 m³/s to 0.98 m³/s.
- At Islambag—Install additional pumps of 1.12 m³/s capacity.
- At Faridabad—Install additional pumps of 0.84 m³/s capacity.
- Toward Islambag—Remove sediment from the main pipe draining toward Islambag: total length of pipe = 2,834 m; volume of sediment to be cleaned = 500 m³ (based on sedimentation depth of 20 percent of diameter).

Additional simulations were conducted with the drainage model to investigate the effectiveness of other solutions to the urban flooding problem. For example, it was seen that converting the existing Dhopkhola playground into a 2-ha dry pond (2.5 m deep) would be effective in reducing shallow (0.1–0.25 m) flooding in that vicinity (Zaman 2014).

Vulnerability from Urban Flooding

It should be noted that only two of Old Dhaka's 19 wards—wards 82 and 83—figure among Dhaka's top 20 wards for urban flood vulnerability, indicating this area's comparatively low overall vulnerability. With socioeconomic changes and planned improvements only (SE + PI), ward 82 ranks third when equal weight (20 percent) is assigned to all five dimensions including flooding and fourth when flooding is assigned 50 percent weight. When the effect of climate change is added (SE + PI + CC), ward 82 ranks second for both equal weight and 50 percent flood weight, indicating that ward's high vulnerability. However, if the envisaged additional investments (AI) are implemented, that ward's vulnerability drops sharply under AI scenarios, falling, for the most part, below the top 20 for both equal weight and 50 percent flood weight. With only PI, ward 83 barely ranks in the top 20 list of vulnerable wards for both equal weight and flood weight, even when the effect of climate change is added. Under the AI scenarios, that ward's vulnerability falls below the top 20 ranking (table 6.4).

As most wards in Old Dhaka fall below the top 20 list, the area's overall vulnerability is relatively low, and these vulnerability rankings are further reduced when higher weightage is assigned to flooding, indicating that the area has relatively fewer problems from urban flooding and climate change. In addition, the suggested investments under the AI scenarios appear quite effective in further reducing these vulnerabilities.

Table 6.4 FVI Rankings of Old Dhaka Wards under Alternative Flooding Scenarios

	Future scenarios									
	Equal weight[a]					*50% flood weight*[a]				
Ward	*SE + PI*	*SE + PI + CC*	*SE + PI + AI*	*SE + PI + AI + CC*	*SE + PI + AI + CC + AD*	*SE + PI*	*SE + PI + CC*	*SE + PI + AI*	*SE + PI + AI + CC*	*SE + PI + AI + CC + AD*
82	3	2	22	19	31	04	2	14	13	27
83	20	17	28	29	37	19	15	28	21	33
60	27	27	50	49	50	13	11	33	23	32
65	30	9	52	52	53	12	1	59	44	64
80	46	46	29	34	27	33	35	24	24	20
81	47	47	46	45	44	46	42	53	43	43
66	53	57	70	66	71	6	13	42	33	63
63	55	53	51	51	51	49	32	29	25	23
59	56	55	54	54	54	66	63	68	66	65
64	57	56	55	55	55	72	66	69	70	69
61	58	58	57	56	56	73	68	71	71	71
79	66	66	75	72	77	27	22	65	57	67
73	83	86	83	82	82	79	78	75	76	76
71	88	91	88	88	88	90	91	89	89	89
72	89	92	89	89	89	91	92	90	90	90
67	90	87	90	90	90	92	83	91	91	91
68	91	80	91	91	91	89	67	88	88	88
69	92	64	92	92	92	93	23	92	92	92
78	93	93	93	93	93	94	93	93	93	93

Note: SE = socioeconomic changes; PI = planned improvements; AI = additional investments; CC = climate change; AD = adaptation to climate change; FVI = Flood Vulnerability Index.
a. Lower numbers indicate higher vulnerability.

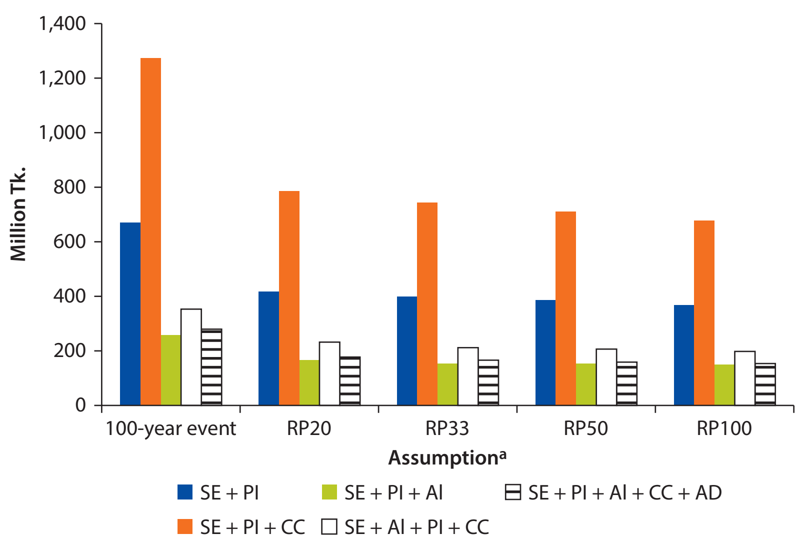
Damage Estimates

The total damage for Old Dhaka in 2050 was estimated for the five future scenarios, using alternative assumptions about how frequently a 100-year, return-period storm would occur (chapter 5). Figure 6.1 shows the total monetary value of the damage that would result from the actual 100-year event in 2050 under the five future scenarios, followed by expected damage estimates using alternative probabilities of the 100-year event's recurrence (i.e., every 20, 33, 50, or 100 years).

Figure 6.2 shows the expected cumulative damage over the 2014–50 period for the five future scenarios, with random assignment of various return-period storms under alternative assumptions of increased frequency of the 100-year event. As described in chapter 5, alternative probabilities of the recurrence of the 100-year event are used to compute the expected value of the total cumulative damage between 2014 and 2050 if the event were to occur every 20, 33, 50, or 100 years.

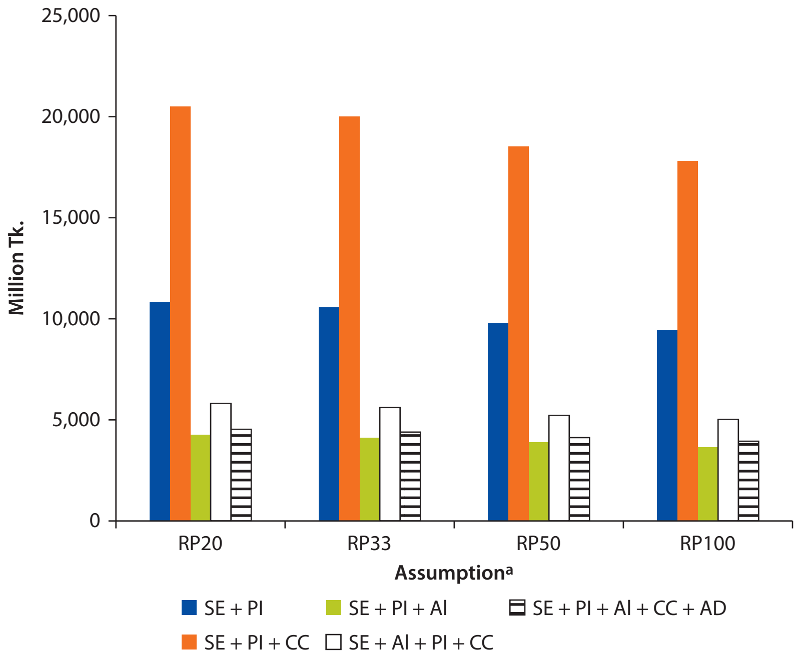
The results show how the damage that would occur under the scenario with planned improvements (PI) alone is reduced when additional investments (AI) are made to address the current adaptation deficit and how climate change exacerbates the extent of damage for each scenario. Comparison of the damage in a changing climate with and without AI reveals that increased damage due to climate change is less if AI are made and the current adaptation deficit is addressed. With adaptation measures for climate change, the damage in

Figure 6.1 Total Estimated Damage for Old Dhaka in 2050



Source: Roy 2014.
Note: SE = socioeconomic changes; PI = planned improvements; AI = additional investments; CC = climate change; AD = adaptation to climate change. RP = return period (years).
a. 100-year event = actual damage from a 100-year event occurring in 2050 with certainty; RP20, 33, 50, and 100 = damage from a 100-year event occurring once every 20, 33, 50, or 100 years, respectively.

Figure 6.2 Total Cumulative Damage for Old Dhaka, 2014–50



Source: Roy 2014.
Note: SE = socioeconomic changes; PI = planned improvements; AI = additional investments; CC = climate change; AD = adaptation to climate change. RP = return period (years).
a. 100-year event = actual damage from a 100-year event occurring in 2050 with certainty; RP20, 33, 50, and 100 = damage from a 100-year event occurring once every 20, 33, 50, or 100 years, respectively.

a changing climate decreases somewhat, but is still larger than in the AI scenario without climate change.

Table 6.5 captures the increased damage caused by climate change under the planned improvements (PI) and additional investments (AI) scenarios for the damage occurring in 2050 and the cumulative damage in 2014–50 using various alternative assumptions. In 2050, the increased damage from a 100-year event due to climate change would amount to Tk. 608 million if only PI were made and would be reduced to Tk. 95 million with AI made to address the adaptation deficit in the current climate. Table 6.5 also indicates that the same result holds for various expected return-period storms in 2050; that is, increased damage from climate change is higher unless AI are made. The cumulative damage from climate change in 2014–50, with random assignment of various return-period storms over the years, is also higher when the current adaptation deficit is not addressed. In terms of sector-wise comparisons, the largest damage for Old Dhaka occurs in residential property (i.e., moveable goods inside the house, including furniture, electronic goods, clothing, and any other stored personal possessions), followed by residential buildings and industry.

Cost of Adaptation

Results of the hydrological modeling exercise show that most of Old Dhaka's needed structural measures against a 100-year return-period rainfall event in 2050 beyond planned improvements involve increasing temporary pump capacity and sludge cleaning (Zaman 2014). For the temporary pumps, two discharge capacities are recommended: 5 ft^3/s (0.14 m^3/s) and 25 ft^3/s (0.70 m^3/s). Limiting DWASA's inventory to two types of stock is expected to ease inventory maintenance. Pump operation requires both pipes and transformers. Keeping DWASA's current inventory in mind, this study recommends 100 kVA and 200 kVA transformers. Each 100 kVA transformer can run three pumps of 5 ft^3/s capacity, while each 200 kVA transformer can run one 25 ft^3/s pump, plus one 5 ft^3/s pump; alternatively, it could run six 5 ft^3/s pumps. The transformers also require cables. Table 6.6 breaks down the total unit costs for the recommended capacity pumps and transformers.

Table 6.5 Increased Damage in Old Dhaka from Climate Change for Future Scenarios under Alternative Assumptions

Increased damage occurring in 2050 (Tk. million)					
	Return period based on probability				
Scenario	*100 year*	*RP20*	*RP33*	*RP50*	*RP100*
SE + PI + CC	608	426	378	352	317
SE + PI + AI + CC	95	83	70	62	52

Increased cumulative damage, 2014–50 (Tk. million)				
	Using random numbers for each return period			
Scenario	*RP20*	*RP33*	*RP50*	*RP100*
SE + PI + CC	9,746	9,489	8,746	8,409
SE + PI + AI + CC	1,554	1,518	1,404	1,357

Source: Roy 2014.
Note: SE = socioeconomic changes; PI = planned improvements; AI = additional investments; CC = climate change; RP = return period (years).

Table 6.6 Unit Costs for Temporary Pumps, Old Dhaka

Component	*Cost*	*Total unit cost (million Tk.)*
Pump, 5 ft^3/s discharge	0.5	0.8
Pipes	0.3	
Pump, 25 ft^3/s discharge	1.4	2.6
Pipes	1.2	
Transformer, 100 kVA	0.7	1.2
Cables	0.5	
Transformer, 200 kVA	1.0	2.0
Cables	1.0	

Source: DWASA officials.

Table 6.7 Estimated Cost of Meeting the Current Adaptation Deficit, Old Dhaka

	Additional temporary pump capacity (Tk. million)								
	Added pumps (5 ft^3/s) and transformers				*Added pumps (25 ft^3/s) and transformers*				
Pump location, added discharge capacity (m^3/s)[a]	*Pumps (no.)*	*Cost of pumps and pipes (0.8/unit)*	*100 kVA transformers (no.)*	*Cost of transformers and cables (1.2/unit)*	*Pumps (no.)*	*Cost of pumps and pipes (2.6/unit)*	*200 kVA transformers (no.)*	*Cost of transformers and cables (2.0/unit)*	*Total cost*
Shahid Nagar, 1.12	3	2.4	1	1.2	1	2.6	1	2.0	8.2
Islambag, 2.80	0	0	0	0	4	10.4	4	8.0	18.4
Swarighat, 1.12	2	1.6	1	1.2	1	2.6	1	2.0	7.4
Imamganj, 0.56	4	3.2	0	0	0	0	1	2.0	5.2
Farashganj, 0.28	2	1.6	1	1.2	0	0	0	0	2.8
Faridabad, 0.98	2	1.6	1	1.2	1	2.6	1	2.0	7.4
Postogola, 0.56	4	3.2	0	0	0	0	1	2.0	5.2
Subtotal		13.6		4.8		18.2		18.0	54.6

	Sludge cleaning (Tk. million)			
Sediment removal from box-culverts	*Removal rate/m^3*	*Removal volume (m^3)*	*Length to clean (m)*	*Total cost*
Debdulai (2.5 m × 2.8 m)	1,000	5,500	2,385	5.5
Dholaikhal (3.8 m × 4 m)	1,000	4,700	940	4.7
Subtotal				10.2
Total cost: 64.8				

Sources: DWASA officials and authors' calculations.
a. Pumping head = 10 m.

Table 6.8 Estimated Cost of Meeting the Climate Change Adaptation Deficit, Old Dhaka

	Additional temporary pump capacity (Tk. million)								
	Added pumps (5 ft^3/s) and transformers				*Added pumps (25 ft^3/s) and transformers*				
Pump location, added discharge capacity (m^3/s)[a]	*Pumps (no.)*	*Cost of pumps and pipes (0.8/unit)*	*100 kVA transformers (no.)*	*Cost of transformers and cables (1.2/unit)*	*Pumps (no.)*	*Cost of pumps and pipes (2.6/unit)*	*200 kVA transformers (no.)*	*Cost of transformers and cables (2.0/unit)*	*Total cost*
Shahid Nagar, 0.42	3	2.4	1	1.2	0	0	0	0	3.6
Islambag, 1.12	3	2.4	1	1.2	1	2.6	1	2.0	8.2
Swarighat, 0.14	1	0.8	1	1.2	0	0	0	0	2.0
Imamganj, 0.70	0	0	0	0	1	2.6	1	2.0	4.6
Farashganj, 1.12	3	2.4	1	1.2	1	2.6	1	2.0	8.2
Faridabad, 0.84	1	0.8	0	0	1	2.6	1	2.0	5.4
Postogola, 0.14	1	0.8	1	1.2	0	0	0	0	2.0
Subtotal		9.6		6.0		10.4		8.0	34.0
	Additional sludge cleaning (Tk. million)								
Description						*Removal rate/m^3*	*Removal quantity (m^3)*	*Length to clean (m)*	*Total cost*
Main drainage pipe toward Islambag						600	500	2,834	0.3
Subtotal									0.3
Total cost: 34.3									

Sources: DWASA officials and authors' calculations.
a. Pumping head = 10 m.

As previously discussed, addressing the current structural adaptation deficit will require temporary pumps at the following points: Shahid Nagar, Islambag, Swarighat, Imamganj, Farashganj, Faridabad, and Postogola. In addition, it will require regular sediment removal from the Debdulai and Dholaikhal box-culverts. Table 6.7 breaks down the cost estimates for meeting the current adaptation deficit. As shown, the cost of added temporary pump capacity and sludge removal are Tk. 54.6 million and Tk. 10.2 million, respectively, for a total estimated adaptation cost of Tk. 64.8 million.

It is argued that nearly 1 m of sludge is deposited in box-culverts each year. The total cost of removing 1 m^3 of sludge (including the costs of dewatering, dam construction, and other related costs) is estimated at Tk. 1,000. Since the average width of a box-culvert is estimated at 5 m, the cost of removing sludge from 1 m of box-culvert is Tk. 5,000. Pipe cleaning is less expensive, at Tk. 600 per m^3. This figure slightly overestimates the cost of cleaning a meter of pipe since the average pipe diameter is less than 1 m.

Adapting to climate change would mean increasing the temporary pump capacity at all points. For sludge cleaning, it would mean cleaning the drainage pipe toward Islambag in addition to removing sediment from the box-culverts at Debdulai and Dholaikhal. Table 6.8 breaks down the total added cost estimates for addressing climate change adaptation. The estimated added expense for pumps, pipes, and transformers is Tk. 34 million, while the cost of additional sludge cleaning is Tk. 0.3 million, for a total additional cost of Tk. 34.3 million.

Finally, table 6.9 provides a summary comparison of the total costs to meet the current adaptation deficit and the added cost of climate change adaptation. As shown, addressing the current deficit totals Tk. 64.8 million, while the cost of meeting the added climate change deficit totals Tk. 34.3 million, for a total combined cost of Tk. 99.1 million (Huq 2014). The damage estimates demonstrate that this investment cost in flood mitigation will lead to a much higher reduction in damage of Tk. 1,002 million in 2050 when faced with a 100-year, return-period storm, with a cumulative damage reduction (2014–50) of Tk. 13,915 million.

Table 6.9 Summary of Adaptation Costs, Old Dhaka

Recommended measure	*Cost (Tk. million)*
Addressing current adaptation deficit	
Temporary pumps	54.6
Sludge cleaning (sediment removal from box-culverts)	10.2
Total estimated cost	64.8
Addressing climate change deficit	
Temporary pumps	34.0
Sludge cleaning (drainage pipe cleaning)	0.3
Total estimated cost	34.3
Total combined cost	**99.1**

Sources: DWASA officials and authors' calculations.

Central Dhaka Results

Hydrological Modeling Output

The study generated maps simulating the inundation depth and duration of urban flooding for the historic 100-year, return-period rainfall event in 2004 and alternative scenarios for 2050 with and without climate change. Upon consultation with local experts, the 0.1 m inundation criteria were adopted for Central Dhaka. For the 100-year rainfall event in 2050 without climate change, there was relatively little additional flooded area; at inundation depths of 0–0.1 m, 0.1–0.25 m, 0.25–0.75 m, 0.75–1.5 m, and >1.5 m, maximum flooded areas were 26.4 km^2, 8.8 km^2, 1.9 km^2, 0.3 km^2, and 1.8 km^2, respectively. However the expected duration of flooding above 0.1 m depth—even without climate change—was significant, at 11.4 hours on average.

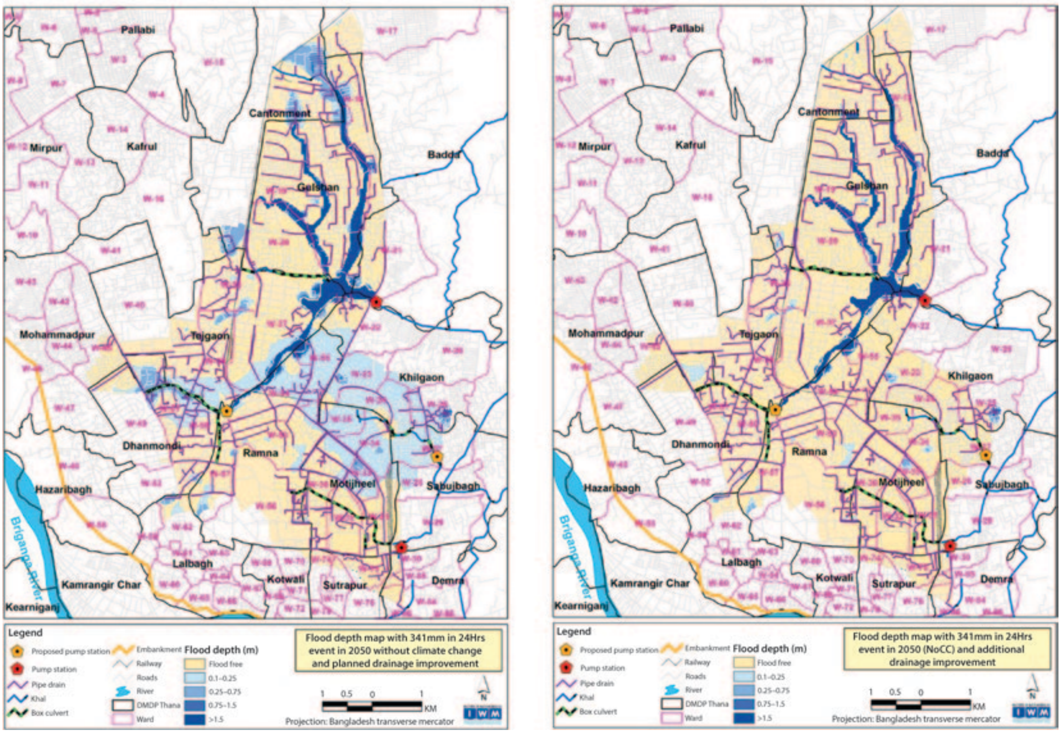
With only planned improvements (PI), the maps generated showed that, even without climate change, the drainage system is unable to cope with a 100-year return-period storm (341 mm per 24 hours) (photo 6.1). Thus, additional investments (AI) were incorporated into the model to satisfy the set criteria for acceptable flooding in Central Dhaka (i.e., 90 percent of each administrative area must have less than 0.1 m flooding, and no area can be inundated for more than 12 hours). Map 6.2 compares the simulated results for the extreme rainfall event in 2050 with PI and the AI to address the adaptation deficit in the current climate. The results highlight the significant reduction in the extent and duration of flooding from the AI (table 6.10).

Photo 6.1 Original Rampura sluice gates (at right) and new bypass channel used when gates are closed (Central Dhaka system)

Credit: © Asif Zaman / World Bank. Used with permission. Further permission required for reuse.

Map 6.2 Extreme Rainfall Scenarios in 2050 with 0.1 m Flood Criteria, Central Dhaka

a. PI (341 mm/24 hour) b. PI + AI (341 mm/24 hour)



Source: IWM 2014.
Note: PI = planned improvements; AI = additional investments.

Table 6.10 2050 Rainfall Event in a Changing Climate, Central Dhaka

Extreme storm in 2050	*Maximum flooded area (km²)* Flood free (0–0.1 m)	0.1–0.25 m	0.25–0.75 m	0.75–1.5 m	>1.5 m	*Average duration above 0.1 m depth (hours to recede)*
Future SE + PI (341 mm/24 hour)	26.4	8.8	1.9	0.3	1.8	10
Future SE + PI + CC (396 mm/24 hour)	25.1	10.1	1.9	0.3	1.8	12
Future SE + PI + AI (341 mm/24 hour)	36.4	0.7	0.3	0.1	1.7	1
Future SE + PI + AI + CC (396 mm/24 hour)	35.7	1.1	0.5	0.2	1.8	2
Future SE + PI + AI + CC + AD (396 mm/24 hour)	36.1	0.9	0.4	0.1	1.8	1

Source: Zaman 2014.
Note: SE = socioeconomic changes; PI = planned improvements; AI = additional investments; CC = climate change; AD = adaptation to climate change.

Photo 6.2 Construction of new pump station at Hatir Jheel, Rampura (Central Dhaka system)

Credit: © Asif Zaman / World Bank. Used with permission. Further permission required for reuse.

The part of Central Dhaka beyond Pragati Sharani is unprotected, and some new roads being constructed may work as embankments. Also, new pump stations are needed to drain out excess water from heavy rainfall (photo 6.2).

The analysis identified the following specific measures to address the current adaptation deficit:

- At Gulshan, Banani, and Hatir Jheel lakes—Reduce initial water levels from 5 m PWD to 4 m PWD (lowering of the lakes' water levels represents early warning of large storm event).
- At outfall of Panthapath Box-Culvert—Install a new pump station with 12.5 m^3/s capacity and 80 percent efficiency.
- Near Bashabo Water Pump Station of DWASA—Install new pump stations and sluice gate; pump capacity is 15 m^3/s, with 80 percent efficiency, and gate size is 4 m × 3 m.

When the effect of climate change was simulated (396 mm per 24 hours), it was found that the AI were insufficient to meet the acceptable flooding criteria in all administrative areas. Thus, further adaptation measures were required to reduce the impact of increased rainfall intensity due to climate change.

Therefore, alternative measures were designed and simulated in the flood model. The process was repeated until the acceptable flooding criteria for

Central Dhaka were met. Further adaptation measures required to cope with climate change were identified as follows:

- Near Russel Square—Install a new sluice gate (3.4 m × 3.4 m) with automatic operation to divert excess water to Dhanmondi Lake at the time of peak runoff and prevent backwater flow from Panthapath Box-Culvert.
- Near Russel Square—Reactivate the existing sluice gate (2 m × 2 m) and automatic operation with the new gate (above) to divert excess water to Dhanmondi Lake at the time of peak runoff.

Vulnerability to Urban Flooding

Despite the more stringent criteria, Central Dhaka is one of the least vulnerable areas in Dhaka, with only two of its 44 wards—25 and 75—figuring among the top 20 vulnerable wards/regions. When the weightage assigned to flooding is increased, with the transition from equal weight to 50-percent flood weight, these two wards become even less vulnerable. Vulnerability also decreases with the transition from planned improvements (PI) to additional investments (AI) as flooding levels fall. From this, one can infer that flooding plays a role in the higher vulnerability of the two wards, but not as large as the lower-than-average indices of the Climate Disaster Resilience Index (CDRI) in the two wards. Table 6.11 provides a comprehensive listing of flood vulnerability indices for all of the constituent wards of Central Dhaka.

Table 6.11 FVI Rankings of Central Dhaka Wards under Alternative Flooding Scenarios

	Future scenarios									
	Equal weight[a]					*50% flood weight*[a]				
Ward	*SE + PI*	*SE + PI + CC*	*SE + PI + AI*	*SE + PI + AI + CC*	*SE + PI + AI + CC + AD*	*SE + PI*	*SE + PI + CC*	*SE + PI + AI*	*SE + PI + AI + CC*	*SE + PI + AI + CC + AD*
25	4	4	14	16	13	11	10	16	17	11
75	19	10	43	43	42	16	12	36	38	37
16	24	21	24	24	23	32	30	40	40	39
23	26	24	21	22	21	31	29	25	27	24
26	31	26	25	25	24	43	40	41	41	40
33	32	31	26	26	26	26	28	22	22	22
28	33	33	30	31	29	35	41	44	47	46
22	34	30	27	28	25	37	37	31	34	31
76	35	32	39	30	28	30	25	35	30	29
85	36	34	42	42	41	39	33	56	58	55
27	37	35	31	32	30	52	47	46	48	47
24	38	36	32	33	32	53	49	47	49	48
29	39	37	35	36	34	51	48	49	50	50
34	40	43	40	40	39	44	44	43	45	44
31	41	38	34	35	33	54	50	50	51	51

table continues next page

Table 6.11 FVI Rankings of Central Dhaka Wards under Alternative Flooding Scenarios *(continued)*

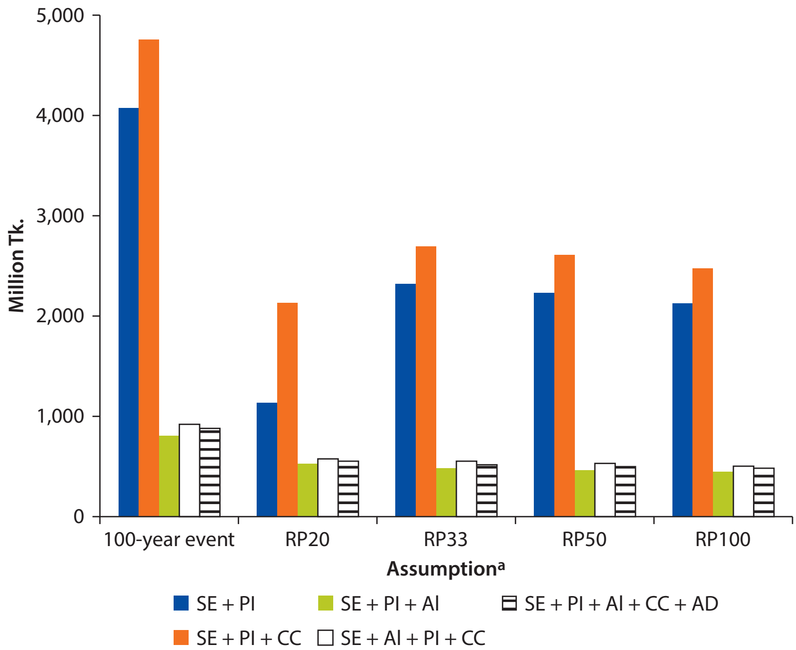
	Future scenarios									
	Equal weight[a]					*50% flood weight*[a]				
Ward	*SE + PI*	*SE + PI + CC*	*SE + PI + AI*	*SE + PI + AI + CC*	*SE + PI + AI + CC + AD*	*SE + PI*	*SE + PI + CC*	*SE + PI + AI*	*SE + PI + AI + CC*	*SE + PI + AI + CC + AD*
30	43	42	37	39	38	58	53	54	55	53
35	45	45	41	41	40	59	56	55	56	54
32	48	48	44	44	43	61	58	58	59	57
84	49	49	45	46	45	62	59	61	60	58
77	50	50	47	47	46	50	45	45	53	49
36	51	51	48	48	47	64	60	62	61	61
62	54	54	53	53	52	38	36	51	36	35
38	59	76	61	59	60	24	79	21	20	17
19	62	62	56	60	57	47	54	19	26	19
37	63	63	62	62	61	45	57	26	32	25
51	67	82	81	81	81	55	84	83	83	83
54	68	67	65	65	65	70	71	57	65	59
55	69	69	68	67	66	67	70	63	62	56
45	70	75	76	75	75	74	80	78	78	77
18	71	74	73	74	73	68	72	72	72	72
39	72	70	71	71	70	77	76	76	74	74
52	73	71	67	69	68	60	64	38	42	38
49	74	68	66	68	67	69	65	39	52	42
21	75	73	72	73	72	75	74	73	73	73
20	76	72	69	70	69	76	73	67	68	68
17	77	77	78	78	78	81	81	79	79	78
40	78	79	74	76	74	80	82	74	75	75
57	80	84	82	83	84	78	77	77	77	80
50	81	83	80	80	80	83	86	82	82	82
44	82	85	79	79	79	84	87	81	81	81
70	84	81	84	84	83	85	75	84	84	84
56	85	88	85	85	85	86	88	85	85	85
53	86	89	86	86	86	87	89	86	86	86
74	87	90	87	87	87	88	90	87	87	87

Note: SE = socioeconomic changes; PI = planned improvements; AI = additional investments; CC = climate change; AD = adaptation to climate change; FVI = Flood Vulnerability Index.
a. Lower numbers indicate a higher vulnerability.

Damage Estimates

The total damage for Central Dhaka in 2050 was estimated for the five future scenarios, using alternative assumptions about how frequently a 100-year, return-period storm would occur (chapter 5). Figure 6.3 shows the total monetary value of the damage that would result from the actual 100-year event in 2050 under the five future scenarios, followed by expected damage estimates using

Figure 6.3 Total Estimated Damage for Central Dhaka in 2050



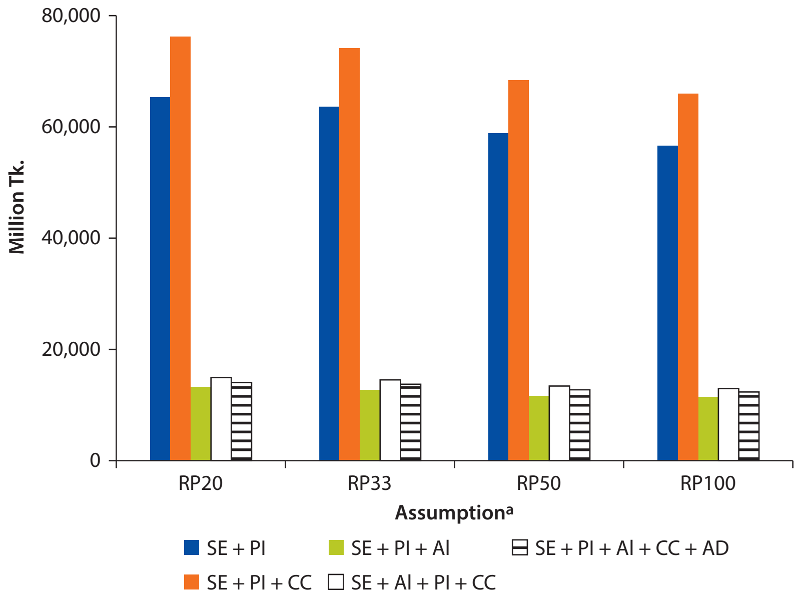
Source: Roy 2014.
Note: SE = socioeconomic changes; PI = planned improvements; AI = additional investments; CC = climate change; AD = adaptation to climate change. RP = return period (years).
a. 100-year event = actual damage from a 100-year event occurring in 2050 with certainty; RP20, 33, 50, and 100 = damage from a 100-year event occurring once every 20, 33, 50, or 100 years, respectively.

alternative probabilities of the 100-year event's recurrence (i.e., every 20, 33, 50, or 100 years).

Figure 6.4 shows the expected cumulative damage over the 2014–50 period for the five future scenarios, with random assignment of various return-period storms under alternative assumptions of increased frequency of the 100-year event. As described in chapter 5, alternative probabilities of the recurrence of the 100-year event are used to compute the expected value of the total cumulative damage between 2014 and 2050 if the event were to occur every 20, 33, 50, or 100 years.

The results show how the damage that would occur under the scenario with planned improvements (PI) alone is reduced when additional investments (AI) are made to address the current adaptation deficit and how climate change exacerbates the extent of damage for each scenario. Comparison of the damage in a changing climate with and without AI reveals that increased damage due to climate change is less if AI are made and the current adaptation deficit is addressed. With measures to address climate change adaptation, the damage in a changing climate decreases somewhat, but is still larger than in the AI scenario without climate change (photo 6.3).

