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Vulnerability of Kolkata Metropolitan Area to Increased Precipitation in a Changing Climate

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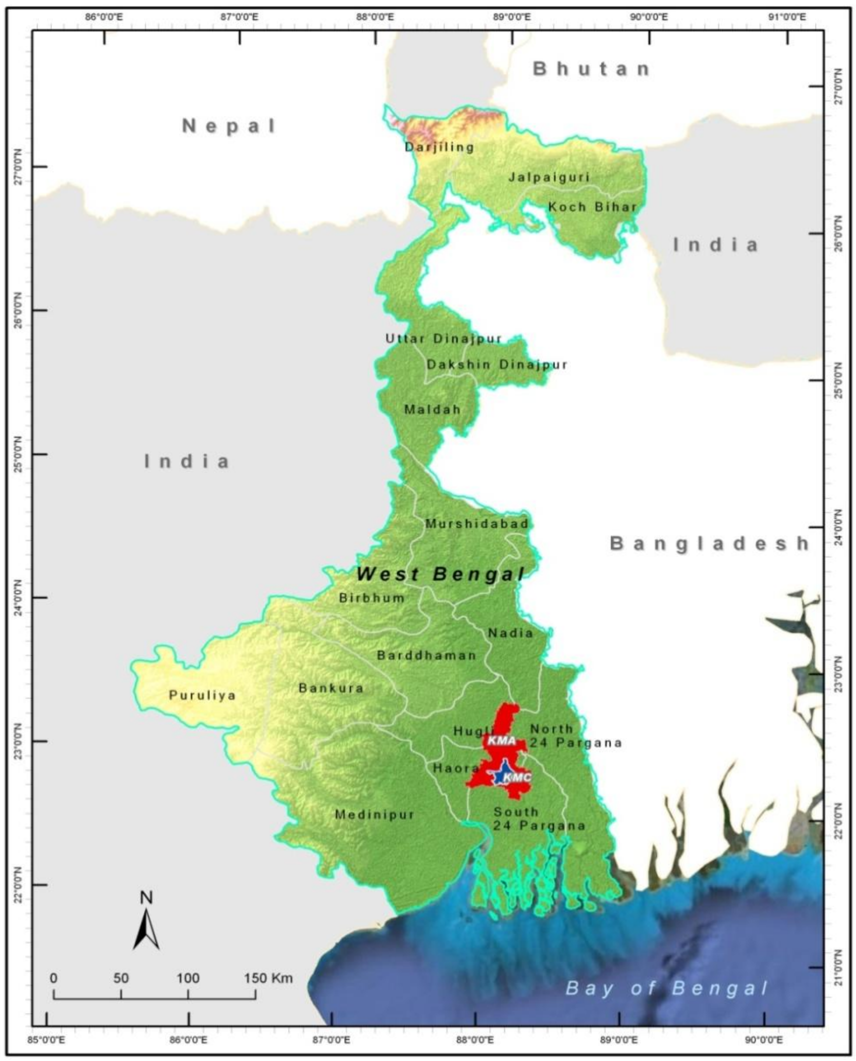
ACRONYMS

ADB	Asian Development Bank
AR4	IPCC Fourth Assessment Report
CC	Climate Change
CMD	Calcutta Metropolitan District
DWF	Dry Weather Flow
EPA	Environmental Protection Agency
GIS	Geographical Information System
HEC-RAS	Hydrologic Engineering Centers River Analysis System
INRM	Integrated Natural Resource Management
IPCC	Intergovernmental Panel on Climate Change
JICA	Japan International Cooperation Agency
JNNURM	Jawaharlal Nehru National Urban Renewal Mission
KEIP	Kolkata Environmental Improvement Project
Km^2	Square kilometers
KMA	Kolkata Metropolitan Area
KMC	Kolkata Municipal Corporation
KMDA	Kolkata Metropolitan Development Authority
KMWSA	Kolkata Metropolitan Water and Sanitation Authority
masl	Meters Above Sea Level
MGD	Million Gallons per Day
MLD	Million Liters per Day
MoEF	Ministry of Environment and Forest
RP	Return Period
SRES	Special Report on Emissions Scenarios
SWAT	Soil and Water Assessment Tool
SWF	Storm Weather Flow
SWMM	Storm Water Management Model
WBPCB	West Bengal Pollution Control Board

Global and Regional Context

Low lying coastal areas are highly vulnerable to flooding. A number of recent studies have shown that coastal areas are vulnerable to a range of risks related to climate change including coastal flooding. Among these coastal areas, the Inter Governmental Panel on Climate Change specifically identifies as hotspots the heavily urbanized megacities in the low-lying deltas of Asia (IPCC, 2007). Within Asian countries, India is particularly vulnerable with its 7,500 km long predominantly low-lying densely populated coastline. The first global assessment of the exposure of port cities lists Kolkata and Mumbai in India among the top ten cities that have high exposure to flooding under the current climate change forecasts (OECD, 2007). The study also shows that exposure will increase in the future and that by 2070 Kolkata is expected to lead the top 10 list in terms of population exposure.



As a response to these potential effects, a regional study to assess the impacts of climate change on major coastal cities in Asia has been undertaken. This work involves the World Bank in collaboration with the Asian Development Bank (ADB) and the Japan Japan International Cooperation Agency (JICA). These three organizations have undertaken four country level studies that will be presented individually and through a joint synthesis report on the main findings. The case studies include those for Manila led by the JICA, Ho Chi Minh City led by the ADB and Bangkok and Kolkata led by the World Bank.

Study Objectives

This study aims to strengthen the understanding of the vulnerability of Kolkata from increased precipitation caused by climate change effects with a specific goal to:

- Compile a data base with past weather related information and damage caused by extreme weather related episodes;
- Determine scenarios most appropriate for assessing the impact of climate change;
- Develop hydrological, hydraulic, and storm drainage models to identify vulnerable areas and determine physical damage estimates resulting from climate change effects;
- Assess monetary, social, and environmental impacts resulting from such climate change events;
- Formulate adaptation proposals to cope with damage arising from climate change effects and explore strategies to mitigate them; and
- Strengthen local capabilities so that the planning process for Kolkata can account for climate related damage effects in future while analyzing all new projects

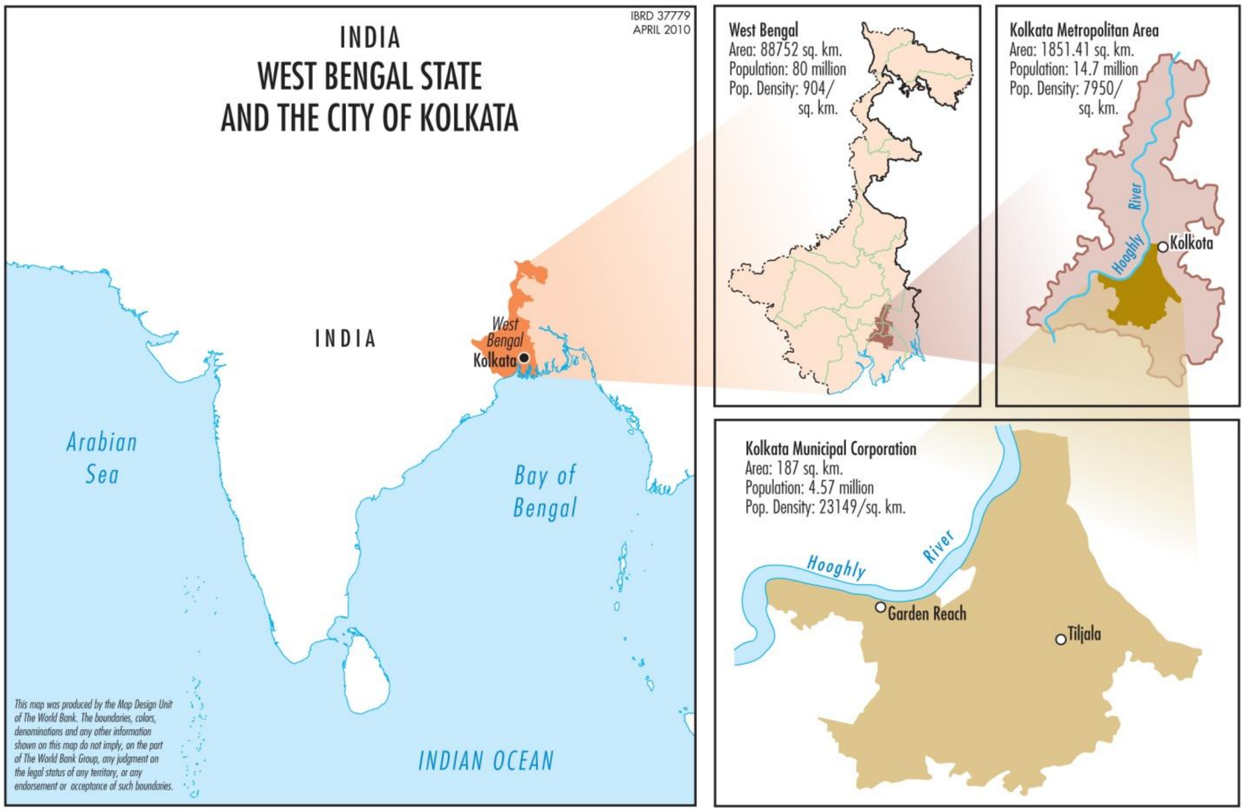
In this study, precipitation events in Kolkata based on available historical rainfall data for 25 years has been considered as a baseline (without climate change) scenario. For modeling climate change, predictions for temperature and precipitation changes in Kolkata in 2050 for A1F1 and B1 emission scenarios from an analysis of 12 GCMs used for the IPCC Fourth Assessment Report were provided by JICA. A sea level rise of 0.27 m by 2050 was also added to the storm surge for the A1F1 and B1 climate change scenarios based on current estimates. All these scenarios (without and with climate change effects) were then modeled to assess the impact in terms of the extent, magnitude, and duration of flooding.

Geographic and Socio-economic Contexts

The geographic area covered in the study is the Kolkata Metropolitan Area (KMA), a continuous urban area stretching in a linear pattern along the east and west bank of the river Hooghly surrounded by some rural areas lying as a ring around the conurbation and acting as a protective green belt. KMA has an area of 1,851 km^2 (square kilometers) and consists of a complex set of administrative entities comprising: 3 Municipal Corporations (incl. Kolkata Municipal Corporation (KMC)), 38 other municipalities, 77 non-municipal urban towns, 16 out growths, and 445 rural areas. KMC, the heart around which KMA has grown, lies along the tidal reaches of the Hooghly and was once mostly a wetland area. The elevation of KMA is within a range of 5 to 11 meters above sea-level (masl). The elevation of KMC area ranges from 1.5 to 9 masl with an average of 6 masl.

KMA features among the 30 largest mega-cities of the world having population in excess of 10 million (United Nations, 2007). As per the 2001 Census, the population of KMA is estimated at 14.7 million, of which KMC accounts for 4.6 million people. The average population density in KMA is 7,950 persons per km^2 while KMC, the more urbanized heart of KMA is denser with a population density of 23,149 persons per km^2. The average per-capita income in KMA in 2001-02 was $341 at 1993-94 prices.

The Study Area



A special characteristic of KMA is its large slum population with more than a third of the total population residing in slums. These slums not only lack basic infrastructure and services but are also the hub of many informal manufacturing activities some of which involve highly toxic industries. Little oversight of such activities is carried out by government agencies. This mixed residential and commercial/industrial character of land use in slums make these areas highly vulnerable to extreme weather related events, especially flooding.

Methodology

The study modeled the impact of climate change on increased flooding in KMA. The main causes of flooding in KMA are intense precipitation, overtopping of the Hooghly River due to water inflow from local precipitation as well as that from the catchment area, and storm surge effects. Land subsidence was not included in the study as it was felt to be a localized problem in only a few pockets. The inputs in the study covered three main sources that aggravate flooding in KMA:

- *Natural factors:* Flat topography and low relief of the area that cause riverine flooding and problems with drainage.

- *Developmental factors:* Unplanned and unregulated urbanization**,** low capacity drainage and sewerage infrastructure that have not kept pace with the growth of the city or demand for services, siltation in available channels, obstructions caused by uncontrolled construction in the natural flow of the storm water, and reclamation of natural drainage areas (marshlands).
- *Climate change factors:* Increase in the intensities of rainfall, sea level rise and increase in storm surge caused by climate change effects.

Firstly, flooding in KMA from intense precipitation was modeled for three scenarios: 30 year, 50 year, and 100 year return period flood events assuming no climate change effects. *Secondly,* the climate change effects were added to the 100 year flood event using the A1FI and the B1 scenarios respectively.

Assumptions about climate changes impact were included as follow: predictions for temperature and precipitation changes in Kolkata in 2050 arising from climate change were provided by JICA (JICA, 2008). It included a temperature increase in Kolkata of 1.8^0C for A1F1 scenario and 1.2^0C for B1 scenario. Precipitation predictions were provided as a fractional increase in the precipitation extremes of about 16 percent for A1F1 and 11 percent for B1 scenario imposed above the baseline distribution of precipitation. A sea level rise of 0.27 m by 2050 was also added to the storm surge for the A1F1 and B1 climate change scenarios based on current estimates. All these scenarios (with and without climate change effects) were then modeled to assess the impact in terms of the extent, magnitude, and duration of flooding.

Models used to determine the extent, magnitude and duration of flooding. Three separate models were used to capture the overall effect of natural, developmental, and climate change factors that lead to flooding in KMA. A *hydrological model* (SWAT model) was used to develop the flow series for the whole Hooghly catchment and the generated data was then fed into a *hydraulic model* (HECRAS model) to analyze the implication of the flood passing through the river stretch. Finally, a *storm drainage model* (SWMM model) was deployed to determine the flooding that will result once the river flooding is combined with local precipitation and drainage capability of the urban area under the extreme flood situation.

Vulnerability analysis. The models provided the increase in depth, duration, and extent of flooding in Kolkata due to climate change effects. However, even the same depth and duration of inundation can have significantly differing impacts on the population and infrastructure depending on the vulnerability of the affected area. So, a separate vulnerability analysis was done to assess the impact of flooding. Since the detailed data needed to do such analysis was available only for the KMC area, this part of the analysis was restricted to only KMC area. The vulnerability analysis was based on three separate indices created based on the depth and duration of flooding, nature of land use, existing infrastructure, and the socio-economic characteristics of the population. Of these, the relevant socio-economic characteristics of the population and the existing infrastructure were combined to develop a *Social Vulnerability*

Index. The outputs from the model that provided the depth and duration of flooding were used to build a *Flood Vulnerability Index*. A *Land-Use Vulnerability Index* was then developed based on the prevailing land-use pattern. Finally, the three separate indices were combined to form a *Composite Vulnerability Index*.

Ward and sub-ward level vulnerability analysis were undertaken. To evaluate the impact from flooding in the KMC area, the vulnerability was first assessed at macro level by taking each *ward* as the smallest unit. This analysis helped identifying the 10 most vulnerable wards that may need specific attention while designing adaptation strategies. Thereafter, to ascertain the vulnerability within each ward in greater detail the analysis was extended to the sub-ward level using spatial data.

Damage assessment. The vulnerability analysis was followed by a separate economic damage assessment. This was also restricted to KMC area as key data used in the analysis were available only for KMC and not for entire KMA. The damage was estimated based on the stock and flow damages. The *stock* damage measured primarily physical damage arising out of water submersion (sectors include residential buildings and property, commercial and industrial establishment as well as major public infrastructure). *Flow* damage includes for example loss of income and increased morbidity, which are primarily linked to the duration of a flood. The damage estimates were based on data extrapolated to KMC population for 2050. However, no additional investments in flood protection measures that may be implemented in future to lower flood damage were assumed in the analysis. Inflation was also not considered, and all estimates were done using 2009 year prices. Damage assessments were estimated for the 100 year flood return period and the A1F1 climate change scenario to determine the additional damage caused by climate change effects.

Adaptation analysis. Finally, a separate analysis was done to examine adaptation measures in KMC that can alleviate some of the problems posed by flooding. The analysis mainly focused on gains from the complete desiltation of trunk sewers by modeling flooding under a completely desilted trunk sewers scenario. Other proposals of building new sewers and upgrading of sewers in vulnerable areas identified by the study were examined. Other infrastructural and non-infrastructural changes including institutional changes that can help cope with future flood damage were also examined.

Main Findings

First finding: The most vulnerable wards to climate change

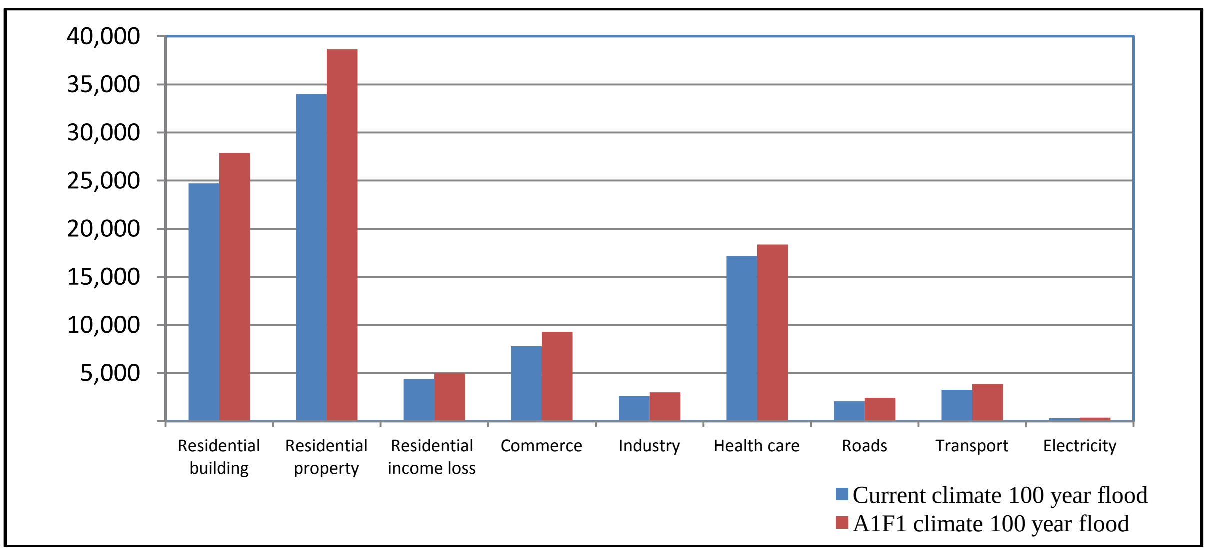
Based on the hydrology, hydraulic and storm drainage modeling as well as on the vulnerability analysis, the study was able to identify the most vulnerable wards to climate change. These wards are: 14, 57, 58, 63, 66, 67, 74, 80, 108 (see Figure 4.2). Of these wards, the vulnerability of 6 wards (14, 57, 58, 66, 67, and 108) in the eastern part and ward 80 can probably be explained by the inadequate infrastructure, unplanned land-use, and poor socio-economic and environmental conditions. The infrastructural problems are getting even worse in recent times with increased building activity as these areas have become attractive to developers after becoming part of KMC.

The other 2 wards (63 and 74) have been identified as highly vulnerable due to their topography. In these wards the capacity of the sewerage systems have not kept pace with the changes in population as the city has evolved. These have been further aggravated by inadequate maintenance as well as the siltation of the existing trunk sewer systems that have considerably reduced their carrying capacity. While the sewer networks in KMC under such partially silted condition still provide reasonable hydraulic capacity for carrying the dry weather flow, they prove highly inadequate for carrying the storm weather flow even with normal precipitation during the rainy season.

Second finding: additional loss likely to occur due to climate change

Overall the study finds that the damage from a 100 year flood will increase by about US$800 million to more than US$ 6.8 billion in 2050 due to climate change (A1F1 scenario). The impacts by sector in India Rupees are shown in the chart below. These are computed at 2009 prices. Local currency is converted to US $ using the Purchase Power Parity index for India of 2.88 (IMF, 2009). The largest component of damage under both the 100 year return period flood and the A1F1 climate change scenario are accounted for by residential property and buildings and health care. Commerce, industry and other infrastructure like roads and transport services also witness significant damage. It is important to note that due to data constraint, some impact could not be quantified in this analysis. Therefore the estimates provided are likely to *understate* the overall impact of climate change.

Total losses in major sectors in KMC (Rs million in 2050)



Third finding: investing in de-silting of trunk sewers will reduce area and population affected by floods.

The study looked at the impact of investing in de-silting trunk sewers both in the town and suburban systems of KMC. The business as usual scenario considers an average 30% silting in trunk sewers. The adaptation scenario considers investing in de-silitng and reducing it to zero. The findings indicate that this simple investment can reduce the area affected by a flood by 4% per cent and the population affected by floods by at least 5%.

Adaptation Measures

The current adaptation deficit. Urban flooding is a recurring phenomenon that Kolkata faces every year during the monsoon period. The local population has learned to adapt by developing a number of coping strategies for facing such periodic episodes of flooding. However, climate change is likely to intensify this problem through a combination of more intense local precipitation, riverine flooding in the Hooghly and coastal storm surges. If such intense precipitations are accompanied by extreme weather events such as cyclones, it can lead to widespread and severe flooding that can bring the city to a standstill for a few days. A major cause of such periodic flooding during the rainy season is the current *adaptation deficit* that Kolkata faces to cope with such recurrent events. This arises not only from deficiencies in physical infrastructure that lead to flooding but also from problems with land-use, socio-economic and environmental factors that can aggravate the impact of such flooding.

Adaptation Strategy. As the impact of flooding is likely to grow in the time horizon of 2050, the city needs a comprehensive and effective strategy that invests in both *soft* and *hard* infrastructure to tackle flooding problems in Kolkata. The goal of the strategy is to (i) reduce the percentage of people affected by flooding and sewage related diseases in KMC; and (ii) target the most vulnerable areas. The strategy should include preparedness both *before* and *during* the event as well as *post*-event rehabilitation strategies.

Investing in hard infrastructure. In order to fulfill the adaptation deficit currently faced by the city investment in hard infrastructure are needed. However the strategy to invest in hard infrastructure should take into account the following:

- The strategy needs to follow a comprehensive approach to planning that recognizes drainage system complexity and interconnectivity of its elements such as storm water drainage, water supply, wastewater, water pollution control, water reuse, soil erosion, and solid waste management.
- A strategy that protects major urban services including roads, traffic, water supply, electricity and telecommunications and that recognized the importance of open space, and green areas as an integral part of city development.
- A strategy that spells out the climate risks and mitigating factors needed in operational

plans for key relevant agencies.

Investing in soft infrastructure. To ensure a longer term financial, institutional and environmental sustainability the adaptation strategy should also include:

- Strengthening of disaster management and preparedness for both pre and post disaster situations.
- Enforcing land use and building codes to reduce obstruction and encroachments of floodplains and environmentally sensitive areas such as canal banks and wetlands and to prevent conversion of green spaces and natural areas that can act as retaining zones during flooding to delay runoffs or reduces their volume through infiltration.
- Introducing sustainable financing for infrastructure investment and maintenance from two angles – cost reduction and cost recovery.
- Increasing the budget for sewerage and drainage maintenance and greater allocation of money for silt removal and mechanical sewer cleaning.
- Adopting flood insurance that incorporate suitable incentives for adaptation and minimize flood damage.
- Strengthening regulatory and enforcement process including improving institutional management and accountability.
- Enforcing pollution management frameworks including introduction of incentives and disincentives to ensure compliance with regulations.

The Government of West Bengal has already started investing in adaptation. Among the suggested adaptation measures, a number of projects are either currently under way or are planned for future implementation in KMA under the Jawaharlal Nehru National Urban Renewal Mission (JNNURM) and the KEIP scheme funded by ADB. The selection and prioritization of projects for adaptation have to be made based on cost benefit analysis using the net present value (NPV) approach. Factoring in the additional impact due to climate change in such cost benefit analysis may render many projects - that did not show an adequate return on investment earlier- economically viable.

Chapter 1. INTRODUCTION

1.1 BACKGROUND

1.1 **Recent climatic events have illustrated that coastal areas are vulnerable to a range of risks related to climate change.** The Inter Governmental Panel on Climate Change (IPCC) specifically identifies as hotspots the heavily urbanized megacities in the low-lying deltas of Asia (IPCC, 2007). Among Asian countries, India is particularly vulnerable with a 7,500 km long coastline that is predominantly low-lying. These coastal areas are also densely populated with about 130 cities, including megacities such as Mumbai, Kolkata, and Chennai. Most cities in India contain large and densely populated conglomerations of slums and shanties that are invariably located in areas most vulnerable to flooding. Indeed, flooding is a recurrent annual feature following the monsoons in these cities. Such flooding conditions and associated impact caused by weather related events may dramatically worsen into disasters with the addition of the increased risk of storm surges, cyclones, and intense precipitation induced by climate change effects.

1.2 **Potential climate changes are likely to cause an increase in the frequency and intensity of these natural disasters.** Anticipated risks include an accelerated rise in sea level of up to 60 cm or more by 2100[1], a further rise in sea surface temperatures by up to three degrees centigrade, an intensification of tropical cyclones, and large extreme waves and storm surges. According to the first global assessment of the exposure of port cities to coastal flooding and likely climate change impact on this flooding (OECD, 2007), Kolkata and Mumbai feature in the top ten cities with the maximum exposure to flooding under the current situation. In fact, the study shows that the exposure only increases by 2070 when Kolkata is expected to lead the top 10 list in terms of population exposure. Although there is considerable uncertainty in the estimation of risks posed by climate change, it is increasingly apparent that cities, particularly those located in low-lying coastal areas, such as Kolkata, need to manage and adapt to those risks as part of their broader planning processes.

1.3 **Adaptation to face the challenges posed by climate change is critical.** While a number of cities are taking steps to mitigate their carbon footprint, there has been relatively less attention on how developing country cities can adapt and respond to climate change risks. Given the ever-increasing urbanization and the importance of cities as drivers of economic growth, the need for adaptation measure at the city level is even more critical, especially to address the vulnerability arising out of informal labor markets and unorganized income generating and production sectors. Furthermore, the characteristic features of many developing country urban areas include large concentrations of population, unplanned and unregulated development with scant attention to environmental issues or building standards, and limited infrastructure and service delivery (such as

[1] Estimates regarding sea level rise vary. A recent *Science* article estimates increases ranging from 80 cm to 200 cm by the end of the century. See http://Sciencenow.Sciencemag.org/cgi/content/full/2008/904/1?etoc

poor drainage, limited solid waste collection, etc.). These pose additional significant challenges to adaptive responses to extreme events.

1.2 OBJECTIVE

1.4 **As a response to these potential effects, a regional study to assess the impacts of climate change on major coastal cities in Asia has been undertaken.** The objective of this work is to improve the understanding of climate change risk to coastal cities and identify potential measures that would help the affected populations adapt to these risks. This work involves the World Bank in collaboration with the Asian Development Bank (ADB) and the Japan International Cooperation Agency (JICA). These three organizations are undertaking four country level studies that will be presented individually and through a joint synthesis report on the main findings. The case studies include those in Manila led by JICA, Ho Chi Minh City led by the ADB and Bangkok and Kolkata led by the World Bank. In all these studies, there is a special emphasis about the impact on the poor and marginalized segments of society, with respect to social, environmental, and economic aspects. The three broad area of focus of the individual city case studies are to:

- Establish a climate change related historical knowledge base for use in the city specific impact analysis and adaptation strategy formulation as well as to raise public awareness;
- Define and evaluate the impacts of climate change (from social, economic, and environmental viewpoints) on the basis of stylized scenarios for the city; and,
- Help formulate city level strategies for implementation in the short-, medium-, and long-term to make adaptation and coastal zone development plans more robust with inclusion of climate change effects, thus enhancing the resiliency of natural and physical systems.

1.5 **The Kolkata case study presented in this report is an important component of these series of case studies.** This study aims to strengthen the understanding of the likely economic, social and environmental impacts of climate change on the city of Kolkata with a specific goal to:

- Compile a data base with past weather related information and current resources in place designed to cope with extreme weather related episodes;
- Determine scenarios most appropriate for assessing the impact of climate change;
- Develop hydrological, hydraulic, and storm drainage models to identify vulnerable areas and determine physical damage estimates resulting from climate change effects;
- Assess economic, social, and environmental impacts resulting from such climate change events;
- Formulate adaptation proposals to mitigate damage arising out of climate change effects
- Strengthen local capabilities to assess climate related damage so that the planning process in the Kolkata Metropolitan Area (KMA) and the government can account for such data in all future projects

1.3 SCOPE

1.6 **The analysis focuses on urban flooding due to (i) increases in extreme precipitation, (ii) sea level rise and (iii) storm surges arising from climate change**.

The scope of the study includes:

- Increased precipitation in Kolkata that can lead to flooding and water-logging due to inadequate sewerage and drainage facilities.
- Riverine flooding in the Hooghly from the simultaneous increased precipitation in the upstream of the Hooghly River that can result in increased water flow in the river basin adjoining Kolkata and its surrounding areas.
- Storm surge arising out of cyclone and other storm activity.
- Sea level rise as these can cause higher water levels in the Hooghly thus exacerbating the flooding.

The study therefore assumes that flooding, whether from urban storms, cyclones, increased precipitation in the larger Gangetic watershed that translates into riverine overflows, and sea surges from storm surge as well as sea-level rise, is the key causal factor for damage of urban infrastructure and loss of livelihoods resulting from weather events.

The scope of the study does not include:

- Increased flooding from other possible extreme events like tsunamis that require specialized oceanic modeling.
- Direct wind damage from increased cyclone and other storms.