Figure 6.4 Total Cumulative Damage for Central Dhaka, 2014–50



Source: Roy 2014.
Note: SE = socioeconomic changes; PI = planned improvements; AI = additional investments; CC = climate change; AD = adaptation to climate change. RP = return period (years).
a. 100-year event = actual damage from a 100-year event occurring in 2050 with certainty; RP20, 33, 50, and 100 = damage from a 100-year event occurring once every 20, 33, 50, or 100 years, respectively.

Photo 6.3 Laying new stormwater pipe in Gulshan area of Central Dhaka system

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Table 6.12 Increased Damage in Central Dhaka from Climate Change for Future Scenarios under Alternative Assumptions

Increased damage occurring in 2050 (Tk. million)					
	Return period based on probability				
Scenario	*100 year*	*RP20*	*RP33*	*RP50*	*RP100*
SE + PI + CC	671	415	390	376	358
SE + PI + AI + CC	111	69	65	63	60

Increased cumulative damage 2014–50 (Tk. million)				
	Using random numbers for each return period			
Scenario	*RP20*	*RP33*	*RP50*	*RP100*
SE + PI + CC	10,884	10,611	9,797	9,439
SE + PI + AI + CC	1,799	1,754	1,621	1,564

Source: Roy 2014.
Note: SE = socioeconomic changes; PI = planned improvements; AI = additional investments; CC = climate change; RP = return period (years).

Table 6.12 captures the increased damage caused by climate change under the planned improvements (PI) and additional investments (AI) scenarios for the damage occurring in 2050 and the cumulative damage in 2014–50 using various alternative assumptions. Thus, in 2050, the increased damage from a 100-year event due to climate change would amount to Tk. 671 million if only PI were made and would be reduced to Tk. 111 million with AI to address the adaptation deficit in the current climate. Table 6.12 shows similar outcomes of increased damage caused by climate change under a weighted probability of various return-period storms for both PI and AI scenarios. It also shows similar cumulative effects of climate change in 2014–50, with random assignment of various return-period storms under alternative assumptions of increased frequency of a 100-year, return-period storm. In terms of sector-wise comparisons, the largest damage for Central Dhaka occurs in residential property, followed by residential buildings, health care, and industry.

Cost of Adaptation

Results of the hydrological modeling exercise show that, for Central Dhaka, the cost of adaptation beyond planned improvements would involve installing two permanent pump stations—a 15 m^3/s capacity station near Bashabo and a 12 m^3/s capacity station on Hatir Jheel behind Hotel Sonargaon; the site location would be the outfall of the Panthapath Box-Culvert (Zaman 2014). The station near Bashabo would be installed adjacent to DWASA's water supply pump station to relieve inundation in large parts of Khilgaon and Bashabo. Pump-station cost components are mechanical, electrical, and civil works. For Bashabo, these are estimated at Tk. 450 million, 100 million, and 160 million, respectively. For Panthapath, they are estimated at Tk. 380 million, 80 million,

Table 6.13 Estimated Cost of Meeting the Current Adaptation Deficit, Central Dhaka

Required item	*Pump capacity (m^3/s)*	*Head (m)*	*Pump price/unit (million Tk.)*	*Unit (no.)*	*Mechanical works (million Tk.)*	*Electrical works (million Tk.)*	*Civil works (million Tk.)*	*Total cost (million Tk.)*
Bashabo								
Pump station, adjacent to DWASA's water supply pump station	15	6	150	3	450	100	160	710
Land acquisition (15 decimals @ 3 million Tk./decimal)[a]								45
Sluice gate (4 m × 3 m) = 92.5 million Tk., plus 2 million Tk. (mechanical hoist)								94.5
Subtotal								849.5
Panthapath								
Pump station at outfall of box-culvert	12.5	6	190	2	380	80	140	600
Subtotal								600
Total cost								**1,449.5**

Sources: DWASA officials and authors' calculations.
a. If land is state-owned, no cost would be incurred.

Table 6.14 Estimated Cost of Meeting the Climate Change Adaptation Deficit, Central Dhaka

Required item	*Total cost (million Tk.)*
Russel Square	
Sluice gate, 3.4 m × 3.4 m	89.1
Mechanical hoist	2.0
Total cost	**91.1**

Sources: DWASA officials and authors' calculations.

and 140 million. At current market prices, pump-station construction costs would total Tk. 710 million for Bashabo and Tk. 600 million for Panthapath (table 6.13).

The Bashabo site would also entail costs for land acquisition and sluice-gate construction. The pump station would be located across the road from a DWASA water supply pump station. Using a portion of land at this existing station as a rest area for pump operators, office space, and storage would minimize the amount of land that would need to be acquired, which is estimated at 15 decimals. If the land is state-owned (i.e., *khas* land), no cost would be incurred. The recommended sluice gate (4 m × 3 m) and mechanical hoist to make it operable would cost an estimated Tk. 94.5 million (table 6.13).

The cost of addressing the current adaptation deficit for Central Dhaka—the area with the most stringent acceptable flooding criteria—totals nearly Tk. 1.45 billion, the highest among the areas studied in the hydrological modeling exercise. However, once the current adaptation deficit is met, only Tk. 91.1 million more would be required to meet the climate change deficit; this would cover the

Table 6.15 Summary of Adaptation Costs, Central Dhaka

Recommended measure	*Cost (Tk. million)*
Addressing current adaptation deficit	
Pump station, Bashabo	849.5
Pump station, Panthapath	600.0
Total estimated cost	1,449.5
Addressing climate change deficit	
Total estimated cost, sluice gate at Russel Square	91.1
Total combined cost	**1,540.6**

Sources: DWASA officials and authors' calculations.

cost of installing a sluice gate near Russel Square to prevent backflow toward Asad Gate (table 6.14).

Table 6.15 summarizes the total adaptation costs for the proposed recommendations (Huq 2014). The damage estimates demonstrate that this investment of Tk. 1,541 million in flood mitigation will lead to a much higher reduction in damage of Tk. 3,888 million when faced with a 100-year, return-period storm and a cumulative damage reduction (2014–50) of Tk. 53,387 million.

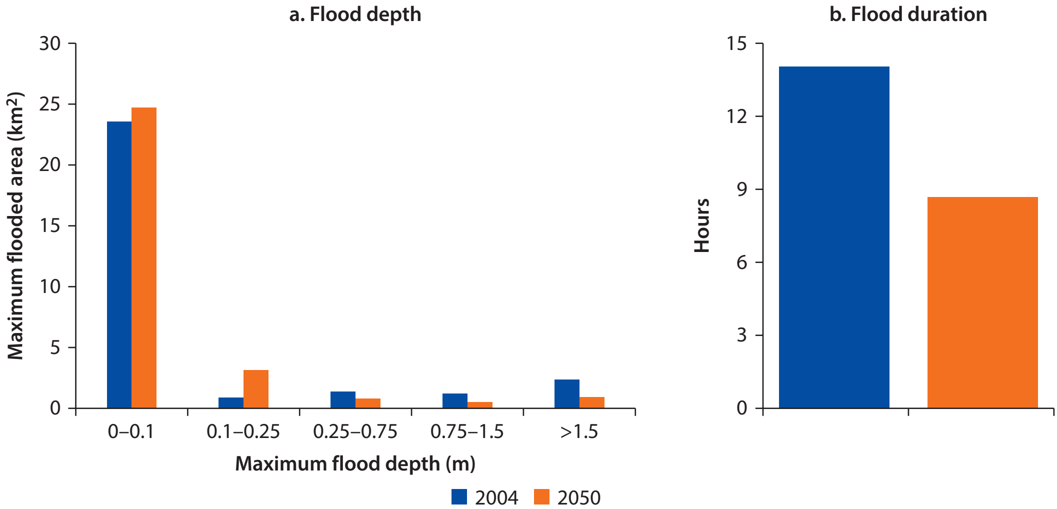
Kallyanpur System Results

Hydrological Modeling Output

The study generated maps simulating the inundation depth and duration of urban flooding for the historic 100-year, return-period rainfall event in 2004 and alternative scenarios for 2050 with and without climate change. The 2004 base scenario led to prolonged flooding, which took an average of 13.5 hours to recede. For 2050, alternative scenarios were simulated using flood criteria of 0.1 m and 0.25 m. Comparison of 100-year, return-period storms for 2004 and 2050 without climate change reveal a greater extent of flooding in 2004 due to considerably less total pump capacity than in future scenarios. In 2050, there was a marked reduction in flooding duration, owing mainly to a doubling of pump capacity and the laying of new drainage pipes (figure 6.5).

Results of the extreme rainfall event in 2050 were re-analyzed using the flood criteria for 0.25 m depth under the premises that inhabitants of Kallyanpur are accustomed to ankle-deep water since flooding is a recurrent phenomenon in their neighborhood. The maps generated showed that, for some areas, there is an adaptation deficit; that is, the planned improvements (PI) are insufficient to cope with rainfall extremes (341 mm per 24 hours) (photo 6.4). Therefore, additional investments (AI) were incorporated into the model. These included increasing the water-body storage volume in one ward (ward 9), laying new pipes in four wards (wards 9, 47, 48, and 58), replacing a pipe in one ward (ward 48), and increasing the working efficiency and capacities at temporary pump locations (photo 6.5). Map 6.3 highlights the impact of making these AI.

Figure 6.5 Depth and Duration of Urban Flood: Comparisons for Rainfall Extremes (341 mm/24 hours) over the Study Period, Kallyanpur System Model



Source: Zaman 2014.

Photo 6.4 Resectioning and lining work at Katashur Khal near Mohammadpur (Kallyanpur system)

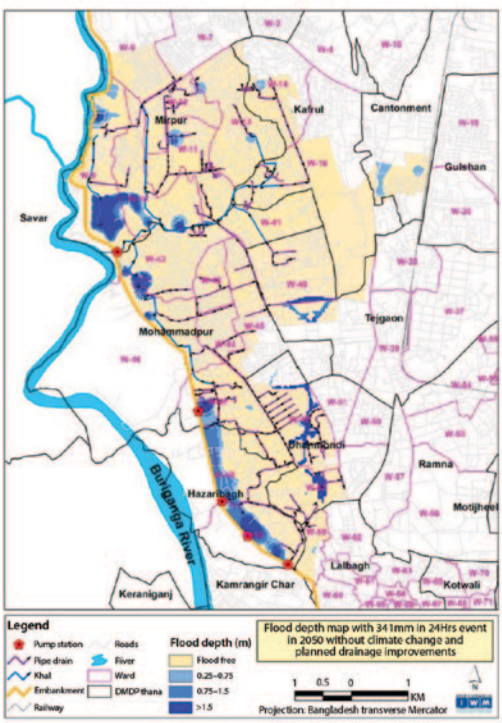
Credit: © Asif Zaman / World Bank. Used with permission. Further permission required for reuse.

Photo 6.5 Temporary pumps located along the Western Embankment, Kallyanpur

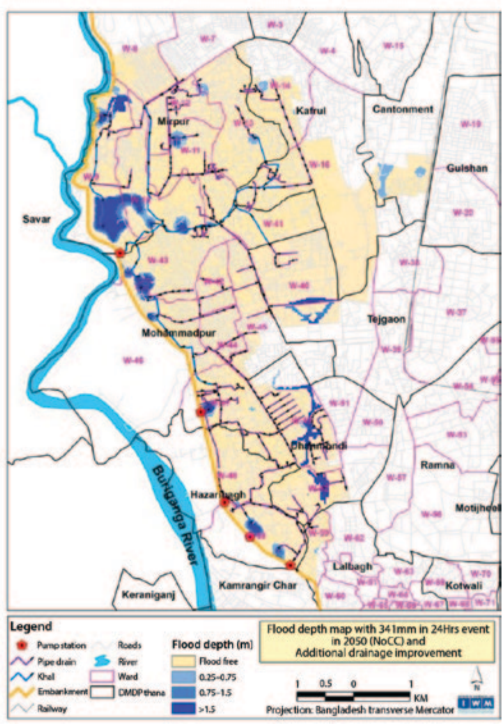
Credit: © Subhendu Roy / World Bank. Used with permission. Further permission required for reuse.

Map 6.3 Extreme Rainfall Scenarios in 2050 with 0.25 m Flood Criteria, Kallyanpur System Model

a. PI (341 mm/24 hour)



b. PI + AI (341 mm/24 hour)



Source: IWM 2014.
Note: PI = planned improvements; AI = additional investments.

The analysis identified the following specific measures to address the current adaptation deficit:

- In ward 9—Deepen water-body storage volume of pond (excavating 262,000 m^3 of soil and not reducing the present pond size).
- In wards 9, 47, 48, and 58—Lay new pipes, of 362 m length, 0.9 m diameter (ward 9); 235 m length, 1.0 m diameter (linking to ward 9 khal); 814 m length, 3.0 m diameter (to Rayerbazar Temporary Pump Station); 565 m length, 2.0 m diameter (to Sikdar Temporary Pump Station); 111 m length, 1.0 m diameter (just south of Sikdar Temporary Pump Station); and 106 m length, 1.0 m diameter (northwest of Hazaribag Temporary Pump Station 2).
- In ward 48—Replace drain pipe (swap direction of drain of 210 m length, 1.52 m diameter).
- At Rayerbazar Temporary Pump Station—Increase working efficiency of temporary pump from 60 percent to 80 percent (i.e., effective capacity of 0.336 m^3/s).
- At Sikdar Temporary Pump Station—Increase working efficiency of temporary pump from 60 percent to 80 percent (i.e., effective capacity of 0.448 m^3/s).
- At Hazaribag Temporary Pump Station—Increase capacity of pump 1 from 0.35 m^3/s to 2.5 m^3/s and working efficiency from 60 percent to 80 percent.
- At Hazaribag Temporary Pump Station—Increase capacity of pump 2 from 0.35 m^3/s to 1.25 m^3/s and working efficiency from 60 percent to 80 percent.

When the effect of climate change was simulated (396 mm per 24 hours), it was found that these additional improvements were insufficient to meet the acceptable flooding criteria, thus making further interventions necessary (table 6.16).

Table 6.16 2050 Rainfall Event in a Changing Climate, Kallyanpur System Model

	Maximum flooded area (km²)				
Extreme storm in 2050	*Flood free (0–0.25 m)*	*0.25–0.75 m*	*0.75–1.5 m*	*>1.5 m*	*Average duration above 0.25 m depth (hours to recede)*
Future SE + P1 (341 mm/24 hour)	25.1	0.9	0.8	1.0	8
Future SE + PI + CC (396 mm/24 hour)	21.6	1.1	0.8	1.0	9
Future SE + PI + AI (341 mm/24 hour)	26.5	0.5	0.3	0.5	3
Future SE + PI + AI + CC (396 mm/24 hour)	26.3	0.6	0.3	0.6	4
Future SE + PI + AI + CC + AD (396 mm/24 hour)	26.5	0.5	0.3	0.5	3

Source: Zaman 2014.
Note: SE = socioeconomic changes; PI = planned improvements; AI = additional investments; CC = climate change; AD = adaptation to climate change.

To cope with the increased rainfall intensity due to climate change, the alternative measures were designed and simulated in the flood model. The process was repeated until the acceptable flooding criteria were met. The required adaptation measures were identified as follows:

- At Hazaribag Temporary Pump Station—Increase capacity of pump 1 from 2.5 m^3/s to 5.0 m^3/s.

Vulnerability to Urban Flooding

Kallyanpur is quite vulnerable, with 6 of its 15 wards—8–11, 48, and 58—figuring among Dhaka's top 20 vulnerable wards/regions. Under planned improvements (PI), ward 9 has the highest vulnerability. Kallyanpur's vulnerable wards generally have lower-than-average CDRI rankings, but three wards (9, 48, and 58) exhibit greater vulnerability due to their high Flood Vulnerability Index (FVI). Their vulnerability decreases from PI to additional investments (AI) scenarios as flooding levels fall and increases as greater weight is assigned to flood vulnerability under the 50 percent flood weight. Wards 8, 10, and 11 are vulnerable mainly because of their lower-than-average CDRI rankings; their vulnerability changes little or falls with the transition from equal weight to 50 percent flood weight and increases from PI to AI scenarios as flooding levels go down (table 6.17).

Table 6.17 FVI Rankings of Kallyanpur Wards under Alternative Flooding Scenarios

	Future scenarios									
	Equal weight[a]					*50% flood weight*[a]				
Ward	*SE + PI*	*SE + PI + CC*	*SE + PI + AI*	*SE + PI + AI + CC*	*SE + PI + AI + CC + AD*	*SE + PI*	*SE + PI + CC*	*SE + PI + AI*	*SE + PI + AI + CC*	*SE + PI + AI + CC + AD*
09	1	1	4	6	6	5	7	20	19	18
10	6	5	2	4	3	22	17	6	11	9
58	7	15	33	27	49	1	3	11	10	21
08	11	7	12	2	5	17	14	10	3	7
11	13	6	6	8	12	23	20	12	18	15
48	18	25	59	57	59	2	5	70	69	70
13	21	16	16	18	15	34	31	27	28	26
41	23	18	19	20	18	41	38	37	37	36
14	25	22	20	21	19	36	34	30	31	30
12	29	23	23	23	22	42	39	32	35	34
07	44	44	38	37	35	56	51	48	46	45
47	61	59	64	64	64	29	21	60	64	60
46	64	61	60	61	62	48	43	23	29	28
43	65	65	63	63	63	63	62	34	39	41
42	79	78	77	77	76	82	85	80	80	79

Note: SE = socioeconomic changes; PI = planned improvements; AI = additional investments; CC = climate change; AD = adaptation to climate change.
a. Lower numbers indicate a higher vulnerability.

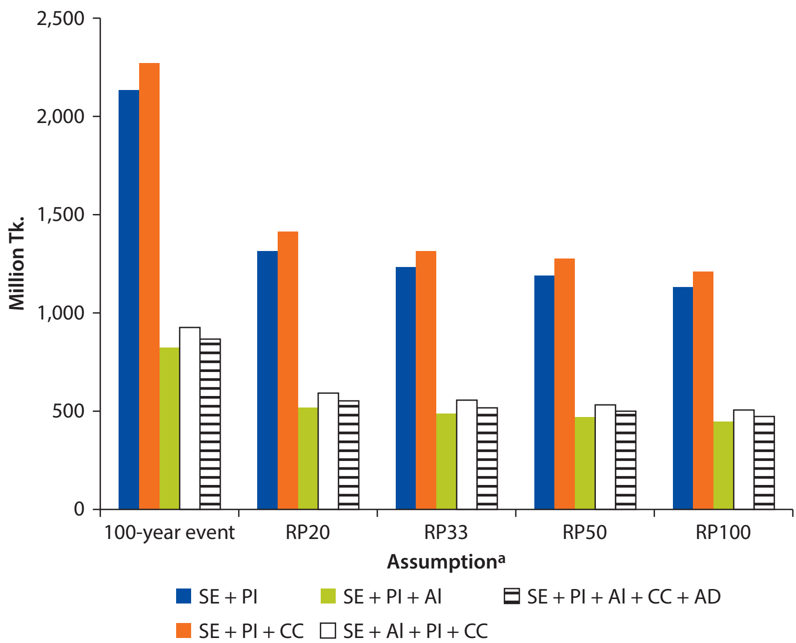
Damage Estimates

The total damage for Kallyanpur in 2050 was estimated for the five future scenarios, using alternative assumptions about how frequently a 100-year, return-period storm would occur (chapter 5). Figure 6.6 shows the total monetary value of the damage that would result from the actual 100-year event in 2050 under the five future scenarios, followed by expected damage estimates using alternative probabilities of the 100-year event's recurrence (i.e., every 20, 33, 50, or 100 years).

Figure 6.7 shows the expected cumulative damage over the 2014–50 period for the five future scenarios, with random assignment of various return-period storms under alternative assumptions of increased frequency of the 100-year event. As described in chapter 5, alternative probabilities of the recurrence of the 100-year event are used to compute the expected value of the total cumulative damage between 2014 and 2050 if the event were to occur every 20, 33, 50, or 100 years.

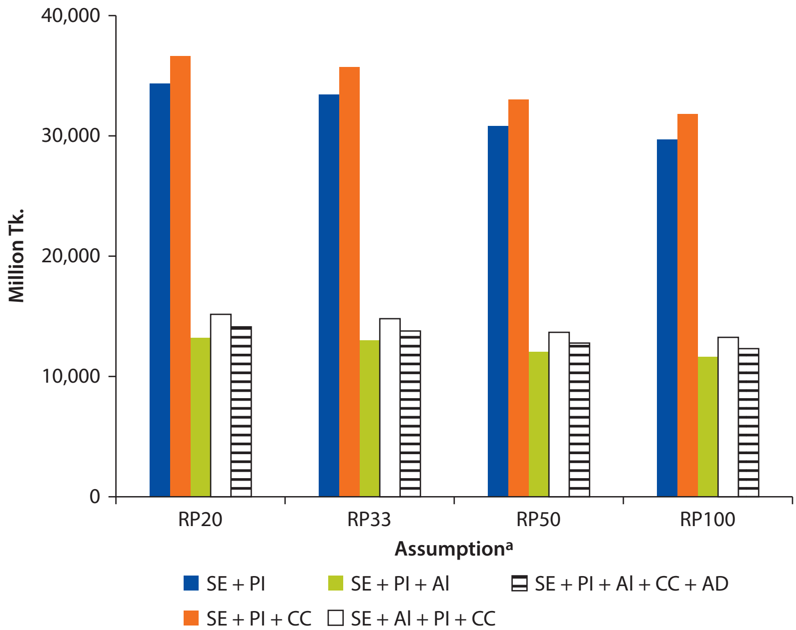
The results show how the damage that would occur under the scenario with planned improvements (PI) alone is reduced when additional investments (AI) are made to address the current adaptation deficit and how climate change exacerbates the extent of damage for each scenario. Comparison of the damage in a

Figure 6.6 Total Estimated Damage for Kallyanpur in 2050



Source: Roy 2014.
Note: SE = socioeconomic changes; PI = planned improvements; AI = additional investments; CC = climate change; AD = adaptation to climate change. RP = return period (years).
a. 100-year event = actual damage from a 100-year event occurring in 2050 with certainty; RP20, 33, 50, and 100 = damage from a 100-year event occurring once every 20, 33, 50, or 100 years, respectively.

Figure 6.7 Total Cumulative Damage for Kallyanpur, 2014–50



Source: Roy 2014.
Note: SE = socioeconomic changes; PI = planned improvements; AI = additional investments; CC = climate change; AD = adaptation to climate change. RP = return period (years).
a. 100-year event = actual damage from a 100-year event occurring in 2050 with certainty; RP20, 33, 50, and 100 = damage from a 100-year event occurring once every 20, 33, 50, or 100 years, respectively.

changing climate with and without AI reveals that the increased damage due to climate change is less if AI are made and the current adaptation deficit is addressed. With measures to address climate change adaptation, the damage in a changing climate decreases somewhat, but is still larger than in the AI scenario without climate change.

Table 6.18 captures the increased damage caused by climate change under the planned improvements (PI) and additional investments (AI) scenarios for the damage occurring in 2050 and the cumulative damage in 2014–50 using various alternative assumptions. In 2050, the increased damage from a 100-year event due to climate change would amount to Tk. 148 million if only PI were made and would be reduced to Tk. 113 million with AI. Table 6.18 shows similar outcomes of increased damage caused by climate change under a weighted probability of various return-period storms for both PI and AI scenarios. It also shows similar cumulative effects of climate change in 2014–50, with random assignment of various return-period storms under alternative assumptions of increased frequency of a 100-year, return-period storm. In terms of sector-wise comparisons for Kallyanpur, the largest damage is to residential buildings, followed by residential property (moveable goods inside the house, including furniture, electronic goods, clothing, and any other stored personal possessions) and industrial units.

Table 6.18 Increased Damage in Kallyanpur from Climate Change for Future Scenarios under Alternative Assumptions

Increased damage occurring in 2050 (Tk. million)					
	Return period based on probability				
Scenario	*100 year*	*RP20*	*RP33*	*RP50*	*RP100*
SE + PI + CC	148	278	192	145	82
SE + PI + AI + CC	113	142	107	87	61
Increased cumulative damage, 2014–50 (Tk. million)					
	Using random numbers for each return period				
Scenario	*RP20*	*RP33*	*RP50*	*RP100*	
SE + PI + CC	2,429	2,372	2,197	2,123	
SE + PI + AI + CC	1,842	1,797	1,661	1,602	

Source: Roy 2014.
Note: SE = socioeconomic changes; PI = planned improvements; AI = additional investments; CC = climate change; RP = return period (years).

Cost of Adaptation

For Kallyanpur, the recommended structural measures against a 100-year return-period rainfall event in 2050 beyond planned improvements focus mainly on increasing temporary-pump capacity and laying new drainage pipes (Zaman 2014). The recommended temporary pumps have 10 m head with two discharge capacities: 5 ft^3/s (0.14 m^3/s) and 25 ft^3/s (0.70 m^3/s). Pump operation requires both pipes and transformers. This study recommends 100 kVA and 200 kVA transformers, whose unit costs are the same as those for Old Dhaka (table 6.19).

Addressing the current structural adaptation deficit will require additional temporary pumps at the following points: Rayerbazar, Sikdar, and Hazaribag. It will also require laying new drainage pipes and switching the direction of an existing pipe in ward 48 by 180 degrees. Installation expenses, in addition to pipe costs, include laying pipes, as well as digging roads, for which compensatory payment must be made to the Dhaka City Corporations (DCCs). The per-meter cost of a pipe is a function of its diameter, and the pipe-laying cost increases with the pipe diameter to be laid. Also, the ditch in which the pipes are laid must be wide enough for laborers to work on the pipe. For road digging, the study assumes a high-end rate (Tk. 6,250 per m^2) to avoid underestimating the needed payment.

According to practitioners, the proposed pipes to temporary pump stations at Rayerbazar (3 m diameter and 814 m length) and Sikdar (2 m diameter and 565 m length) cannot be easily installed. For Rayerbazar, they suggest building a brick sewer. Assuming a cost of Tk. 0.25 million per meter, the total cost of the brick sewer is about Tk. 223.9 million. For the link to Sikdar Temporary Pump Station, they suggest that two 1.52 m diameter pipes be laid, one on top of the other. This study estimates the total cost of the pipes, pipe laying, and payment for road digging at about Tk. 55.4 million. The pipe whose direction is to be switched has

Table 6.19 Estimated Cost of Meeting the Current Adaptation Deficit, Kallyanpur

Additional temporary pump capacity (Tk. million)

Temporary pump location, added discharge capacity (m^3/s)[a]	*Added pumps (5 ft^3/s) and transformers*				*Added pumps (25 ft^3/s) and transformers*				
	Pumps (no.)	*Cost of pumps and pipes (0.8/unit)*	*100 kVA transformers (no.)*	*Cost of transformers and cables (1.2/unit)*	*Pumps (no.)*	*Cost of pumps and pipes (2.6/unit)*	*200 kVA transformers (no.)*	*Cost of transformers and cables (2.0/unit)*	*Total cost*
Rayerbazar, 0.12	1	0.8	1	1.2	0	0	0	0	2.0
Sikdar, 0.15	1	0.8	1	1.2	0	0	0	0	2.0
Hazaribag, pump 1, 2.27	2	1.6	0	0	3	7.8	3	6.0	15.4
Hazaribag, pump 2, 1.02	3	2.4	1	1.2	1	2.6	1	2.0	8.2
Subtotal									27.6

New pipe laying/switching pipe direction (Tk. million)

Location/link to temporary pump station	*Pipe diameter (m)*	*Pipe length (m)*	*Pipe price/m*	*Pipe installation cost/m*	*Road-cutting cost/m*	*Total cost*
Ward 9	0.9	362	5,126	14,400	12,000	11.4
Ward 9 khal	1	235	7,885	20,400	12,500	9.6
Rayerbazar (brick sewer)	3	814	250,000	0	25,000	223.9
Sikdar	2	565	30,600	50,000	17,500	55.4
South of Sikdar	1	111	7,885	20,400	12,500	4.5
Northwest of Hazaribag, 2	1	106	7,885	20,400	12,500	4.3
Switching pipe direction in ward 48	1.52	210	0	26,400	15,100	8.7
Subtotal						317.8
Total cost: 345.4						

Sources: DWASA officials and authors' calculations.
a. Head = 10 m.

Table 6.20 Estimated Cost of Meeting the Climate Change Adaptation Deficit, Kallyanpur

	Additional temporary pump capacity (Tk. million)								
	Added pumps (5 ft³/s) and transformers				*Added pumps (25 ft³/s) and transformers*				
Temporary pump location, added discharge capacity (m^3/s)[a]	*Pumps (no.)*	*Cost of pumps and pipes (0.8/unit)*	*100 kVA transformers (no.)*	*Cost of transformers and cables (1.2/unit)*	*Pumps (no.)*	*Cost of pumps and pipes (2.6/unit)*	*200 kVA transformers (no.)*	*Cost of transformers and cables (2.0/unit)*	*Total cost*
Hazaribag, pump 1, 2.5	3	2.4	0	0	3	7.8	3	6	16.2
Subtotal									**16.2**
Total cost: 16.2									

Sources: DWASA officials and authors' calculations.
a. Head = 10 m.

Table 6.21 Summary of Adaptation Costs, Kallyanpur

Recommended measure	*Cost (Tk. million)*
Addressing current adaptation deficit	
Temporary pumps	27.6
Laying new pipes/switching pipe direction	317.8
Total estimated cost	345.4
Addressing climate change deficit	
Total estimated cost, temporary pumps	16.2
Total combined cost	**361.6**

Sources: DWASA officials and authors' calculations.

a 1.5 m diameter and is 210 m in length; the cost of changing its direction is estimated at Tk. 8.7 million. Since an older pipe can be reused for this purpose, no purchase is necessary. Four additional pipes, with lengths in a range of 106–363 m, are required; three are of 1 m diameter and the other is of 0.9 m diameter.

Table 6.19 breaks down the cost estimates for meeting the current adaptation deficit. As shown, the costs for added temporary-pump capacity and pipes are Tk. 27.6 million and Tk. 317.8 million, respectively, for a total estimated adaptation cost of Tk. 345.4 million. Adapting to climate change would mean increasing Hazaribag's temporary pump capacity. Table 6.20 breaks down the total additional cost for addressing climate change adaptation, estimated at Tk. 16.2 million.

Finally, table 6.21 provides a summary comparison of the total costs to meet the current adaptation deficit and the added cost of climate change adaptation. As shown, addressing the current deficit would cost Tk. 345.4 million, while meeting the climate change deficit would require another Tk. 16.2 million, for a total combined adaptation cost of Tk. 361.6 million (Huq 2014). The adaptation cost estimate for the area's drainage system excludes the hydrological modeling exercise's recommended deepening of water bodies, which would provide a one-time income source rather than an added expense. Chapter 8 discusses this proposed activity in detail. The damage estimates demonstrate that this investment of about Tk. 362 million in flood mitigation will lead to a much higher reduction in damage of Tk. 1,410 million in 2050 when faced with a 100-year, return-period storm and a cumulative damage reduction (2014–50) of Tk. 19,562 million.

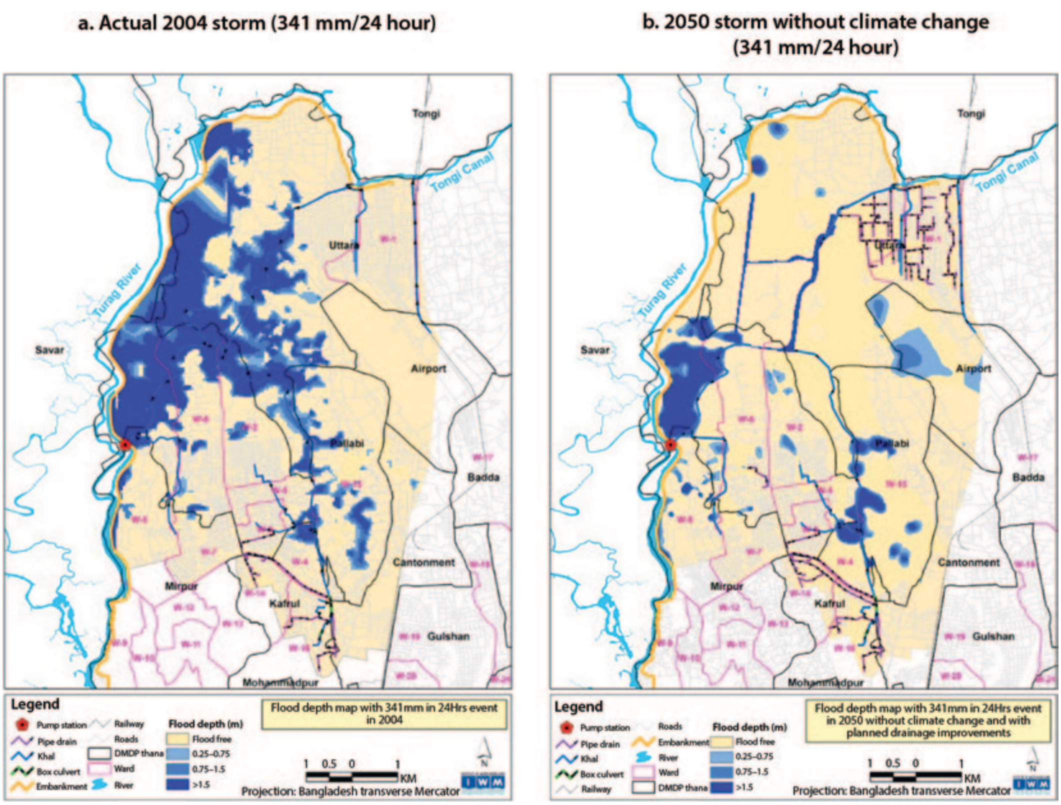
Goranchatbari System Results

Hydrological Modeling Output

Simulations of inundation depths and flood duration were run for the historic 100-year, return-period rainfall event in 2004 and alternative scenarios for 2050 with and without climate change. The average duration of the actual 100-year flood in 2004 was 15 hours. For 2050, alternative scenarios were simulated using flood criteria of 0.25 m (i.e., 90 percent of the administrative areas with a maximum inundation depth less than 0.25 m and duration less than 12 hours).

Comparison of the 100-year rainfall event in 2050 with the actual 2004 storm showed a marked improvement in the flooding situation (map 6.4), with

Map 6.4 Changes in Extent of Flooding for Extreme Rainfall Event over Study Period, Goranchatbari System Model



Source: IWM 2014.