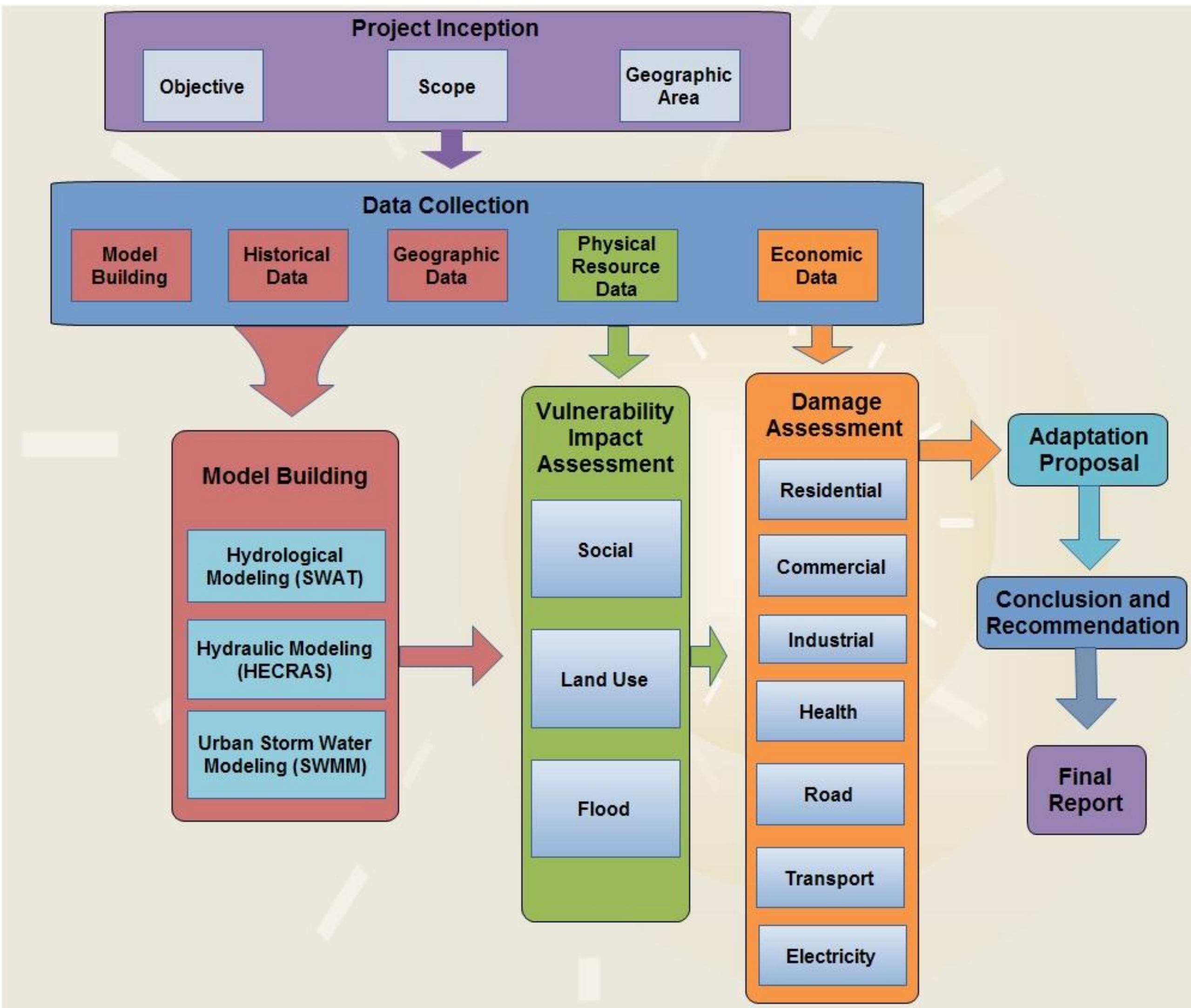
1.7 **The geographical area covered under the scope of this study was determined as Kolkata Metropolitan Area –** the heart of the urban area with considerable ongoing and projected development. KMA accounts for an area of about 1,851 km^2 and consists of 3 Municipal Corporations (incl. Kolkata Municipal Corporation), 38 other Municipalities, 77 non-municipal urban towns, 16 out growths, and 445 rural areas. Flooding in the KMA area arises from a cumulative effect of local precipitation and riverine flooding from Hooghly River. This flooding situation can get extremely severe when local flooding conditions combine with riverine flooding and storm surges[2]. However, in the case of KMC, flooding is usually caused only by intense local rainfall or urban storms. This is primarily a function of the urbanization and the condition of sewerage networks in the city that intensify the flooding event.

[2] This would be like the 'perfect storm' where river overtopping combines with local intense urban storms (perhaps related to the precipitation event in the larger watershed or a cyclonic event), storm surges and high tides. This would result in rapid and increased flooding in KMC with few areas for outflow (particularly if the storm drains flowing into the Hooghly are shut to prevent storm surges entering the city), thereby likely resulting in more flooding and a longer period of water retention.

1.4 APPROACH AND METHODOLOGY

1.8 **The study has been carried out in a number of phases.** Figure 1.1 below provides the workflow of the methodology used for the study. Once the scope and the project area for the study were identified, relevant information that could prove useful for future modeling and analysis was collected by Integrated Natural Resources Management (INRM), the principal consultants for the study. The counterparts for the study in the Government of India include the Ministry of Environment and Forestry (MOEF) at the Federal level and the West Bengal Pollution Control Board (WBPCB) at the State level. Detailed modeling of the effects of climate change as it relates to increased precipitation and water flow was carried out next to assess the likely extent and duration of inundation in the study area.

Figure 1.1 Workflow methodology for climate change impact assessment in Kolkata



1.9 **Emission Scenarios.** The uncertainties of possible future climate change conditions mandate the use of a range of scenarios while conducting impact studies. The IPCC Special Report on Emission Scenarios (SRES)[3] categorizes the possible future climate change effects into four broad scenarios (Table 1.1). The current study focuses on two of those scenarios, the **A1F1 and B1 as these represent two extreme scenarios and the other scenarios will be somewhere in between**. In the A1 scenario the story-line involves a rapid economic growth, low population growth and a convergence of income and way of life between regions. The A1 scenario develops into 3 groups that describe alternative directions of technological change in the energy system. The three A1 groups are: fossil intensive (A1F1), non fossil energy sources (A1T) or a balance across all sources (A1B). The scenario with fossil intensive (A1FI) scenario is chosen as the scenarios for the study. The B1 scenario assumes low population growth with development taking place in an environmentally sustainable manner using clean and resource efficient technologies that place emphasis on global solutions to achieve economic, social, and environmental sustainability.

Table 1.1 Summary of IPCC emissions scenarios

A1 Scenario World: Convergent world Economy: Market oriented, rapid economic growth Population: Peaks in 2050 and then gradually declines Governance: A convergent world in which regional average income per capita converge, current distinction between “poor” and “rich” countries eventually dissolve. Energy: There are three subsets to the A1 family **A1FI** – Fossil fuels intensive A1B - Balanced on all energy sources. A1T - Non- fossil energy sources.	**A2 Scenario** World: Differentiated world Economy: Regionally oriented, lowest per capita income Population: Continuously increasing population Governance: Independently operating, self-reliant nations Technology: Slower and more fragmented
B1 Scenario World: Convergent world Economy: service and information based, lower growth than A1 Population: Same as A1. Governance: Global solutions to economic, social and environmental stability Technology: Clean and resource efficient technologies	**B2 Scenario** World: Differentiated world Economy: Intermediate levels of economic development Population: Continuously increasing population, but at a slower rate than in A2. Governance: Local solutions to economic, social and environmental stability Technology: more rapid A2, less rapid more diverse A1/B1

Source: Nakicenovic, N. et al (2000)

1.5 PREPARATION PROCESS

1.10 **Building local capacity.** One of the key tasks within the study process was to ensure capacity building of the local departments involved in the study, particularly on the analysis and the modeling aspect. Accordingly, steps were taken to involve representatives from the local agencies

[3] Nakicenovic, N. et al (2000)

on a continuing basis throughout the course of the study. In an inception meeting, the team of consultants conducting the analysis made presentations before local government stakeholders about the approach of the study. Officials from the WBPCB, the Institute of Wetland Management and Ecological Design, and a number of specially identified agencies, departments and organizations attended that meeting. Opportunities were also created for these representatives to interact with the study team at various points during the timeline of the study. The many valuable suggestions received from the participants during such discussions were duly incorporated in the final study.

1.11 **Specific training was also provided about the modeling.** A training workshop was held in Kolkata during the mid-course of the study (February 20-21, 2009). The training was attended by members of the *climate change cell* in WBPCB as well as by various government departments identified as key stakeholders for this study. The workshop covered all the models namely, SWAT (Soil and Water Assessment Tool) hydrological model, HECRAS (Hydrologic Engineering Centers River Analysis System) hydraulic model, and SWMM (Storm Water Management Model) urban hydrological model. Besides presentations on the theoretical background of these models, live demonstrations were made using the data of the Kolkata case study. All the models were loaded[4] on the computers in the WBPCB along with the appropriate databases of Kolkata. This will enable future refinement of the modeling and analysis by local officials as improved data becomes available. Besides the live running of the models, the background material and manuals were installed on the systems. Specialized tutorials were also formulated using the Kolkata case study and were used for hands-on sessions by the participants. These databases and the various scenarios used under alternative model runs were subsequently updated on the occasion of a later interaction with the members of the *climate change cell*.

1.6 ORGANIZATION OF THE REPORT

1.12 **The report consists of two primary segments, the main report and a set of annexes.** The main report consists of six chapters and an executive summary. Chapter 1 is an introduction to the study while the Chapter 2 describes the study area with historical background information. Model development and simulation to determine the timing and magnitude of floods of different return periods used for flood hazard analysis is covered in Chapter 3. Chapter 4 describes methodology to determine vulnerability of the area and subsequently provides analysis utilizing the results of the flood modeling to identify areas, populations, and facilities that are vulnerable to flood hazards. Chapter 5 presents the damage assessment. Chapter 6 covers local institutional capacity, details of ongoing projects addressing possible mitigation, local coping strategy and adaptation options. Details of all the simulation models used for the study and complete scenario results are presented as Annexes.

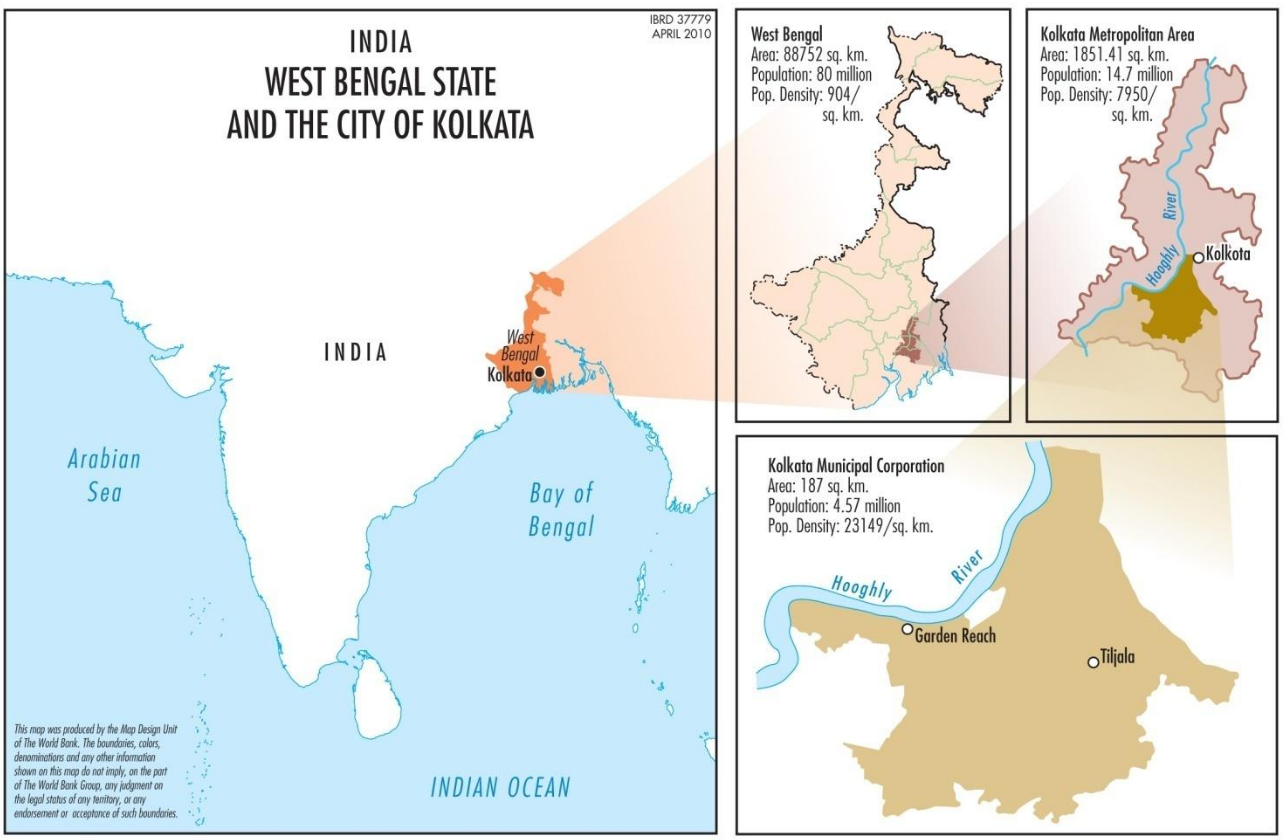
[4] All these models are public domain models and thus do not require licenses for use.

Chapter 2. KOLKATA – A - PROFILE

2.1 GEOGRAPHIC AND PHYSIOGRAPHIC CHARACTERISTICS OF THE STUDY AREA

2.1 **Administrative boundary of Kolkata Metropolitan Area.** Kolkata, earlier known as Calcutta, the capital of the State of West Bengal in India, first started as a British trade settlement. The city of Kolkata is one of Asia's largest urban centers. Kolkata urban agglomeration, called Kolkata Metropolitan Area (KMA), has continuously expanded over the years and presently extends over 1,851 km^2. It consists of a complex set of administrative entities comprising: 3 Municipal Corporations (incl. Kolkata Municipal Corporation), 38 other Municipalities, 77 non-municipal urban towns, 16 out growths, and 445 rural areas (Annex A). Kolkata Municipal Corporation has an area of 185 km^2 and is divided into 141 wards.

Figure 2.1 The study area



2.2 **The study area focuses on KMA as defined in the Vision 2025 document.** The study area of this report was adopted in order to benefit from other ongoing government programs like the Jawaharlal Nehru National Urban Renewal Mission (JNNURM, 2005). However, given the paucity of available data for the entire KMA for all aspects of the study, some of the more detailed vulnerability and damage analysis were confined to KMC.

2.3 **KMA's physiographic location is** between $22^0$19' N to $23^0$01' North Latitude and $88^0$04' E to $88^0$33' East Longitude and within that KMC is located between 22^0 37' N to $22^0$30' North Latitude and $88^0$23' E to $88^0$18' East Longitude (Figure 2.1). The KMA is made up of a continuous urban area stretching in a linear pattern along the east and west bank of the river Hooghly surrounded by some rural areas lying as a ring around the conurbation and acting as a protective green belt. Within KMA, the KMC lies along the tidal reaches of the Hooghly and was once mostly a wetland area. Reflecting its previous character, a number of natural depressions remain; many of which are dead river channels. The remaining wetlands, known as the East Calcutta Wetlands have been designated as a "wetland of international importance" under the Ramsar Convention. While Kolkata is often perceived as a coastal city, in reality it is about 145 km away from the Bay of Bengal.

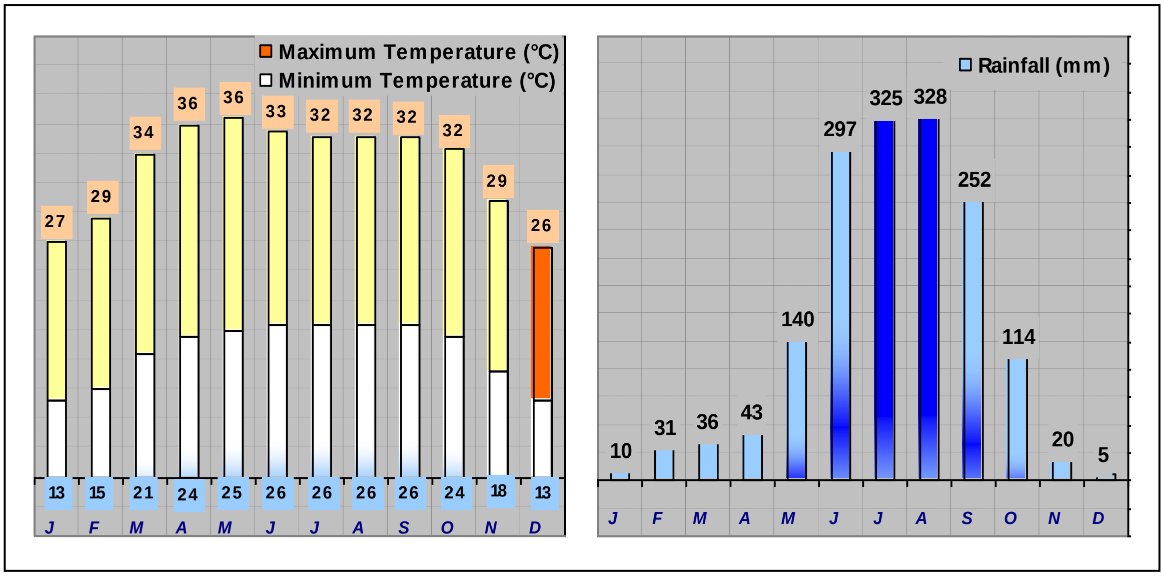
2.4 **The slope and the transformation of the marshy eastern land into an urban sprawl have made drainage inevitably difficult for Kolkata.** The elevation of KMA is within a range of 5 to 11 meters above sea-level (masl) with an overall average of about 8 masl. The elevation of KMC ranges from 1.5 to 9 masl with an average elevation of 6 masl. The overall slope in KMC is from north to south and from west to east - from the east bank of the Hooghly River to the Salt Lakes. The highest parts of KMC lie along the eastern bank of the Hooghly River. The land slopes downward steeply in the northern side while in the southern side, the slope is more gradual. The riverside levee is the highest part of the city. At Garden Reach on the riverside, the levee is nearly 7 masl. Towards Tiljola on the eastern fringes, the height of the levee comes down to less than 3 masl (Bhattachrya, M. 2008).

2.5 **Geologically, the area in KMA forms a part of the Bengal Basin** and is underlain by Quaternary sediments of fluvio-deltaic origin consisting of a succession of clay, silt and sand of varying texture from fine to coarse grain size (Chaterji et al., 1964). The principal water bearing horizons occur at depths between 60 and 180 m in medium to coarse sand and pebble layers (Biswas & Saha, 1985). The overlying clay layers with wood stumps and peat beds are highly compressible that can lead to land subsidence during over extraction of groundwater (Chatterjee et al., 2006).

2.2 CLIMATE

2.6 **The region around KMA is subject to short, high intensity precipitation, especially during the monsoon months.** This along with occasional coincidence of high tide is the usual source of urban flooding. KMA has a tropical wet-and-dry climate with an annual mean temperature of 26.8^0C and monthly mean temperatures in the range of 19-30^0C (Figure 2.2). The area receives most of its rainfall from the South-West monsoon between June and September. The annual rainfall is about 1,600 mm and the highest rainfall usually occurs during the monsoon in the month of August. The study of storm patterns (KEIP, 2007) revealed that peak rainfall intensities occur anywhere between 15 to 180 minutes after the start of rainfall and such storm events often occur two or more times in a day during the monsoon.

Figure 2.2 Mean monthly temperature and rainfall in KMA

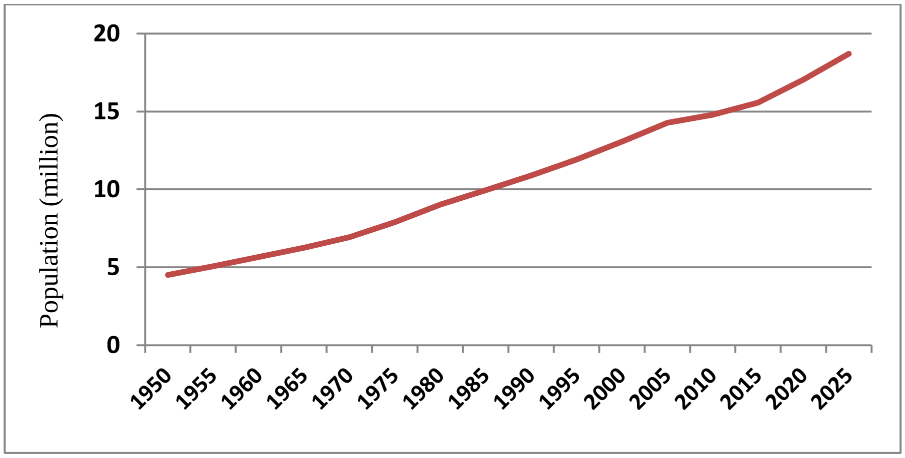


2.3 DEMOGRAPHY

2.7 **KMA features among the 30 largest mega-cities of the world** having population in excess of 10 million (United Nations, 2007). As per the 2001 Census, the population of KMA is 14.72 million, of which KMC accounts for 4.6 million people. Average population density in KMA is 7,950 persons/ km^2. KMC, the more urbanized heart of KMA is denser with a population density of **23,149 persons/ km^2** as it accounts for 31% of KMA's population with only 10% of its area. Population growth rate of KMA has been in the 1.8-2.6% range. KMA population is projected to rise to 17 million in 2011, 20 million in 2021, and 21.1 million in 2025[5] (Figure 2.3). Although population growth rate in KMA shows a declining trend, the absolute size of the population and its high density continue to pose challenges to urban growth. In addition, the urban continuum around the cities of Kolkata and Howrah in KMA area is continuing to grow and may have its impact on the projected population for KMA (Annex A).

[5] http://www.kmdaonline.org/html/about-us.html Official website of the Kolkata Metropolitan Development Authority

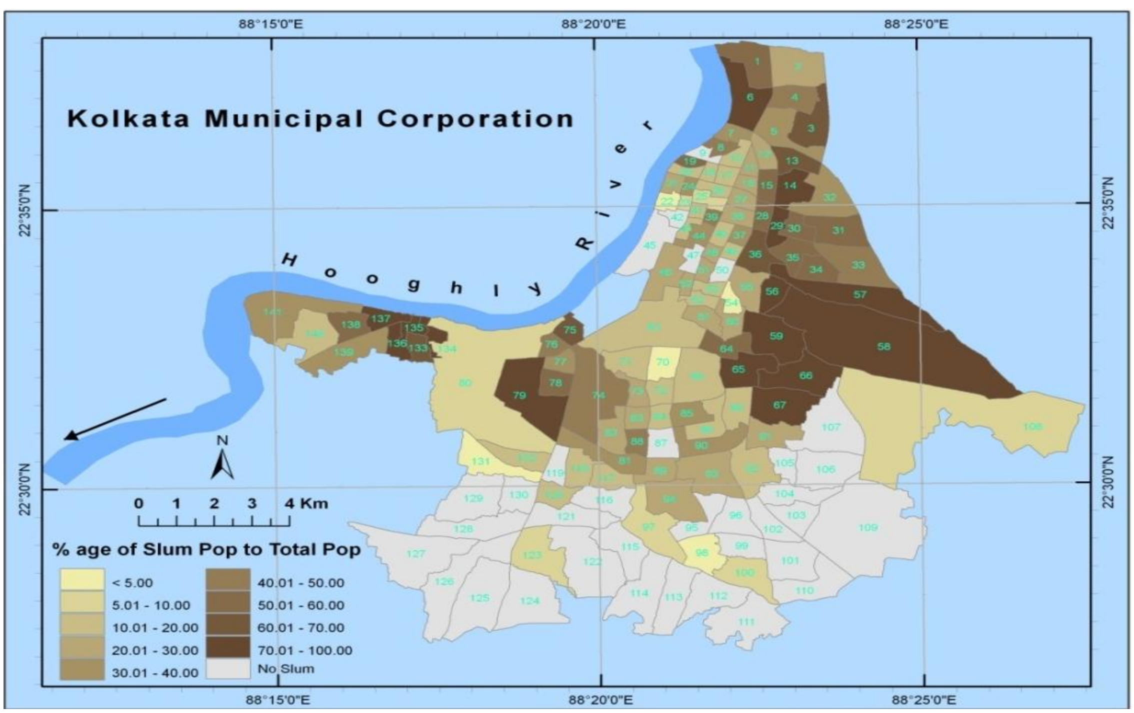
Figure 2.3 Population growth in KMA (1950-2025) in millions



Source: United Nations, World Urbanization Prospects: 2007

2.8 **A special feature of the population of KMC is its large share of slum population that increases its vulnerability to natural disasters**. More than a third of the population of KMC resides in slums. The area under KMC has 2,011 registered, and 3,500 unregistered slums. Spatial concentration of slum population in KMC area is shown in Figure 2.4. Six wards (Numbers 58, 29, 137, 134, 65, 135) out of the 141 wards in KMC have slum population in excess of 90 % (Annex A shows the characteristics of these 6 wards). The increasing population pressure, dense urban environment and low coping capacity of population living in slums make these wards some of the most vulnerable parts of the city.

Figure 2.4 Spatial distribution of slum population in KMC



Source: Census of India, 2001

2.4 ECONOMY

2.9 **KMA has witnessed a rise in the secondary and tertiary sectors over time.** KMA has witnessed a fall in the share of primary sector (largely agriculture) and an increase in the secondary (industrial) and tertiary (services) sectors. Manufacturing industries and construction activities constitute the core of secondary sector activities in the metropolitan area and the banking, insurance and transport sub-sectors constitute the core tertiary sector. The jute textile industry has been traditionally dominant in KMA and is the largest in the country. Table 2.1 shows the growth rate of *State Domestic Product* that reflects the recent trends of structural changes in the economy of KMA.

Table 2.1 Annual average growth rate of state domestic product for KMA & West Bengal

	KMA		**West Bengal**	
Sectors	Average Annual Growth (%)		Average Annual Growth (%)	
	1985-86 to 1993-94	1993-94 to 2001-02	1985-86 to 1993-94	1993-94 to 2001-02
Primary	1.58	-4.79	5.62	4.18
Secondary	1.81	5.71	4.92	6.36
Tertiary	3.8	11.06	8.42	9.5
Total	2.96	9.04	6.51	7.13

Source: JNNURM, 2005

2.10 **The majority of industries are concentrated in KMC (68%) and Howrah Municipal Corporation (14%)**. The important industries in KMC are jute manufacturing, light and heavy engineering, leather products, textiles, paper, pharmaceuticals, chemicals, tobacco, food products, glass products, and electrical and electronic products. Of the approximate 9,000 industries in KMC about 1% are categorized as large, 3% as medium, and the remaining 96% as small scale industries[6].

2.11 **Industries have been categorized according to their pollution potential.** Figure 2.5 and their location is depicted in the ward using the respective categories. West Bengal Pollution Control Board have categorized[7] all industries in descending order of their pollution potential as Red (like Jute processing with dyeing, Tanneries, metal smelters), Orange (like Automobile servicing, repairing and painting, Hotels & Restaurants, Pharmaceutical formulation) and Green (Acid lead battery, Leather cutting and stitching, Power looms without dyeing and bleaching). Based on these classifications, there are 18% red, 31% orange, and 51% green industries in the KMC area. An inset in the top right corner of figure 2.6 depicts the category wise composite number of these industries in some of the selected wards with large number of industries. The yellow hue used in the wards depicts the total number of industries present in the ward.

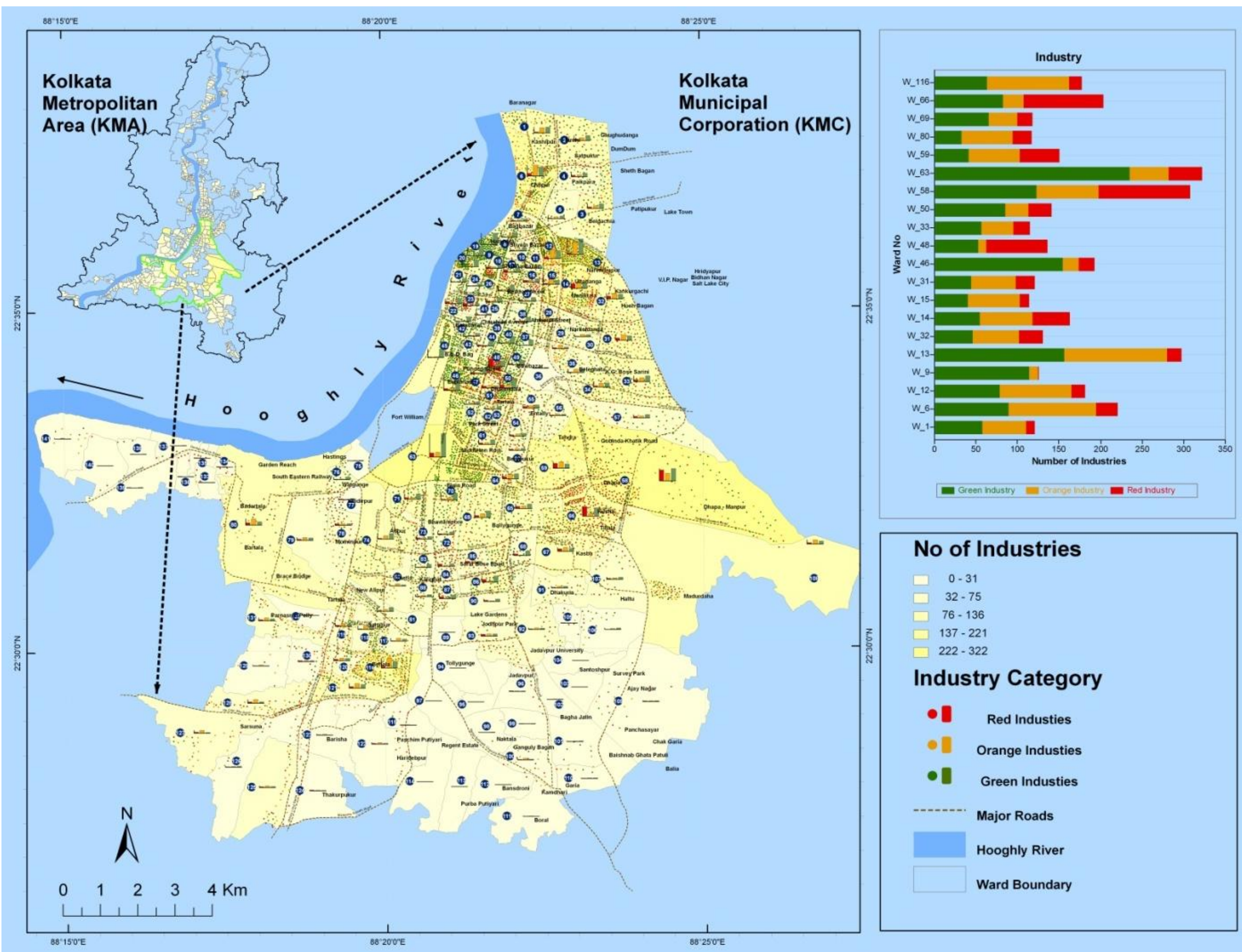
[6] A small scale industrial unit has investment in fixed assets of less than Rs 10 million. The large scale industries are defined by the category of industries.