Table 6.22 Comparison of Flooding Results, Goranchatbari System Model

Extreme storm (341 mm/24 hour)	*Maximum flooded area (km²)*				*Average duration above 0.25 m depth (hours to recede)*
	Flood free (0–0.25 m)	*0.25–0.75 m*	*0.75–1.5 m*	*>1.5 m*	
2004 (actual storm)	45.3	3.0	4.5	11.0	15
2050 (SE + PI)	56.1	2.5	1.7	3.5	6

Source: Zaman 2014.

significantly less flooding depth and average duration of flooding (table 6.22). The improved performance is made possible by the laying of new drainage pipes, doubling the capacity of the Goranchatbari Pump Station, and better drainage to the pump's retention pond. The raising of land levels with the ongoing process of urbanization in the area also contributes to the reduced extent of flooding.

However, even with the planned improvements (PI), the analysis showed that some areas were unable to cope with extreme rainfall events (i.e., 341 mm per 24 hours). The extent of shallow submergence remained significantly higher in 2050 than in 2004. Therefore, additional investments (AI) were incorporated into the model to address the existing adaptation deficit.

The additional investments identified to meet the current adaptation deficit were as follows.

- From the airport to Baunia Khal and Uttara Model Town Lake—Lay two new pipes, with a total length of 5,325 m and a 1.524 m diameter.
- From Pallabi—Redirect flow from catchment 403 (ward 15) to Baunia Khal.
- At Mirpur Zoo and Botanical Garden—Deepen ponds by excavating about 702,400 m^3.

Simulating the likely impacts of these additional investments in the flood model showed they were insufficient to meet the acceptable flooding criteria under the A1FI climate change scenario (table 6.23). Thus, to cope with the impact of increased rainfall intensity due to climate change, supplementary adaptation measures were required. These were identified as follows:

- From Pallabi to Diabari Khal—Lay a new pipe, with a total length of 518 m and a pipe diameter of 2 m.
- From Catchment 272_1 (ward 4)—Divert flow to Diabari Khal.

Vulnerability to Urban Flooding

Goranchatbari is somewhat vulnerable to urban flooding, with three of its eight areas (i.e., seven wards and Uttara, which is outside the DCC wards) included among Dhaka's top 20 vulnerable wards/regions. All three vulnerable wards—wards 2, 4, and 15—have lower-than-average rankings for all four dimensions in the CDRI index (physical, social, economic, and institutional). These wards also have higher-than-average flood vulnerability; when combined with their lower CDRI indices, they become quite vulnerable and thus place among the

Table 6.23 2050 Rainfall Event in a Changing Climate, Goranchatbari System Model

	Maximum flooded area (km²)				*Average duration above 0.25 m depth (hours to recede)*
Extreme storm in 2050	*Flood free (0–0.25 m)*	*0.25–0.75 m*	*0.75–1.5 m*	*>1.5 m*	
Future SE + PI (341 mm/24 hour)	56.0	2.5	1.7	3.5	6
Future SE + PI + CC (396 mm/24 hour)	55.1	3.2	1.7	4.1	7
Future SE + PI + AI (341 mm/24 hour)	57.4	1.6	1.2	3.5	4
Future SE + PI + AI + CC (396 mm/24 hour)	56.5	2.0	1.3	3.9	5
Future SE + PI + AI + CC + AD (396 mm/24 hour)	56.7	1.9	1.2	3.9	4

Note: SE = socioeconomic changes; PI = planned improvements; AI = additional investments; CC = climate change; AD = adaptation to climate change.

Table 6.24 FVI Rankings of Goranchatbari Wards/Region under Alternative Flooding Scenarios

	Future scenarios				
	Equal weight [a]				
Ward/region	*SE + PI*	*SE + PI + CC*	*SE + PI + AI*	*SE + PI + AI + CC*	*SE + PI + AI + CC + AD*
15	14	11	15	14	16
02	16	13	17	11	17
04	17	19	8	10	11
05	22	20	13	15	14
06	28	28	18	17	20
03	42	40	36	38	36
01	60	60	58	58	58
Uttara	94	94	94	94	94
50% flood weight [a]					
15	18	16	15	14	12
02	21	18	18	12	14
04	20	19	7	9	10
05	25	24	13	16	13
06	28	27	17	15	16
03	57	52	52	54	52
01	71	69	66	67	66
Uttara	94	94	94	94	94

Note: SE = socioeconomic changes; PI = planned improvements; AI = additional investments; CC = climate change; AD = adaptation to climate change; FVI = Flood Vulnerability Index.
a. Lower numbers indicate a higher vulnerability.

top 20 vulnerable wards/regions under planned improvements with equal weight (table 6.24).

Vulnerability to urban flooding and the four CDRI dimensions play equally important roles in increasing vulnerability in Goranchatbari. The area's vulnerability rankings generally are little changed as greater weight is assigned to flooding vulnerability under the 50 percent flood weight or AI scenarios, where the effect of flooding decreases (table 6.24).

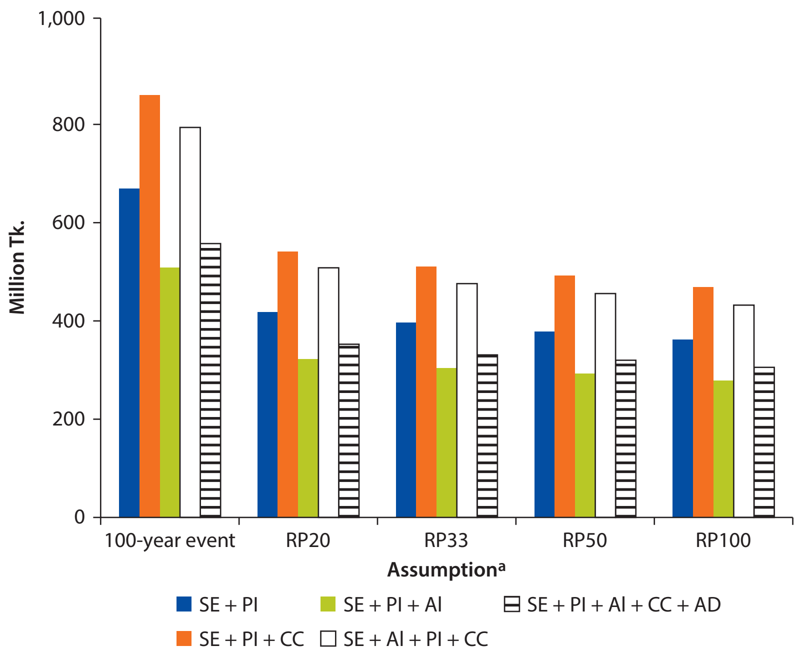
Damage Estimates

The total damage for Goranchatbari in 2050 was estimated for the five future scenarios, using alternative assumptions about how frequently a 100-year, return-period storm would occur (chapter 5). Figure 6.8 shows the total monetary value of the damage that would result from the actual 100-year event in 2050 under the five future scenarios, followed by expected damage estimates using alternative probabilities of the 100-year event's recurrence (i.e., every 20, 33, 50, or 100 years).

Figure 6.9 shows the expected cumulative damage over the 2014–50 period for the five future scenarios, with random assignment of various return-period storms under alternative assumptions of increased frequency of the 100-year event. As described in chapter 5, alternative probabilities of the recurrence of the 100-year event are used to compute the expected value of the total cumulative damage between 2014 and 2050 if the event were to occur every 20, 33, 50, or 100 years.

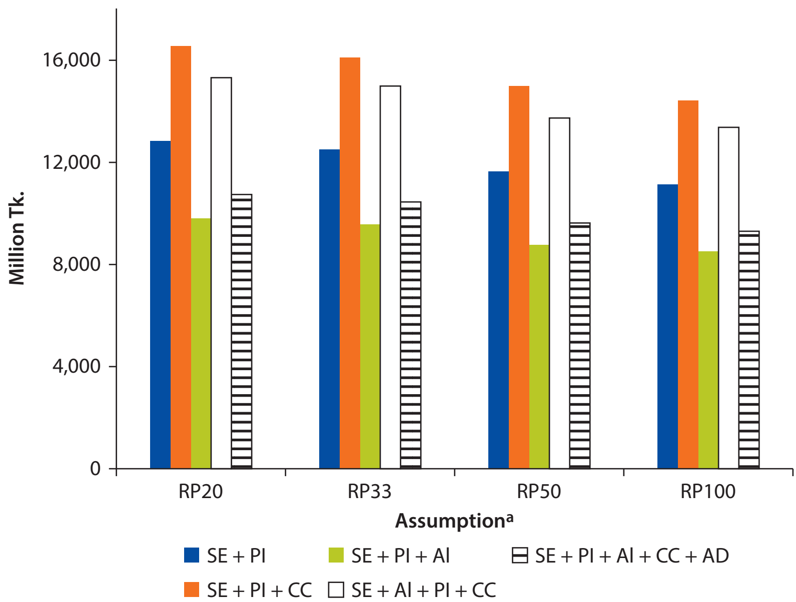
The results reveal how the damage that would occur under the scenario with planned improvements (PI) alone decreases with additional investments (AI)—but less so than for the other modeled zones—and how climate change exacerbates the extent of damage under each scenario. In Goranchatbari, unlike other

Figure 6.8 Total Estimated Damage for Goranchatbari in 2050



Source: Roy 2014.
Note: SE = socioeconomic changes; PI = planned improvements; AI = additional investments; CC = climate change; AD = adaptation to climate change. RP = return period (years).
a. 100-year event = actual damage from a 100-year event occurring in 2050 with certainty; RP20, 33, 50, and 100 = damage from a 100-year event occurring once every 20, 33, 50, or 100 years, respectively.

Figure 6.9 Total Cumulative Damage for Goranchatbari, 2014–50



Source: Roy 2014.
Note: SE = socioeconomic changes; PI = planned improvements; AI = additional investments; CC = climate change; AD = adaptation to climate change. RP = return period (years).
a. 100-year event = actual damage from a 100-year event occurring in 2050 with certainty; RP20, 33, 50, and 100 = damage from a 100-year event occurring once every 20, 33, 50, or 100 years, respectively.

areas of Dhaka, the increased damage caused by climate change is higher with AI, compared to the scenario with PI. With climate change adaptation, the damage decreases somewhat, but is still larger than that under the scenario with AI without climate change.

Table 6.25 captures the increased damage caused by climate change under the planned improvements (PI) and additional investments (AI) scenarios for the damage occurring in 2050 and the cumulative damage in 2014–50 using various alternative assumptions. Thus, in 2050, the increased damage from a 100-year event due to climate change would amount to Tk. 224 million if only planned improvements were made and would rise to Tk. 339 million with AI. Table 6.25 shows similar outcomes of increased damage caused by climate change under a weighted probability of various return-period storms for both PI and AI scenarios. It also shows similar cumulative effects of climate change in 2014–50, with random assignment of various return-period storms under alternative assumptions of increased frequency of a 100-year, return-period storm. In terms of sector-wise comparisons for Goranchatbari, the largest damage is to residential buildings, followed by industry and health care.

Cost of Adaptation

Meeting the current adaptation deficit to safeguard Goranchatbari against a 100-year, return-period rainfall event in 2050 beyond planned improvements involves

Table 6.25 Increased Damage in Goranchatbari from Climate Change for Future Scenarios under Alternative Assumptions

Increased damage occurring in 2050 (Tk. million)					
	Return period based on probability				
Scenario	*100 year*	*RP20*	*RP33*	*RP50*	*RP100*
SE + PI + CC	224	213	175	154	126
SE + PI + AI + CC	339	266	231	212	186

Increased cumulative damage, 2014–50 (Tk. million)				
	Using random numbers for each return period			
Scenario	*RP20*	*RP33*	*RP50*	*RP100*
SE + PI + CC	3,687	3,603	3,339	3,231
SE + PI + AI + CC	5,527	5,393	4,989	4,817

Source: Roy 2014.
Note: SE = socioeconomic changes; PI = planned improvements; AI = additional investments; CC = climate change; RP = return period (years).

Table 6.26 Estimated Cost of Meeting the Adaptation Deficit, Goranchatbari

Laying new pipe (location/link)	*Pipe diameter (m)*	*Pipe length (m)*	*Pipe price/m*	*Pipe installation cost/m*	*Road-cutting cost/m*	*Total cost*
Meeting current adaptation deficit (Tk. million)						
From airport to Baunia Khal and Uttara Model Town	1.52	5,325	15,295	26,400	15,100	302.4
Meeting climate change adaptation deficit (Tk. million)						
From Pallabi to Diabari Khal	2.00	518	30,600	50,000	17,500	50.8

Sources: DWASA officials and authors' calculations.

only laying of a new drainage pipe (Zaman 2014). The total cost of laying the new pipe, which would run from the airport to Baunia Khal and Uttara Model Town, is estimated at Tk. 302.4 million (table 6.26).

Addressing the climate change adaptation deficit would require only a 2 m diameter pipe from Pallabi to Diabari Khal. Because of space constraints, the modeling study recommends laying two 1.52 m diameter pipes, one atop the other, which would have the equivalent discharge capacity of a 2 m diameter pipe (Zaman 2014). The cost of laying this pipe is estimated at Tk. 50.8 million (table 6.26).

The total combined adaptation cost for Goranchatbari is Tk. 353.2 million (table 6.27) (Huq 2014). The estimate excludes the hydrological modeling exercise's recommended deepening of ponds at the Mirpur Zoo and Botanical Garden, which should provide a one-time source of income rather than an added expense. The damage estimates demonstrate that this investment of about Tk. 353 million in flood mitigation will lead to a reduction in damage of Tk. 359 million in 2050 when faced with a 100-year, return-period storm and a cumulative damage reduction (2014–50) of Tk. 5,062 million.

Table 6.27 Summary of Adaptation Costs, Goranchatbari

Recommended measure	*Cost (Tk. million)*
Addressing current adaptation deficit	
Total estimated cost, laying new drainage pipe	302.4
Addressing climate change deficit	
Total estimated cost, laying new drainage pipe	50.8
Total combined cost	**353.2**

Sources: DWASA officials and authors' calculations.

Eastern Dhaka Results

Hydrological Modeling Output

Simulations of inundation depths and duration of river flood were run for the historic 100-year, return-period rainfall event in 2004 and 2050 alternative scenarios with and without climate change.

For 2050, alternative scenarios were simulated using flood criteria of 0.25 m (i.e., 90 percent of the administrative areas with a maximum flood depth less than 0.25 m and duration less than 12 hours). Table 6.28 shows a significant decrease in flooded areas for all inundation depths in 2050, including more than a threefold increase in flood-free area; however, the time required for flooding to recede decreased only slightly compared to the 2004 event.

Analysis of the flood maps generated for the extreme rainfall event in 2050 using the 0.25 flood criteria showed that the planned improvements (PI)—protection from river flooding, increased conveyance capacity of khals, introduction of drainage pumps, and raising of land levels—if completed as planned and on time, could cope with the 100-year storm (341 mm per 24 hours). Thus, no additional investments (AI) would be required for the Eastern Dhaka area. Furthermore, the PI could cope with effect of climate change (396 mm per 24 hours) (map 6.5). Thus, no additional adaptation measures would be required for Eastern Dhaka (table 6.29). These results highlight the effectiveness of the planned land use and drainage improvements and their value in reducing the vulnerability of this area to the impacts of climate change.

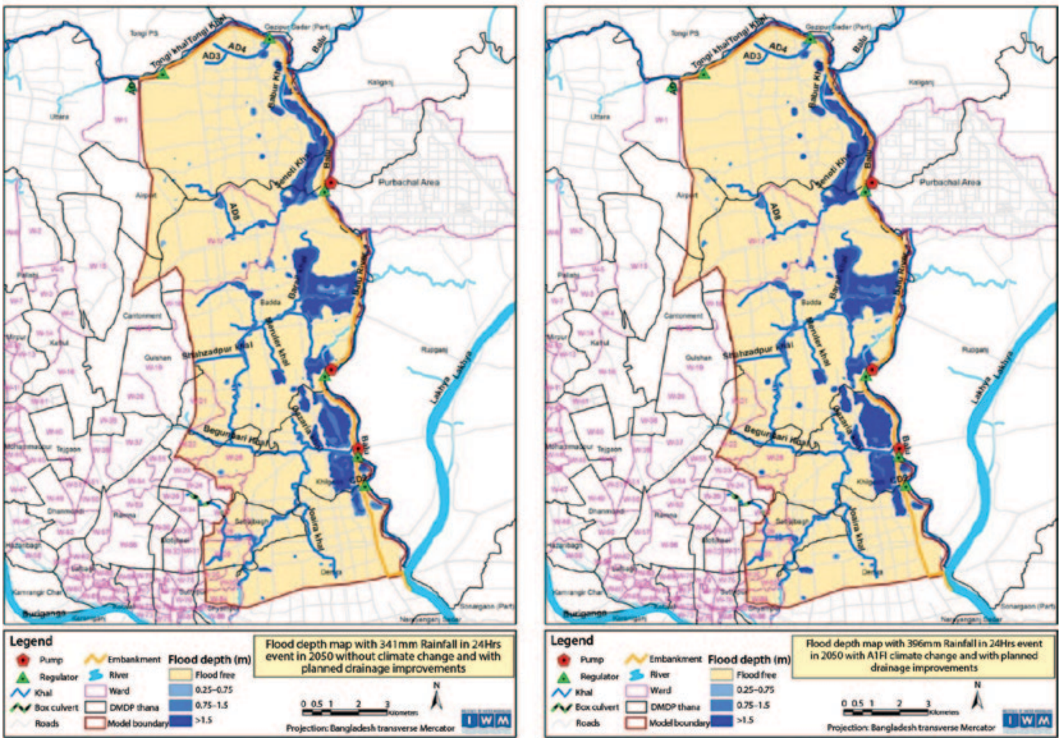
Table 6.28 Comparison of Flooding Results, Eastern Dhaka Model

	Maximum flooded area (km^2)					*Average duration above 0.25 m depth (hours to recede)*
Scenario	*Flood free (0–0.25 m)*	*0.1–0.25 m*	*0.25–0.75 m*	*0.75–1.5 m*	*>1.5 m*	
2004 (actual storm, 341 mm/24-hour)	34.40	2.87	7.89	10.81	64.73	>240
2050 100-year event (SE + PI, 341 mm /24-hour)	104.8	1.1	2.2	4.0	8.6	234

Source: Zaman 2014.

Map 6.5 Flood-Depth Comparisons of Extreme Rainfall Scenarios in 2050, Eastern Dhaka Model

a. Without climate change (341 mm/24 hour) **b. With A1F1 climate change (396 mm/24 hour)**



Source: IWM 2014.

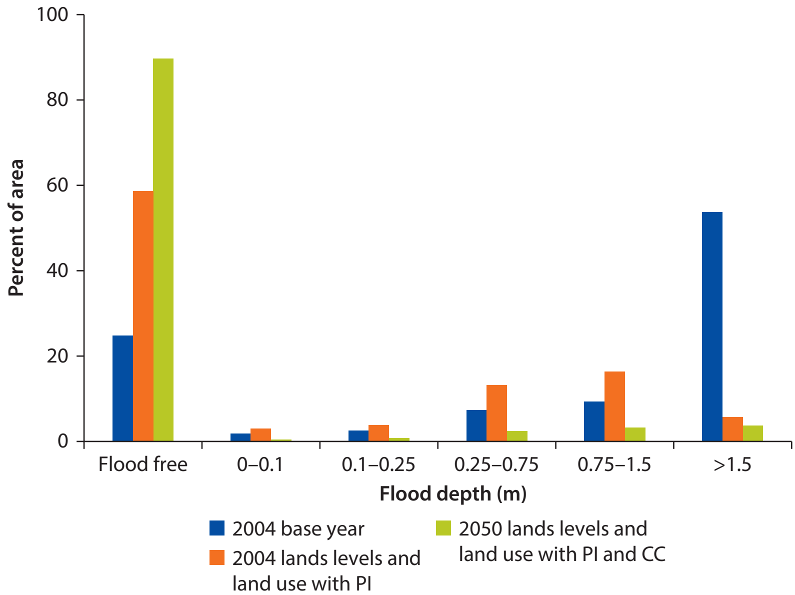
Table 6.29 2050 Rainfall Event in a Changing Climate, Eastern Dhaka Model

Extreme storm in 2050	*Maximum flooded area (km²)* *Flood free (0–0.25 m)*	*0.25–0.75 m*	*0.75–1.5 m*	*>1.5 m*	*Average duration above 0.25 m depth (hours to recede)*
Future SE + PI (341 mm/24 hour)	106.0	2.24	3.97	8.58	>240
Future SE + PI + CC (396 mm/24 hour)	104.6	2.73	2.91	10.59	>240

Source: Zaman 2014.
Note: SE = socioeconomic changes; PI = planned improvements; CC = climate change.

Additional scenarios were simulated for 2050, using various assumptions regarding planned improvements (PI), including changes in the drainage system, land levels, and land use. The first simulation assumed that only socioeconomic changes (SE) would occur by 2050, with no PI to the drainage system (i.e., no river embankment, regulators, or pumps). The results showed that, for the 30-year event with A1FI climate change, more than 80 percent of the area would remain flood free. This finding is attributed to the raising of land levels in

Figure 6.10 Flood-Depth Simulations for 30-Year Rainfall Event in Eastern Dhaka, Showing Effects of Planned Improvements



Source: Zaman 2014.

built-up areas that is likely to occur and prevention of encroachment of khals and ponding areas.

A second simulation asked what would have happened in 2004 if planned improvements (PI) had been made to the drainage system without changing 2004 land levels and land use. Results for the 30-year event with A1FI climate change showed that, in this case, about 59 percent of the area would have remained flood-free (compared to 24 percent for 2004 base case). By raising land levels, along with making the drainage PI, the percentage of flood-free area would reach 90 percent by 2050 (figure 6.10). These findings highlight the value of raising land levels and planned development in reducing the extent of flooding in Eastern Dhaka.

Vulnerability to River Flood

For Eastern Dhaka, the flood vulnerability estimate covers two regions outside the DCC. Since larger proportions of the DCC wards that lie in Eastern Dhaka are found in the adjacent areas of Central Dhaka and DND, the relevant wards are covered in the flood vulnerability assessments of those areas and thus are excluded here. Since both of Eastern Dhaka's outside regions figure among Dhaka's top 20 vulnerable wards/regions, the Eastern Dhaka area figures high on the FVI. The two outside regions rank low in terms of the CDRI's institutional and social dimensions but exhibit high flood vulnerability; when combined with their other lower CDRI indices, these areas become quite vulnerable and thus

Table 6.30 FVI Rankings of Eastern Dhaka Regions under Alternative Flooding Scenarios

	Future scenarios				
	Equal weight[a]				
Region	*SE + PI*	*SE + PI + CC*	*SE + PI + AI*	*SE + PI + AI + CC*	*SE + PI + AI + CC + AD*
Badda, outside DNCC	12	8	n.a.	n.a.	n.a.
Khilgaon, outside DNCC	10	14	n.a.	n.a.	n.a.
50% flood weight[a]					
Badda, outside DNCC	8	8	n.a.	n.a.	n.a.
Khilgaon, outside DNCC	3	2	n.a.	n.a.	n.a.

Note: SE = socioeconomic changes; PI = planned improvements; AI = additional investments; CC = climate change; AD = adaptation to climate change; n.a. = not applicable.
a. Lower numbers indicate a higher vulnerability.

place among Dhaka's top 20 vulnerable wards/regions under planned improvements (PI) for equal weight (table 6.30).

Unlike other areas, only two scenarios were created for Eastern Dhaka. Flood vulnerability and the four CDRI dimensions play equally important roles in increasing Eastern Dhaka's vulnerability. The area's vulnerability rankings generally increase slightly as greater weight is assigned to flood vulnerability for 50 percent flood weight.

Damage Estimates

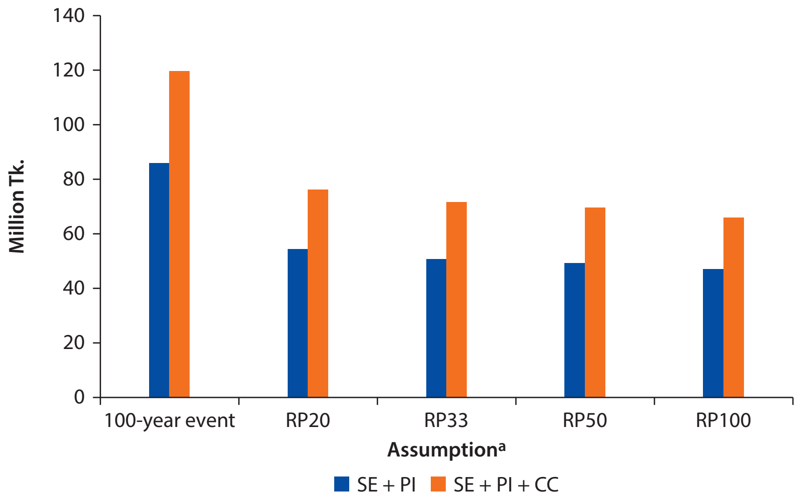
The total damage for Eastern Dhaka in 2050 was estimated for two future scenarios—planned improvements with and without climate change—using alternative assumptions about how frequently a 100-year, return-period storm would occur (chapter 5). Figure 6.11 shows the total monetary value of the damage that would result from the actual 100-year event in 2050 for these two future scenarios, followed by expected damage estimates using alternative probabilities of the 100-year event's recurrence (i.e., every 20, 33, 50, or 100 years).

Figure 6.12 shows the expected cumulative damage over the 2014–50 period for the two future scenarios, with random assignment of various return-period storms under alternative assumptions of increased frequency of the 100-year event. As described in chapter 5, alternative probabilities of the recurrence of the 100-year event are used to compute the expected value of the total cumulative damage between 2014 and 2050 if the event were to occur every 20, 33, 50, or 100 years.

The findings show how the damage that would occur under the scenario with planned improvements increases with climate change.

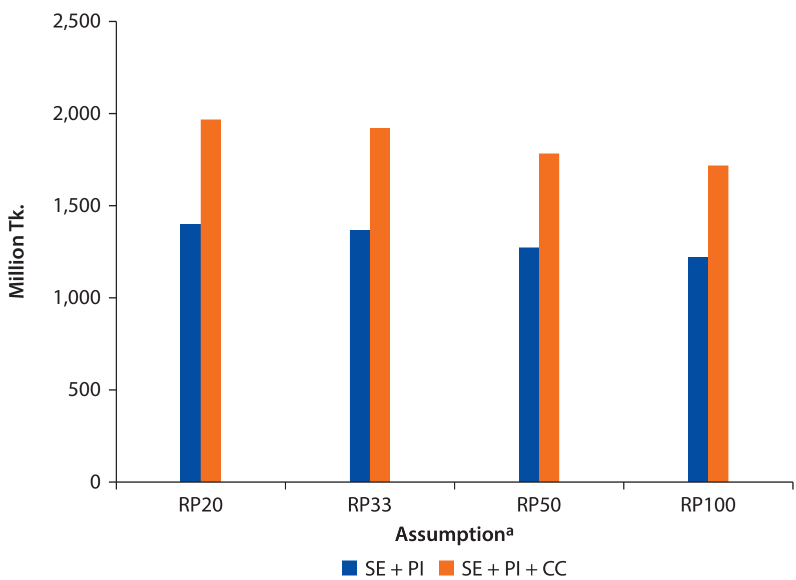
Table 6.31 captures the increased damage caused by climate change under the planned improvements (PI) scenario for the damage occurring in 2050 and the cumulative damage in 2014–50 using various alternative assumptions. Thus, in 2050, the increased damage from a 100-year event due to climate change would amount to Tk. 34 million if PI were made. Table 6.31 shows similar outcomes of increased damage caused by climate change under a weighted probability of

Figure 6.11 Total Estimated Damage for Eastern Dhaka in 2050



Source: Roy 2014.
Note: SE = socioeconomic changes; PI = planned improvements; CC = climate change. RP = return period (years).
a. 100-year event = actual damage from a 100-year event occurring in 2050 with certainty; RP20, 33, 50, and 100 = damage from a 100-year event occurring once every 20, 33, 50, or 100 years, respectively.

Figure 6.12 Total Cumulative Damage for Eastern Dhaka, 2014–50



Source: Roy 2014.
Note: SE = socioeconomic changes; PI = planned improvements; CC = climate change. RP = return period (years).
a. 100-year event = actual damage from a 100-year event occurring in 2050 with certainty; RP20, 33, 50, and 100 = damage from a 100-year event occurring once every 20, 33, 50, or 100 years, respectively.

Table 6.31 Increased Damage in Eastern Dhaka from Climate Change for Future Scenarios under Alternative Assumptions

Increased damage occurring in 2050 (Tk. million)					
	Return period based on probability				
Scenario	*100 year*	*RP20*	*RP33*	*RP50*	*RP100*
SE + PI + CC	34	22	21	20	19
Increased cumulative damage, 2014–50 (Tk. million)					
	Using random numbers for each return period				
Scenario	*RP20*	*RP33*		*RP50*	*RP100*
SE + PI + CC	565	552		511	494

Source: Roy 2014.
Note: SE = socioeconomic changes; PI = planned improvements; AI = additional investments; CC = climate change; RP = return period (years).

various return-period storms for the PI scenario. It also shows similar cumulative effects of climate change in 2014–50, with random assignment of various return-period storms under alternative assumptions of increased frequency of a 100-year, return-period storm. In terms of sector-wise comparisons for Eastern Dhaka, the largest damage is found in industry, followed by other surface transport and residential buildings.

DND Results

Hydrological Modeling Output

The study generated flood maps showing inundation depths and duration of urban flooding for the historic 100-year, return-period rainfall event in 2004 and alternative scenarios for 2050 with and without climate change using the 0.25 m flood criteria. The actual 100-year, return-period storm in 2004 inundated more than 70 percent of the DND area. Only 12.25 km^2 remained flood free, while 11.42 km^2 experienced inundation above 1.5 m depth. Compared to the 2004 storm, the simulated 2050 100-year event showed a decrease in deeper pockets of waterlogging (>1.5 m depth), even for the A1FI climate change scenario (table 6.32). The improved flooding situation is attributable to planned drainage improvements (i.e., increased conveyance capacity of khals, installation of new pump stations, and increased capacity at Shimrail Pump Station), as well as greater land elevation to accommodate future population growth in built-up areas.

For the 100-year event in 2050 without climate change (341 mm per 24 hours), the flood-free area is increased to 48.64 km^2, meaning that about 84 percent of the modeled area remains flood free (table 6.32). When the effect of A1FI climate change (396 mm per 24 hours) is simulated, the DND's flood-free area is reduced to 66 percent. About three-fifths of the area is inundated at 0.25 m depth, while another 15 percent is under more than 1.5 m flood depth—9 percent more than in the simulation without climate change (map 6.6).

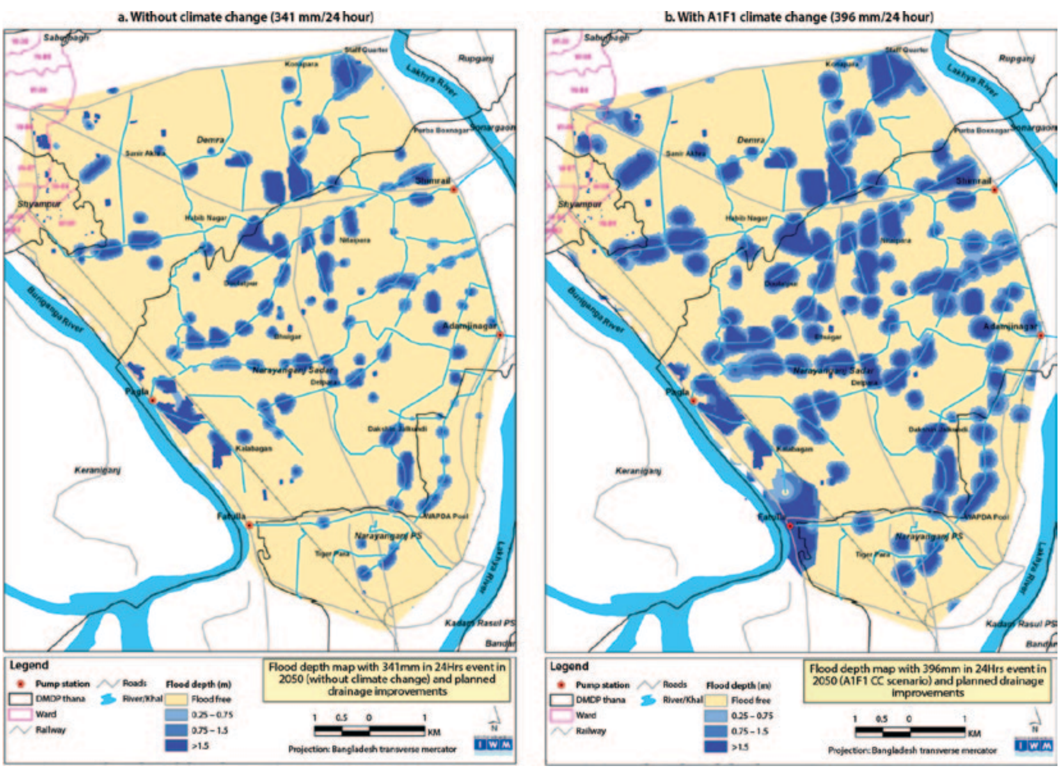
Because these findings showed that planned improvements would be insufficient to cope with extreme rainfall events, even without climate change,

Table 6.32 Flood-Depth Comparisons, DND Model

	Maximum flooded area (km²)				
Scenario simulated	*Flood free (0–0.1 m)*	*0.1–0.25 m*	*0.25–0.75 m*	*0.75–1.5 m*	*>1.5 m*
2004 100-year event (actual storm, 341 mm/24-hour)	12.25	4.59	11.33	19.55	11.42
2050 100-year event (SE + PI, 341 mm/24-hour)	48.64	1.59	2.60	2.83	3.52
2050 100-year event (SE + PI + CC, 396 mm/24-hour)	1.20	37.70	5.68	5.61	8.99

Source: Zaman 2014.
Note: DND = Dhaka-Narayanganj-Demra.

Map 6.6 Flood-Depth Comparisons of Extreme Rainfall Events in 2050, DND Model



Source: IWM 2014.

additional measures were incorporated into the model to meet acceptable flood criteria for the DND study area.

The following additional investments were identified to address the current adaptation deficit:

- At Shimrail Pump Station—Increase planned pump capacity by 10 percent to 42.25 m^3/s.