[7] Depending upon the pollution potential of different industries, the West Bengal Pollution Control Board has classified the industrial units into three different categories: *red*, *orange* and *green*. The *red* category units have maximum pollution potential, the *orange* category units have moderate pollution potential and the *green* units have the least pollution potential.

2.12 **Economic profile of KMA.** An analysis of the economic profile of KMA under JNNURM indicates that:

- The average per-capita income for 2001-02 in KMA was Rs.15, 281 (at 1993-94 prices).
- Value added in the manufacturing sector has increased significantly in recent years (net value added by factories showed an increase of about 31.5% per year between 1990- 1998 compared to 10.5% between 1985-1991).
- There appears to be an increased emphasis on capital-intensive or labor-saving technologies within manufacturing processes (labor-output ratio has fallen from 0.79 in 1985-86 to 0.19 in 1996-97)
- Growth **industries** include drugs and pharmaceuticals, electrical and electronics, leather and rubber, metallurgical (excluding steel), plastic, IT software, telecom, and textiles (jute, wool, silk, readymade garments, etc.). **Sectors** such as manufacturing, engineering (forging, metallic articles, machinery, generators, transformers, electric motors, ships and vessels and related accessories, etc.), construction (real estate and infrastructure development), and transport have also observed a high growth rate.

Figure 2.5 Industries in KMA and KMC

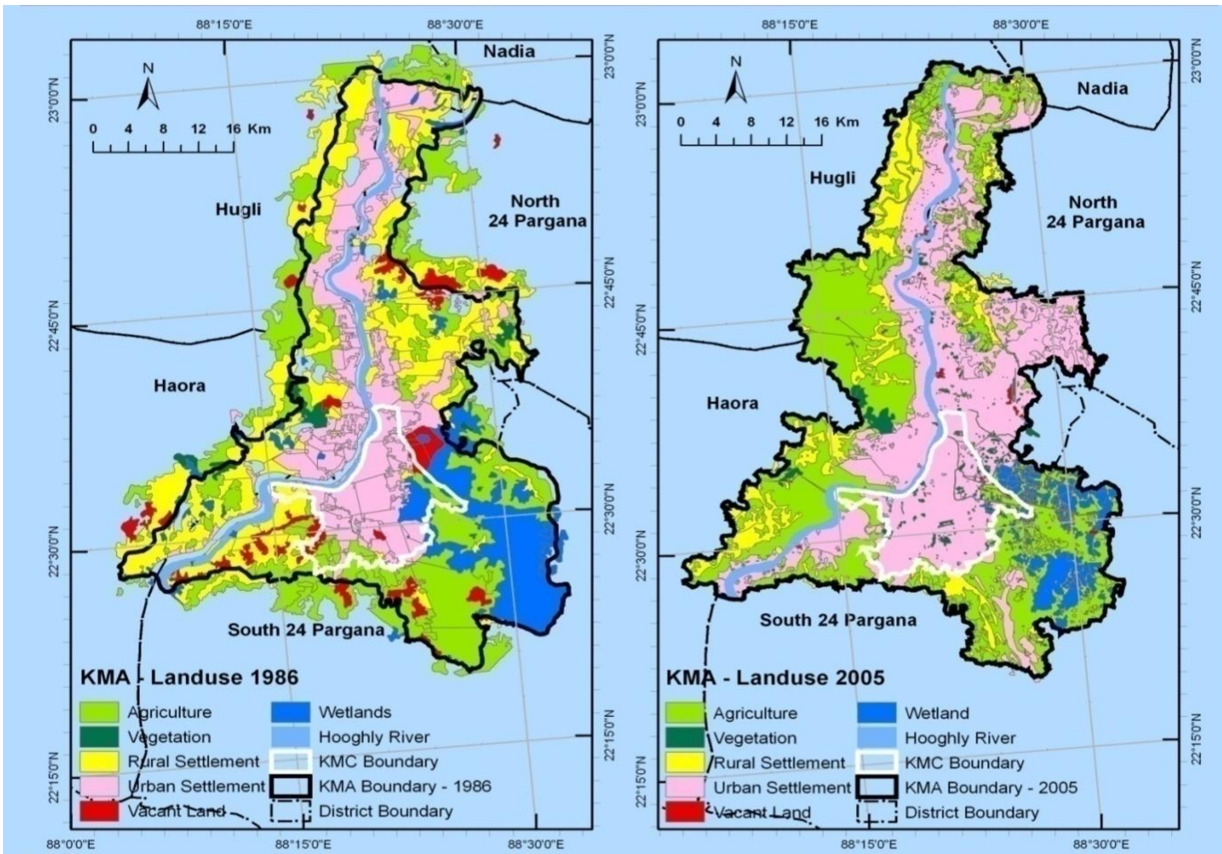


Source: Data collected and computed by Mr. Tapas Ghatak during the preparation of this study

2.5 LAND USE

2.13 **Urban built up land constitute 54.2% of the total area of KMA** with the remaining under non-urban use. Among urban uses, residential use is pre-dominant (31.2% of total area), followed by industrial, transportation, public and recreational uses (14.7% of total area) and the remaining is under mixed built up land use (8.3% of total area). Figure 2.6 depicts the changes in land use between 1986 and 2005.

Figure 2.6 Changes in land use pattern between 1986 and 2005 in KMA



Source: Data collected and computed by Mr. Tapas Ghatak during the preparation of this study

2.14 **Existing land use pattern in KMC is even more urban reflecting 300 years of organic growth**. The city of Calcutta, as described by Kipling, was: "*chance directed and chance erected*." The description is apt and relevant because of the challenges presented by its location and its exposure to flooding. The land over which urban expansion have occurred were earlier mostly marshlands or wastelands requiring reclamation. Various organizations have progressively converted the wetlands over time for urban use. The Calcutta Improvement Trust reclaimed considerable area to the east and south, and developed planned colonies for residential purposes. With almost nonexistent land-use planning or control, the bulk of land use reflects mixed use. Both residential and non-residential uses co-mingle in most areas with little or no demarcations. In KMC area, residential or mixed residential accounts for 68% of land use followed by 9.5% for open space and parks, 6% for industrial, 5% for commercial, 4% for agriculture, and 3% for transportation and storage.

2.15 **Slums in KMC are a hub for many informal manufacturing sectors** some of which involve highly toxic industries producing acids and chemicals. Little oversight of such activities is done by government agencies with only some limited purview by the pollution control agency. This highly **mixed** residential and commercial/industrial character of land use in KMC is challenging for the assessment of flood vulnerability and required careful handling within the modeling.

> **Reducing pollution by relocating tannery industries**. A positive example of pollution control in the industrial sector is the effort to relocate tanneries. It was earlier located on the eastern fringes of the city. Because of its highly polluting effluents, the tannery industry is being relocated in a well designed Leather Complex 15 km from Kolkata at Bantala (CPCB, 2005). The complex can house 1,500 leather units spread over an area of about 4.5 km^2. The complex has the capacity to process about 1,000 metric tons per day of raw hide that can generate about 30 million liters per day (MLD) of polluted liquid effluents. Six modules of Common Effluent Treatment Plant with a capacity of 5 MLD each have been constructed in that facility. The treated effluent is then discharged to a storm water channel that meets the Kulti river at a distance of about 14 km from the area. The Kulti river also receives sewerage and other storm water discharge from Kolkata and ultimately flows into the Bay of Bengal.

2.6 INFRASTRUCTURE

2.16 **Limited and outdated infrastructure in KMA pose the biggest challenge to cope with climate change related impacts.** The following provides an overview of the transport, water supply, sewerage and drainage networks in KMA.

2.6.1 Transport

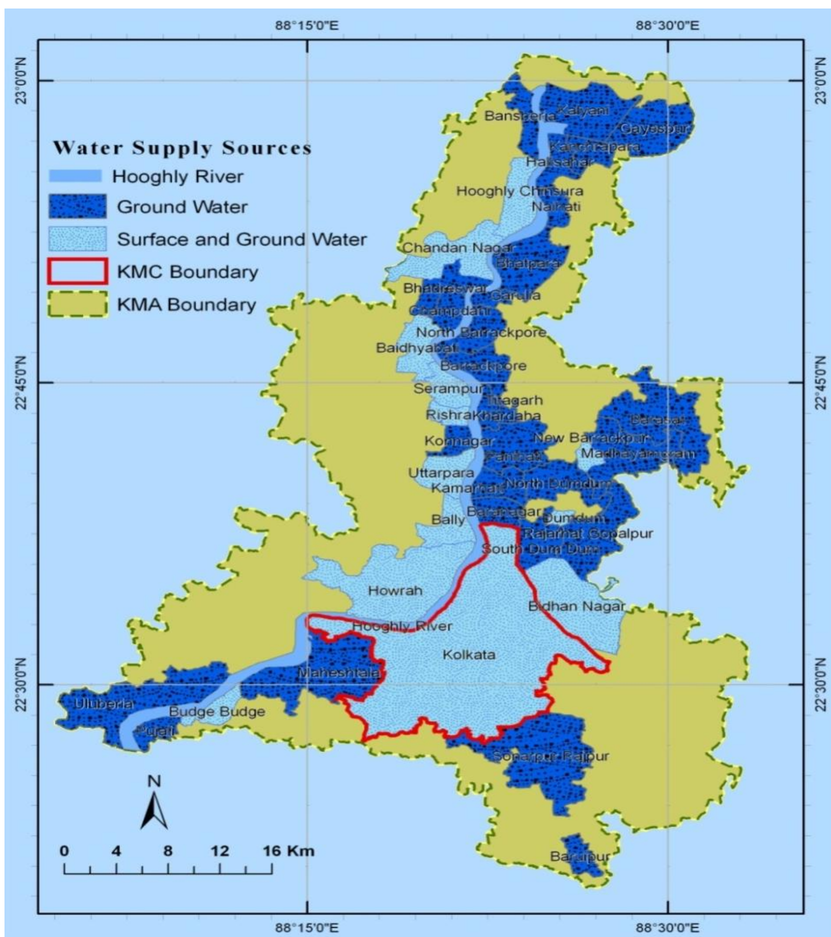
2.17 **The inadequate transport system in KMA leads to extreme overcrowding, especially during peak traffic periods.** The road space in Kolkata, at 6 percent of the total area, is woefully inadequate. As a result the vehicle density in Kolkata is at a very high level of 345 vehicles per km and is subject to frequent traffic snarl-ups. The total road length of the highways and arterial roads within KMA is about 500 km. Of this, 400 km are in the metropolitan centers of KMA and 100 km in rest of KMA. Four national highways criss-cross the area. Other roads include 18 state highways and/or district link roads, 16 metropolitan highways, and 40 major arterial roads. The total length of surfaced and un-surfaced roads in KMC is 1,680 km. More than 21 million passengers avail of various modes of transportation on a daily basis in the KMA area. The multi-modal transport system consist of surface transport system of buses, minibuses, trams and para-transit (taxis, trekkers, auto rickshaws, cycle rickshaws, and cycle vans), railways including underground Metro network, and passenger ferry services.

2.18 **Kolkata Port is the oldest major port in the country.** It serves a vast hinterland that comprises almost half of the Indian states (whole of the eastern and north-eastern regions) and the two neighboring countries - the Himalayan Kingdoms of Nepal and Bhutan. The Kolkata Dock System handled traffic of 12.4 million tons in 2008-2009.

2.6.2 Water Supply

2.19 **Surface water from the River Hooghly is the primary water supply source within KMA.** The Sector Committee on Water Supply of the Kolkata Metropolitan Planning Committee has fixed a supply norm of 50 gallons per capita per day (gpcd) in KMC, 40 gpcd in Howrah Municipal Corporation, and 35 gpcd in other Municipal and Non-Municipal areas. Based on this the daily water supply needs for KMA is 600 million gallons per day (MGD) of which KMC accounts for 360 MGD. Table 2.2 presents water supply plants serving the KMA. The current filtered water supply capacity using surface water from the Hooghly is only 421.60 MGD. Taking into account the average utilization of the existing capacity, KMA faces a supply deficit of filtered water of about 250 MGD. This is partially met through pumping of ground water using deep tube wells with average yield of 135 MGD (Figure 2.7). Augmentation process for another 142.50 MGD using surface water sources is going on at present to meet the current shortfall.

Figure 2.7 Spatial distribution of water supply sources in KMA



Source: Data collectedby Mr. Tapas Ghatak for the preparation of this study

Table 2.2 Surface water supply plants and locations served in KMA

Name of the Plants	Latitude/Longitude Elevation (m)	Existing Capacity (MGD)	Area served (Km^2)	Population served (Million)	Locations served
Palta	22.8N, 88.3E, 6.0 m	220	197.5	4.58	KMC (P), Bidhannagar, S. Dum Dum & Dum Dum
Baranagar-Kamarhati Water Treatment Pl.	22.66N, 88.37E, 7.7 m	30	77.5	1.54	Baranagar, Kamarhati, Panihati, Khardah, Titagarh & N. Dum Dum. Bhadreswar
Serampore	22.75N, 88.36E, 7.4 m	20	40.8	0.68	Champdani, Baidyabati, Serampore, Rishra, Konnagar, Uttarpara-Kotrung & Bally (P).
Bansberia	22.94N, 88.41E, 0.1 m	0.6	20.1	0.19	Bansberia & Hooghly, Chinsurah
Chandan-nagar	22.86N, 88.37E	1	22	0.16	Chandannagar M. Corporation
Garden Reach Water Works	22.52N, 88.27E, 5.9 m	120	53	0.46	Southern KMC, Maheshtala, Budge Budge & Pujali.
Howrah	22.57N, 88.29E, 3.4 m	30	62.7	1.16	HMC & Bally (P)
Total		**421.6**	**473.8**	**8.78**	

Source: JNNURM, 2005

2.6.3 Drainage and sewerage

2.20 **Most areas of KMA have a century old drainage and sewerage system.** The drainage system is divided into 25 drainage basins (Catchment Area) with 18 basins on the east bank and 7 on the west bank of the river Hooghly (Annex A). These basins have been categorized on the basis of topography, land use pattern, outfall system, and various drainage master plans. Similarly, the entire metropolitan area of KMA is divided into 20 sewerage zones, 14 on the east bank and 6 on the west bank (Figure 3.2 in Chapter 3). The sewerage network in KMA is highly sparse and not commensurate with its area of 1,851 km^2. Piped sewer network is confined to mainly KMC, Panihati, Titagarh, Bhatpara, and Kalyani on the East Bank and Howrah MC, Bally, Serampore, Chandannagar, and Hoogly-Chinsurah on the West Bank. However, it is intended that all municipal towns of KMA will be connected by sewer lines by 2025. Dry season discharge of wastewater is about 480 MGD in KMA.