Table 6.33 2050 Rainfall Event in a Changing Climate, DND Model Area

	Maximum flooded area (km²)				
Extreme storm in 2050	*Flood free (0–0.25 m)*	*0.25–0.75 m*	*0.75–1.5 m*	*>1.5 m*	*Average duration above 0.25 m depth (hours to recede)*[a]
Future SE + PI (341 mm/24 hour)	48.6	1.6	2.6	2.8	35
Future SE + PI + CC (396 mm/24 hour)	1.2	37.7	5.7	5.6	77
Future SE + PI + AI (341 mm/24 hour)	51.5	1.2	2.0	2.1	20
Future SE + PI + AI + CC (396 mm/24 hour)	43.2	2.4	3.8	4.0	64
Future SE + PI + AI + CC + AD (396 mm/24 hour)	51.3	1.3	2.1	2.2	34

Source: Zaman 2014.
Note: SE = socioeconomic changes; PI = planned improvements; AI = additional investments; CC = climate change; AD = adaptation to climate change; DND = Dhaka-Narayanganj-Demra.
a. Analysis of depth duration could not be calculated directly since drainage-system simulations used the 1-dimensional hydrodynamic model. Thus, for each administrative area, flooding duration was estimated by analyzing the change in water levels at appropriate points in the drainage system. For flood depths above 1.5 m, duration calculations used GIS analysis and generated area elevation curves for each administrative area. Lowest land level was estimated by comparing the total water body area (proposed by the DAP) and area elevation curve. Details are provided in Zaman (2014).

- At Adamjinagar Station—Increase planned pump capacity by 20 percent to 36.25 m^3/s.
- At Pagla Station—Increase planned pump capacity by 20 percent to 3.84 m^3/s.

Even with these additional investments, the findings showed that, with climate change, about 23 percent of the DND study area would be inundated, and some areas would experience more than 0.25 m inundation over 12 hours (table 6.33). Thus, further adaptation measures were needed to meet acceptable flooding criteria under the A1FI climate change scenario in 2050.

The specific adaptation measures required to cope with climate change were identified as follows:

- At Shimrail Pump Station—Increase pump capacity by another 30 percent to 54.92 m^3/s.
- At Adamjinagar Pump Station—Increase pump capacity by another 30 percent to 47.13 m^3/s.
- At Fatulla Pump Station—Increase planned pump capacity by 25 percent to 4.06 m^3/s.

With the implementation of these adaptation measures, 90 percent of the DND area will be flood-free.

Additional 2050 Scenarios

Owing to political, social, and other pressures, it may be difficult to maintain the recommended design of khal cross-sections in the future (BWDB 2010). Thus, additional simulations including bank encroachment of khals were run for

Table 6.34 2050 Flood-Depth Comparisons in a Changing Climate, Highlighting the Impact of Khal Encroachment

	Maximum flooded area (km²)				
Scenario	*Flood free (0–0.1)*	*0.1–0.25 m*	*0.25–0.75 m*	*0.75–1.5 m*	*>1.5 m*
211 mm/6 hour rainfall event					
Without climate change	57.61	0.27	0.34	0.24	0.71
Without climate change + encroachment	57.05	0.42	0.53	0.39	0.79
With 16% rainfall increase due to climate change	56.63	0.50	0.72	0.48	0.84
With 16% rainfall increase due to climate change + encroachment	54.57	0.85	1.33	1.15	1.28
341 mm/24 hour rainfall event					
Without climate change	48.64	1.59	2.60	2.83	3.52
Without climate change + encroachment	1.51	0.21	0.48	43.08	13.90
With 16% rainfall increase due to climate change	1.20	37.70	5.68	5.61	8.99
With 16% rainfall increase due to climate change + encroachment	0.12	0.08	0.16	0.21	58.60

Source: Zaman 2014.

various 2050 scenarios (30- and 100-year rainfall events with and without climate change) (table 6.34).

Results of simulations for the 211 mm per six-hour rainfall event (30-year, return-period design storm) show little change in the extent of inundation due to the effect of climate change, even with bank encroachment (table 6.34). However, findings for the 341 mm per 24-hour event show that no area would remain flood-free. Without climate change, about 72 percent of the area would experience inundation at 0.75–1.5 m depth, while about 23 percent would be under 1.5 m water depth. With A1FI climate change, the situation would worsen markedly, with nearly 99 percent of the DND study area inundated at a depth above 1.5 m.

Interestingly, the findings show that bank encroachment has a significant impact on the 2050 scenarios for the 341 mm per 24-hour event. Without climate change or encroachment, about 80 percent of the DND study area would remain flood free. The addition of encroachment would have a significant impact, resulting in about 70 percent of the area being inundated at a 0.75–1.5 m depth. For the A1FI climate change scenario, the impact is even greater. Without encroachment, about 60 percent of the area would be inundated at 0.25 m water depth. With encroachment, however, nearly 100 percent of the DND study area would experience waterlogging above 1.5 m depth.

Vulnerability to River Flood

The DND area includes five wards inside the DCC and one outside region to the south, adjacent to the DSCC wards. Wards 86–88, 90 and the outside region are among Dhaka's top 20 vulnerable wards/regions, making DND the most vulnerable of the six areas analyzed for flood vulnerability. All five wards—86, 87, 88, 89, and 90—rank low in terms of the CDRI's economic and physical dimensions, while the outside region ranks low for the institutional and physical dimensions. In terms of the flood dimension, four of the five wards—86, 87, 88, and 90—and the outside region show high flood vulnerability as well; when combined with their other lower CDRI indices, they become quite vulnerable, placing among the top 20 vulnerable wards/regions under planned improvements (PI) scenarios for equal weights (table 6.35).

High flood vulnerability is a significant factor in increasing vulnerability in the DND area; however, the four CDRI dimensions play an even larger role. This impact is evidenced by the general increase in vulnerability rankings for the DND wards/region as flooding levels go down with the transition from planned improvements to additional investments scenarios under equal weights and 50 percent flood weight.

Damage Estimates

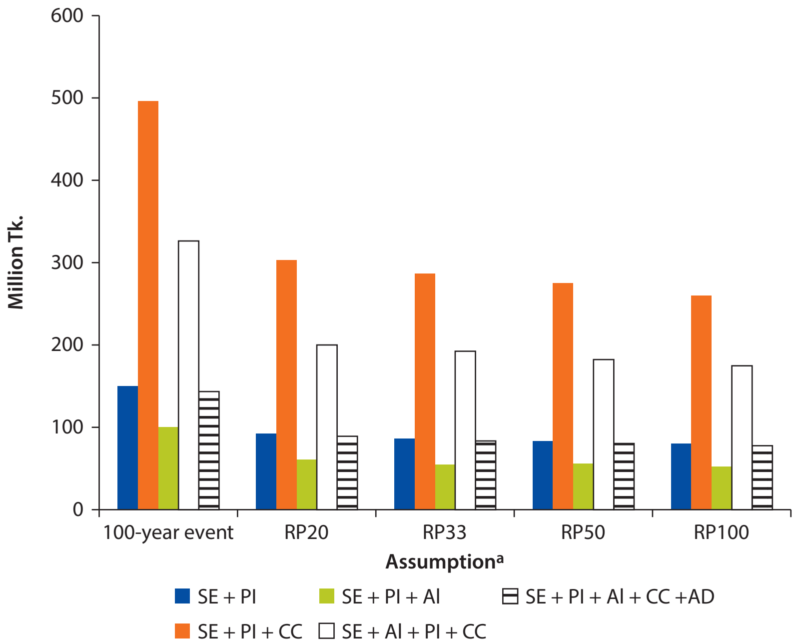
The total damage for the DND area in 2050 was estimated for the five future scenarios, using alternative assumptions about how frequently a 100-year, return-period storm would occur (chapter 5). Figure 6.13 shows the total monetary value of the damage that would result from the actual 100-year event in 2050 under the five future scenarios, followed by expected damage estimates using

Table 6.35 FVI Rankings of DND Wards/Region under Alternative Flooding Scenarios

	Equal weight [a]				
	Future scenarios				
Ward/region	*SE + PI*	*SE + PI + CC*	*SE + PI + AI*	*SE + PI + AI + CC*	*SE + PI + AI + CC + AD*
Outside DCC, south area	15	12	7	5	10
86	5	3	1	1	2
87	2	29	3	3	1
88	8	39	10	7	4
89	52	52	49	50	48
90	9	41	11	9	8
50% flood weight [a]					
Outside DCC, south area	10	9	3	2	4
86	7	4	1	1	1
87	9	26	4	4	2
88	14	46	8	7	6
89	65	61	64	63	62
90	15	55	9	8	8

Note: SE = socioeconomic changes; PI = planned improvements; AI = additional investments; CC = climate change; AD = adaptation to climate change; DND = Dhaka-Narayanganj-Demra; FVI = Flood Vulnerability Index.
a. Lower numbers indicate a higher vulnerability.

Figure 6.13 Total Estimated Damage for DND in 2050



Source: Roy 2014.
Note: SE = socioeconomic changes; PI = planned improvements; AI = additional investments; CC = climate change; AD = adaptation to climate change. RP = return period (years).
a. 100-year event = actual damage from a 100-year event occurring in 2050 with certainty; RP20, 33, 50, and 100 = damage from a 100-year event occurring once every 20, 33, 50, or 100 years, respectively.

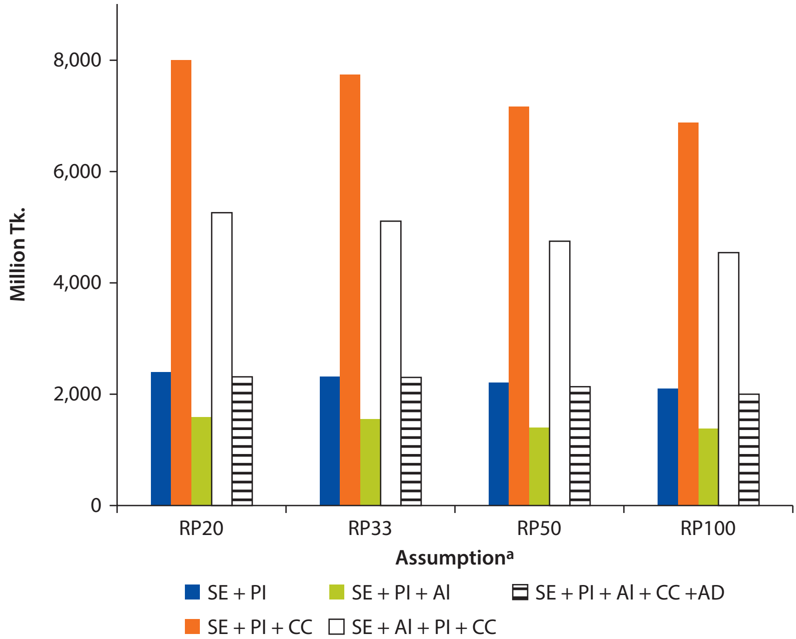
alternative probabilities of the 100-year event's recurrence (i.e., every 20, 33, 50, or 100 years).

Figure 6.14 shows the expected cumulative damage over the 2014–50 period for the five future scenarios, with random assignment of various return-period storms under alternative assumptions of increased frequency of the 100-year event. As described in chapter 5, alternative probabilities of the recurrence of the 100-year event are used to compute the expected value of the total cumulative damage between 2014 and 2050 if the event were to occur every 20, 33, 50, or 100 years.

The results show how the damage that would occur under the scenario with planned improvements (PI) alone is reduced when additional investments (AI) are made to address the current adaptation deficit and how climate change exacerbates the extent of damage for each scenario. Comparison of the damage in a changing climate with and without AI reveals that increase in the damage due to climate change is less if AI are made and the current adaptation deficit is addressed. With measures to address climate change adaptation, the damage in a changing climate decreases somewhat, but is still larger than in the AI scenario without climate change.

Table 6.36 captures the increased damage caused by climate change under the planned improvements (PI) and additional investments (AI) scenarios for the

Figure 6.14 Total Cumulative Damage for DND, 2014–50



Source: Roy 2014.
Note: SE = socioeconomic changes; PI = planned improvements; AI = additional investments; CC = climate change; AD = adaptation to climate change. RP = return period (years).
a. 100-year event = actual damage from a 100-year event occurring in 2050 with certainty; RP20, 33, 50, and 100 = damage from a 100-year event occurring once every 20, 33, 50, or 100 years, respectively.

Table 6.36 Increased Damage in DND from Climate Change for Future Scenarios under Alternative Assumptions

Increased damage occurring in 2050 (Tk. million)					
	Return period based on probability				
Scenario	*100 year*	*RP20*	*RP33*	*RP50*	*RP100*
SE + PI + CC	348	224	205	195	181
SE + PI + AI + CC	228	149	137	130	121

Increased cumulative damage, 2014–50 (Tk. million)				
	Using random numbers for each return period			
Scenario	*RP20*	*RP33*	*RP50*	*RP100*
SE + PI + CC	5,574	5,427	5,003	4,811
SE + PI + AI + CC	3,687	3,593	3,317	3,195

Source: Roy 2014.
Note: SE = socioeconomic changes; PI = planned improvements; AI = additional investments; CC = climate change; RP = return period (years); DND = Dhaka-Narayanganj-Demra.

damage occurring in 2050 and the cumulative damage in 2014–50 using various alternative assumptions. Thus, in 2050, the increased damage from a 100-year event due to climate change would amount to Tk. 348 million if only PI were made and would decrease to Tk. 228 million with AI. Table 6.36 shows similar outcomes of increased damage caused by climate change under a weighted probability of various return-period storms for both PI and AI scenarios. It also shows similar cumulative effects of climate change in 2014–50, with random assignment of various return-period storms under alternative assumptions of increased frequency of a 100-year, return-period storm. In terms of sector-wise comparisons for the DND area, the largest damage is to residential property, followed by industry and residential buildings.

Cost of Adaptation

Results of the hydrological modeling exercise show that, for the DND drainage system, the cost of meeting the current adaptation deficit beyond planned improvements (PI) would require increasing the capacity of permanent pump stations at Shimrail and Adamjinagar by 3.85 m^3/s and 6.05 m^3/s, respectively. It would also require increasing the temporary pump capacity at Pagla by 0.65 m^3/s (Zaman 2014). Among the PI, only the Shimrail Pump Station has been installed to date. This study's cost estimates assume that all PI will be made. The costs of these additional investments (AI) are estimated at Tk. 540.0 million and Tk. 4.6 million, for a total cost of Tk. 544.6 million (table 6.37).

Table 6.37 Estimated Cost of Meeting the Current Adaptation Deficit, DND

Increased pump capacity	*Pump capacity (m^3/s)*	*Head (m)*	*Pump price/unit (million Tk.)*	*Unit (no.)*	*Mechanical works (million Tk.)*	*Electrical works (million Tk.)*	*Civil works (million Tk.)*	*Total cost (million Tk.)*
Shimrail								
Permanent pump station	3.85	6	80	1	80	65	70	215
Adamjinagar								
Permanent pump station	6.05	6	150	1	150	75	100	325
Subtotal								540
Pagla								
Increased pump capacity	*Pump capacity (m^3/s)*	*Head (m)*	*25 ft^3/s pumps (pumps and pipes) (no.)*	*Unit cost of pump and pipes (million Tk.)*	*200 kVA transformers needed (no.)*	*Unit cost of 200 kVA transformers and cables (million Tk.)*		*Total cost (million Tk.)*
Temporary pump station	0.65	10	1	2.6	1	2.0		4.6
Subtotal								4.6
Total cost								**544.6**

Sources: DWASA officials and authors' calculations.
Note: DND = Dhaka-Narayanganj-Demra.

Adapting to climate change would require further enhancement of the permanent pump capacity at Shimrail and Adamjinagar by 12.7 m^3/s and 10.9 m^3/s, respectively. In addition, the temporary pump capacity at Fatulla would need to be increased by 0.82 m^3/s. The cost of these adaptation measures to address climate change would total nearly Tk. 1.11 billion (table 6.38).

Finally, table 6.39 provides a summary comparison of the costs required to meet the current adaptation deficit and the added expense of climate change adaptation. As shown, Tk. 544.6 million would be required to close the current gap, while addressing the climate change deficit would require an additional Tk. 1.1 billion, for a total combined cost of Tk. 1.65 billion. It should be noted that the figure for DND's climate change adaptation is far higher than those

Table 6.38 Estimated Cost of Meeting the Climate Change Adaptation Deficit, DND

Increased pump capacity	*Pump capacity (m^3/s)*	*Head (m)*	*Pump price/unit (million Tk.)*	*Unit (no.)*	*Mechanical works (million Tk.)*	*Electrical works (million Tk.)*	*Civil works (million Tk.)*	*Total cost (million Tk.)*
Shimrail								
Permanent pump station	12.7	6	190	2	380	80	140	600
Adamjinagar								
Permanent pump station	10.9	6	150	2	300	75	125	500
Subtotal								1,100
Fatulla								
Increased pump capacity	*Pump capacity (m^3/s)*	*Head (m)*	*5 ft^3/s pumps (pumps and pipes), 0.8 per unit (million Tk.)*		*25 ft^3 /s pumps (pumps and pipes), 2.6 per unit (million Tk.)*		*200 kVA transformers and cables, 2.0 per unit (million Tk.)*	*Total cost (million Tk.)*
Temporary pump station	0.82	10	0.8		2.6		2.0	5.4
Subtotal								5.4
Total cost								**1,105.4**

Sources: DWASA officials and authors' calculations.
Note: DND = Dhaka-Narayanganj-Demra.

Table 6.39 Summary of Adaptation Costs, DND

Recommended measure	*Cost (Tk. million)*
Addressing current adaptation deficit	
Total estimated cost, increasing pump capacity	544.6
Addressing climate change deficit	
Total estimated cost, increasing pump capacity	1,105.4
Total combined cost	**1,650.0**

Sources: BWDB, DWASA officials, and authors' calculations.
Note: DND = Dhaka-Narayanganj-Demra.

for the other drainage systems in the detailed study area. In fact, DND accounts for more than 85 percent of the total Tk. 1.3 billion required to address the climate change–induced adaptation deficit (Huq 2014). The damage estimates demonstrate that this investment of Tk. 1,650 million in flood mitigation will lead to a reduction in damage of Tk. 352 million in 2050 when faced with a 100-year, return-period storm and cumulative damage reduction (2014–50) of Tk. 4,868 million.

Narayanganj Results

Hydrological Modeling Output

River flood maps were generated simulating the inundation depth and duration of 2004 rainfall events (10-, 30-, and 100-year return-periods) and alternative 2050 scenarios with and without climate change. In 2004, the flooding extent and duration for the 30-year rainfall event is higher than for the 10-year event; however, the difference in flooding is minimal. By comparison, the actual 100-year, return-period storm exhibited more extensive flooding, with greater depth and prolonged duration. The average duration for the actual 100-year event to recede was 12 hours, compared to 3 hours and 2 hours, respectively, for the 30-year and 10-year events (table 6.40).

For 2050, the study modeled 211 mm per six-hour event (equivalent to the 30-year return-period, 24-hour event in 2004) with and without climate change, as well as 341 mm per 24-hour event (equal to the 100-year event in 2004) without climate change. The maps generated for the 211 mm per six-hour event showed a minimal increase in flood depth and duration due to A1FI climate change. As expected, the 341 mm per 24-hour event showed less flood-free area compared to the smaller events, but only marginally (table 6.41). Compared to the actual 2004 storm, the 341 mm per 24-hour event in 2050 exhibited a reduction in the extent and average duration of flooding, attributed mainly to the planned increase in land elevation and planned improvements to the drainage system by 2050.

Table 6.40 Comparison of 2004 Flooding Results, Narayanganj Model

	Maximum flooded area (km^2)					
Scenario	*Flood free (0–0.1 m)*	*0.1–0.25 m*	*0.25–0.75 m*	*0.75–1.5 m*	*>1.5 m*	*Average duration above 0.25 m depth (hours to recede)*
10-year event	30.64	3.54	2.11	0.65	2.29	2
30-year event	29.53	4.11	2.57	0.63	2.39	3
100-year event (actual 2004 storm)	28.62	2.86	3.89	0.96	2.91	12

Source: Zaman 2014.

Table 6.41 Comparison of 2050 Flooding Results, Narayanganj Model

Scenario	Maximum flooded area (km^2) Flood free (0–0.1 m)	0.1–0.25 m	0.25–0.75 m	0.75–1.5 m	>1.5 m	Average duration above 0.25 m depth (hours to recede)
211 mm/6 hour (without climate change)	27.84	8.39	1.15	0.15	1.71	3
245 mm/6 hour (with A1FI climate change)	25.94	9.96	1.45	0.16	1.73	4
341 mm/24 hour (without climate change)	26.41	8.81	1.90	0.33	1.79	11

Source: Zaman 2014.

Table 6.42 2050 Rainfall Events in a Changing Climate, Narayanganj Model Area

Extreme storm in 2050	Maximum flooded area (km^2) Flood free (0–0.25 m)	0.25–0.75 m	0.75–1.5 m	>1.5 m	Average duration above 0.25 m depth (hours to recede)
One-dimensional model area					
Future SE + PI (341 mm/24 hour)	3.4	0.7	2.4	3.4	>240
Future SE + PI + CC (396 mm/24 hour)	3.3	0.7	2.4	3.4	>240
Future SE + PI + AI (341 mm/24 hour)	3.4	0.7	2.4	3.4	>240
Future SE + PI + AI + CC (396 mm/24 hour)	3.3	0.7	2.4	3.4	>240
Two-dimensional model area					
Future SE + PI (341 mm/24 hour)	12.2	0.1	0.1	0.1	2
Future SE + PI + CC (396 mm/24 hour)	11.2	0.2	0.2	0.9	3
Future SE + PI + AI (341 mm/24 hour)	12.3	0.1	0.1	0.1	2
Future SE + PI + AI + CC (396 mm/24 hour)	12.3	0.1	0.1	0.1	2

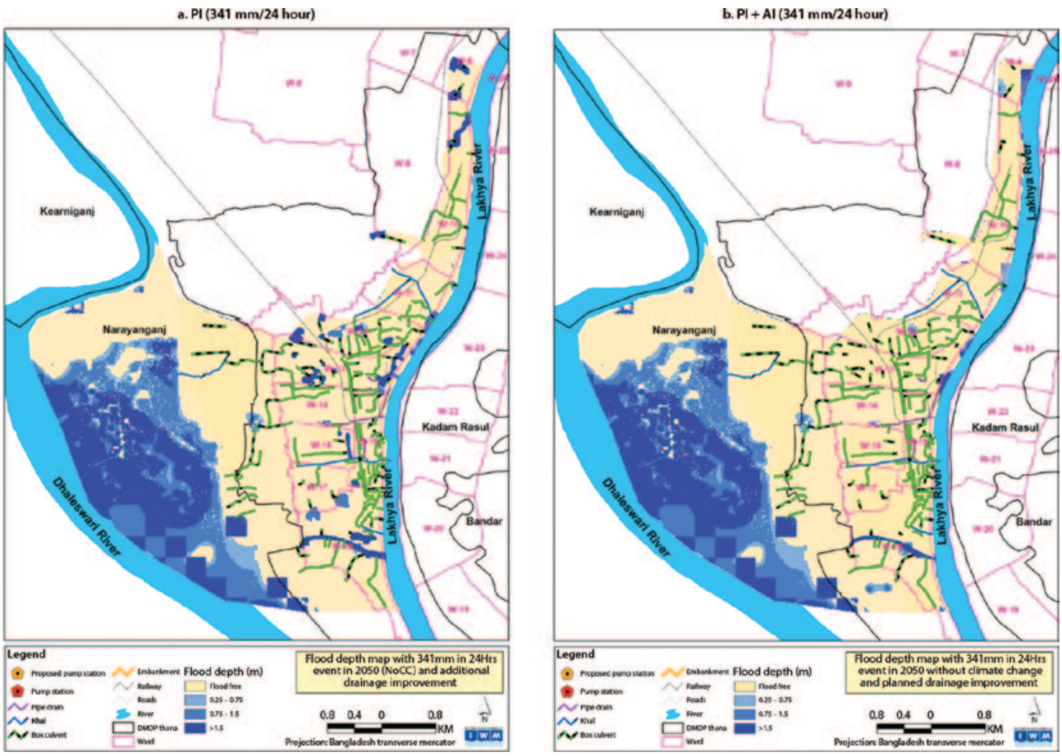
Source: Zaman 2014.
Note: SE = socioeconomic changes; PI = planned improvements; AI = additional investments; CC = climate change; AD = adaptation to climate change.

Results of the 341 mm per 24-hour rainfall event were analyzed with regard to meeting the acceptable 0.25 m flood criteria. Table 6.42 summarizes the simulation results for the extreme rainfall events.

The findings showed that, for some areas, the planned drainage system was marginally unable to cope with extreme rainfall events (341 mm per 24 hours) (map 6.7). Therefore, additional drainage improvements were identified and incorporated into the model.

Because some water bodies were not explicitly represented in the Digital Elevation Model (DEM) for 2050, the DEM was adjusted by lowering the land level by approximately 2 m in locations where water bodies were identified in the planned land use of the Detailed Area Plan (DAP).

Map 6.7 Extreme Rainfall Event (341 mm/24 hours) in 2050 with 0.25 m Flood Criteria, Narayanganj Model



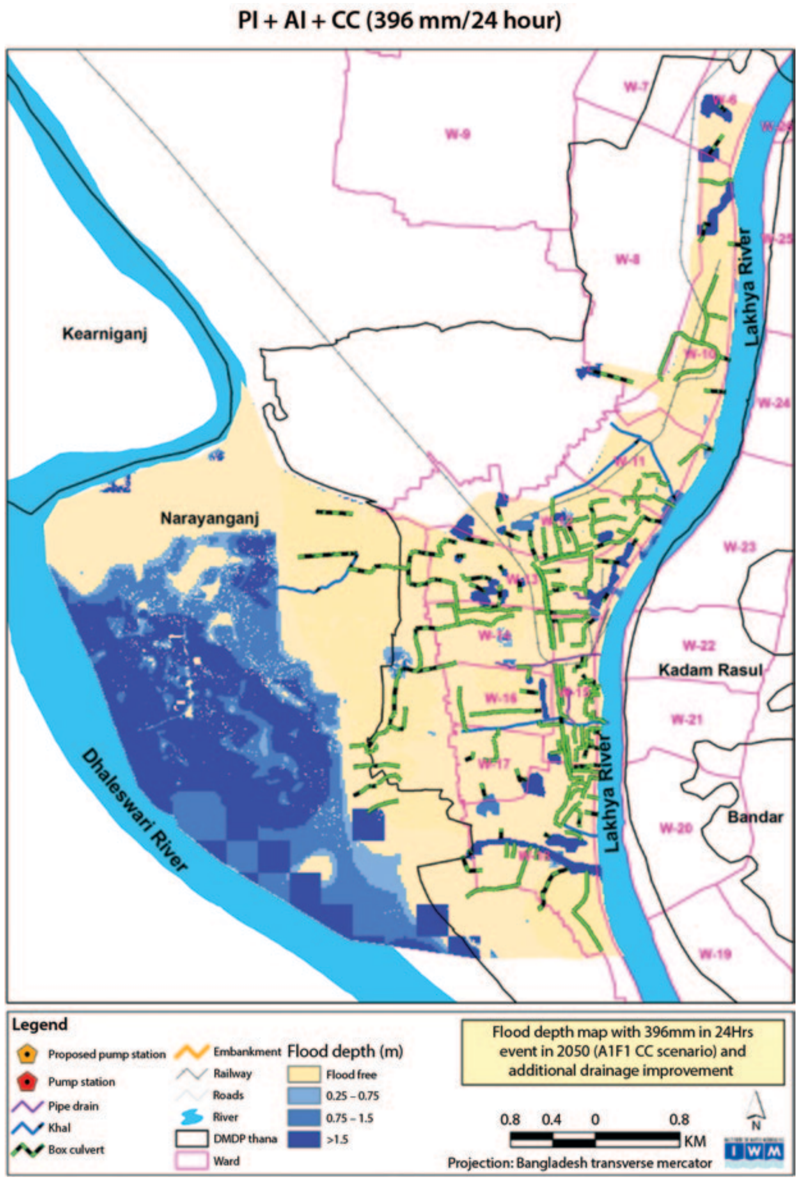
Source: IWM 2014.
Note: PI = planned improvements; AI = additional investments.

The additional drainage improvements (i.e., refinements in the drainage model) to meet the adaptation deficit were identified as follows:

- In wards 8, 12–18, and 25–26—Create local area ponds, as identified in the DAP, to store stormwater runoff during extreme events.

When these additional drainage improvements were incorporated into the model, simulation of the A1FI climate change effect (396 mm per 24 hours) showed that the added measures were sufficient to meet acceptable flood criteria (map 6.8). Therefore, no measures for climate change adaptation were required for the Narayanganj area.

Map 6.8 Flood Depth of A1FI Rainfall Event in 2050, with Additional Drainage Improvements, Narayanganj Model



Source: IWM 2014.
Note: PI = planned improvements; AI = additional investments; CC = climate change.

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CHAPTER 7

Assessment of Dhaka City's Flood Resilience

Introduction

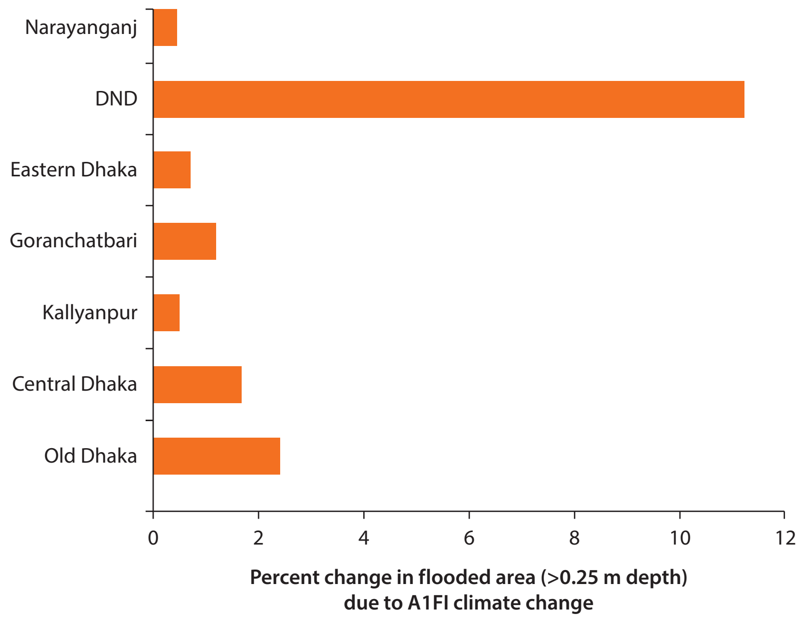
While the previous chapter provided the study findings by modeled zone, this chapter presents overall results for Dhaka city. First, findings from the hydrological modeling exercise are summarized for the detailed study area, highlighting the varying effects of climate change by region. Results of the flood vulnerability assessment follow, including a ward-level analysis. Subsequent sections present total (2050) and cumulative (2014–50) estimated damage, including sector-wise estimates, using alternative-probability cases for extreme rainfall events; and the cost of adaptation and estimated benefits from these investments. Finally, the chapter considers what added expenditures might be needed to achieve a flood-free Dhaka.

Summary of Modeling Findings

Since the year 2000, Dhaka city has experienced three extreme rainfall events that far exceeded previous records. The underlying assumption is that such events will become more frequent in the future due to climate change processes. The simulation results (chapter 6) show that, with planned improvements, the detailed study area can cope with rainfall events of 200–250 mm per day—that is, up to a 50-year, return-period event, based on data up to 1990 (JICA 2000), with a peak intensity of about 100 mm per hour under the 2050 A1FI scenario. But for larger events exceeding 300 mm per day, which are becoming more frequent, additional structural measures will be required; these include installing new permanent and temporary pump stations and increasing the capacity of existing ones, laying new drainage pipes, deepening existing water bodies, and installing automatic sluice gates to prevent backflow in box-culverts.

Implementing the recommended additional investments to address the current adaptation deficit would, except for rural parts of Narayanganj and DND, meet the study's acceptable flooding criteria for the extreme event in 2050

Figure 7.1 Impact of Climate Change on Flooded Area in 2050



Source: Zaman 2014.
Note: A1FI = Intergovernmental Panel on Climate Change scenario with future based on fossil fuel–intensive development; DND = Dhaka-Narayanganj-Demra.

without climate change (341 mm per 24 hours). The effects of climate change (A1FI) by 2050 on the improved drainage system would have varying effects by region. With a 16 percent increase in rainfall—396 mm per day in 2050 versus 341 mm per day in the 2004 base year—the DND area would experience a 12 percent increase in flooded area, while the other six areas would remain within a 3 percent increase (figure 7.1).

What Is Dhaka's Flood Vulnerability?

Results of the vulnerability assessment show that, when equal weight is assigned to the five dimensions—20 percent weight given to the physical, social, economic, and institutional CDRI dimensions used and the flood dimension (chapter 4)—the relative vulnerability among the study areas remains unchanged across all five alternative future scenarios. But increasing the weight assigned to flooding to 50 percent causes minor changes in the study areas' relative rankings, especially for the SE + PI + CC scenario, where flooding is higher; Eastern Dhaka and Old Dhaka show some increased vulnerability, implying that flooding may have a larger impact in some pockets of these areas (table 7.1).

Ward-Level Analysis

Table 7.2 shows the Flood Vulnerability Index (FVI) rankings of Dhaka's 20 most vulnerable wards/regions, which figured repeatedly under the five future

Table 7.1 FVI Rankings of Dhaka Study Areas

	Future scenarios				
	Equal weight[b]				
Study area[a]	*SE + PI*	*SE + PI + CC*	*SE + PI + AI*	*SE + PI + AI + CC*	*SE + PI + AI + CC + AD*
DND	1	1	1	1	1
Eastern Dhaka	2	2	2	2	2
Kallyanpur	3	3	3	3	3
Goranchatbari	4	4	4	4	4
Central Dhaka	5	5	5	5	5
Old Dhaka	6	6	6	6	6
50% flood weight[b]					
DND	1	2	1	1	1
Eastern Dhaka	2	1	2	2	2
Kallyanpur	3	3	4	4	4
Goranchatbari	4	5	3	3	3
Central Dhaka	6	6	5	5	5
Old Dhaka	5	4	6	6	6

Source: Roy 2014.
Note: SE = socioeconomic changes; PI = planned improvements; AI = additional investments; CC = climate change; AD = adaptation to climate change; DND = Dhaka-Narayanganj-Demra; FVI = Flood Vulnerability Index.
a. The flood vulnerability of each study area is separately examined in chapter 6, using the FVI to determine the relative vulnerability among wards and regions in each area; Narayanganj is excluded from the vulnerability analysis due to lack of detailed data.
b. FVI rankings progress from 1 (highest vulnerability) to 6 (lowest vulnerability).

scenarios for equal-weighted and 50 percent flood-weighted dimensions). Seven wards—02, 04, 08, 09, 15, 25, and 86—and two regions—Khilgaon (outside DNCC) and Demra (outside DSCC)—were among the top 20 under all 10 scenarios and thus appear the most vulnerable. Wards 11 and 87, which were among the top 20 in 9 out of the 10 scenarios, appear equally vulnerable.

These top 20 vulnerable wards/regions were further examined to determine which of the CDRI (physical, social, economic, and institutional) and flood dimensions accounted for their added vulnerability and, within these dimensions, which particular parameters were driving the results. The findings showed that, in each ward/region, dimensions that scored below the first quartile (bottom 25 percent) for all wards/regions were the main cause of greater vulnerability. For all such dimensions, the indicators found to be "poor" were the main contributors to the dimension falling below the first quartile. All of the top 20 vulnerable wards/regions faced vulnerability from flooding extent and duration, and this vulnerability was heightened further by the other non-flood factors (table 7.3).

The dimension of flood vulnerability in the overall vulnerability is based on the likely infrastructure in each area with a 100-year, return period storm, assuming completion of investments currently being implemented. The identified wards with high flood vulnerability can help local planners to focus on areas that need additional structural investments to minimize the higher vulnerability

Table 7.2 FVI Rankings of Dhaka Wards and Regions

		Future scenarios									
		Equal weight[a]					*50% flood weight*[a]				
Area	*Ward or region*	*SE + PI*	*SE + PI+ CC*	*SE + PI + AI*	*SE + PI+ AI + CC*	*SE + PI + AI + CC+ AD*	*SE + PI*	*SE + PI + CC*	*SE + PI + AI*	*SE + PI + AI + CC*	*SE + PI+ AI + CC+ AD*
Kallyanpur	09	1	1	4	6	6	5	13	20	19	6
DND	87	2	>20	3	3	1	9	>20	3	4	1
Old Dhaka	82	3	2	>20	19	>20	4	>20	14	13	>20
DND	86	4	3	1	1	2	7	>20	1	1	2
Central Dhaka	25	5	4	14	16	13	11	>20	16	17	13
Kallyanpur	10	6	5	2	4	3	>20	14	6	11	3
Kallyanpur	58	7	15	>20	>20	>20	1	>20	11	10	>20
DND	88	8	>20	10	7	4	14	>20	8	7	4
DND	90	9	>20	11	9	7	15	>20	9	8	7
Eastern Dhaka	Khilgaon, outside DNCC	10	14	5	13	8	3	2	2	5	8
Kallyanpur	08	11	7	12	2	5	17	12	10	3	5
Eastern Dhaka	Badda, outside DNCC	12	8	8	12	9	8	1	5	6	9
Kallyanpur	11	13	6	6	8	12	>20	15	12	18	12
Goranchatbari	15	14	10	15	14	16	18	19	15	14	16
DND	Demra, outside DSCC	15	12	7	5	10	10	3	4	2	10
Goranchatbari	02	16	13	17	11	17	>20	6	18	12	17
Goranchatbari	04	17	19	9	10	11	20	8	7	9	11
Kallyanpur	48	18	>20	>20	>20	>20	2	>20	>20	>20	>20
Central Dhaka	75	19	11	>20	>20	>20	16	>20	>20	>20	>20
Old Dhaka	83	20	17	>20	>20	>20	19	>20	>20	20	>20

Note: SE = socioeconomic changes; PI = planned improvements; AI = additional investments; CC = climate change; AD = adaptation to climate change; DND = Dhaka-Narayanganj-Demra; FVI = Flood Vulnerability Index.

a. Wards are listed in descending order of vulnerability from 1 (highest) to 20 (lowest).

Table 7.3 Main Drivers of Greater Vulnerability for Dhaka's Top 20 Vulnerable Wards/Regions

Dimension	*Parameters: wards/regions*
Physical	Electricity: 04, 08, 15
	Water: 02, 04, 08, 15, 86, 87, 88, 90
	Sanitation and solid-waste disposal: 04, 08
	Road accessibility: 04, 08
	Housing and land use: 04, 08, 86, 87, 88, 90
Social	Population: 09, 11, 25
	Health: 09, 10, 11
	Education and awareness: 09, 10, 11, 25, Khilgaon
	Social capital: 09, 10, 11, 25
	Community preparedness: Khilgaon
Economic	Income: 75, 82, 83, 86, 87, 88, 90
	Employment: 09, 10, 11, 75, 82, 83, 86, 87, 88, 90
	Household assets: 75, 82, 83, 86, 87, 88, 90
	Finance and savings: 09, 10, 11, 75, 82, 83, 86, 87, 88, 90
	Budget and subsidy: 09, 10, 11, 75, 82, 83, 86, 87, 88, 90
Institutional	Mainstreaming of disaster risk reduction (DRR) and climate change adaptation (CCA): 09, 10, 11, Khilgaon, Badda, Demra
	Effectiveness of city's crisis management framework: 09, 10, 11, Khilgaon, Badda, Demra
	Knowledge dissemination and management: 09, 10, 11, Khilgaon, Badda, Demra
	Institutional collaboration with other organizations and stakeholders during a disaster: Khilgaon, Demra
	Good governance: 09, 10, 11, Khilgaon, Badda, Demra
Flooding	Extent: 02, 04, 08, 09, 10, 11, 15, 25, 48, 58, 75, 82, 83, 86, 87, 88, 90, Khilgaon, Badda, Demra
	Duration: 02, 04, 08, 09, 10, 11, 15, 25, 48, 58, 75, 82, 83, 86, 87, 88, 90, Khilgaon, Badda, Demra

Source: Adapted from Jahan 2014.
Note: Khilgaon and Badda are regions outside the DNCC; Demra is a region outside the DSCC.

caused by flooding. The variation in non-flood drivers of greater flood vulnerability across the top 20 vulnerable wards/regions can help planners to identify location-specific interventions that may be needed to minimize vulnerability. For example, in ward 9, Dhaka's most vulnerable ward, more attention may be required to improve most parameters in the social, economic, and institutional dimensions, but not in the physical dimension (table 7.3).

Summing Up

Limited financial and other resource constraints make it necessary to tackle Dhaka's river and urban flooding problems in a timely and planned manner. This requires prioritizing the city's most vulnerable wards/regions and finding cost-effective solutions. The ward-level FVI results presented above can provide local policymakers a useful roadmap for future planning to minimize the effects of climate change. As noted, some wards have increased vulnerability owing to non-flood factors, which may exacerbate the impact caused by even low levels of flooding. In these wards, adaptation may need to focus more on reducing the non-flood drivers of vulnerability. Conversely, in more flood-prone wards, reducing the direct impact of flooding may take a higher priority.

Damage Estimates

Flooding in an urban area like Dhaka can lead to widespread damage resulting from submersion of buildings and property, as well as livelihood disruption among the flood-affected population. The damage is further aggravated as flooding duration persists. To estimate the overall potential economic damage from urban flooding in the study area for alternative future scenarios, damage was estimated separately for the following major affected sectors of the economy: residential (buildings and property), commerce and industry, health care, roads and railway, and other surface transport (chapter 5). In each case, efforts were made to estimate the damage to physical capital and earnings, to the extent possible.

Sector-Wise Estimates

This section provides a detailed, sector-wise analysis of damage from the occurrence of a 100-year, return-period storm in 2050 under the five alternative flood scenarios. Sector-wise cumulative damage between 2014 and 2050 is similarly examined, using random assignment of various return-period storms.

Residential Buildings

With the occurrence of a 100-year, return-period storm in 2050, 9.7 percent of Dhaka's households—0.50 million out of 4.61 million households[1]—will face flooding and damage to their residential buildings to varying degrees if only planned improvements are made. When the added precipitation from climate change is taken into account, the number of affected households climbs to 0.61 million or 11.8 percent. Without climate change, 0.22 million households or 4.7 percent of all households are affected when additional investments to address the existing adaptation deficit are implemented along with planned improvements. However, when the extra flooding resulting from climate change is considered, the figure rises to 0.26 million households or 5.7 percent. Finally, with climate change adaptation, the number of households likely to be affected falls to 0.25 million or 5.6 percent of all households.

Under a 100-year flood in 2050, the financial loss to residential buildings with planned improvements alone amounts to Tk. 1,458 million and increases by more than 70 percent (i.e., to Tk. 2,535 million) if the effect of climate change is included. Without climate change, losses total Tk. 230 million if additional investments for the current adaptation deficit are made along with planned improvements. With the added effect of climate change, losses increase somewhat to Tk. 365 million, but fall to Tk. 266 million with the implementation of adaptation measures.

The cumulative damage to residential buildings from 2014 to 2050 was estimated under varying return-period floods for each year picked at random for future years up to 2050 under the five future scenarios. The respective damage estimates amounted to Tk. 21,955 million (SE + PI), Tk. 38,177 million (SE + PI + CC), Tk. 3,460 million (SE + PI + AI), Tk. 5,492 million (SE + PI + AI + CC), and Tk. 3,998 million (SE + PI + AI + CC + AD).

The additional investments to meet the existing deficit in drainage infrastructure appear to have a large beneficial effect on reducing likely damage in the housing sector.

Residential Property

The property damage that households face from a 100-year flood in 2050 with planned improvements only amounts to Tk. 1,672 million; this figure increases to Tk. 3,002 million with the added effect of climate change. With additional investments to address the adaptation deficit, along with planned improvements without climate change, losses amount to Tk. 346 million. With the effect of climate change, they increase to Tk. 491 million, but fall to Tk. 404 million with adaptation.

The cumulative property damage for households from 2014 to 2050 was estimated under varying return-period floods picked at random for future years up to 2050 under the five future scenarios. The respective damage estimates amounted to Tk. 27,879 million (SE + PI), Tk. 50,041 million (SE + PI + CC), Tk. 5,763 million (SE + PI + AI), Tk. 8,193 million (SE + PI + AI + CC), and Tk. 6,734 million (SE + PI + AI + CC + AD). Once again, the additional investments in drainage infrastructure appear to have a large beneficial effect on reducing property damage among households.

Commerce and Industry

With the occurrence of a 100-year flood in 2050, the loss to business from damage to assets and property totals Tk. 372 million if only planned improvements are made, and climate change causes that figure to rise to Tk. 442 million. Without climate change, the loss amounts to Tk. 224 million if additional investments are made along with planned improvements. While the added effect of climate change causes the figure to climb to Tk. 263 million, implementing adaptation measures causes it to fall to Tk. 262 million. In addition, the cumulative loss to commercial establishments from 2014 to 2050 was estimated under varying return-period floods picked at random for future years up to 2050 under the five future scenarios. These respective estimates amounted to Tk. 6,150 million (SE + PI), Tk. 7,305 million (SE + PI + CC), Tk. 3,707 million (SE + PI + AI), Tk. 4,352 million (SE + PI + AI + CC), and Tk. 4,332 million (SE + PI + AI + CC + AD).

The damage to assets and finished products faced by industry in 2050 from a 100-year, return-period flood with planned improvements amounts to Tk. 967 million. With the effect of climate change, the figure increases to Tk. 1, 146 million. If additional investments for the current adaptation deficit are made along with planned improvements without climate change, the damage totals Tk. 591 million. The added effect of climate change causes the figure to rise to Tk. 694 million. However, with adaptation, the figure falls to Tk. 691 million. The cumulative loss to industry from 2014 to 2050 was estimated under varying return-period floods picked at random for future years up to 2050 under the five future scenarios. These respective estimates amounted to Tk. 15,980 million (SE + PI), Tk. 18,929 million (SE + PI + CC), Tk. 9,768 million (SE + PI + AI), Tk. 11,456 million (SE + PI + AI + CC), and Tk. 11,406 million (SE + PI + AI + CC + AD).

Health Care

In Dhaka, diarrhea and dengue fever are the two main diseases with increased incidence resulting from flooding, which cause increased mortality and morbidity in the affected area. The total quantifiable health damage in 2050 from a 100 year, return-period flood with planned improvements only amounts to Tk. 906 million, and this figure rises to Tk. 1,127 million with the effect of climate change. With additional investments for the existing adaptation deficit, along with planned improvements without climate change, it totals Tk. 414 million. With the added effect of climate change, it increases to Tk. 495 million. However, with adaptation, it falls to Tk. 491 million. The cumulative health damage from 2014 to 2050 was estimated under varying return-period floods picked at random for future years up to 2050 under the five future scenarios. These respective estimates amounted to Tk. 14,961 million (SE + PI), Tk. 18,620 million (SE + PI + CC), Tk. 6,832 million (SE + PI + AI), Tk. 8,183 million (SE + PI + AI + CC), and Tk. 8,113 million (SE + PI + AI + CC + AD).

Roads and Railway

The total economic loss to road infrastructure in 2050 from a 100-year, return-period flood with planned improvements amounts to Tk. 516 million, and it increases to Tk. 601 million with climate change effects. With additional investments to address the adaptation deficit in the current climate, along with planned improvements without climate change, it amounts to Tk. 414 million. The effect of climate change causes it to increase to Tk. 378 million. However, with adaptation to climate change, it falls to Tk. 372 million. The cumulative road damage from 2014 to 2050 was estimated under varying return-period floods picked at random for future years up to 2050 under the five future scenarios. These respective estimates amounted to Tk. 8,524 million (SE + PI), Tk. 9,930 million (SE + PI + CC), Tk. 5,268 million (SE + PI + AI), Tk. 6,252 million (SE + PI + AI + CC), and Tk. 6,139 million (SE + PI + AI + CC + AD).

The total economic loss to rail infrastructure in 2050 from a 100-year flood event with planned improvements alone totals Tk. 13 million, and rises to Tk. 18 million when the effect of climate change is taken into account. With additional investments to address the existing adaptation deficit, along with planned improvements without climate change, the loss falls to Tk. 8 million. With the added effect of climate change, it rises to Tk. 11 million. With adaptation to climate change, however, it again decreases to Tk. 9 million. The cumulative damage to railways from 2014 to 2050 was estimated under varying return-period floods picked at random for future years up to 2050 under the five future scenarios. These respective estimates amounted to Tk. 212 million (SE + PI), Tk. 301 million (SE + PI + CC), Tk. 137 million (SE + PI + AI), Tk. 179 million (SE + PI + AI + CC), and Tk. 157 million (SE + PI + AI + CC + AD).

Other Surface Transport

The total economic loss to other forms of surface transport in 2050 from a 100-year flood with planned improvements amounts to Tk. 601 million, and increases to Tk. 690 million with climate change effects. With additional investments for the adaptation deficit, along with planned improvements without climate change, it totals Tk. 426 million, but climate change causes it to climb to Tk. 495 million. With adaptation to climate change, however, it falls to Tk. 494 million. The cumulative damage in the transport sector from 2014 to 2050 was also estimated under varying return-period floods picked at random for future years up to 2050 under the five future scenarios. These respective estimates amounted to Tk. 9,934 million (SE + PI), Tk. 11,396 million (SE + PI + CC), Tk. 7,029 million (SE + PI + AI), Tk. 8,173 million (SE + PI + AI + CC), and Tk. 8,152 million (SE + PI + AI +CC+ AD).

Indirect Damage from Income Loss

Loss of income for Dhaka residents and migratory labor commuting to Dhaka in 2050 from a 100-year flood with planned improvements amounts to Tk. 130 million, and increases to Tk. 214 million with the effect of climate change. With additional investments to address the current adaptation deficit, along with planned improvements without climate change, it totals Tk. 49 million, but rises to Tk. 61 million with the added effect of climate change. With climate change adaptation, however, it falls to Tk. 56 million. The cumulative income loss for Dhaka residents and migratory labor from 2014 to 2050 was also estimated under varying return-period floods picked at random for future years up to 2050 under the five future scenarios. These respective estimates amounted to Tk. 2,069 million (SE + PI), Tk. 3,410 million (SE + PI + CC), Tk. 787 million (SE + PI + AI), Tk. 977 million (SE + PI + AI + CC), and Tk. 839 million (SE + PI + AI + CC + AD).

Summary of Sector-Wise Results

Table 7.4 demonstrates how the total sector-wise damage changes under the five alternative scenarios and various assumptions about the frequency of a 100-year, return-period storm. The highest damage of Tk. 9,938 million in 2050 occurs under planned improvements with climate change when a 100-year, return-period storm happens with certainty. The damage drops rapidly with additional investments (without climate change) to Tk. 2,580 million and rises somewhat when the effect of climate change is factored in. With adaptation, the effect of climate change is greatly mitigated.

A similar trend continues under each of the various assumptions about the frequency of a 100-year, return period storm. Table 7.4 shows that the damage decreases as the frequency of a 100-year, return period storm goes down from once every 20 years (RP 20), to once every 33 (RP 33), 50 (RP 50), and 100 years (RP 100).

Aggregate Damage for Dhaka

The total combined damage for Dhaka in 2050 was estimated for the five future scenarios, using alternative assumptions about how frequently a 100-year, return-period storm would occur. Figure 7.2 shows the total monetary value of the

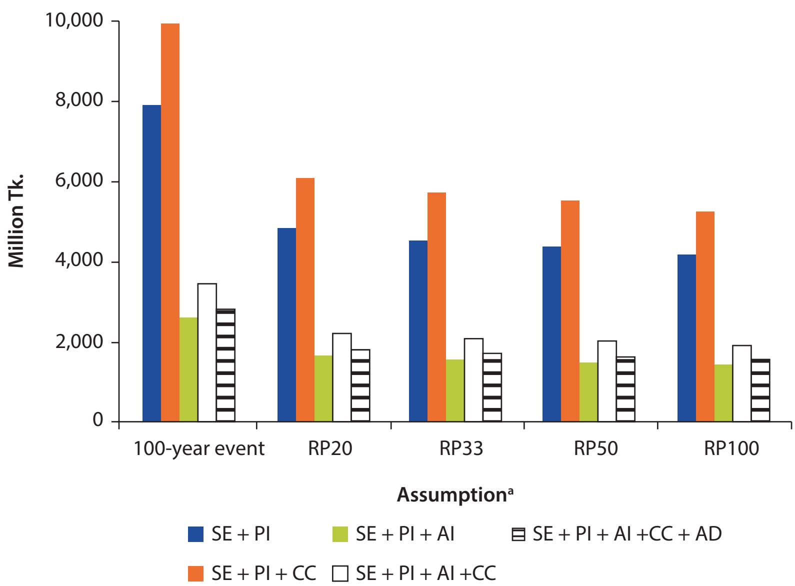
Table 7.4 Summary of Sector-Wise Damage in Dhaka under Alternative Scenarios

	Damage occurring in 2050 (Tk. million)				
	Return period based on probability				
Scenario	*100 year*	*RP20*	*RP33*	*RP50*	*RP100*
SE + PI	7,904	4,840	4,544	4,380	4,161
SE + PI + CC	9,938	6,097	5,725	5,520	5,245
SE + PI + AI	2,580	1,639	1,542	1,488	1,416
SE + PI + AI +CC	3,469	2,196	2,067	1,995	1,898
SE + PI + AI + CC + AD	2,818	1,788	1,683	1,623	1,546

	Cumulative damage, 2014–50 (Tk. million)			
	Using random numbers for each return period			
Scenario	*RP20*	*RP33*	*RP50*	*RP100*
SE + PI	127,183	123,883	114,273	109,971
SE + PI + CC	160,069	155,936	143,868	138,479
SE + PI + AI	42,135	41,123	38,048	36,743
SE + PI + AI + CC	56,575	55,208	51,070	49,305
SE + PI + AI + CC + AD	46,004	44,898	41,541	40,113

Source: Adapted from Roy 2014.
Note: Sectors covered include residential buildings, residential property, commerce, industry, health care, roads, railway, other surface transport, and income loss. SE = socioeconomic changes; PI = planned improvements; AI = additional investments; CC = climate change; AD = adaptation to climate change; RP = return period (years).

Figure 7.2 Total Estimated Damage for Dhaka in 2050



Source: Roy 2014.
Note: SE = socioeconomic changes; PI = planned improvements; AI = additional investments; CC = climate change; AD = adaptation to climate change; RP = return period (years).
a. 100-year event = actual damage from a 100-year event occurring in 2050 with certainty; RP20, 33, 50, and 100 = damage from a 100-year event occurring once every 20, 33, 50, or 100 years, respectively.

damage that would result from the actual 100-year event in 2050 under the five future scenarios, followed by expected damage estimates using alternative probabilities of the 100-year event's recurrence (i.e., every 20, 33, 50, or 100 years), as explained in chapter 5.

Table 7.5 demonstrates that, with a 100-year, return-period storm, the total additional damage from climate change for Dhaka in 2050 would amount to Tk. 2,033 million with only planned improvements. With additional investments, that figure would fall to Tk. 888 million, reducing the extent of climate change damage by Tk. 1,145 million. Table 7.5 also provides damage estimates assuming a probability distribution of return-period storms under alternative assumptions of increased frequency of 100-year storms.

Figure 7.3 shows the expected cumulative damage over the 2014–50 period for the five future scenarios, with random assignment of various return-period storms under alternative assumptions of increased frequency of the 100-year event. As described in chapter 5, alternative probabilities of the recurrence of the 100-year event are used to compute the expected value of the total cumulative damage between 2014 and 2050 if the event were to occur every 20, 33, 50, or 100 years.

Table 7.6 demonstrates that, with random assignment of various return-period storms between 1-year and 100-year, return-period storms, the total additional cumulative damage (2014–50) for Dhaka from climate change would amount to Tk. 28,508 million with only planned improvements. With additional investments, that figure would fall to Tk. 12,562 million, reducing the extent of climate change damage by Tk. 15,946 million. Table 7.6 also shows cumulative damage estimates under alternative assumptions of increased frequency of 100-year storms.

Overall Damage from Climate Change

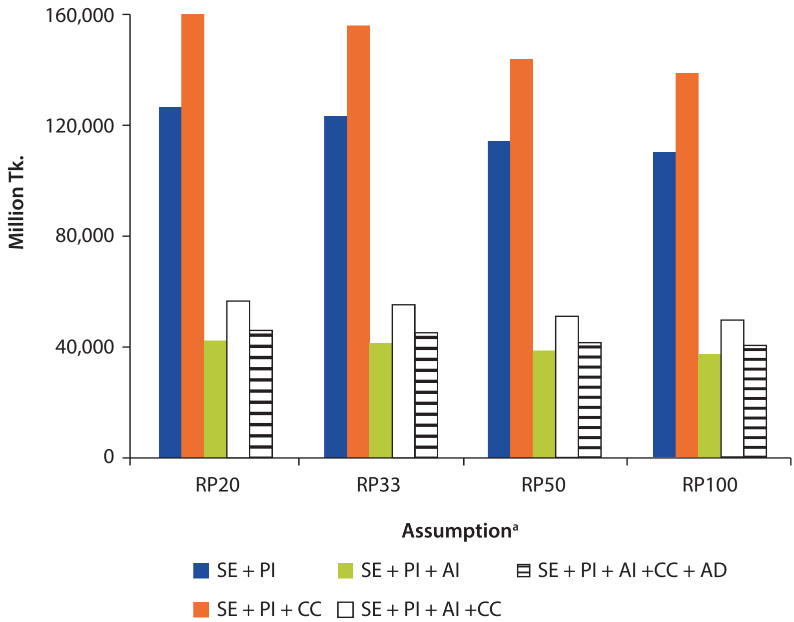
The study examined damage-estimate changes under a number of scenarios with varying levels of infrastructure improvements. As these improvements continue to provide benefits over a long period of time, it is more useful to examine the cumulative damage resulting from climate change between 2014 and 2050 in Dhaka under the A1FI scenario since this may help in comparing the costs and

Table 7.5 Damage Differences from Climate Change for Future Scenarios Using Alternative Probabilities

	Increased damage in 2050 (Tk. million)				
		Return period based on probability			
Scenario	*100 year*	*RP20*	*RP33*	*RP50*	*RP100*
SE + PI + CC	2,033	1,935	1,563	1,358	1,083
SE + PI + AI + CC	888	781	650	578	482
Reduced damage in 2050 due to climate change adaptation (Tk. million)					
SE + PI + AI + CC + AD	651	409	384	371	353

Source: Roy 2014.
a. SE = socioeconomic changes; PI = planned improvements; AI = additional investments; CC = climate change.
b. RP = return period (years).

Figure 7.3 Total Cumulative Damage for Dhaka, 2014–50



Source: Roy 2014.
Note: SE = socioeconomic changes; PI = planned improvements; AI = additional investments; CC = climate change; AD = adaptation to climate change. RP = return period (years).
a. 100-year event = actual damage from a 100-year event occurring in 2050 with certainty; RP20, 33, 50, and 100 = damage from a 100-year event occurring once every 20, 33, 50, or 100 years, respectively.

Table 7.6 Differences in Cumulative Damage (2014–50) from Climate Change for Future Scenarios Using Alternative Probabilities

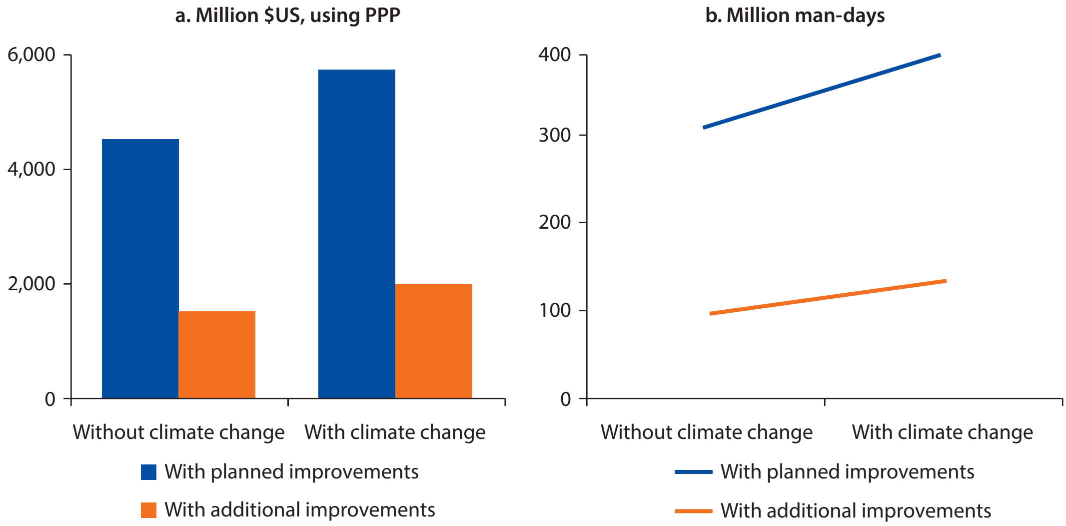
Increased cumulative damage (Tk. million)				
	Using random numbers for each return period			
Scenario	*RP20*	*RP33*	*RP50*	*RP100*
SE + PI + CC	32,886	32,054	29,594	28,508
SE + PI + AI + CC	14,441	14,086	13,021	12,562
Reduced cumulative damage due to climate change adaptation (Tk. million)				
SE + PI + AI + CC + AD	10,572	10,310	9,530	9,192

Source: Roy 2014.
Note: SE = socioeconomic changes; PI = planned improvements; AI = additional investments; CC = climate change; RP = return period (years).

benefits from these infrastructure changes in the future. For estimating the damage caused by climate change, this study used the 100-year, return-period storm as the most severe event and the scenario with the probabilistic estimate of various return-period storms occurring in the years between 2014 and 2050.

With only planned improvements (PI), climate change causes a cumulative expected damage of Tk. 32,886 million. The climate change impact falls rapidly

Figure 7.4 Cumulative Climate Change Damage for Total Dhaka, Using PPP and Man-Days



Source: Roy 2014.

under the additional investments (AI) scenario when the current adaptation deficit is addressed, with cumulative damage amounting to Tk. 14,441 million. A more meaningful comparison is gained by converting the damage estimates from local currency to U.S. dollars, using the purchasing power parity (PPP) index. Because of the uncertainty about the likely PPP index in 2050 and given that losses for the period between 2014 and 2050 are expressed in 2013 prices, the PPP adjustment is made, based on the PPP index for Bangladesh in 2005 of 2.84.[2] Using PPP U.S. dollars, the additional economic loss from climate change effects under the A1FI scenario with PI amounts to US$1,197 million in 2050 and decreases to $556 million with AI undertaken to address the deficit in adaptation to the current climate (figure 7.4a).

Another useful method to estimate the extent of damage from climate change effects is to assess the number of man-days needed to recover from the economic loss. This is based on the average daily wage of urban workers in Dhaka. For this analysis, the average wage of an urban worker is assumed at Tk. 10,000 a month, for a daily income of about Tk. 400. Figure 7.4b shows that, under the A1FI scenario, an additional 82 million man-days are lost due to the effects of climate change between 2014 and 2050 with PI only. With AI, this extra loss decreases to 36 million.

Cost and Benefits of Adaptation

Separating the costs of meeting the current adaptation deficit and adapting to climate change gives one a better understanding of the total costs required to lessen people's suffering in the years ahead. Table 7.7 shows that, once the

Table 7.7 Total Estimated Cost of Adaptation for Detailed Study Area

Area modeled[a]	*Current adaptation deficit (million Tk.)*	*Climate change deficit (million Tk.)*	*Total cost (million Tk.)*	*Damage avoided in 2050 (million Tk.)*	*Cumulative damage avoided to 2050 (million Tk.)*
Old Dhaka	64.8	34.3	99.1	1,002	13,915
Central Dhaka	1,449.5	91.1	1,540.6	3,888	53,387
Kallyanpur	345.4	16.2	361.6	1,410	19,562
Goranchatbari	302.4	50.8	353.2	359	5,062
DND	544.6	1,105.4	1,650.0	352	4,868
Total cost	**2,706.7**	**1,297.8**	**4,004.5**	**7,011**	**96,794**

Source: Huq 2014.
Note: These cost estimates are not based on detailed engineering estimates, which were beyond the scope of this study. Depending on their source of origin, equipment costs may rise sharply. DND = Dhaka-Narayanganj-Demra.
a. Eastern Dhaka and Narayanganj are excluded since the structural measures recommended in the hydrological modeling exercise apply only to the five areas listed.

current adaptation deficit of approximately Tk. 2.7 billion is addressed, the added cost of closing the climate change gap would require another Tk. 1.3 billion, for a total estimated cost of about Tk. 4.0 billion. The damage avoided in 2050 would total more than Tk. 7.0 billion, with a cumulative (2014–50) damage savings of nearly Tk. 96.8 billion.

Scope for Further Improvement

In considering these cost figures, one should keep in mind that additional expenditures would be required to achieve a flood-free Dhaka. This study's modeling exercise has assumed that pipes, khals, and culverts will perform according to their designated capacity and that stormwater will reach them without undue difficulty. However, it appears these assumption are not in accordance with Dhaka city's current situation, and further studies are needed that focus on identifying and removing these impediments. All khals and water bodies need to be protected from encroachment and accumulation of solid waste, and appropriate waste management is urgently needed. Because rainfall patterns appear to be changing temporally and spatially, more rain gauges are needed around Dhaka. The two main stations at Banani and Agargoan are not sufficient for collecting the required detailed data. Also, rainfall data should be collated centrally, and forecasts should be readily communicated to pump operators and drainage engineers as soon as a large event is expected. Furthermore, water-level data at the outfalls should be regularly recorded to know the response of drainage systems.

An updated, detailed land-level survey of the Greater Dhaka region that considers the confining effects of buildings and other roadside structures on surface flows is required for more accurate, location-specific inundation modeling and mapping. Because local-level changes in land use and land levels are likely to have a greater impact on urban flooding than current estimated changes in rainfall intensities—a major finding of this study—the updated DAP and DMDP need to ensure that effective monitoring-and-enforcement measures are put in place so that the drainage system is not adversely affected by future urban development. Recent conveyance improvements in some areas (e.g., Central Dhaka) tend to be ad hoc, meaning that flooding problems are often shifted from one location to another. In the DND area, for example, urban flooding problems persist or are worsening. With new urban development projects in Uttara (phase three) and Purbachal and private-housing projects in eastern Dhaka catchments, there is scope to introduce improved urban drainage practices. In this context, the ongoing Preparation/Updating of Stormwater Drainage Master Plan for Dhaka City can play a vital role (DWASA 2014). Not only will the master plan help to reduce the impacts of urban flooding caused by annual monsoon rainfall; it can also help to address the impacts of extreme rainfall events, which may occur with more frequency due to climate change processes.

Accounting for the added expenditures needed to achieve a flood-free Dhaka would raise the total cost of adaptation substantially. Thus, a careful study incorporating such expenditures should be undertaken to provide local policymakers a comprehensive cost estimate. The next chapter considers the non-structural flood-mitigation measures that are most urgently needed.

Notes

1. This number refers only to households within DNCC and DSCC and thus excludes portions of the DND area and Narayanganj.
2. International Monetary Fund figure.

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CHAPTER 8

Complementary Flood-Mitigation Measures

Introduction

Given Dhaka's land scarcity, growing population density, and other prevailing socioeconomic, environmental, and geophysical conditions, the recommended conveyance-centric approach to urban flood mitigation described in the previous chapters—featuring mainly pipes, khals, and pumps—appears sound. What non-conveyance and non-structural flood-mitigation measures might then be designed to complement these conveyance-centric solutions? This chapter explores the secondary measures most urgently needed and how key institutional, technical, and financial challenges to their implementation can be effectively addressed (Huq 2014).

Institutional Challenges to Stormwater Management

To date, multiple agencies have assumed shared responsibility for the planning, design, construction, and maintenance of Dhaka's drainage system. These mainly include the Dhaka Water Supply and Sewerage Authority (DWASA) and Dhaka City Corporations (DCCs), as well as the Bangladesh Water Development Board (BWDB), Rajdhani Unnayan Kartripakkha (RAJUK), and Cantonment Board. Coordination among these agencies—a key ingredient for a well-functioning drainage system—is a commonly acknowledged challenge for Dhaka that has often been exacerbated by scarce resources and unplanned development. Results of the Climate Disaster Resilience Index (CDRI) analysis confirm that the city has only moderate resilience to climate disasters in terms of institutional collaboration and ranks even lower in terms of good governance, knowledge dissemination, effectiveness of crisis management, and mainstreaming of disaster risk reduction and climate change adaptation (Jahan 2014).