2.21 **KMC has a combined system of sewage and storm water that is old and is further incapacitated by excessive storm flow during the monsoon**. The central part of Kolkata sewerage network system (Town system) is almost 140 years old and the southern part of the sewer system (Suburban system) is around 100 years old. The trunk sewers laid along the east-west direction carry the wastewater and storm runoff from the western part of the city to the eastern part through different pumping stations like *Palmer's Bridge Pumping Station*, *Ballygunge Drainage Pumping Station* and *Dhapa Lock Pumping Station* where water is pumped to the dry weather flow channel and storm water flow channel for disposal into the Kulti river almost 36 km away from the city.

Before discharging to the Kulti river the sewage receives partial treatment as it passes through the East Kolkata Wetlands – a large fishery ponds occupying 5,000 ha to the east of the city. The wetland area is an urban facility that treats the city's huge wastewater and utilizes the treated water for pisciculture and agriculture through recovery of wastewater nutrients in an efficient manner. Provision is made to raise the sewage water to a reasonable head and subsequently to supply sewage to most of the fishponds by gravity. Additionally, there are three small sewage treatment plants in Bangur, Garden Reach, and South Suburban East.

2.22 **KMC area is divided into 9 major drainage basins,** each with independent sewer networks and a terminal pumping station (Figure 2.9). Three of the basins drain into the Hooghly river on the west and 6 drain into the Kulti system in the east. Eleven sluice gates on Hooghly prevent tidal ingress during heavy storms and high tide into the sewer system. The existing sewer network covers a length of 1,610 km. The length of open drain is about 950 km. Only about 55% of KMC is covered by a sewerage system. Heavy siltation and inadequate maintenance of the channel outfall structures have resulted in a significant reduction in the hydraulic capacity of the sewerage system.

2.23 **KMA generates around 6,700 metric tons per day of municipal solid waste** at an average rate of 210 gm per capita per day (out of which KMC generates around 3,000 tons per day at a rate of 450-500 gm per capita per day). Municipal solid waste is collected, transported and disposed of in open dumping grounds or closed trenching grounds. The main disposal sites in KMC are at Dhapa (21.5 ha) and at Garden Reach (8 ha). The Dhapa disposal site, on the eastern fringe of the city, receives about 95% of the city's solid waste generation. As the existing capacity at Dhapa is nearing exhaustion, another facility, Dhapa II has been identified as a landfill facility.

Figure 2.8 Pumping stations in KMC

2.7 URBAN PLANNING AND DEVELOPMENT IN KMA

2.24 **Multiple urban development plans have been prepared since the 1950s.** The *Calcutta Metropolitan Planning Organization* was created in 1961. Along with a team of eminent international and Indian planners, and supported by the Ford Foundation, it prepared the *Basic Development Plan for 1966-1986* for the urban development of Calcutta Metropolitan District (CMD)[8]. This *plan* analyzed the land use and population growth patterns and recommended the development of a counter magnet in the northern-most periphery of CMD. In 1970, the *Calcutta Metropolitan Development Authority* was created by a state legislation and was given the responsibility of implementing the *plan*. However, substantial changes had taken place in the urban structure during the intervening two decades. Population growth in Calcutta had declined whereas it had grown considerably in the suburbs. Addressing these changes, another plan was developed in

[8] Calcutta Metropolitan District or (CMD) became a legal entity called the Calcutta Metropolitan Area (CMA) by the West Bengal Town and Country Planning Act of 1979.

1976 (called the Perspective Plan) and recommended a multi-modal development with a number of growth centers. The plan was further revised in 1982 and has also witnessed additional changes over the years based on ground realities.

2.25 **A City Development Plan for KMA has been prepared under JNNURM (a Government of India program launched in 2005).** This program aims at creating economically productive, efficient, equitable and responsive cities, with a focus on

- Improving and augmenting the economic and social infrastructure of cities;
- Ensuring basic services to the urban poor including security of tenure at affordable prices;
- Initiating wide-ranging urban sector reforms with a primary objective of eliminating legal, institutional and financial constraints that impede investment in urban infrastructure and services;
- Strengthening municipal governments and their functioning in accordance with the provisions of the 74th Constitutional Amendment Act of 1992.

2.26 **The City Development Plan for KMA project only up to 2025 and do not account for long-term climate change impacts**. Current development plans for KMA do not account for the possible long-term effects of climate change nor do they explore the any adaptation strategy. The likely increased precipitation intensity and rise of sea level because of climate change may worsen the drainage in Kolkata causing expansion of the waterlogged areas and longer duration of annual flooding events. Areas further south of KMA may suffer even more to the point of becoming un-inhabitable. Under such conditions, land-use patterns may have to be altered with possible relocation of population. Considering these risks, any future development plans for Kolkata has to take into account the likely long-term impacts of climate change.

2.8 NATURAL HAZARDS

2.27 **Kolkata is vulnerable to a number of natural hazards including earthquakes, cyclones and flooding.** Kolkata falls under <u>seismic zone-III</u>, on a scale of I to V[9] and under very <u>high damage risk zone for wind and cyclone zoning</u>[10]. Other hazards include tidal upsurge, urban storms and extreme local precipitation that lead to water-logging and flooding. Table 2.3 summarizes these hazards and their spatial vulnerability.

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[9] Bureau of Indian Standards

[10] UNDP, “Hazard profiles of Indian districts" National Capacity Building Project in Disaster Management. /http: //www.undp.org.in/dmweb/hazardprofile.pdf

Table 2.3 Types of hazards, vulnerable areas and communities in KMC

Hazard	Vulnerable Areas of Kolkata	Vulnerable Communities
Earthquake	Southern part of the city, along the Hooghly River is more vulnerable due to its closeness to the Epicenter. Kolkata is in Seismic Zone III.	Middle income people living in high rise buildings of low quality construction. People in slums and in old and ill- maintained houses.
Tidal upsurge	Low lying areas near the River Hooghly like Garden Reach, Kidderpur, Tollygunge.	Mainly poor or lower middle class people living in shanties and old houses in congested areas near the channels.
Cyclone	Exposed areas near the Maidan, South and West Kolkata	Tile roofed houses. Houses near big trees. Kuccha houses of shanties.
Urban storm/ heavy rains related flooding and water-logging	Major parts of the city: Camac St., Amherst St., Theatre Road, College St., M G Road, Ultadanga, Kankurgachi, Phoolbagan, New Alipore, Southern Avenue, Rashbehari Avenue, Deshapriya Park, Sovabazar, Shyambazar and AJC Bose Road	Single storied houses at level lower than road, Kucha houses, and houses in the vicinity of flyover/bridges.
Fire hazard	Congested old areas in North-West Kolkata, Burrabazar, all old markets at Kalighat, Posta, Gariahat.	Schools, shops in vulnerable areas, old houses with old wiring, old multi offices in congested buildings of Esplanade.
Health epidemics	Congested slums in most parts of the city except the central zone.	Slum-dwellers, low-income class, elderly and children.
Air pollution	The heavy traffic and business zones in and around Central Kolkata, Esplanade, and Gariahat.	Daily commuters in bus, traffic police, driver, elderly, sick people and children
Land subsidence and water layer loss	Machhua Bazar, Calcutta University and Raja Bazar science college area is subsiding at the rate of 6.5mm/yr.	High rise buildings and old houses in subsidence zone, people dependent on tube wells for drinking.

Source: Samanjit Sengupta, Status of Kolkata megacity disaster management system in view of recent natural disasters, http://siteresources.worldbank.org/CMUDLP/Resources/SamanjitSengupta.pdf

2.28 **Among these hazards, this study focuses: on flooding from increased precipitation, storm surges and sea level rise due to climate change effects.** The effect of land subsidence was not considered as it was found to be a localized problem in a few small pockets in KMC and was largely a consequence of human interventions, primarily ground water extraction (Chatterjee et.al, 2007; Bhattacharya, 2008). Increased flooding (from other possible extreme events like tsunamis) and direct wind damage from increased cyclone and other storms were not included in the study as they either required specialized oceanic modeling or data that was at the time unavailable.

2.29 **Flooding in the study area is an annual feature during the monsoon; it could be devastating when accompanied with a major storm**. Most areas in KMA experience moderate flooding on an annual basis. As such, the population has gradually learned to adapt by taking care of critical assets and preparing for health risks. However the state of West Bengal has also experienced major storms with devastating effects (Table 2.4). These major floods resulted in deaths of hundreds and thousands and significant economic damage. This situation may intensify as a result of climate change impacts.

Table 2.4 Records of large floods in West Bengal

Period	Vulnerable Areas of Kolkata
1978: Sept 4-Sept 10	Monsoon rains caused unprecedented damage and made millions of people homeless in large parts of Northern India. Some areas of the state of West Bengal were 18 feet (5.5 meters) below water.
1986: Sept 24-Oct10	Flooding from heavy rains in some areas of Kolkata, Hooghly, Howrah, Parganas and Midnapore
1999: Sept 24-Sept 29	Tropical cyclones caused destruction of an estimated number of 1500 villages. Floods due to brief torrential rains affected areas of Kolkata, Burdwan and Birbhum
2000: Sept 18-Oct 21	Late monsoon rains that triggered flash floods
2001: July31–Sept01	Monsoonal rains caused flooding in Kolkata
2004: June 20 Oct 07	Heavy monsoonal rains affected several districts
2006: Sept18- Oct05	Monsoonal rains and tropical cyclone-driven storms in the Bay of Bengal hit India and Bangladesh. West Bengal re- corded 50 deaths, 300 were injured and 30,000 mud houses destroyed. Heavy rains left large parts of Kolkata city under water; subsequently 2,000 people were evacuated from the city
2007: July03- Sept22	The hazard affected Kolkata and several other districts. Eighty-three deaths were reported, and millions of people were marooned in 3000 villages in coastal areas of the state

Source: Dartmouth flood observatory global archive,

2.30 **Flooding in KMC and KMA** can be caused by:

- *Natural factors*: High intensity rainfall, storm surge, and cyclonic storms. In addition to these factors, the flat topography and low relief of the area intensify the flooding in KMA. In KMC about 15% of the total population reside by the river side and remain vulnerable to flooding from the Hooghly river (Ghosh, A. 2010).
- *Developmental factors*: These include **unplanned and unregulated urbanization**, low capacity drainage and sewerage infrastructure that have not kept pace with the growth of the city or demand for services, siltation in available channels, obstructions, mainly through uncontrolled construction in the natural flow of storm water, reclamation of and construction in natural drainage areas (marshlands), etc.
- *Climate change aspects*: Changes such as increase in the intensities of rainfall, sea level rise and the increase in the storm surges may increase the intensity and duration of the flooding event.

Chapter 3. MODELING CLIMATE CHANGE

3.1 BACKGROUND

3.1 **The effect of climate change in any study area can show up in a number of different ways.** In the present analysis, only the hydrological and hydraulic impacts resulting from climate change effects have been studied as they are likely to be the most significant factor in an urban area like KMA. The key variables used in the analysis to address hydrological issues were precipitation, maximum and minimum temperature, solar radiation, relative humidity and wind speed[11]. Storm surge that often develops as a combined effect of many of these factors was also considered in the study. In addition, sea level rise from climate change was also included as it can cause increased flooding. Each of these climate related parameters can be highly variable and when intense precipitation coincides with high tide and extreme storm surge, the result can be devastating, especially for areas that are already vulnerable to flooding.

3.2 **In assessing the magnitude of flooding events, the key factors considered were the inflow and outflow of water in and around the study area.** The inflow depends on the precipitation not only in the study area but also in the catchment area upstream for the rivers flowing through the area as it can lead to riverine flooding events, and storm surge effects. For the outflow, important considerations are the natural discharge through drainage basins and sewerage systems in place as well as installed pumping capacity. The rate of discharge is also affected by tide levels and storm surge effects. An imbalance between inflow and outflow, especially caused by short duration intense precipitation, will normally cause local flooding as the water inflow can overwhelm the normal drainage, sewerage, and pumping capacity.

3.3 **This study modeled the impact of climate change on flooding in KMA**. Main causes of flooding in KMA are intense precipitation, overtopping of the Hooghly river due to water inflow from local precipitation as well as that from the catchment area, and storm surge effects. Initially, the flooding arising from intense precipitation was modeled assuming no climate change effects[12]. The climate change effects were then added by multiplying the precipitation for a 100 year occurrence by a factor provided by JICA for the A1FI and the B1 scenarios respectively and using the same precipitation distribution pattern as in the 100 year occurrence without climate change effects. The expected sea level rise was also included in the climate change scenarios. In all these scenarios with and without climate change effects, the model then assessed the impact in terms of the <u>extent</u>, <u>magnitude</u>, and <u>duration</u> of flooding.

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[11] The key weather variables of minimum and maximum temperature, solar radiation, relative humidity and wind speed have been considered in the SWAT model for computing first the Potential Evapotranspiration (ET), which is the maximum evapotranspiration that can take place at a location. This is described in more detail in Annex B.

[12] Three separate scenarios with precipitation levels for 30 year, 50 year, and 100 year occurrence were used.

3.2 THE MODELS USED

3.4 **Three models were used to capture the effect of all factors that lead to flooding in KMA.** A *hydrological model* was used to develop the flow series for the whole Hooghly catchment. The generated data was then fed into a *hydraulic model* to analyze the implication of the flood passing through the river stretch. Finally, an *urban storm drainage model* was deployed to determine the flooding that will result once the river flooding is combined with local precipitation and drainage capability of the urban area under the extreme flood situation[13].

3.5 **The Hydrological Model: Soil and Water Assessment Tool (SWAT).** As a **first step**, the water flow in the Hooghly River system was estimated using a hydrological model: SWAT. The water flow in the river arises from high rainfall occurring in the whole Hooghly river catchment. The river flow was modeled using the rainfall and temperature data obtained from India Meteorological Department[14]. Water flow from diversions made into Hooghly from Ganga River upstream was also added while estimating the total flow in the Hooghly River[15]. The SWAT model generated daily flow series at various locations along the Hooghly River.

3.6 **The Hydraulic Model: Hydrologic Engineering Centre – River Analysis System (HEC-RAS).** As a **second step,** daily water flow along the Hooghly River was used to generate flood waves using a hydraulic model: HEC-RAS**.** HEC-RAS is a one-dimensional steady and unsteady flow hydraulic model developed by the U.S. Army Corps of Engineers (U.S Army Corp of Engineers, 2002). The HEC-RAS hydraulic model used the daily flow series obtained from the SWAT and translated the flood events into flood waves moving through the river channel. These flood waves cause inundation when the carrying capacity of the channel is exceeded by the volume of the wave. The tidal and storm surge effects were fed into the HEC-RAS model as boundary conditions. Output from the model provided the water surface profiles all along the river coupled with change in flow depth during the flood period. Simulations were done using the HEC-RAS model for existing scenarios with and without climate change effects to get the flow profiles and the consequent inundation of the areas in and around KMA.

3.7 **The Urban Storm Drainage Model: Storm Water Management Model (SWMM).** As a **third step,** an storm drainage model: SWMM was used to simulate the flooding due to the local rainfall by incorporating the prevailing urban characteristics of the area as well as other specific structures such as lock gates, drainage pumps, etc. SWMM is a dynamic rainfall-runoff simulation model used for single event or long-term (continuous) simulation of water runoff from primarily urban areas. For the present study, the urban hydrological model was setup for KMA and KMC separately to simulate the flooding conditions during the flood events of various magnitudes. The intense local rainfall and the flow of water determined by HEC-RAS provided the inflow in the

[13] The details on the data used for the study for various models are provided in Annex B.

[14] Daily gridded rainfall data was available from the meteorological department for a 35 year period.

[15] Water is diverted from the Ganga River to the Hooghly River at Farakka 257 kms upstream from Kolkata.

model while the outflow depended upon the drainage conditions, any sewerage in place, pumping capacity, and the likely operation of lock gates during the flooding period.

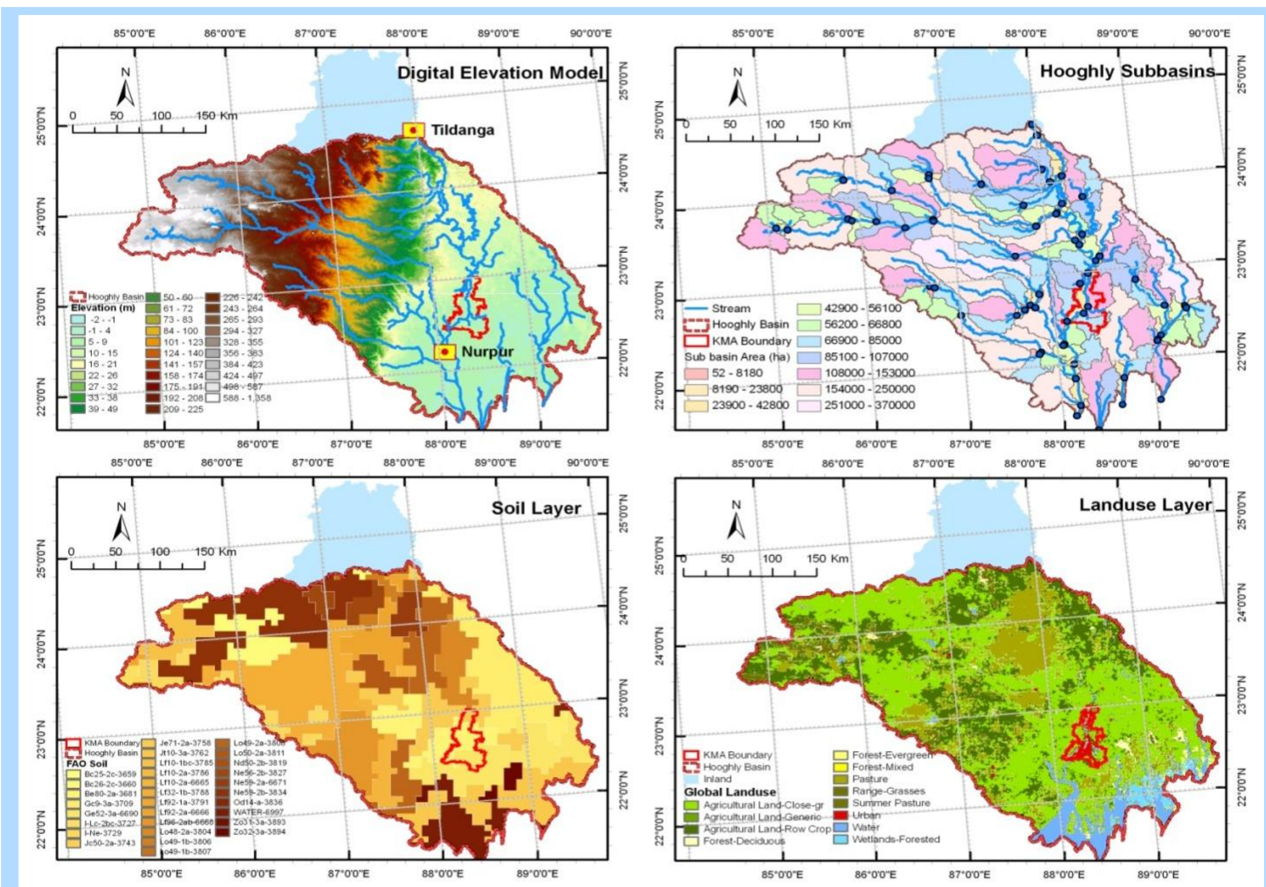
SWAT Model Input

SWAT used daily precipitation and temperature data along with spatial data to derive the flow series for the river. The spatial data as listed below were obtained from global data sources because of ready availability and reliability:

- Digital Elevation Model: SRTM of 90 m resolution[1]
- Drainage network[2]
- Soil maps and associated soil characteristics[3]
- Land use[4]
- Precipitation and temperature data were obtained from India Meteorological Department.

Figure 3.1 provides a snapshot of all the spatial layers used for the SWAT modelling. Since the data on the rainfall stations falling in the catchment of Hooghly were not available, daily gridded (0.5° × 0.5°) rainfall data and daily gridded (1.0° × 1.0°) temperature data from IMD was used in the SWAT model. The gridded data was developed based on the observed data that was available from 1971-2004.

Figure 3.1 Spatial data for the Hooghly basin used for the SWAT modeling



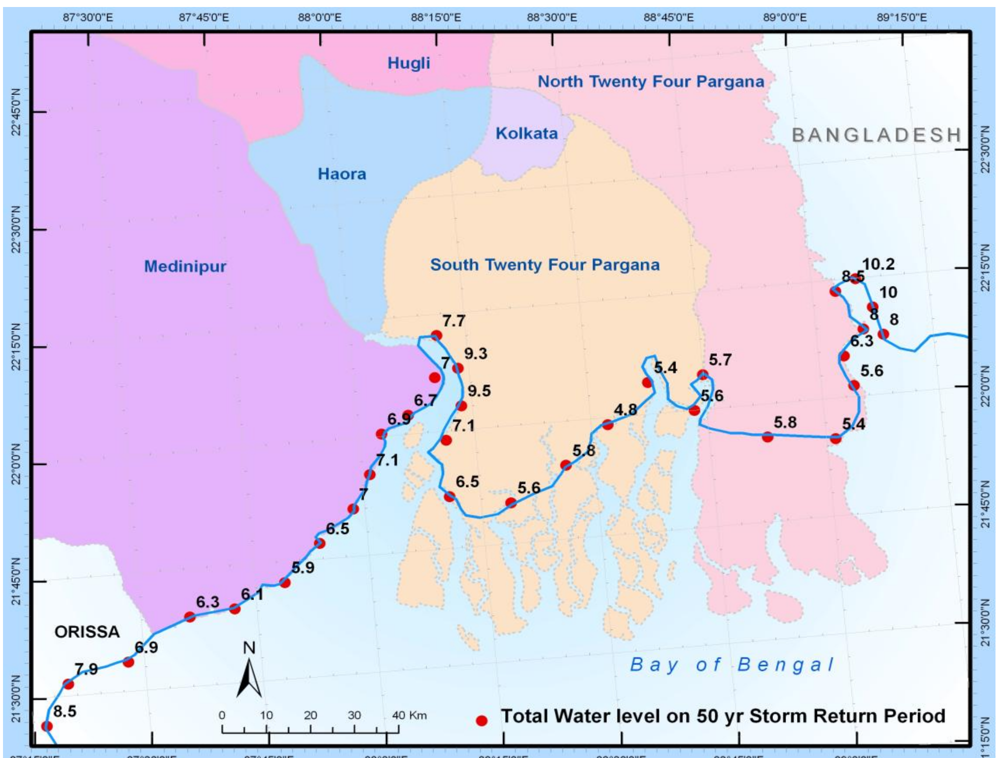
[1] http://srtm.csi.cgiar.org/ ; [2] Digital Chart of the World, 1992, http://www.maproom.psu.edu/dcw/
[3] FAO Global soil, 1995, http://www.lib.berkeley.edu/EART/fao.html; [4] Global land use, Hansen et al. 1999 http://glcfapp.umiacs.umd.edu:8080/esdi/index.jsp

HEC- RAS Model Input

Input parameters for the HEC-RAS included topographic data in the form of river cross-sections, a friction parameter in the form of Manning's n values[1] across each cross-section, flow data including flow rates, flow change locations, and tide and storm surge data as boundary conditions. In addition, flood hydrograph from September to October for different return periods was also used as inputs for each relevant scenario.

The storm surge data used in the analysis are based on available literature. Kolkata is about 120 km away from the open sea and does not experience storm surge as frequently as the lagoon areas of the Hooghly River. The highest tidal height experienced in the area is around 6 m. A surge of around 3 to 4 m (Dube et al, 1997) is seen few times above high tide value and this data was used for the simulation (Table 3.1). The water level on a 50 year storm return period in the coastal area downstream from Kolkata is shown in Figure 3.3.

Figure 3.2 Peak water level rise in the event of a 50 year storm for the coastal districts of West Bengal



Source: Adopted from Jain et al. (In Press)

Table 3.1 Maximum storm surge for various return periods for the average coastal length of West Bengal

	Return Period (year)			
	10	**25**	**50**	**100**
Maximum Wind Speed (kmph)	*167*	*195*	*215*	*231*
Maximum Storm Surge height (m)	*4.5*	*6.3*	*7.8*	*9.2*

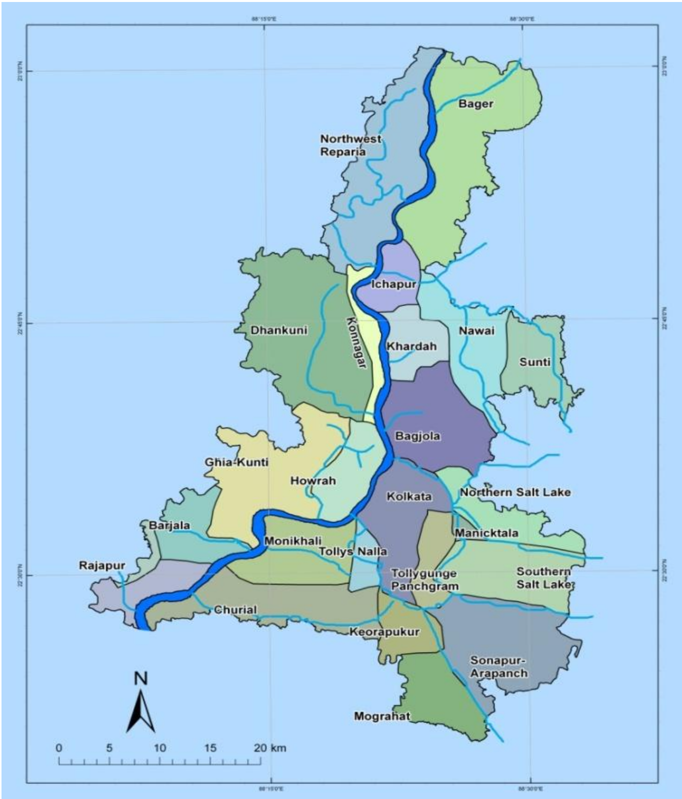
[1] http://www.fsl.orst.edu/geowater/FX3/help/8_Hydraulic_Reference/Mannings_n_Tables.htm

SWMM Model Input

The primary input in the SWMM was the characteristics of the 25 drainage basins with 18 basins on the east bank and 7 basins on the west bank of the river Hooghly (Figure 3.2). All drain shapes were taken as open rectangular drains and their depth, width and invert elevation were derived using Digital Elevation Model and Google Earth Images. It was assumed that no interventions like pump, sump, weir, gates, diversions etc existed in the flow path in the rest of KMA outside KMC. Because of lack of availability of short interval rainfall data for the whole of KMA, data available for KMC area (Dumdum in the North and Alipore in the South) were used for the rest of KMA. The Manning Roughness coefficient was taken as 0.035 for open natural channels. The flow in Hooghly at the entry point to KMA simulated by the HEC-RAS model was used as the inflow into the Hooghly. Since KMA boundary is not the natural watershed boundary to balance rainfall runoff generation, area adjustment was made for other natural drains.

For KMC the SWMM inputs came from the prevailing urban characteristics of the area. Thus the existing extensive sewerage network data in KMC area were used in the SWMM model and it also included other specific structures such as lock gates, drainage pumps, etc that make a difference in the water flow (Annex B). The brick sewers built over many phases in the city's development was an important input in the model. Since the hydraulic capacity of the sewerage system and discharge canal systems have been considerably reduced due to the build-up of silt, the simulation was run with an overall siltation level of 30%. The simulations were also repeated later with assumption of no siltation to test the effects of adaptation measures (these results are detailed in Chapter 6). The model used the current system of storm water passage (drain → sewer lines → pumping stations → trunk sewers → canals →Hoogly River or Wetland/Kulti River).

Figure 3.3 Drainage basins of KMA



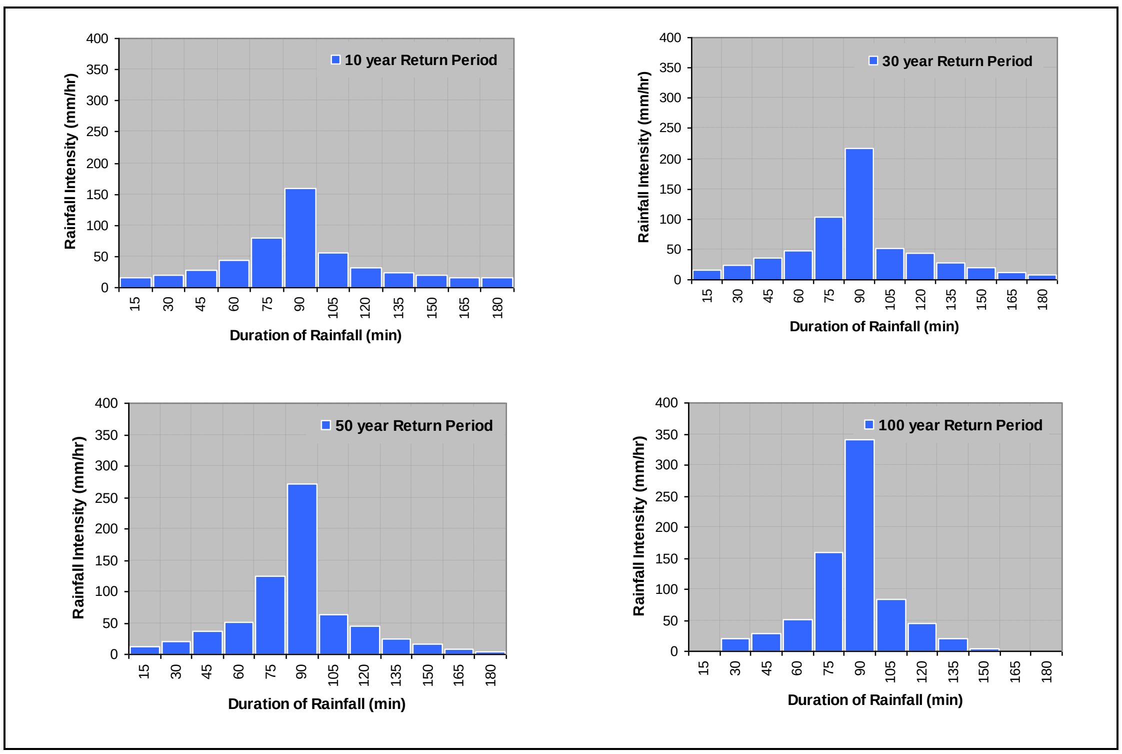
Data Source: JNNURM (2005)

3.3 MODELING SCENARIOS

3.3.1 Base Case Scenario

3.8 **The return periods of precipitation events in KMC was based on available historical rainfall data for 25 years.** The data was available in the form of raw chart values from continuous recording rain gauges and were collected from Kolkata Environmental Improvement Project for the monsoon period (April to September) from 1976 to 2001 (excluding 1990). The rainfall data was processed to get rainfall at each successive 15-minute interval. These data were further processed to extract maximum rainfall events corresponding to different storm durations for the two recording stations for their respective 25 years of data. Hyetographs (graphs of the distribution of rainfall over time) provided data from the storm intensities for each period of 15 minutes for each of the 10, 30, 50 and 100 year return period storms (Figure 3.4).