It has frequently been suggested that a single coordinating agency should be established with overriding authority for Dhaka's drainage system. However, past efforts to create such a coordinating agency—including an initiative in the 1990s that involved the minister, mayor, and other high-ranking officials—fell short of expectations. Senior practitioners and officials agree that, given the city's institutional track record, forming yet another coordinating agency would likely yield similar results. Instead, they suggest making a single authority responsible for stormwater management. The existing institutions best qualified to shoulder this key role would be the DCCs or DWASA.

Dhaka's two DCCs—Dhaka North City Corporation (DNCC) and Dhaka South City Corporation (DSCC)—currently have jurisdiction over tertiary/surface drains and roadside inlets. Recently, in response to larger volumes of rainwater runoff, they have begun to build secondary drains. Because the DCCs are responsible for surface drains, a portion of the stormwater drainage system is under their jurisdiction. However, they lack adequate experience in managing stormwater drainage systems, which differ markedly from surface systems. Also, the DCCs lack a separate drainage division or unit, and their engineers do not follow a formal design manual for solving problems. Such organizational weaknesses and lower level of operational efficiency weaken the case for assigning the DCCs sole authority for stormwater management. Moreover, because the city is divided into two DCCs, institutional coordination would be further complicated.

By comparison, DWASA appears better qualified to assume overall responsibility for the operation and maintenance of Dhaka's drainage infrastructure. DWASA has the requisite capacity and experience in planning, development, and operation and maintenance of the city's stormwater drainage system. DWASA was mandated under the Water Supply and Sewerage Authority Act of 1996 to provide stormwater drainage services to Dhaka City, having already assumed this responsibility in 1989 and having had its jurisdiction extended the following year to include Narayanganj township. DWASA has a mandated coverage area of about 360 km^2, representing 12.5 million people; however, only 140 km^2 is covered by stormwater drainage facilities (DWASA 2013).

Given that only 39 percent of Dhaka is covered by the stormwater drainage system and that DWASA is not responsible for surface or tertiary drains, assigning DWASA full responsibility for stormwater management would require expanding its institutional capacity substantially. In addition, it would need to coordinate the installation and widening of drains with the DCCs, which are responsible for road development, maintenance, and improvement within the city limits. Also, a more extensive stormwater drainage system will need to be installed in the future to accommodate the city's expansion and growing population density, emphasizing the need for strengthened institutional capacity.

If current institutional arrangements remain unchanged in the foreseeable future, policy and organizational changes will be needed within the responsible agencies. For example, it will be imperative to establish separate drainage divisions or units within the DCCs. The DCCs' drainage network is an integral part of the overall drainage system, and separate divisions can strengthen these corporations' capacity to handle their current responsibilities. In addition, RAJUK should include a stormwater drainage plan as a requirement for approving land development plans. Before clearance is given, DWASA should approve the drainage plan. If the approved drainage plan is not followed, utility services to the developed area should not be extended. Also, RAJUK should strictly follow its own area plan; that is, it should not approve any development plan in an explicitly stated wetland area or flood-free zone.

Improved Approach to Solid Waste Management

A sound system for managing solid waste disposal is a critical determinant of the success of any city's drainage system. In Dhaka, the responsibility for solid waste disposal currently lies with the DCCs. However, for both the DNCC and the DSCC, the extent of uncollected waste is quite substantial. For example, according to DSCC officials, Dhaka South generates an estimated 3,300 tons of solid waste per day, of which only two-thirds (2,200 tons) are collected; of this collected amount, 1,900 tons are processed in landfills, while the remaining 300 tons are recycled. The situation for Dhaka North is quite similar.

Results of the CDRI analysis show that the physical parameter of sanitation and solid waste management has important implications for inter-zonal variations in physical resilience to climate disasters. The findings show that the poorer performance of Narayanganj township and Western Dhaka (i.e., Central Dhaka, Goranchatbari, and Kallyanpur) results mainly from poor collection of waste and lack of waste treatment and recycling facilities (Jahan 2014).

The clogging of stormwater drains and manholes with solid waste is a primary reason for frequent, localized flooding in Dhaka. Uncollected solid waste often finds its way into the drainage system with rainwater, restricting its passage and thus slowing the evacuation of rainwater runoff from the affected areas. In addition, citizens frequently use drains or khals as though they were designated garbage dumps. Such practices reduce the drainage capacity of box-culverts and khals and severely worsen the drainage system's water quality. Even worse, the DCCs lack adequate capacity to satisfactorily perform their solid waste management jobs.

To adequately address the issue of solid waste management, a three-pronged approach is suggested, involving specific roles and responsibilities for the DCCs and Dhaka residents, along with a recycling strategy to reduce the need for primary and secondary solid waste collection (photo 8.1).

Role of Dhaka City Corporations and Local Community

Achieving a more livable, less flooded city requires enhancing the DCCs' solid waste collection and disposal capacity substantially. Of primary concern is their lack of capacity to collect the total amount of generated waste. Resolving this issue requires increasing the number of compactors in existing fleets and replacing outdated trucks and compactors. The DSCC requires smaller-sized compactors since roads and lanes in South Dhaka are narrower. A second concern is constricted passages in the stormwater drainage system from accumulated sediment caused by dust and finer particles being swept into the drainage system.

Photo 8.1 DWASA sign next to Segunbagicha Khal warning against encroachment, connecting wastewater line to the khal, and garbage dumping

Credit: © Asif Zaman / World Bank. Used with permission. Further permission required for reuse.

Resolving this problem requires raising awareness among street sweepers, who have the daily responsibility of piling and moving solid waste to the nearest secondary transfer point. It is also necessary to monitor whether the street sweepers follow instructions properly and perhaps provide them incentives to do so. A third issue is resolving the mismatch between primary collection equipment and the secondary collection system. The current practice of dumping waste from the primary collection equipment on the ground and then transferring it to the secondary collection unit is quite inefficient.

Dhaka's local community clubs and other neighborhood organizations have a critical role to play in minimizing inappropriate solid-waste disposal behavior among local residents. Findings of the CDRI analysis show that local people's education and awareness tend to be lower among disadvantaged groups and people living in hazard-prone zones. Massive awareness-raising campaigns involving local organizations should be launched, particularly in poorer areas (e.g., South Dhaka) to help educate residents on the link between their disposal behavior and localized inundation.

Local residents can also play a key role in reducing the contribution of sand at house construction sites to sedimentation of the drainage system. Most houses in Dhaka are built by either plot owners or small developers. Typically, a portion of the sand and dug-up soil stocks maintained by builders during construction finds its way into the drainage system when it rains. By monitoring construction sites, the local community can persuade contractors to properly maintain their stock to avoid its contributing to drainage system sedimentation. In addition, the DCCs should launch awareness-raising campaigns so that local residents learn appropriate ways to maintain construction sites.

Minimizing Waste Collection and Transfer: Compost Plants

In addition to the above measures, the DCCs should aim to reduce the amount of solid waste that must be collected, transported, and safely disposed of. To a great extent, the primary collection of solid waste has become unintentionally privatized; that is, local community based organizations (CBOs) and nongovernmental organizations (NGOs) collect solid waste door-to-door, while the DCCs cover the cost of transport from secondary collection points to landfills. The presence of readily perishable, organic waste necessitates frequent trips by the DCCs, putting even more pressure on their limited capacity. Constructing many decentralized plants that convert the generated organic waste from nearby areas into compost would go a long way toward reducing the amount that must be collected, transported, and safely disposed of. The aim would be to cover as many households, kitchen markets, and restaurants as possible.

Overcoming Barriers to Composting

Land scarcity is a primary obstacle to setting up localized composting plants. It appears that both the DNCC and DSCC suffer from land crisis, even for utilizing a portion of secondary transfer points, some of which are situated on the main roads. Both DCCs own numerous plots across Dhaka that they cannot utilize owing to illegal occupation by entities with support from powerful quarters. Thus, it is imperative that a process be initiated to recover illegally occupied land. Evidently, in many past instances, authorities have successfully recovered public land from illegal occupants.

Additional problems include the foul odor emitted from the composting plants and their unseemly sight, likely resulting in Not in My Back Yard (NIMBY) syndrome among local residents, as well as the potential for plant leakage in flooded areas due to intense rainfall. The first two obstacles can be overcome by carefully selecting composting technologies and other innovative ways to minimize odor, such as the use of rock phosphate, and by constructing high walls around the plants to hide them from public view. The third obstacle can be overcome by installing the composting system on a raised platform to avoid any leakage to the surrounding environment.

The primary collection of solid waste and composting activities should be considered separate responsibilities since assigning the same entity responsibility for both could invite trouble from the current primary collector. Because primary collection from households is a profitable activity, public sentiment against establishing a composting plant in their locality could be used by the aggrieved existing primary collector.

Cost-Benefit Analysis

A composting plant with a three-ton daily capacity could process approximately 900 tons of organic waste per year. According to Waste Concern (2014), one ton of organic waste, when aerobic composted, would produce one-quarter ton of compost and reduce greenhouse gases (GHGs) by one-half ton. This means that 225 tons of compost would be produced each year, with GHGs lowered by 450 tons. Assuming a compost price of Tk. 10 per kg, the annual sales proceed from composting would total about Tk. 2.25 million.

The other major portion of return on investment in the composting plant would come from the reduced cost of secondary collection, transport, and environmentally sound disposal of biodegradable waste. For example, with 900 fewer tons of waste to transport and dispose of, the DSCC would save about Tk. 1.8 million per year.[1] Evidently, the positive externality of manufacturing compost is substantial.

It would be difficult to value the reduced GHGs, given the pricing uncertainty in the international market. However, if the market price for GHG emissions were to bounce back to US$5 per ton, the annual value of certified emission reductions (CERs) would total $2,250 ($5 × 450), equivalent to Tk. 175,500 per year.

When positive externalities in the form of reduced transport and disposal costs are internalized, the financial benefit from a three-ton-per-day composting plant would total Tk. 4.05 million per year, even without considering CER benefits. On the cost side, such a plant would entail annual fixed and variable costs estimated at Tk. 1.16 million and Tk. 0.38 million, respectively.[2] Fixed capital is assumed to have a life span of five years, after which residual value would be equivalent to zero. Clearly, the extent of net benefit calls for special attention from the DCC authorities. It is in their interest to provide the composting entities land free of leasing cost and even provide them financial and logistical support to set up the system.

Increasing Market Demand

Composting plants frequently face marketing problems since the quality of the produced compost is often at variance with acceptable standards, resulting in a relatively lower price. The presence of heavy metals and other impurities in the lower-quality compost is due to inorganic waste not having been separated from biodegradable waste in the raw materials used to produce the compost.

This inefficiency can be reduced by using the source-separation method after primary collection.

Extensive household awareness-raising campaigns, along with some form of payment for inorganic waste, would go a long way in instilling the practice of source separation. In some areas of the Philippines, for example, households are paid by inorganic waste collectors, who then separate out and sell the recyclables to generate revenue (Gozun and Palomata 2000). In Dhaka, the purchase of inorganic waste from households would further reduce the amount of waste the DCCs must handle.

The lower price of compost in Dhaka is also due to weak demand, suggesting the need to popularize the benefits of composting. It is observed that raw compost has less user appeal than products mixed with nutrients. Widespread publicity should be undertaken on how composting increases the soil's water-retention capacity and slows the process of soil erosion. With vermicomposting, the land's water-retention capacity would be higher, reducing the amount of required irrigation, which, in turn, would save farmers money.

Conveyance System Maintenance

Even with the best solid waste management system in place, litter, debris, and sediment cannot be entirely prevented from entering the stormwater drainage system and thus impeding the passage of rainwater runoff. Considering Dhaka's current and probable drainage system situation over the medium term, continued clogging and sediment accumulation are quite likely. Clearly, DWASA's urgent need for modern equipment and regular cleaning of khals will continue in the foreseeable future (photo 8.2).

Routine Cleaning: Sludge Removal

It is argued that one meter of sludge is deposited in Dhaka's khals and box-culverts every year. Close attention must be paid to sediment deposits in the drainage system in order to keep it in good condition. Cutting, removal, and such processes as dewatering and dam construction for dewatering altogether cost nearly Tk. 1,000 per m^3 of sludge. The advantage of cleaning khals versus box-culverts is offset by the khals' relative inaccessibility. An average width of 5 m is assumed for both khals and box-culverts. The cleaning of pipes is less expensive, at an estimated cost of Tk. 600 per m^3.

Table 8.1 presents the length of Dhaka's pipes, box-culverts, and khals by system and a tentative cost estimate for cleaning them. As shown, pipes and box-culverts are concentrated mainly in Central Dhaka, while open khals, in terms of length, are found mostly in the Goranchatbari system. Based on the existing length of the infrastructure, the annual cost of sludge removal is estimated at Tk. 425.5 million. For the Goranchatbari system alone, the annual cleaning cost is Tk. 175.5 million.

Opting for biennial sediment removal would cost DWASA about Tk. 212.8 million per year, based on the existing length of the drainage system. During the

Photo 8.2 Motorized solid-waste collector belt at Hatir Jheel outlet of Panthapath Box-Culvert near Sonargaon Hotel (Central Dhaka system)

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Table 8.1 Length of Drainage System Infrastructure and Estimated Cleaning Cost by System

Drainage component	*Kallyanpur*	*Old Dhaka*	*Central Dhaka*	*Goranchatbari*
Infrastructure length (km), 2004				
Round pipes	31.5	24.1	112.8	10.8
Box-culverts	0	0.3	9.7	0.5
Open khals	15	3.3	1.5	33.3
Annual cleaning cost (million Tk.)[a]				
Round pipes	18.9	14.5	67.7	6.5
Box-culverts	0.0	1.5	48.5	2.5
Open khals	75.0	16.5	7.5	166.5
Total cost	93.9	32.5	123.7	175.5

Sources: IWM and DWASA.
a. Per-kilometer cleaning cost is Tk. 0.6 million for round pipes, Tk. 5 million for box-culverts, and Tk. 5 million for open khals.

off-year, DWASA could simply remove floating garbage. Alternatively, a step-by-step process could be implemented, whereby initial cleaning and sludge removal would occur annually in Old Dhaka and Central Dhaka, along with Kallyanpur, at an estimated cost of about Tk. 250 million. Considering Goranchatbari's comparatively low population density and limited resources, that system could be added later to the program as resource flows increase. However, a better option would be to prioritize locations for annual cleaning, leaving less problematic areas for biennial cleaning. In fact, the slower rate of sludge accumulation in many segments of khals and box-culverts suggests that biennial cleaning would suffice for those segments.

Financial Resources for Routine Cleaning

This study proposes creating a fund to cover DWASA's routine drainage cleaning needs by adding 1 percent of the assessed base of holding tax to the DCCs' current tax rate. This would mean adding one percentage point to the current applicable rate of 12 percent—covering property tax, conservancy, and lighting rates—for a new total rate of 13 percent. Despite serious weaknesses in the collection system, the DCCs brought in Tk. 3.83 billion from holding taxes in fiscal year July 2012–June 2013; the DNCC collected more than Tk. 2.28 billion, while the DSCC brought in Tk. 1.55 billion (DNCC 2014; DSCC 2013).[3] At this rate, an extra percentage point would generate about Tk. 319 million a year. The DCCs would transfer the collected amount to DWASA's account. It is hoped that, with a better performing collection system and continued economic growth, revenue collection will be set to rise. If so, the augmented amount should generate sufficient resources to cover DWASA's fund.

Hydraulic Jetting and Vacuum/Suction Machines

Water recycling trucks fitted with a hydraulic jetting system and vacuum/suction machine can be quite useful in removing sludge from Dhaka's clogged pipes and manholes, which contribute significantly to localized urban flooding. Unlike a freshwater system, which requires resources for production, the water recycling system utilizes recycled sewer water as jet to loosen clogs. The process can be repeated many times until the sludge tank is full, after which the accumulated sludge can be safely disposed of. For convenience sake, the hydraulic jetting systems and vacuum/suction machines can be purchased separately.

Both DWASA and the DCCs are in need of such equipment to meet their drainage cleaning responsibilities. In the case of DWASA, only three sets may be needed, according to officials. Each set would cost about Tk. 120 million—Tk. 80 million for the hydraulic jetting system and Tk. 40 million for the vacuum/suction machine—for a total cost of Tk. 360 million. DWASA could also use the recycling trucks to earn income by offering septic-tank cleaning services to private, commercial, and public buildings.[4] Cleaning septic tanks would be in DWASA's interest since partially treated waste would otherwise infiltrate the drainage network, severely deteriorating its water quality. In the case of the DCCs, experts suggest that the DNCC and DSCC would each need five sets.

Given that the DCCs are responsible for tertiary drainage systems, the required equipment could be less powerful than that required by DWASA. Each set would cost about Tk. 80 million, for a total estimated cost of Tk. 800 million.

Remote-Controlled Excavators

Direct access to areas of the drainage system pinpointed for cleaning is usually difficult. In addition, manually cleaning box-culverts is an often risky process requiring dewatering, which, in turn, disrupts normal economic activities. More developed economies are increasingly utilizing robotic excavators, also known as remote-controlled excavators, to address this problem. Use of excavators protects operators from exposure to the toxic gases that accumulate inside box-culverts. Also, if used during the dry season, dewatering is not required. Currently, DWASA has a project under way demonstrating how to operate remote-controlled excavators and their usefulness in cleaning box-culverts.

The cost of remote-controlled excavators is about Tk. 40 million per unit. This study's calculations show that DWASA would need only three such machines to cover the entire city. Thus, the required investment would total Tk. 120 million.

Privatization

Private-sector participation could improve Dhaka's capacity in stormwater evacuation and solid waste management in several critical ways. First, it would introduce competition and efficiency into service delivery. Second, because of its constant need to enhance profit margin, it could rapidly adopt international best practices on efficient management and new cost-effective technologies. Finally, it would be able to substitute public-sector investment with its own resources. Clearly, the chronic shortage of investable resources suffered by such agencies as DWASA and the DCCs demonstrates the urgent need for such assistance. In the case of DWASA, the equipment needed for appropriate service delivery would require substantial financial resources. Under a suitable arrangement, the private sector could share the burden with the public agency.

In order to attract their interest, private-sector participants would need to be given a certain amount of assurance that they would be able to recover and make a reasonable profit on their initial investment. A well-designed contracting system would go a long way toward achieving this aim. In some cases, activities could be unbundled into smaller components, which would offer the private sector opportunities for participating in the service delivery of DWASA and the DCCs.

Shaving Peak Flow

A major objective of stormwater management is to shave peak flow by delaying, diverting, or detaining runoff. Among the variety of ways that may be used to achieve this objective, discussion in this section is limited to (a) the potential role of green roofs or rooftop gardens, (b) management of impervious surfaces, and (c) using the city's water bodies as temporary detention ponds.

Green Roofs

Since ancient times—from the hanging gardens of Babylon to modern-day rooftop gardens—human beings have been familiar with green roofs, and Dhaka is no stranger to the concept. Any casual observation of the city's buildings reveals abundant greenery on the rooftops. The most encouraging aspect of this phenomenon is that it does not result from governmental laws or regulations; rather, citizens inherently enjoy practicing rooftop gardening.

Modern-day green roofs are categorized into two groups: (a) intensive and (b) extensive. Intensive ones usually have a thicker substrate layer, which can sustain larger trees, as well as shrubs. Extensive ones have a shallower substrate, suited only for smaller plants and vegetation. Intensive green roofs require a comparatively higher level of maintenance.

Many researchers have shown that replacing an impermeable rooftop with a permeable substrate substantially delays the commencement of runoff and peak flow and reduces the runoff rate and volume (Getter and Rowe 2006). In addition, a green rooftop can retain a certain amount of rainwater runoff. The extent of retention is a function of the nature of the substrate, its thickness, and level of moisture in the substrate before commencement of the rainfall event. For example, Beattie and Berghage (2004) found that, for each dry substrate of 25 mm thickness, a green roof can retain up to 10 mm of precipitation. Dividing the remainder between solids (40 percent of total volume) and aerated space (20 percent of total volume) would create an ideal balance for vegetation growth and water-retention capacity.

Green roofs contribute to reducing and delaying runoff and shaving peak flow. However, as precipitation volume and intensity increase, a stand-alone green-roof system is a poor substitute for a well-designed stormwater drainage system with adequate capacity. For example, MacMillan (2004) found that storm-size ranges of 10–19 mm, 20–29 mm, 30–39 mm, and 40 mm had average peak-flow reductions of 85, 82, 68, and 46 percent, respectively. It is expected that increased storm size will cause peak-flow reduction to drop dramatically. Clearly, in Dhaka's worst-case scenario (396 mm of precipitation in 24 hours), a roof garden would be of little use as a stand-alone system. However, in response to smaller-sized storm events, green roofs can be quite useful.

The relative importance of green roofs in addressing Dhaka's stormwater runoff problem can be illustrated by making a rough calculation for Shankhari Bazar, one of Old Dhaka's most densely populated areas. In 2006, 13.29 percent of Shankhari Bazar's total land area was used either for the communications network or not at all. The remaining 86.71 percent was used for residential, commercial, religious, recreational, and other purposes. It was found that buildings covered an average of 68.9 percent of each plot; that is, the building-coverage ratio was 68.9 percent, meaning that 59.74 percent of its total land area was covered by buildings (under roof).

Converting half of Shankhari Bazar's roof area into green roofs would equal 29.84 percent of the locality's area. Following Beattie and Berghage (2004), one can assume that a green roof has an average of 25 cm of substrate that can retain up to 10 cm of precipitation. Considering that an equivalent of 29.84 percent of the locality would be under green roof, the area's roof gardens could retain nearly 3 cm (2.98 cm) of the area's total rainfall, provided that the substrate is dry when precipitation starts. In the case of a rainfall event of 300 mm in 24 hours,[5] a green-roof system could retain about 10 percent of total rainwater volume.[6]

Clearly, a green-roof system can help to reduce runoff volume and shave peak flow, and can be quite effective when used in conjunction with a well-designed conveyance system. The effectiveness of roof gardens is primarily a function of the overall proportion of roof-covered land; proportion of roof covered by substrate; and nature, thickness, and dryness of the media; among others. One caveat is that, during the dry season, green roofs must be watered using socially expensive DWASA resources, putting further burden on Dhaka's water supply system.

The argument for deploying a rainwater harvesting system, using structures built specifically for that purpose, is an expensive proposition for Dhaka. From an economic standpoint, rainwater harvesting—an inherently sound concept—is not the most appropriate tool for combating the city's urban flooding problems.

Management of Impervious Surfaces

As discussed in previous chapters, much of Dhaka is being paved with impervious surfaces (e.g., buildings, roads, and parking lots) to accommodate its growing population density. As mentioned, paved surfaces prevent rainwater from being absorbed into the ground, increasing a given area's runoff volume. With the city's future development, the proportion of paved surfaces is expected to continue increasing, generating more stormwater runoff.

The proportion of rain that forms runoff is known as runoff coefficient. Table 8.2 shows the runoff coefficient values used by the Public Utilities Board of Singapore for designing that city's surface drainage system.

Given that Dhaka is situated on deltaic land, there is a natural tendency for its citizens to pave over the land. However, a recent trend among developers to pave whole plots on which they construct buildings must be discouraged to prevent the runoff situation from worsening. Building permits should clearly state that non-permeable surface is allowable only on the constructed area of the plot and that paving over vacant portions will incur tax for generating stormwater runoff. In Washington, DC, for example, such a policy has been implemented,

Table 8.2 Values of Runoff Coefficient for Various Catchments

Catchment characteristics when fully developed	*Runoff coefficient value*
Roads, highways, airport runways, and paved areas	1.00
Urban areas, closely and fully built-up	0.90
Residential and industrial areas, densely built-up	0.80
Residential and industrial, not densely built-up	0.65
Rural areas with fish ponds and vegetable gardens	0.45

Source: Public Utilities Board of Singapore 2011.

whereby impervious surface results in a stormwater generation fee. Dhaka could consider adopting a similar system to discourage the conversion of permeable surfaces (e.g., the imposed fee could be collected along with the holding tax).

Permeable pavements are frequently cited as a desirable measure. However, their porous material is prone to clogging by fine dust particles, which would necessitate occasional vacuuming. For a poor, deltaic country like Bangladesh, this costly option would work as a negative incentive and thus appears inappropriate. Alternatively, using interlocking bricks with gaps between them would allow rainwater to permeate the ground. Some of Dhaka's pavements already utilize interlocking bricks. It is suggested that an interlocking brick system be used for all new pavements and replacement of paved surfaces.

Using Water Bodies as Detention Ponds

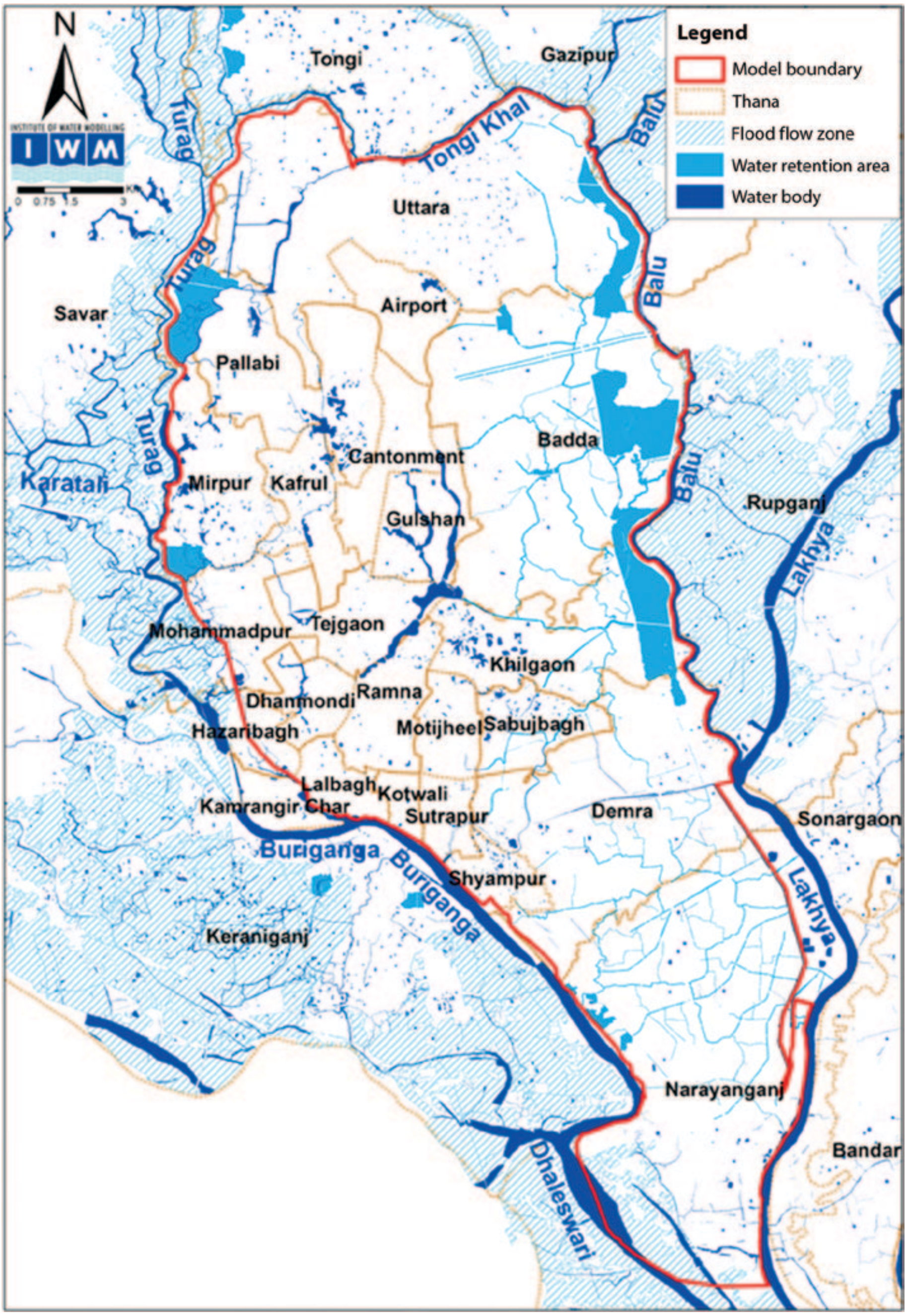
One way to alleviate the sudden onrush of stormwater during heavy rainfall is to detain water temporarily, say for few days, to curtail peak flow. After peak flow, the water can be released in a staggered manner to avoid congestion. Fortunately, the Detailed Area Plan (DAP) has identified and proposed many water-retention areas and water bodies, such as ponds within the city (map 8.1). Most of Dhaka's wards have some water bodies located within their boundaries that could be used as temporary detention ponds to minimize urban inundation resulting from heavy rainfall (appendix D).

In the selected water bodies, water should normally be kept at a certain level so that it serves the purpose of city beautification. It should be evacuated in response to the Meteorological Department's weather forecasts. If it is reported that an extreme storm is on the way, the water bodies should have enough room to accept at least a portion of the total incoming deluge.[7] Once peak stormwater flow has passed, truck-mounted pumps can be utilized, if needed, to pump out the extra water into the nearest stormwater drain. At the same time, water in the drainage system should be pumped out until it reaches a normal level. Once the rainfall event ends and peak water flow subsides, it is critical to promptly relieve the water bodies of extra water in preparation for the next heavy storm.

To illustrate, if an extreme rainfall event with precipitation of 244 mm per day were to occur (JICA 2000), 10 percent of total precipitation would be lost either to evapotranspiration or due to small local depressions, assuming a reduction factor of 0.9. Thus, 10 percent of precipitation would not contribute to runoff volume. The remaining 90 percent could potentially form the surface flow. If one assumes that only 10 percent of this portion permeates the ground, then 81 percent of total precipitation would reach the drainage system.[8]

For example, in 2004, Central Dhaka's total area of approximately 39.2 km^2 consisted of 36.8 km^2 land and 2.39 km^2 water bodies (i.e., 6.1 percent of the total area). For an extreme rainfall event with 244 mm of daily precipitation, the volume of stormwater flow reaching the stormwater drainage system would be calculated as $(36.8 \times 10^6)\ (244/1{,}000) \times (0.9 \times 0.9) = 36.8 \times 244 \times 10^3 \times 0.81 = 7.27 \times 10^6\ m^3$. Similarly, for a rainfall event with 160 mm of precipitation per day, the amount of rainwater reaching the stormwater

Map 8.1 Water Bodies of Dhaka



Source: IWM 2014.

drainage system would be calculated as (36.8×10^6) $(160/1{,}000) \times (0.9 \times 0.9)$ $= 36.8 \times 160 \times 10^3 \times 0.81 = 4.77 \times 10^6$ m^3. Compared to the 160 mm per-day event, the 244 mm per-day event would see an additional 84 mm rise in the level of the water bodies, even without stormwater runoff from the land area.

The difference in rainwater runoff volume from land area between the two events is 2.5×10^6 m^3. Since the total area of the water body is 2.39×10^6 m^2, the water level will rise by another 1.04 m. In the case of the 244 mm per-day event, the level of the water bodies will rise by an additional 1.13 m (1.04 m + 0.084 m), compared to the 160 mm per-day event. Thus, if 1.13 m of water were pumped out of Central Dhaka's water bodies before the rainfall event,[9] a 244 mm precipitation event would be downgraded to a 160 mm event in terms of flood impact. One caveat, however, is that the ponds would need to be situated at the downward end of the drains in order to be able to capture runoff.

These findings suggest that a rigorous study should be undertaken to identify which water bodies have maximum impact on reducing water congestion in various areas of Dhaka. DWASA should acquire the identified ones that are not state-owned properties as soon as possible. The landscape design should prevent rainwater of lighter precipitation events (say, less than 30-year, return-period storms) from entering the water bodies. To deter encroachment, the water bodies should be lined with walkways. In addition, the DCCs should be encouraged to transform the walkway-lined water bodies into urgently needed, passive recreation zones, where city residents can enjoy open-air activities.

Last Resort: Truck-Mounted Water Pumps

Despite meticulous planning, Dhaka's land-elevation pattern will remain unpredictable for a variety of reasons. The rainfall-generated surface flow may move in unexpected directions, and rainwater may accumulate in areas that cannot be foreseen. Thus, it would be prudent to prepare for addressing emergency circumstances regarding urban flooding. One way to prepare is to build water-evacuation capacity that is quickly deployable, easy to operate, and of sufficient strength to be effective. Truck-mounted water pumps or mobile pump stations could be useful for this purpose. Such equipment is quickly deployable and can be operated without an external power supply or generator. Truck-mounted pumps can dewater at a rate above 1 m^3 per second, and pumps with even higher capacities are available. Truck-mounted, mobile pump stations will be particularly useful in dewatering areas considered sensitive, such as key business districts, diplomatic zones, areas with critical infrastructure facilities, and densely populated areas. At this stage, it is suggested that DWASA acquire a few such pumps and add more as its financial resources improve.

Stormwater Quality Control

Modern stormwater management systems rely not only on conveyance-centric structural methods. Increasingly, detention ponds, as well as non-structural and source-control measures, are being utilized. Control of stormwater quality, as well as quantity, is being considered. Currently, a major objective of urban floodwater management is control of non-point source pollution. Grassed swales, wetlands, and gross pollution traps, among other measures, are frequently used to address this problem. In the case of Dhaka, storm-generated floodwater is of poor quality. Frequently black in color, it emits a foul odor and is full of decaying solid waste. The primary sources of pollution are uncollected solid waste, raw or partially treated sewage, partially or wholly untreated industrial effluents, and oil and grease. The subsections below discuss how pollution from these sources can be alleviated.

Reducing Uncollected Solid Waste

Rainwater runoff carries a variety of solids (e.g., litter, debris, and coarse sediment) into the stormwater drainage system (photo 8.3). Removal of gross pollutants from stormwater runoff can be achieved using both structural and non-structural measures. Non-structural measures, discussed earlier in this chapter, include awareness-raising, source control, and better strategies for solid waste management. The various structural measures that can be used include gully baskets, trash racks, and mechanical screens. Gross pollutant traps are meant to remove solids and coarse sediment from rainfall runoff. A mechanical screen installed near Sonargaon crossing could be replicated in various parts of the drainage system as required. A prerequisite for such a system is the timely evacuation of accumulated solids; otherwise, accumulated gross pollutants would wash back into the drainage system when the next rainfall event occurs.

Photo 8.3 Hazaribagh Khal outlet (looking toward river) on the Western Flood Embankment near Rayerbazar

Improving Domestic Wastewater Quality

Only 30 percent of Dhaka currently enjoys a formal sewerage system. In surrounding slums, the sanitation system is such that a substantial portion of human waste is held in situ; during flooding, it washes up, contaminating stormwater. Other households directly discharge their sewage into the drainage system or use a septic tank system. Because most septic tanks are not regularly desludged, the sewage is only partially treated before entering the drainage system. Even when sludge is removed, it is frequently dumped into the drainage system (photo 8.4).

Clearly, this situation calls for regular desludging of septic tanks. Vacuum/suction machines, as previously mentioned, could be quite useful in performing such a service for payment. The removed sludge could then be transported to sewerage treatment facilities for safe disposal, in which case, many more hydraulic jetting systems and vacuum/suction machines would be needed.

Slums should be targeted for a vigorous campaign to install septic systems, including the extension of subsidized loans for communities to cover upfront costs. Those residents who can afford the septic systems but continue to discharge their sewage directly into the drainage system should be encouraged to promptly install the systems or otherwise face steep fines.

Even the DCCs are found to direct wastewater from surface drains into nearby ditches or lowlands when development of a new area is initiated. Before surface drains are connected to the appropriate drainage system, wastewater from these ditches and lowlands gets mixed with stormwater as water levels rise, resulting in contaminated, foul-smelling floodwater. Until a sewerage and

Photo 8.4 Low-lying area of Kallyanpur, showing floodwater mixed with wastewater

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drainage system is in place that covers the entire city, solutions can only be ad hoc. Even so, effective interim measures should be undertaken to minimize the problem to the extent possible.

Minimizing Industrial Effluents

Untreated industrial effluents discharged by thousands of variously sized processing units currently in operation within Dhaka's city limits are another major source of stormwater-quality deterioration. Along with the garment industry, chemical, leather, hide, and other types of processing units continuously discharge their raw or partially treated effluents into the drainage system. In 2008, the Institute of Water Modelling estimated the daily discharge of industrial wastewater at 1.3 million m^3—nearly three times more than the volume of domestic wastewater discharge, at 0.5 million m^3 per day. A substantial portion of industrial wastewater finds its way into Dhaka's drainage system. The Department of Environment, which is responsible for addressing industrial pollution in Bangladesh, must take effective measures to minimize the problem.

The enormous rise in Dhaka's land prices has greatly reduced the feasibility of implementing land-intensive measures, including grassed swales, wetlands, and construction of new detention ponds. Results of the CDRI analysis echo the fact that natural aspects of the city, particularly ecosystem services, have been deteriorating, while implementation of environmental conversation policies are unsatisfactory (Jahan 2014). Thus, the conveyance-centric system, as recommended in previous chapters, appears to be the best solution for mitigating urban flooding. However, Eastern Dhaka and Narayanganj can opt for such land-intensive measures in the future. The relevant authorities should apply lessons learned from the city's rain-induced, flood-management predicament.

Removing Oil and Grease

Like many other large, motorized, and partially industrialized cities, Dhaka suffers from the presence of oil and grease in its stormwater conveyance system and floodwater (photo 8.5). To minimize their presence, oil and grease traps/separators should be installed in the stormwater drainage system. Another, perhaps cheaper option would be to install absorbents, such as polymethane foam, in sewer inlets. Absorbents are inexpensive, easy to maintain, and simple to replace.

Such areas as Gulistan, Mohakhali, Syedabad, and Gabtoli—the city's major bus-truck transportation hubs—should be targeted initially. In addition, the stormwater drainage systems of areas that feature numerous vehicle repair garages due to economic agglomeration (e.g., Tejgaon and Rasulbagh) should be fitted with oil-and-grease removal systems.

Summing Up

At this stage of development, the aim of controlling urban floodwater pollution can only be limited. The immediate objective should be for floodwater to appear clean and free of unpleasant odor, even though it may still contain heavy metals,

Photo 8.5 Discharge from Kallyanpur Retention Pond into Turag River

Credit: © Subhendu Roy / World Bank. Used with permission. Further permission required for reuse.

other toxic chemicals, and bacteria. Given Dhaka's current socioeconomic situation, only the above-described, limited measures appear feasible. However, implementing such policies would not protect downstream communities from having to face the adverse impacts of polluted, albeit clean-looking, stormwater generated upstream in Dhaka. With regard to khals, the focus should be to enhance their aesthetic value for pedestrians using walkways along them; that is, they should be maintained as passive recreation areas.

Khals of Dhaka

Dhaka's extensive network of khals forms a vital component of the city's stormwater drainage system. The khals carry rainwater to pump stations, where it is pumped out to the other side of the embankments. The subsections that follow describe the present status of Dhaka's khals and highlight areas that require priority attention.

Water-Flow Status

At present, Dhaka has 26 khals under DWASA's jurisdiction. Except for two khals—Debdulai and Kashaibari—these khals are maintaining their flow. Water flow in Debdulai is meager, while Kashaibari requires re-excavation and recovery of encroached land in order for flow to restart. A few other khals need widening. Appendix E provides a complete list of the 26 khals and their status.

Encroachment

While most khals are currently free from encroachment, several have been encroached on by land grabbers and public entities. For example, the Local Government Engineering Department (LGED) has constructed roads using a portion of Debdulai Khal, while RAJUK has encroached on Digun Khal and filled in 2 km of Baunia Khal. Segunbagicha, Rupnagar (main khal), and Kashaibari Khal face encroachment from the private sector, and portions of Kallyanpur "ka," Journalist Colony, and Baishteki khals are on private property (photo 8.6). Steps are being taken to acquire those pieces of land.

A simulation exercise was undertaken to investigate the impacts of khal encroachment in the DND area. The foreshore areas of the proposed khals were

Photo 8.6 Segunbagicha Khal, Central Dhaka system

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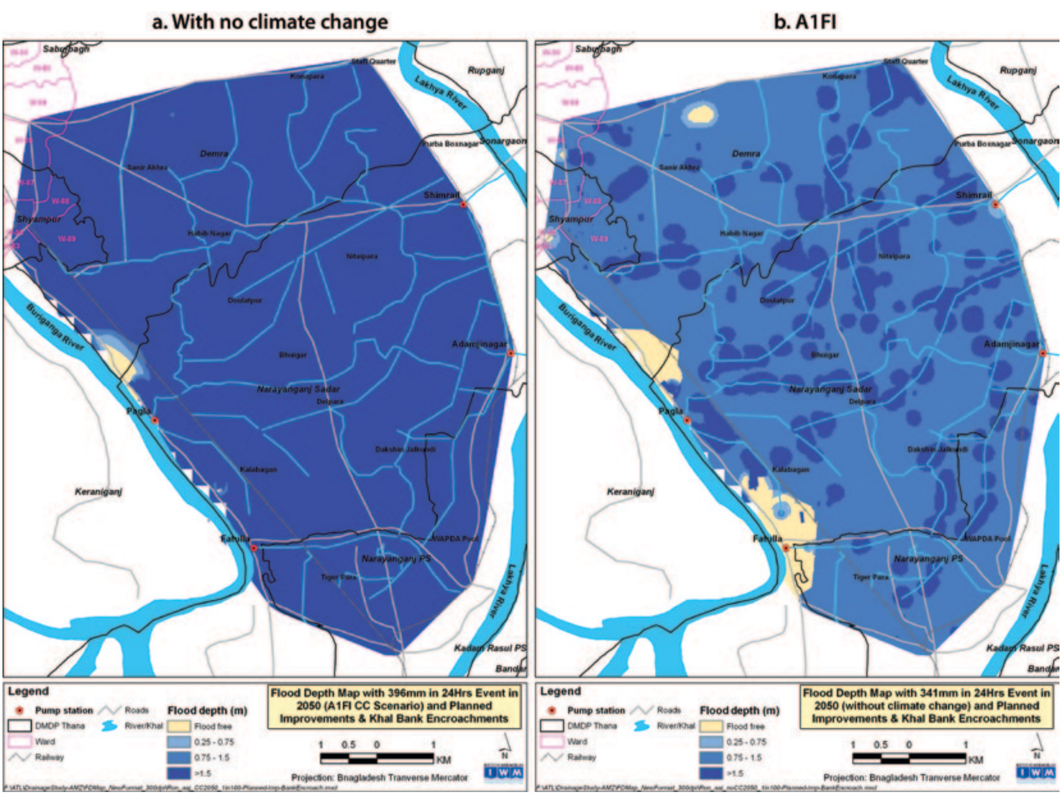
removed in the model (representing encroachment), with just the main khal section left for water flow and storage. The results showed that, if the 2004 extreme rainfall event were to occur in 2050, most of the area would be inundated at a depth of 0.75–1.5 m. Adding the effect of climate change would mean that nearly all of the area would be under more than 1.5 m of water (map 8.2).

Need for Pedestrian Walkways

The World Bank is financing a number of projects to construct walkways along Dhaka's khals, open channels, and U-channels in the khals. Building walkways along both sides of the khals should be done as soon as possible to demarcate their proprietary boundaries. Dhaka's walkways serve many purposes, some of which have strong positive externalities; these include the following:

- The clear demarcation of khal borders makes urban residents aware of the boundaries between public and private property (some khals are situated on private property). Having clear boundaries gives neighbors more confidence in reporting encroachment on public property to the authorities and media, making it quite difficult for encroachment to occur.

Map 8.2 Flood Maps for Extreme Event in 2050 with Planned Improvements and Khal Bank Encroachments



Source: IWM 2014.

- For encroachers, it becomes problematic to justify claims that their land continues beyond the walkways.
- The popularity of Dhaka's existing walkways among pedestrians can help to reverse the city's "pedestrian-unfriendly" reputation and, in the process, save the city many rickshaw- and passenger-hours, in turn, reducing traffic congestion and pollution, even if only by a small portion.
- If enough space is available, benches can be added so that the walkways become passive recreational areas. Before that can occur, however, water quality must be improved dramatically.

The walkways should be exclusively for pedestrian use.[10] To prevent plying by rickshaws, the walkways should not exceed 1.2 m in width. Small bushes or trees planted in the middle of the walkways can deter rickshaw plying. To prevent plying by motorcycles, rotating gates can be installed at various points along the walkways.

Road Building

Building roads along khals is problematic for two major reasons and should be strongly discouraged. First, it is well-known that khals have little land availability; thus, it would be unwise to use scarce, spare land for any purpose other than drainage. Second, building any needed roads along khals using public land may not be justified on economic grounds; other locations would perhaps better serve the purpose.

Closing Remarks

This chapter has discussed key secondary flood-mitigation measures that can complement the primary conveyance-centric, structural solutions recommended in this book to combat Dhaka's urban flooding problem. As discussed, better waste management and use of existing water bodies as detention ponds can substantially alleviate the city's flooding problem, while investment in green-roof systems can play an important complementary role. However, rainwater harvesting infrastructure—an inherently useful and cost-effective approach—would be of little use in minimizing the extent of flooding in the context of extreme intense rainfall in Dhaka.

A variety of options are available for better maintenance of the conveyance system, including routine sludge removal, hydraulic jetting and vacuum/suction machines, and remote-controlled evacuators. Wetlands and other common measures for controlling floodwater pollution no longer appear feasible owing to rising land prices, but future provisions should be made for implementing such solutions in Narayanganj and Eastern Dhaka. Designing and implementing an appropriate human-waste disposal system is a priority for improving the city's floodwater quality, along with developing effective disposal systems for solid waste and industrial effluents.

Notes

1. The cost of transport and landfill disposal is assumed at Tk. 2,000 per ton, based on estimates of DSCC officials.
2. These cost estimates are based on quite dated information gleaned from Enayetullah and Sinha (2000). The cost figures have been adjusted for the current price level. Even if the actual cost is twice the amount presented here, the benefit clearly outweighs the cost of establishing and running the composting plants.
3. In some cases, the assessed amount was no more than 5 percent of what should have been collected.
4. Cleaning a septic tank can cost up to Tk. 10,000.
5. According to JICA analyses (JICA 2000), a 100-year, return-period rainfall event has 244 mm per-day precipitation.
6. Given these assumptions, the 3-cm retention capacity approximates the highest limit; in reality, however, it would be substantially lower.
7. Fear of encroachment from keeping water levels too low can be minimized by pumping water out only after being warned that a severe rainfall event is imminent.
8. To be conservative, a low infiltration rate has been intentionally assumed.
9. Due to sloping ground, the water level of water bodies must be lowered by slightly more than 1.13 m.
10. It has been observed that walkways in Katasur are also used by rickshaws, whereas those in Gulshan are used only by pedestrians.

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CHAPTER 9

Toward an Integrated Adaptation Strategy

Introduction

Urban flooding and waterlogging caused by intense rainfall are a recurring phenomenon in the Dhaka metropolis. Bangladesh's capital city has a long history of flooding as a natural hazard and is regularly inundated during the monsoon season, when about 70 percent of annual rainfall occurs. But recent floods have been worse in terms of inundation and duration of floodwater in the city's fringe areas, and extreme rainfall events appear to be increasing in frequency. Climate science predicts that extreme rainfall events will become more frequent over time. Thus, Dhaka may experience a number of intense rainfall events between now and 2050, meaning that the return-period of the September 2004 baseline event (341 mm per day) may be less than 100 years in the future.

The Challenge of Managing Urban Flooding

Dhaka has experienced three extreme rainfall events since the year 2000, highlighting the growing challenge of managing urban flooding in the future. Since 2004, urban flooding conditions have improved in parts of Central Dhaka due to key investments. DWASA has worked hard to lay new drainage pipes, reclaim encroached khals, and improve conveyance in pipes and khals through desilting. Despite these efforts, problems persist or are worsening in other parts of the city (e.g., DND area). The identified causes are combined sewer and stormwater drainage, disposal of solid waste in the drainage system, illegal encroachment of khals, filling of lowlands, and lack of coordination among key stakeholder institutions. As a result, city dwellers, family assets, the urban-built environment, and vital public infrastructure are more vulnerable to the risks of urban flooding and waterlogging.

Climate Change Impact

The effects of climate change in the South Asia region, including greater rainfall intensity and increased frequency of extreme weather events, are expected to aggravate Dhaka's flood vulnerability. The Intergovernmental Panel on Climate Change (IPCC) predicts that South Asia will experience an increase in both average and extreme rainfall during summer monsoon seasons of longer duration. By 2050, the average monsoon flows in the Brahmaputra (Jamuna) River at Chilmari could increase by up to 14 percent. In a changing climate, it is expected that extreme rainfall events in Greater Dhaka could increase by 16 percent by 2050. In the rivers around Dhaka, monsoon-season water levels may increase by about 30 cm. Even with increased upstream flow, internal rainfall increases, and increased river levels, the total flooded area of Greater Dhaka is expected to decrease. The main reason is the predicted increase in land levels resulting from urbanization, as identified in RAJUK's Detailed Area Plan (DAP), highlighting how local-level planned improvements can offset the effects of climate change on urban flooding and thus the urgency of implementing them.

With planned improvements—all improvements to Dhaka's drainage infrastructure, including those already planned and proposed by the relevant drainage-system authorities—the detailed study area can cope with medium-sized rainfall events (200–250 mm per day), with a peak intensity of approximately 100 mm per hour. However, coping with larger events—those exceeding 300 mm per day—will require additional investments. In this study, the additional investments scenario is limited to the investment needed to meet the acceptable flooding criteria before the effect of climate change. With climate change, flooding once again increases over those limits, requiring adaptation investment to lower the flood level to meet the selected criteria. The findings of this study show that the extent of additional investments required to address the existing adaptation deficits, as well as the added investment needed to address the effect of climate change, varies among the modeled zones.

Furthermore, the 100-year event that occurred in September 2004 (341 mm per day) will likely become more frequent in the future as a result of climate change processes. Analyses of rainfall data for Dhaka have shown that the return period of extreme rainfall events is lessening. Uncertainty analyses conducted by IWM on the magnitude and timing of climate change risk highlight the need to make required investments in structural measures that adapt the drainage system to more frequent extreme rainfall events. Given the likelihood of more frequent extreme rainfall events due to climate change, it is pragmatic for investment plans to include all adaptation measures to meet climate change.

Recommendations

This study recommends a prudent strategy that begins by addressing the current adaptation deficit that Dhaka's residents already face in coping with rainfall extremes. Closing the current adaptation gap is an attractive, no-regrets option that can provide policymakers a solid foundation on which to prioritize and sequence additional measures to reduce potential future damage from climate risk. The design of this study, documented in Part I of this book (chapters 2–5), provides Dhaka's local decision-makers such a planning approach.

General

General recommendations from the hydrological modeling study include protecting all remaining khals and water bodies from encroachment, installing more rain gauges around Dhaka, and readily communicating rainfall forecasts to pump operators. An updated, detailed land survey of the Greater Dhaka region should be conducted. In light of changing rainfall frequencies and intensities, existing design practices should be reviewed and incorporated into the design manual being developed by DWASA for the Drainage Master Plan Study. Due to the potential for heavy-rainfall events in the pre-monsoon season, maintenance schedules should be reviewed. In addition, box-culverts should no longer be constructed in urban areas, drainage outlets to rivers should be regularly de-silted and protected from encroachment, and the foreshore of surrounding rivers should be protected to prevent river-water levels from rising significantly during the monsoon season. Furthermore, effective monitoring and enforcement of RAJUK's DAP is required, and appropriate solid waste management is urgently needed. Finally, better coordination is required among all institutional stakeholders.

Detailed Study Area

For each of the seven modeled zones of the detailed study area—Old Dhaka, Central Dhaka, Kallyanpur, Goranchatbari, Eastern Dhaka, DND, and Narayanganj (chapter 3)—the hydrological modeling exercise recommends specific structural measures to address the current adaptation deficit (chapter 6). These additional investments include installing new permanent and temporary pump stations, increasing the capacities of existing pump stations, laying new drainage pipes, deepening existing water bodies, and installing automatic sluice gates to prevent backflow in box-culverts.

For **Old Dhaka**, the study recommends increasing temporary pump capacities, removing sediment from Debdulai and Dholaikhal box-culverts, operating all three pumps at Dholaikhal Pump Station during extreme events, and protecting khals and drains from solid waste. For **Central Dhaka**, two new pump stations are recommended—one 12.5 m^3/s station at the downstream end of Panthapath Box-Culvert and a 15 m^3/s station and sluice gate near the Bashabo water pump. In addition, khals should be protected from encroachment and solid waste. The **Kallyanpur** drainage system requires deepening of the water body in ward 9, installing new pipe drains to drain low pockets to khals and temporary pump station locations, increasing temporary pump capacities, maintaining a 100-ha retention pond at the Kallyanpur Pump Station, and protecting khals and water bodies from encroachment and solid waste. For the **Goranchatbari** system, the study recommends connecting new drains in developing areas to the khal system, deepening ponds at Mirpur Zoo and Botanical Garden, and protecting khals from encroachment and solid waste. In the **DND** area, pump capacities need to be increased at Shimrail, Adamjinar, and Pagla, retention ponds identified in the BWDB feasibility study need to be incorporated into the updated DAP, and water bodies and khals need to be protected. In **Narayanganj**, all water bodies identified in the DAP need protection, and khals and drains should be protected from solid waste. In **Eastern Dhaka**, planned land use, as identified in the DAP, must be enforced, water retention ponds require protection, and khals should be protected from encroachment and solid waste.

By implementing the additional investments recommended in chapter 6, all study areas, with the exception of rural parts of Narayanganj and the DND area, would meet the acceptable flooding criteria set forth in this study for the extreme rainfall event in 2050 without climate change (i.e., 341 mm per 24 hours). The effects of A1FI climate change by 2050 on the improved drainage system would have varying effects on the detailed study area. With a projected 16 percent increase in rainfall (i.e., 396 mm per day in 2050), the DND area would experience a 12 percent increase in flooded area, while the other six areas would remain within a 3 percent increase.

Cost of Closing the Adaptation Gap

The cost of meeting Dhaka's current adaptation deficit without climate change would total approximately Tk. 2.7 billion, while the added cost of closing the climate change gap would require another Tk. 1.3 billion, for a total estimated cost of about Tk. 4.0 billion. Central Dhaka would require the largest investment to meet its current adaptation deficit, at about Tk 1.4 billion, while Old Dhaka would require the least, at just under Tk. 65 million (chapter 7).

The study findings show that the cost of the damage caused by not taking these recommended measures would be quite significant for the modeled zones and Dhaka city overall (chapters 6 and 7). For example, if a single 100-year, return-period storm were to occur in 2050, the increased damage caused by climate change would amount to more than Tk. 2.0 billion under a scenario with planned improvements only, but would be reduced to just Tk. 09 billion if additional investments had also been made. Such savings in damage of Tk. 1.1 billion in just one year reveal how quickly the investment of Tk. 2.7 billion in current adaptation deficit can be paid back. The results showed similar outcomes for increased climate change damage under a weighted probability of various return-period storms for both planned-improvement and additional-investment scenarios. Similar cumulative effects of climate change (2014–50) were found with the random assignment of various return-period storms under alternative assumptions of increased frequency of a 100-year, return-period event. Thus, the cumulative damage caused by climate change between 2014 and 2050 would go down from Tk. 28.5 billion with only planned improvements to Tk. 12.6 billion, representing a savings of Tk. 15.9 billion—a much larger amount than the investment of Tk. 2.7 billion in current adaptation deficit.

Study Assumptions

This study's hydrological modeling exercise for 2050 is based on a number of optimistic assumptions. For example, the study assumes that Dhaka's land cover will change according to RAJUK's DAP. It also assumes that all planned and proposed improvements to the city's drainage infrastructure by the relevant drainage-system authorities will be implemented. In Bangladesh, however, there is skepticism about appropriate enforcement of these plans. As noted in chapter 7, it is assumed that drainage pipes, khals, and box-culverts will perform according to their designated capacity and that rainwater will reach them without undue difficulty. But given that these assumptions somewhat contradict Dhaka's current reality, a careful study accounting for the required added expenditures would need to be conducted, including comprehensive cost estimates.

Complementary Adaptation Measures

In addition to the conveyance-centric solutions recommended in chapters 6 and 7, achieving a flood-free Dhaka will require an array of non-conveyance and non-structural adaptation measures. As discussed in chapter 8, implementation of these "soft" adaptation measures will require overcoming key institutional, technical, and financial barriers. Better solid waste management, including composting, and the use of existing water bodies as detention ponds can substantially alleviate Dhaka's flooding problem. Most of the city's wards have some water bodies located within their boundaries that could be used as temporary detention ponds to minimize urban inundation resulting from heavy rainfall. For example, it is estimated that pumping out 1.13 m of water from Central Dhaka's water bodies before a rainfall event would result in downgrading a 244 mm precipitation event to a 160 mm event in terms of flood impact. Such findings suggest the need for undertaking a rigorous study to identify which water bodies have maximum impact on water congestion in various areas of the city. To deter encroachment, the water bodies should be lined with pedestrian walkways. In addition, Dhaka City Corporations (DCCs) should be encouraged to transform walkway-lined water bodies into urgently needed, passive recreation zones, where city residents can enjoy open-air activities.

Rainwater harvesting infrastructure—an inherently useful and cost-effective approach—would be of little use in minimizing the extent of flooding in the context of Dhaka. A variety of options are available for better maintenance of the conveyance system, including routine sludge removal, hydraulic jetting and vacuum/suction machines, and remote-controlled evacuators. A fund could be established to cover DWASA's routine drainage cleaning needs by adding 1 percent of the assessed base of holding tax to the DCCs' current tax rate.

Owing to rising land prices, wetlands, grass swales, and other common measures for controlling floodwater pollution no longer appear feasible in Dhaka; however, future provisions should be made for implementing such solutions in Eastern Dhaka and Narayanganj township. Designing and implementing an appropriate human-waste disposal system is a priority for improving the city's floodwater quality, along with developing effective disposal systems for solid waste and industrial effluents.

Toward an Integrated Strategy

In addition to this book's recommended primary and secondary flood-mitigation measures, results of the flood vulnerability assessment can provide local policy-makers a powerful tool for identifying wards and regions outside the DCCs that may require greater attention, while designing adaptation methods to cope with flooding resulting from extreme weather events (chapter 6). As discussed in chapter 7, some wards and regions have increased vulnerability owing to non-flood factors that may exacerbate the impact caused by even low levels of flooding. In such areas, adaptation may need to focus more on physical, social, economic, and institutional factors. In other areas more prone to flooding, it may be important to focus on flood mitigation and reducing the direct impact of flooding, in addition to addressing the physical, social, economic, and institutional aspects.

Equipped with a menu of options designed to close the current adaptation deficit and further climate-proof urban infrastructure, local decision-makers can better evaluate their choices and develop more effective strategies that prioritize and sequence activities as resources permit. The benefits of addressing the current adaptation deficit are significant, even without climate change, making such investments an attractive no-regrets option. The "hard" infrastructure investments recommended in this book cannot yield the expected benefits if implemented in isolation. Primary structural solutions must be complemented by urgently needed, "soft" adaptation measures designed to overcome key institutional, technical, and financial barriers within a framework of sound development policies. In this way, Dhaka will have a solid foundation on which to build and sustain local resilience to the risk of urban flooding now and in the future.

Appendixes

APPENDIX A

Individuals Consulted in Dhaka to Estimate Adaptation Costs

This appendix lists key practitioners who were consulted in Dhaka to estimate the costs of implementing the structural measures recommended in this study.

Dhaka Water Supply and Sewerage Authority

Ching, Kyaw Sha. Superintending Engineer and Project Director, Removal of Water Logging in Dhaka City (Phase II), Drainage (R&D) Circle.

Habib Ullah, Kazi. Executive Engineer, Dhaka Water Supply and Sanitation Project (World Bank–assisted).

Rahman, Md. Shafiqur. Executive Engineer.

Rahaman, Mostafizur. Sub-Divisional Engineer, Drainage (R&D) Division-1.

Vries, Taco de. Resident Project Manager, Urban Dredging Demonstration Project, Drainage (O&M) Circle.

Uddin, A. K. M. Shahid. Superintending Engineer.

Institute of Water Modelling

Bhuiyan, Md. Anwar Hossain. Senior Water Resource Planning and Design Specialist, Water Resources Planning Division.

Khan, Md. Arzel Hossain. Senior Water Resources Management Specialist, Water Resources Planning Division.

Bangladesh Water Development Board

Alam, Choudhury Nazmul. Executive Engineer, Design Circle-3.

Islam, K.M. Nurul. Superintending Engineer, Design Circle-3.

Rahman, Md. Habibur. Ex. Addl. Director General, Deputy Team Leader, CEIP project.

Other Practitioners

Ali, Md. Liakath. Climate Change and Environment Adviser, Department for International Development, Bangladesh.

Islam, Shariful. Assistant Manager (Sales), Milnars Pumps Ltd.

Khondoker, Md. Ekramul Hoque. Assistant Engineer (Mechanical), Waste Management Division, Dhaka North City Corporation.

Rahman, Md. Shafiqur. Chief Executive Officer, Megatech Engineers, Uttara.

APPENDIX B

Basin and Region Modeling and Rainfall Analyses

The study area is under the influence of the water level of the Brahmaputra, as mentioned in chapter 2. Therefore, the river flooding situation depends on the water level of the Brahmaputra (Jamuna) River and its distributaries in the north-central region of Bangladesh during the monsoon months. But urban flooding is influenced by the amount of precipitation over the city area, as well as the prevailing water level in the surrounding rivers that act as outfall channels.

Change in Monsoon River Flows: Basin Model Output

As discussed in chapter 2, Institute of Water Modeling (IWM)'s GBM basin model was used to estimate the changes in flows of the Brahmaputra (Jamuna) River due to future climate change. The results showed significant increases in monthly river flows, especially during July–August, for the A1FI scenario in 2050 (figure B.1).

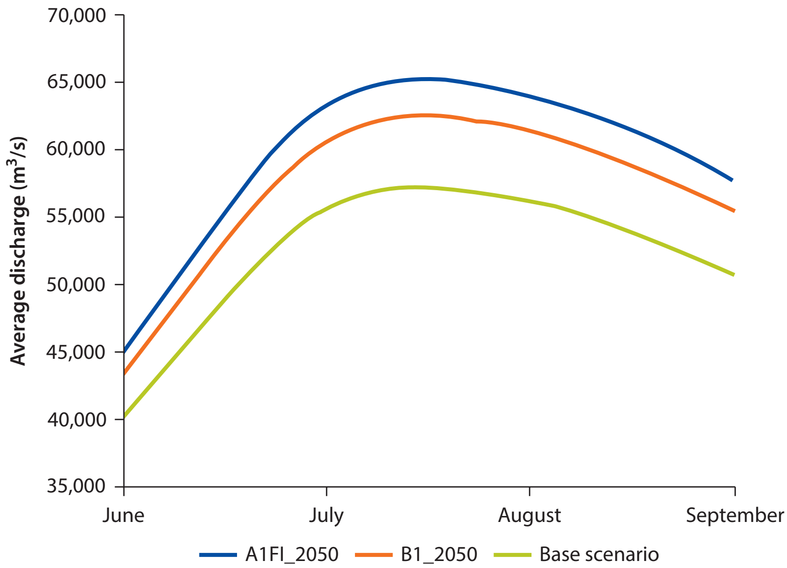
The change in average monsoon flows—the average change in flow from June to September—was 5.8 percent for the A1FI scenario in 2025. By 2050, the average monsoon flow for this scenario increased by 13.6 percent, compared to the 2004 base period (figure B.2).

The monsoon flow changes of the Brahmaputra (Jamuna) River were used in the upstream boundary point of IWM's North Central Region Hydrodynamic (NCRHD) model to simulate the monsoon season flows and water levels of the river network in the extended study area.

Change in Sea Levels

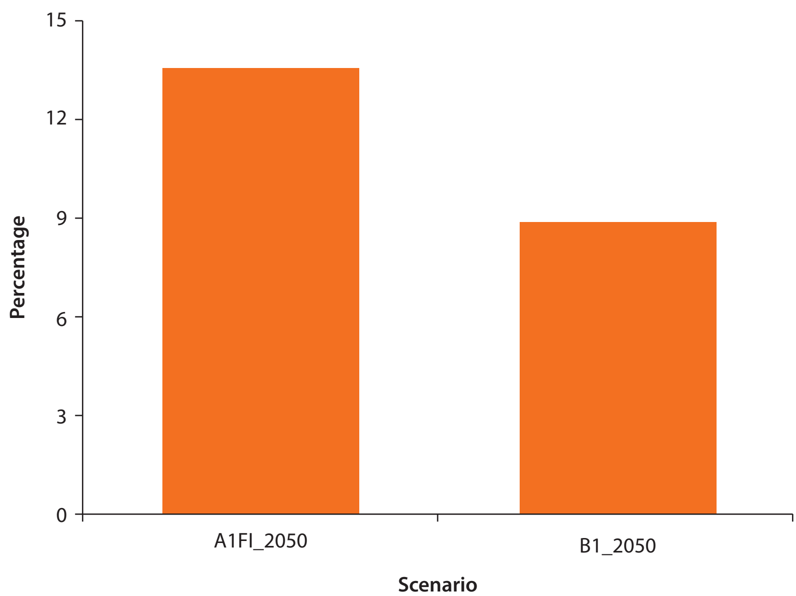
Based on recent assessments by the Intergovernmental Panel on Climate Change (IPCC), this study considered the effect of sea-level rise as negligible for the future scenarios modeled for the year 2050. Citing Vermeer and Rahmstorf

Figure B.1 Average Monthly Flow of Brahmaputra (Jamuna) River at Chilmari



Source: Zaman 2014.
Note: A1FI = Intergovernmental Panel on Climate Change (IPCC) scenario with future based on fossil fuel–intensive development; B1 = IPPC scenario with future based on a high level of environmental and social consciousness combined with a globally coherent approach to a more sustainable development.

Figure B.2 Change in Monsoon Discharge of Brahmaputra (Jamuna) River at Chilmari



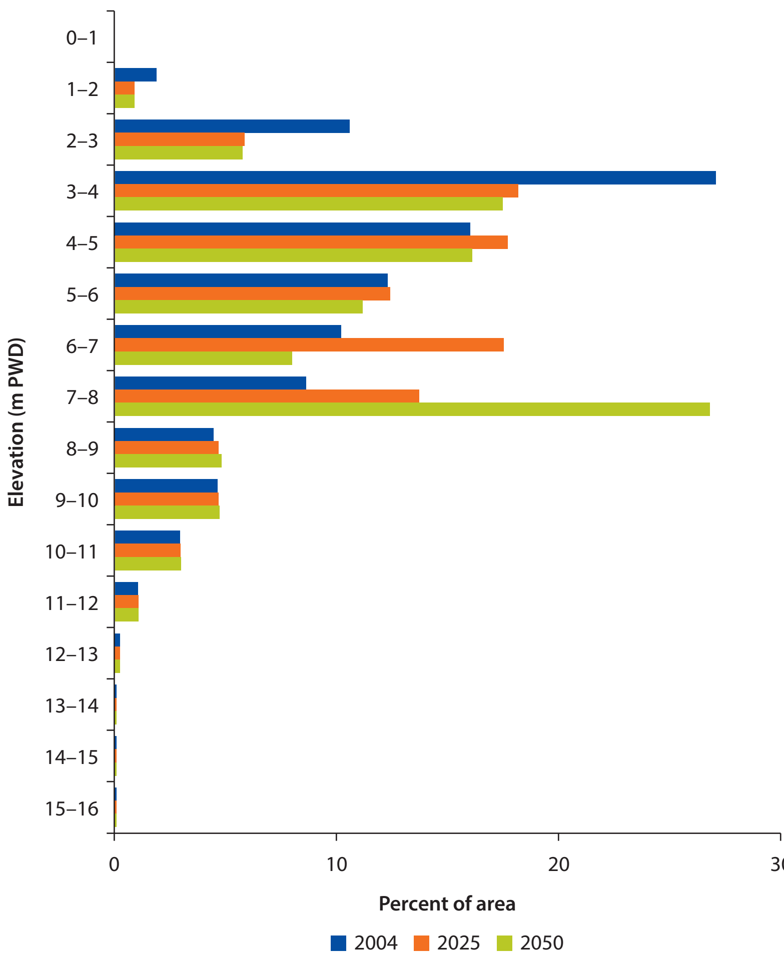
Source: Zaman 2014.
Note: A1FI = Intergovernmental Panel on Climate Change (IPCC) scenario with future based on fossil fuel–intensive development; B1 = IPPC scenario with future based on a high level of environmental and social consciousness combined with a globally coherent approach to a more sustainable development.

(2009), the IPCC (2012) indicates that sea-level rise would amount to 1.90 m for the A1FI scenario by 2100. Further, the IPCC (2013), citing Pfeffer, Harper, and O'Neel (2008), finds that sea-level rise of more than 2 m by 2100 is physically implausible. An estimate of 0.8 m by 2100 that includes increased ice dynamics is considered the most plausible.

Change in Land Use and Land Levels

Figure B.3 shows the frequency distribution of land levels for Greater Dhaka. In the 2004 base scenario, the main land-level category is 3–4 m Public Works Department (PWD). However, due to population growth, subsequent land-filling, and density increases, the proportion of higher-elevation land levels increases in 2025 (i.e., the

Figure B.3 Frequency Distribution of Land Levels for Greater Dhaka



Source: Zaman 2014.

distribution shifts to the right). By 2050, the main land-level category is 7–8 m PWD. Such changes can already be seen in land development works undertaken for Uttara Phase 3 developments in northwestern Dhaka and also land-level changes in Badda Thana, located in the eastern part of the city. Given the further planned urbanization in the DAP's proposed land use and expected population growth, this dramatic change in land use could be seen by 2025.

Change in River Water Level: Regional Model Output

The NCRHD model used the basin-level output, along with climate and river network data to simulate river flows and water levels of key rivers in north-central Bangladesh. The simulated water levels, in turn, were used to generate indicative flood maps for the DMDP area.

The 2004 base-run simulation of hydrological and hydrodynamic conditions showed that most parts of central Dhaka, Savar core area, Gazipur Sadar core area, and Purbachal were nearly flood free. Other areas were flooded to various depths. The total flood free area (<0.25 m depth) was 22 percent, while deep-flooded areas (>1.5 m depth) comprised 64 percent. Based on the 2050 DEM, flood-depth maps were generated for the 2050 A1FI climate change scenario. The flood-free area was about 39 percent, while deep-flooded area was about 60 percent. The increase in flood-free area was due to local people's initiative to raise the plinth level of their houses above anticipated inundation levels. Compared to 2004 monsoon flooding, the total flooded area (>0.25 m depth) decreased from 78 percent to 61 percent in the 2050 A1FI scenario. This occurred despite increased upstream flow from Chilmari, internal rainfall increases of 9.9 percent, and increased water levels (about 30 cm) of rivers around Dhaka. The main reason for the decrease in flooded areas is the projected increase in land levels in proposed built-up areas, as identified in the DAP.

Changes in peak water levels of rivers around Dhaka City were simulated for the worst-case (A1FI) scenario in 2050. The simulated increase was less than 30 cm, suggesting that climate change is unlikely to have a major impact on peak water levels compared to the 2004 level of flooding (figure B.4).

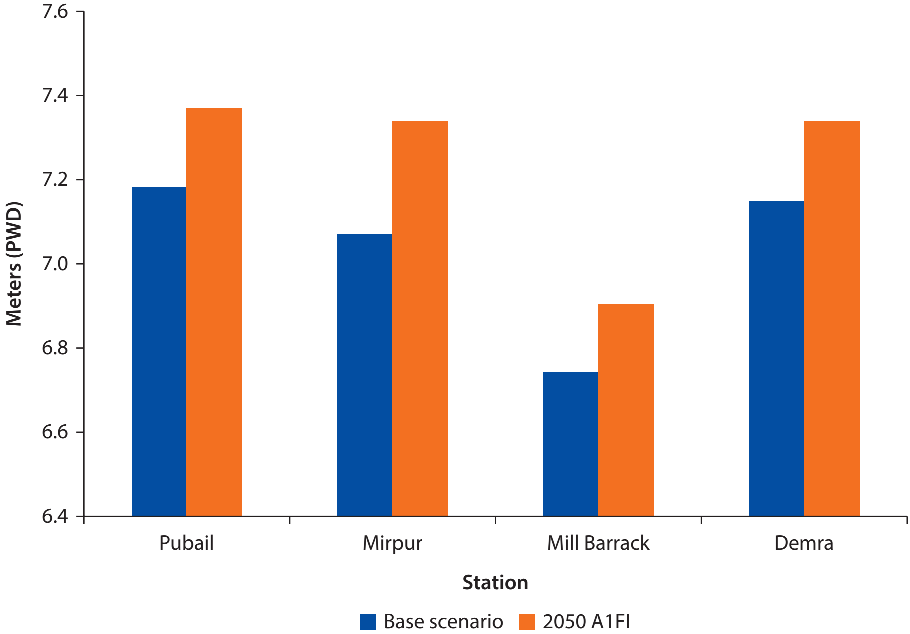
Change in Rainfall

Heavy rainfall is one of the main factors that cause urban flooding. Therefore, changes in rainfall intensities need to be studied in order to model urban flooding and its impacts. As mentioned in chapter 3, rainfall data from the Bangladesh Water Development Board (BWDB) and Bangladesh Meteorological Department (BMD) were analyzed.

Analyses of BWDB Data

The study analyzed daily rainfall data from several BWDB stations around Dhaka. The Banani Station covered the longest period (1957–2011). The time-series record showed that two recent extreme events have broken previous records:

Figure B.4 Changes in Peak River Water Levels around Dhaka City Due to Climate Change



Source: Zaman 2014.
Note: The gauge points (i.e., locations of water-level gauges) for these Bangladesh Water Development Board–maintained stations are as follows: Balu River (Pubail), Turag River (Mirpur), Buriganga River (Mill Barrack), and Lakhya River (Demra). PWD = Public Works Department.

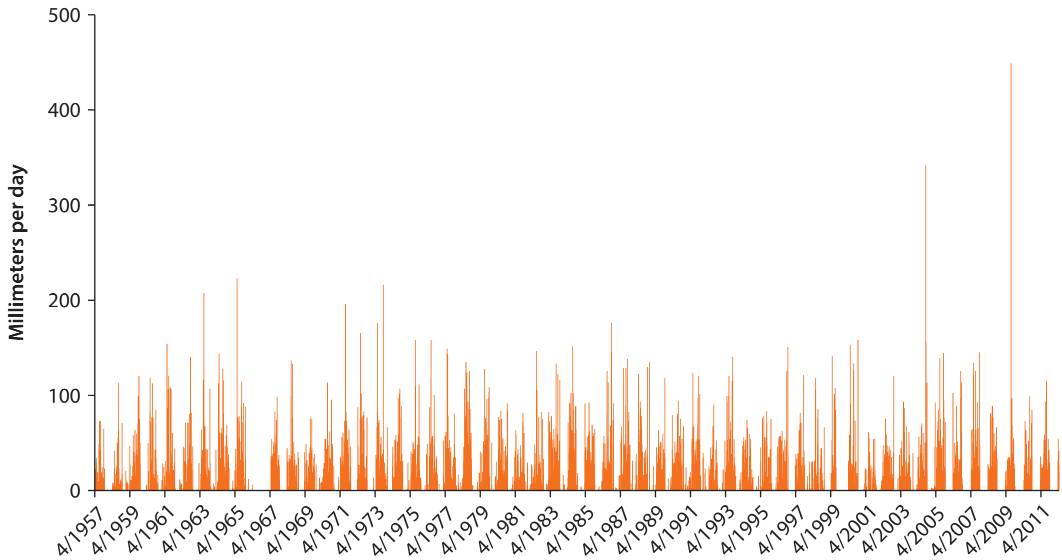
September 13, 2004 (341 mm per day) and July 28, 2009 (448 mm per day). The previous record was set on May 12, 1965 (222 mm per day). These findings highlight a trend of increasing variability in daily rainfall (figure B.5).

Frequency analyses were conducted on the Dhaka (Banani) station data and compared to JICA (2000) findings. According to the JICA analyses, the September 2004 event of 341 mm per day would be classified as more than a 1,000-year, return-period event. However, the IWFM (2005) classified the event as a 100-year return-period event. The inclusion of more recent data—including the extreme event of July 2009—further reduced the return period to 50 years. These findings clearly show that return periods are decreasing; that is, larger events are occurring more frequently (figure B.6).

Analyses of BMD Data

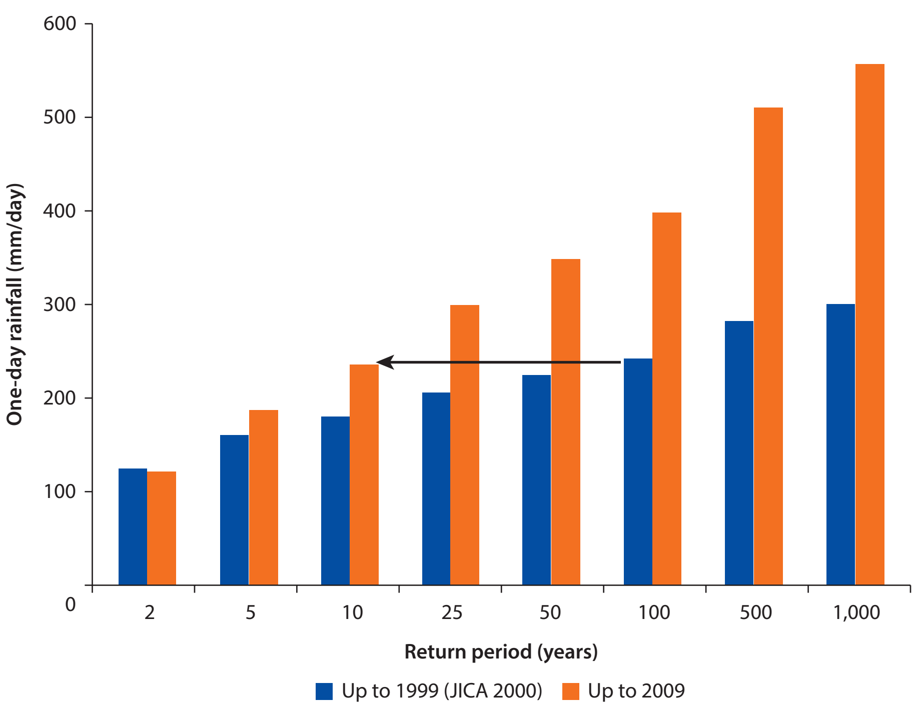
The study also analyzed BMD Dhaka station data, including more detailed, sub-daily rainfall data, which are required for urban flood modeling. An interesting observation is that, compared to the BWDB data, the 2004 event is recorded as larger than the 2009 event (figure B.7a). The reason is that the two agencies collate daily rainfall data at different times of the day. BMD's three-hourly rainfall data reveals that the 2009 event was much more intense compared to other rainfall events since 2003 (figure B.7b).

Figure B.5 Daily Rainfall Time Series at BWDB Dhaka Station



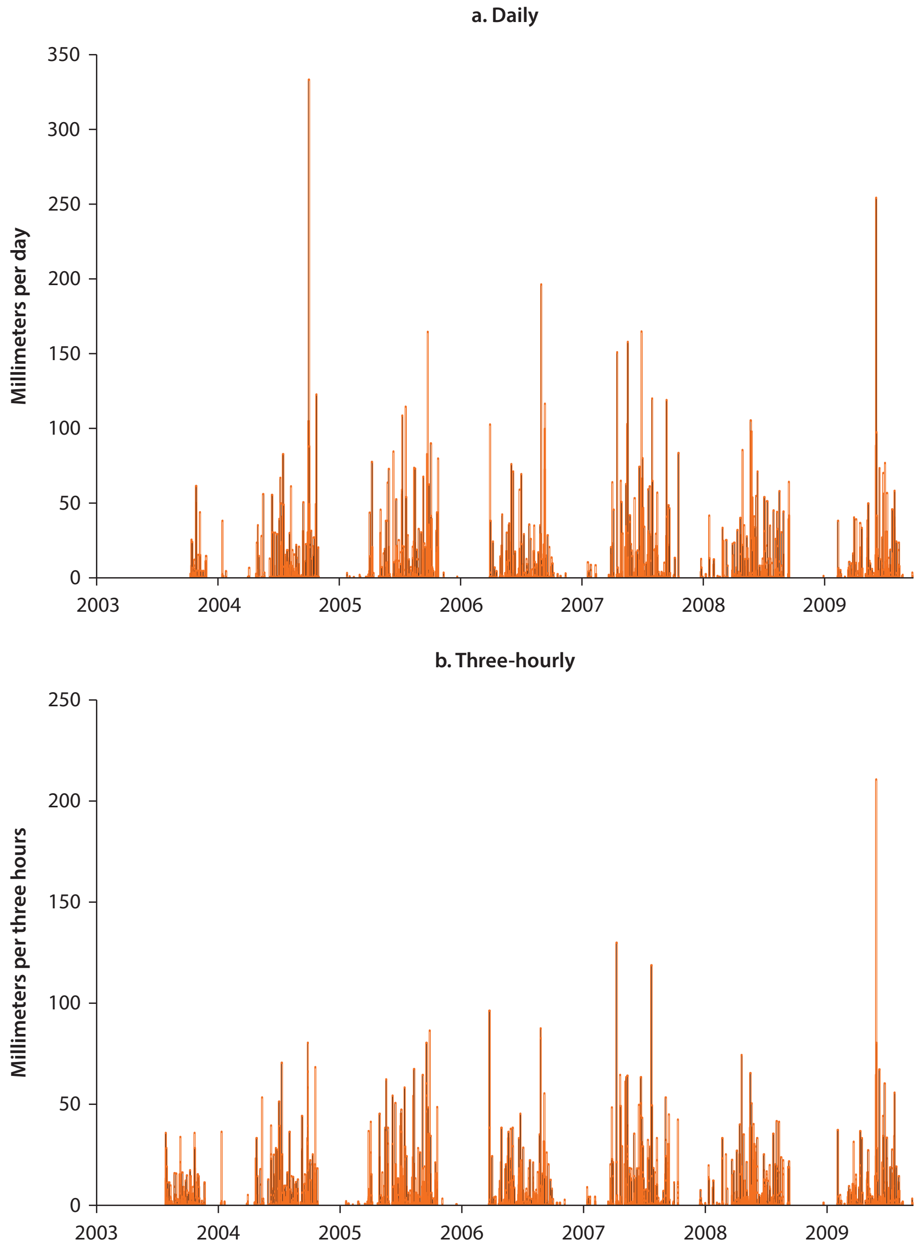
Source: Zaman 2014.
Note: BWDB = Bangladesh Water Development Board.

Figure B.6 Change in Return Periods of Daily Rainfall Events at BWDB Dhaka Station



Source: Zaman 2014.
Note: BWDB = Bangladesh Water Development Board.

Figure B.7 Rainfall Data at BMD Dhaka Station, 2003–09



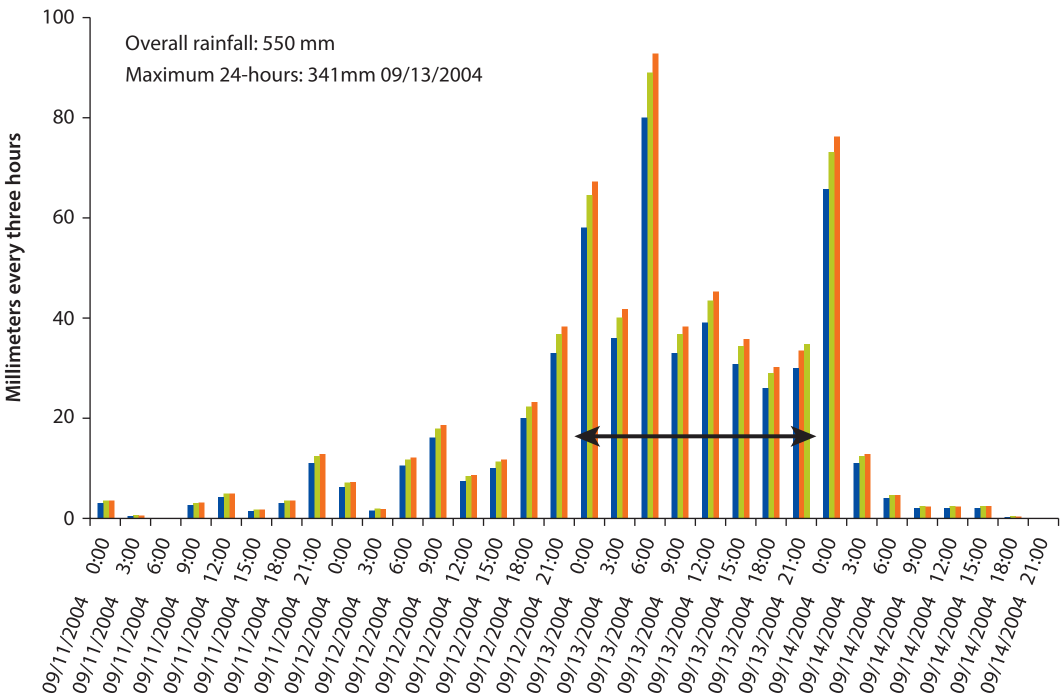
Source: Zaman 2014.
Note: BMD = Bangladesh Meteorological Department.

These findings reveal how the extreme rainfall events of 2004 and 2009 differed. The 2004 event was a high-volume event of relatively low intensity. Over a four-day period, about 550 mm rainfall was recorded, with 341 mm maximum over a 24-hour period. This event is of particular interest for this study as it caused extensive flooding in Dhaka at the time and corresponds well with the availability of other datasets. Therefore, 2004 was chosen as the base year for the modeling simulations. The changes in three-hourly rainfall due to climate change in 2050 were then analyzed for the high-emissions (A1FI) scenario. Figure B.8 shows that the intensities increase to 16 percent by 2050.

Design Storms

This study adopted the widely accepted JICA (2000) estimates for one-day rainfall amounts for different return-period events. For the purpose of urban drainage modeling, these one-day rainfall amounts were distributed into an hourly synthetic storm pattern (i.e., design storm). JICA (1987) was followed

Figure B.8 Three-Hourly Rainfall for September 2004 Event at BMD Dhaka Station

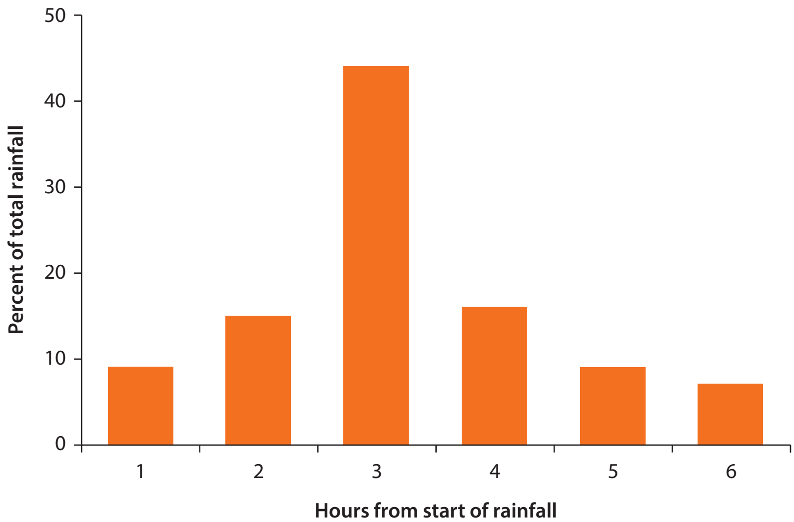


Time period	Observed	2025 B1	2025 A1FI	2050 B1	2050 A1FI
Total rainfall (mm)	550	582	589	611	638
Change (%)		106	107	111	116

■ Observed ■ 2050 A1FI ■ 2050 B1

Source: Zaman 2014.
Note: A1FI = Intergovernmental Panel on Climate Change (IPCC) scenario with future based on fossil fuel–intensive development; B1 = IPPC scenario with future based on a high level of environmental and social consciousness combined with a globally coherent approach to a more sustainable development; BMD = Bangladesh Meteorological Department.

Figure B.9 Hourly Fractions of Six-Hour Design Storm Event



Source: Zaman 2014.

for the first day's rainfall pattern of the two-day, five-year design storm. Figure B.9 shows that the pattern consists of a peak intensity three hours after the rain starts, when 44 percent of the total rainfall falls within an hour.

Based on the above pattern, theoretical storms were developed for 10-, 20-, and 30-year return periods with and without climate change in 2025 and 2050. The drainage models were used to simulate the impacts of these design storms with and without climate change.

Summary Remarks

The study area of Greater Dhaka lies in a delta region, where the flooding pattern is dominated by spills from the Brahmaputra River, as well as intense local rainfall. Simulations of climate change effects with the Brahmaputra Basin model provided estimates of average monsoon-flow increases of up to about 14 percent by 2050 at Chilmari (northern Bangladesh) for the A1FI scenario. The knock-on effect on regional rivers around Dhaka, combined with increased monsoon-season rainfall, was simulated using IWM's NCRHD model. In the worst-case scenario, an increase of approximately 30 cm was found in the peripheral rivers. As a result, in some areas of Greater Dhaka, the depth of flooding increased. However, in such areas as Eastern Dhaka, where urbanization is driving land-raising, flood depths decreased or even became flood free.[1] This finding highlights the importance of local effects on urban flooding, which sometimes can exceed global/regional climate change effects. The finding also highlights that land-raising is not driven primarily by climate change risks, but it does reduce such risks as a co-benefit. This complex interaction has been investigated further for the detailed study area.

Note

1. In Eastern Dhaka, which is vulnerable to flooding from the Balu River, land is being raised before houses and office buildings are constructed; it is possible that the entire area will be raised by land filling before the planned embankment along the Balu River is completed.

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APPENDIX C

Dhaka City Rainfall Analyses: Previous Study Findings

This study reviewed previous research that investigated trends and changes in rainfall frequencies in and around Dhaka city. The Climate Change Cell (CCC) (2009) analyzed rainfall trends at 8 BMD and 11 BWDB stations around Bangladesh, including Dhaka, for 1960–2001. The findings showed that mean monsoon rainfall in Dhaka decreased marginally for the 1960–80 and 1981–2001 periods. However, for the latter period, the standard deviation doubled. The decade trend for monsoon rainfall (June–October) was decreasing, at −27 mm per decade; however, it was increasing for the other seasons: 13 mm per decade in winter (November–February), 28 mm per decade in summer (March–May), and 16 mm per decade in the critical period (March 11–May 10). The decade trend for September alone was also positive, at 11 mm per decade. Trends in 10-day rainfalls were analyzed, and findings similar to the monthly analyses were reported. The research also found that the trend in annual maximum rainfall for Dhaka was –10 mm per decade. The study did not examine changes in return period for rainfall events.

Murshed, Islam, and Khan (2011) also investigated the impact of climate change on rainfall intensity in Bangladesh. For the 1953–2009 period, it was found that the annual maximum rainfall at BMD's Dhaka station was decreasing at a rate of 0.0154 mm per year. However, over a more recent period (1979–2009), the trend was increasing at 2.7 mm a year. The main factors identified for the increase were the two quite large events that occurred during the most recent 10-year period. Omitting these two events results in a declining trend of 1.06 mm per year. The study also compared observed mean daily rainfall data with similar output from PRECIS, a regional climate model. The observed data showed an increasing trend of 0.0103 mm per year for the 1953–2009 period, and the model showed a trend of 0.014 mm per year. The model was then used to predict the trend in monsoon rainfall up to the year 2100 for the high-emissions scenario (A1FI) of the Intergovernmental Panel on Climate Change (IPCC). The simulated results showed an increasing trend of

0.121 mm per year for monsoon rainfall. But the study did not investigate possible changes in return period for different-size rainfall events.

Ahammed and Hewa (2012) analyzed rainfall data from BMD's Dhaka station for the 1953–2009 period. Various frequency analyses of daily rainfall data were conducted. For rainfall events with return periods of 3, 20, 45, and 100 years, the respective daily rainfall amounts were 200 mm, 325 mm, 375 mm, and 425 mm. The study also developed intensity-duration-frequency diagrams based on BMD rainfall data.

Hossain et al. (2013) studied Dhaka's rainfall trends in the context of the city's expansion over the past few decades. The analysis covered 20 years of rainfall data (1985–2005) from 254 BMD and BWDB stations. The findings showed that urban areas tended to receive less rainfall, in terms of frequency and intensity, than did rural areas. They further showed that areas downwind of urban centers tended to receive more rainfall than upwind areas.

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APPENDIX D

DAP-Proposed Water Retention Areas and Water Bodies

Table D.1 DAP-Proposed Water Retention Areas and Water Bodies

	Proposed land use and area (km^2)			*Proposed land use and area (km^2)*			*Proposed land use and area (km^2)*	
Ward no. or thana	*Water retention area*	*Water body*	*Ward no. or thana*	*Water retention area*	*Water body*	*Ward no. or thana*	*Water retention area*	*Water body*
90	0.00	0.02	20	0.00	0.16	40	0.00	0.14
89	0.00	0.01	19	0.00	0.89	39	0.00	0.02
88	0.00	0.01	18	0.00	0.07	38	0.00	0.02
87	0.00	0.09	17	0.67	0.03	37	0.00	0.59
86	0.00	0.09	16	0.00	0.18	36	0.00	0.03
85	0.03	0.00	15	0.00	0.56	35	0.00	0.02
84	0.04	0.01	14	0.00	0.03	34	0.00	0.01
83	0.00	0.01	13	0.00	0.04	33	0.00	0.00
82	0.00	0.02	12	0.00	0.05	32	0.00	0.00
81	0.00	0.02	11	0.00	0.11	31	0.00	0.01
80	0.00	0.02	10	0.31	0.14	30	0.00	0.00
79	0.00	0.01	09	0.58	0.17	29	0.06	0.02
77	0.00	0.00	08	0.10	0.32	28	0.04	0.07
76	0.00	0.01	07	0.00	0.03	27	0.00	0.11
75	0.00	0.01	06	0.50	0.17	26	0.09	0.20
73	0.00	0.01	05	0.00	0.09	15, Narayanganj	0.00	0.02
71	0.00	0.00	04	0.00	0.19	14, Narayanganj	0.00	0.03
70	0.00	0.00	03	0.00	0.02	13, Narayanganj	0.00	0.04
68	0.00	0.00	02	0.00	0.20	12, Narayanganj	0.00	0.03
66	0.00	0.01	01	0.00	0.05	11, Narayanganj	0.01	0.03
65	0.00	0.01	Uttara	1.85	1.13	10, Narayanganj	0.02	0.03
63	0.00	0.00	Savar	0.01	0.00	09, Narayanganj	0.33	0.02
62	0.00	0.02	Sabujbagh	0.14	0.07	08, Narayanganj	0.16	0.00
60	0.00	0.01	Pallabi	1.75	0.15	07, Narayanganj	0.15	0.01

table continues next page

Table D.1 DAP-Proposed Water Retention Areas and Water Bodies *(continued)*

	Proposed land use and area (km²)			*Proposed land use and area (km²)*			*Proposed land use and area (km²)*	
Ward no. or thana	*Water retention area*	*Water body*	*Ward no. or thana*	*Water retention area*	*Water body*	*Ward no. or thana*	*Water retention area*	*Water body*
59	0.00	0.00	18, Narayanganj	0.00	0.12	06, Narayanganj	0.03	0.00
58	0.00	0.04	17, Narayanganj	0.00	0.02	05, Narayanganj	0.01	0.00
57	0.00	0.02	16, Narayanganj	0.00	0.02	04, Narayanganj	0.08	0.00
56	0.00	0.03	51	0.00	0.00	03, Narayanganj	0.06	0.01
55	0.00	0.07	50	0.00	0.00	02, Narayanganj	0.16	0.00
54	0.00	0.14	49	0.00	0.18	01, Narayanganj	0.17	0.00
53	0.00	0.01	48	0.00	0.04	Narayanganj	1.24	1.88
52	0.00	0.03	47	0.00	0.09	Khilgaon	3.88	0.02
25	0.00	0.05	46	0.00	0.09	Demra	1.03	0.44
24	0.00	0.09	45	0.00	0.01	Cantonment	0.00	0.06
23	0.00	0.15	43	0.01	0.09	Badda	6.79	0.11
22	0.02	0.17	42	0.00	0.01	Airport	0.00	0.14
21	0.00	0.09	41	0.00	0.04	**Total**	**20.32**	**10.95**

Sources: DAP and IWM.
Note: DAP = Detailed Area Plan.

APPENDIX E

Status of 26 Khals under DWASA Jurisdiction

Table E.1 Status of 26 Khals under DWASA Jurisdiction

		Khal size		
Serial no.	*Khal name*	*Length (m)*	*Width (m)*	*Status (updated to May 31, 2013)*
1	Katasur	1,722	12	No encroachment; uninterrupted flow
2	Ramchandrapur	2,940	18–30	No encroachment; uninterrupted flow
3	Khilgaon-Bashabo	2,540	9–18	No encroachment; uninterrupted flow
4	Begunbari	10,940	20–60	No encroachment; uninterrupted flow
5	Shahjadpur	1,910	9	Uninterrupted flow
6	Sutibhola	3,680	15–20	Uninterrupted flow
7	Abdullahpur	3,160	18–36	Uninterrupted flow
8	Segun Bagicha	3,887	9–24	Encroachment in a few places; uninterrupted flow
9	Mohakhali	2,320	9–18	No encroachment; uninterrupted flow
10	Ibrahimpur	1,260	9–18	No encroachment; uninterrupted flow
11	Digun	4,588	22–60	RAJUK encroached on 700 m; uninterrupted flow using alternate route
12	Baunia	8,828	18–30	RAJUK filled in 2 km and re-excavation needed; but continuous flow
13	Kallyanpur A	1,540	10	740 m on private property; being acquired
14	Kallyanpur B	2,408	8–12	No encroachment; uninterrupted flow
15	Kallyanpur D	1,564	9–12	No encroachment; uninterrupted flow
16	Kallyanpur E	288	9	No encroachment; uninterrupted flow
17	Kallyanpur F	982	9–24	300 m under PWD; being transferred to DWASA; uninterrupted flow
18	Kallyanpur Main	3,460	18–36	No encroachment; uninterrupted flow
19	Debdulai	2,000	9–15	Encroachment; LGED built road using a portion; little flow.
20	Rupnagar Main	2,430	18	Eastern Housing problem; some encroachment by others; inadequate width
	Rupnagar Branch-1 (Zoo)	897	3	No encroachment; uninterrupted flow

table continues next page

Table E.1 Status of 26 Khals under DWASA Jurisdiction *(continued)*

Serial no.	*Khal name*	*Khal size*		*Status (updated to May 31, 2013)*
		Length (m)	*Width (m)*	
	Rupnagar Branch-2 (Arambagh)	1,160	12	No encroachment; uninterrupted flow
	Rupnagar Branch-3 (Duaripara)	823	18	No encroachment; uninterrupted flow
21	Jirani	5,500	9–24	Uninterrupted flow
22	Manda	5,000	9–15	Uninterrupted flow; proposal made to acquire for widening
23	Hazaribagh (including Kalunagar section)	3,000	10–18	Encroachment in Kalunagar section; uninterrupted flow
24	Kashaibari	8,000	10–12	Encroachment; needs to be recovered and re-excavated to facilitate flow
25	Journalist Colony	1,157	9	669 m on private property; proposal sent to acquire land; uninterrupted flow
26	Baishteki	1,280	12	853 m on private property; needs to be acquired; uninterrupted flow

Source: DWASA.
Note: DWASA = Dhaka Water Supply and Sewerage Authority; LGED = Local Government Engineering Department; PWD = Public Works Department; RAJUK = Rajdhani Unnayan Kartripakkha (Capital Development Authority of Bangladesh).

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Intense rainfall floods Dhaka, Bangladesh, one of the world's fastest-growing megacities, year in and year out, and those in the city's slums and shanties are usually the most affected. Low-lying flood plains, rivers, and canals that once drained water are gradually filling up as a result of indiscriminate urbanization and now magnify rather than help solve the problem. The climate outlook for South Asia in the 21st century is heavier and more erratic rainfall during the monsoon season, according to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change and the World Meteorological Organization. Thus, climate change may further aggravate Dhaka's flood vulnerability.

As such, Dhaka needs to better manage its flood drainage infrastructure and strengthen the city's climate-disaster resilience and adaptive capacity. But climate-smart policies require local planners to better understand the likely damage from current flooding, potential damage from climate-related risks, and measures that can be taken to cope with current and future flooding and adaptation costs. *Urban Flooding of Greater Dhaka in a Changing Climate: Building Local Resilience to Disaster Risk* assesses Dhaka's preparedness for urban flood emergencies, estimates probable damage from extreme rainfall events by 2050 with or without climate change, develops structural adaptation measures to cope with current and future flooding, evaluates the reduction in economic damage resulting from implementing these measures, and estimates their cost.

The analysis in this book will help Bangladesh's policy makers take targeted steps to mitigate urban flooding in Dhaka and improve the city's resilience in the face of climate change and variability. Equipped with a host of investment options designed to address current flooding and further climate-proof urban infrastructure, local decision makers will be able to develop realistic, yet effective, strategies that prioritize interventions and sequence activities.

"The topic of this book is right on target and quite timely, particularly in the context of the frequent flooding that Dhaka has been facing. The authors' data-intensive multidisciplinary analysis of the megacity's urban flooding problem with and without climate change, deep insights into the flood-damage risks it already faces, and practical policy recommendations that local decision makers can act on are most welcome. This book will make a real difference."

—Professor Jamilur Reza Choudhury, Vice Chancellor, University of Asia Pacific

"This book meticulously synthesizes hydrological modeling and socioeconomic analysis—a rare practice—to offer a deeper understanding of how to tackle the multifaceted problem of urban flooding. It will be useful for practitioners and academics alike, not only in Dhaka, but also in other megacities of the region now facing similar challenges."

—Professor M. Monowar Hossain, Executive Director, Institute of Water Modelling

"This is the most comprehensive technical analysis of Dhaka's urban flooding problem yet. The authors' down-to-earth recommendations need to be taken seriously. As someone who handles the megacity's flooding and waterlogging issues at the highest level of responsibility, I feel this book is a must-read for government officials and practitioners working to achieve our dream of a flood-free Dhaka."

—Taqsem A. Khan, Managing Director, Dhaka Water Supply and Sewerage Authority (DWASA)

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ISBN 978-1-4648-0710-7

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SKU 210710