Figure 3.4 Rainfall Hyetograph based on Alipore rainfall data



3.3.2 Climate Change Scenarios

3.9 **Inputs for the climate change scenarios were provided by Japan (JICA, 2008)** [16] **for Kolkata** based on the analysis of a subset of the models[17] used for IPCC Fourth Assessment Report (AR4)**.** The scenario predictions included a temperature increase in Kolkata of about 1.8^{0}C for

[16] JICA, 2008. "Interim Report, Study on Climate Impact Adaptation and Mitigation in Asian Coastal Mega Cities" prepared by the Integrated Research System for Sustainability Science, University of Tokyo.

[17] 12 models out of the models in IPCC AR4 were used.

A1F1 scenario and 1.2^{0}C for B1 scenario. Precipitation predictions were provided as a fractional increase in the precipitation extremes of about 16 percent for A1F1 and 11 percent for B1 scenario imposed above the baseline distribution of precipitation. A sea level rise of 0.27 m by 2050 was also added to the storm surge for the A1F1 and B1 climate change scenarios based on current estimates[18].

3.4 MODEL CALIBRATION AND VALIDATION

3.10 **The theoretical distribution of rainfall patterns for a 100 year return period was compared with observed 15 minute rainfall intensities in the study area in the past.** A comparison with the 1978 rainfall pattern on September 27, 1978 from 5:03 PM to 8:00 PM, a period with the highest rainfall intensity in recent times, showed a very good match with the theoretical 100 year return period rainfall (Annex B). It is thus found that the return period of precipitation event of 1978 that caused the most damaging flood in Kolkata in recent times can be used for the 100 year return period precipitation. While it was entirely coincidental that an event of 100 years magnitude occurred in the observation duration of 25 years, it strengthened the confidence about the analysis using indirect assessment process of precipitation and for the analysis of flooding due to the climate change impacts.

3.11 **The flow obtained from the SWAT model for flood peaks was matched with theoretically generated flow from a number of distributions**. Of these, the distribution that fitted the best was the Gumbel Extreme Value Type I distribution[19]. With a resultant R^2 of 0.98 between the two variables, the simulated flow using SWAT and the synthetic flow using Gumbel distribution, the match was found to be near perfect. The peak flow for all the return periods were therefore based on the Gumbel distribution (Annex B).

3.12 The analysis of the flood events requires the complete flood (rather than just the peak used to fit the theoretical distribution). To remedy this, the complete flood events were obtained by applying a ratio of rainfall corresponding to the respective return periods derived using the rainfall analysis. The observed rainfall time series was then updated with these ratios and SWAT simulations were carried out for each of these return periods.

[18] There is considerable variability in the estimates of these weather related changes. A recent study by Knutson et. al. (2010) indicates that greenhouse warming will cause the globally averaged intensity of tropical cyclones to shift towards stronger storms with substantial increases in the frequency of the most intense cyclones. The current study does not include these assumptions as it was done before the publication of these results.

[19] http://www.itl.nist.gov/div898/handbook/eda/section3/eda366g.htm

3.5 MODEL SIMULATION RESULTS

3.5.1 Flood depth categories

3.13 The model was set up and run for the *baseline* (for 30, 50 and 100 year return period storms) as well as for the *climate change scenarios* A1F1 and B1 (superimposed on a 100 year return period storm). The flood inundation depths obtained from the model simulation were categorized in to 7 classes. Table 3.2 shows the categories along with the associated threat index levels.

Table 3.2 Flood depth and threat level category

Flood Depth (m)	Threat Index Level	Description
0.00 - 0.10	Non-Threatening	Threat: No discernible threat to life and property. Potential Impact: None expected
0.10 - 0.25 Ankle Deep	Low	Threat: A low threat to life and property. Potential Impact: The potential for isolated locations to experience minor inland flooding
0.25 - 0.50 Half Knee Deep	Moderate	Threat: A moderate threat to life and property. Potential Impact: The potential for scattered locations to experience minor inland flooding
0.50 - 0.75 Knee Deep	High	Threat: A high threat to life and property. Potential Impact: The potential for isolated locations to experience minor flooding.
0.75 - 1.00 Waist Deep	Very High	Threat: An extreme threat to life and property. Potential Impact: The potential for isolated locations to experience major inland flood damage and scattered locations of minor to moderate inland flooding.
1.00 - 1.50 Ground Floor Inundation	Extreme	Threat: Extreme threat to life and property. Potential Impact: The potential for scattered locations to experience major inland flood damage and many locations of minor to moderate inland flooding.
Above 1.50	Exceptional	Threat: A very exceptional threat to life and property.

Source: Adopted from http://www.srh.noaa.gov/mlb/ghls/index.php?threat=inland

3.5.2 Results for KMA

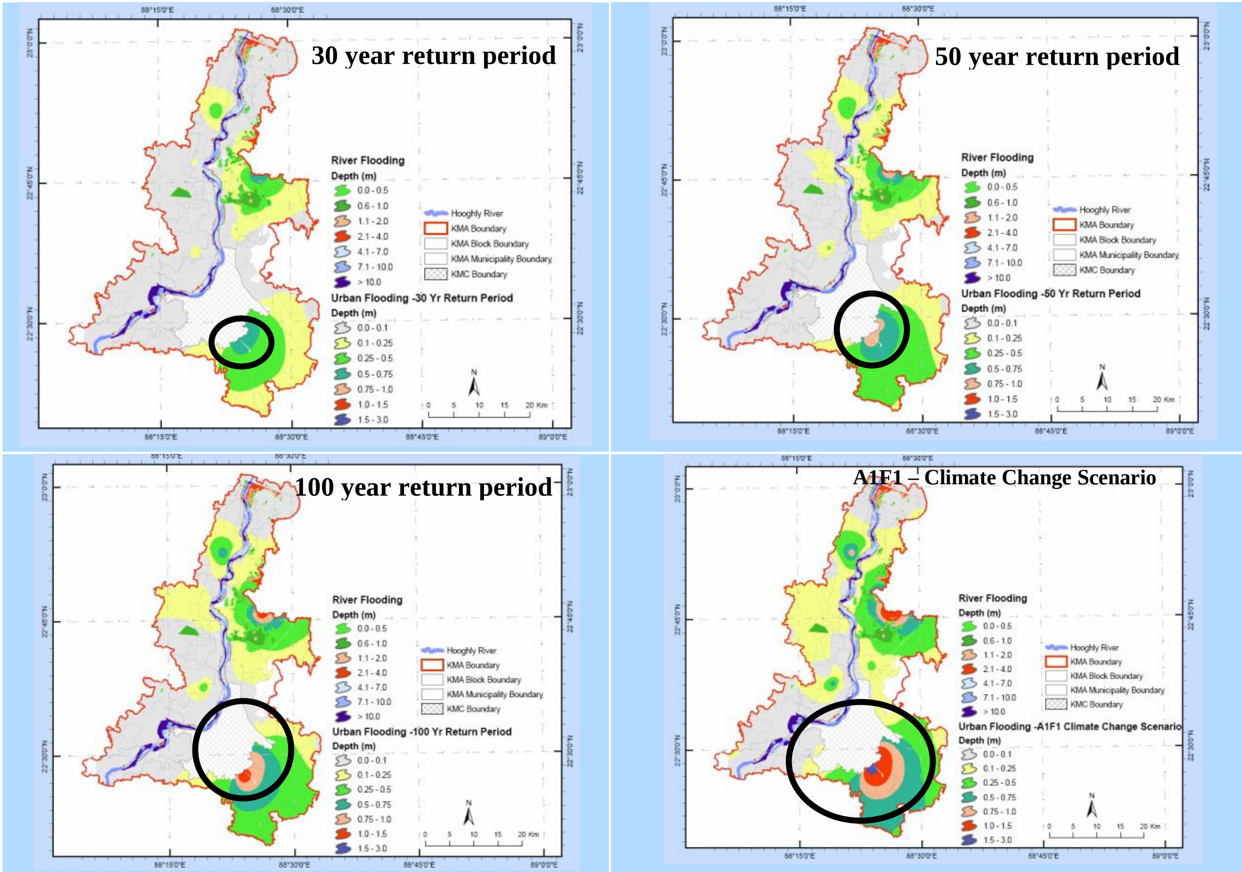
3.14 **The percentage of KMA area inundated under different flood depth categories for various scenarios is shown in Table 3.3.** This was based on the KMA area excluding the KMC as the KMC area is modeled separately with sewerage networks in position. While a very large segment of KMA gets inundated under all the flooding scenarios, the majority of the area affected belongs to the low threat depth categories. One reason is that the KMA area is mainly peri-urban and does not have a formalized network of sewerage covering the entire area. Water is therefore expected to follow the natural drainage patterns. The lower paved area in KMA also contributes to lesser surface flow of water.

Table 3.3 Percentage of area inundated in KMA various scenarios

Flood depth range (m)	Percentage of Area inundated *(excluding KMC)* 30yr	50yr	100yr	A1F1 (added to 100yr)	B1 (added to 100yr)
0.00 - 0.10	56.47	47.81	40.65	29.36	34.06
0.10 - 0.25	21.43	22.23	23.79	26.85	24.55
0.25 - 0.50	9.38	14.92	16.72	15.97	16.4
0.50 - 0.75	1.61	3.13	5.42	10.53	9.24
0.75 - 1.00	0.0	0.8	1.86	3.74	2.91
1.00 - 1.50	0.0	0.0	0.44	2.22	1.64
1.50 - 3.00	0.0	0.0	0.0	0.22	0.09

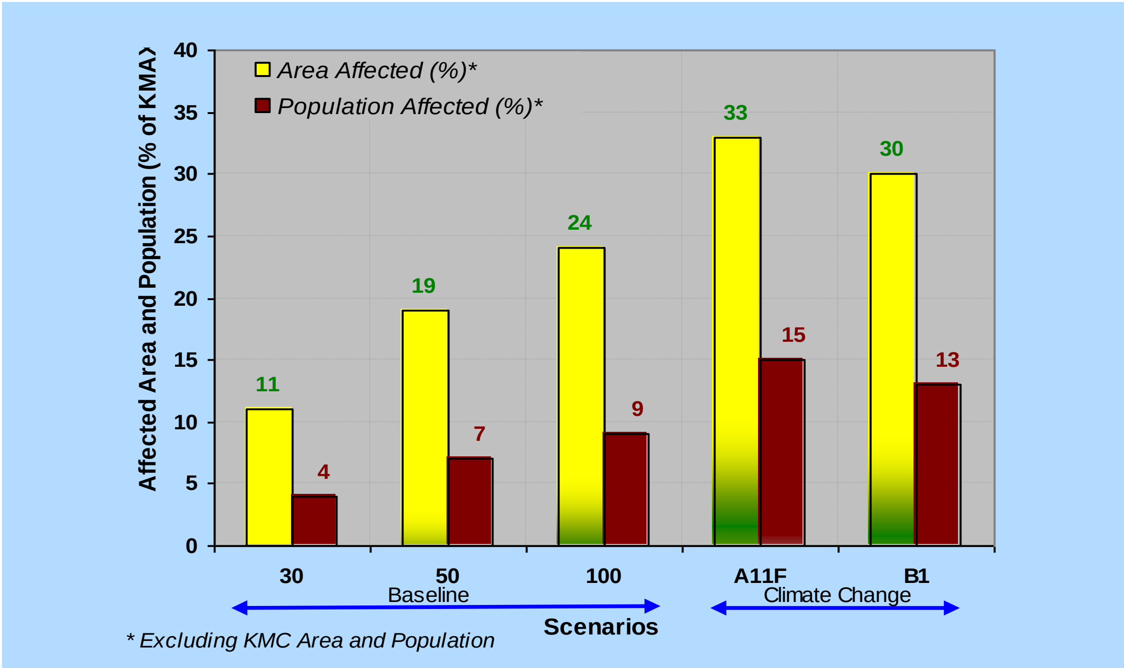
3.15 **Inundation depth and area for different scenarios**. Figure 3.5 shows inundation area and depth for the baseline scenarios (30, 50, and 100 year return storm periods) and for the climate change scenario A1F1 (over a 100 yr return storm). It is seen that the spread area increases for higher return periods (area under black circle is one such depiction for change in inundation extent). It is found that there is also a general shift of flooding from the lower depths to the higher depths as we move from 100 year return period flood to climate change scenario A1F1. However, the maximum increase in inundation from 100 year return period flood to climate change scenario A1F1 occurs for the flood depth range of 0.5-0.75 m.

Figure 3.5 Depth and spread of inundation in KMA for the baseline and climate change scenario



3.16 **Affected population**. In KMA area, flood water depths below 0.25 m cause little damage to the affected area and population. So, flooding over 0.25 m depth is used for comparison among various scenarios. Figure 3.6 provides a snapshot of the inundation depths > 0.25 m in KMA for different base line scenarios and those with climate change. The results indicate that as the scenario changes from a storm with a 30 year return period to one with a 100 year return period, such area inundated increases by 13 percent, from 11 percent to 24 percent and the population affected goes up by 5 percent, from 4 percent to 9 percent. When the climate change effects are added, the area affected goes up to 30 percent under B1 scenario and to 33 percent under the A1F1 scenario. The population affected goes up to 13 percent under B1 scenario and to 15 percent under the A1F1 scenario. In addition, the lower density of population in KMA causes the percentage of population being impacted being less than the percentage of area affected by such storms.

Figure 3.6 Percentage of area and population affected in KMA for various scenarios (Depth > 0.25m)



3.5.3 Results for KMC

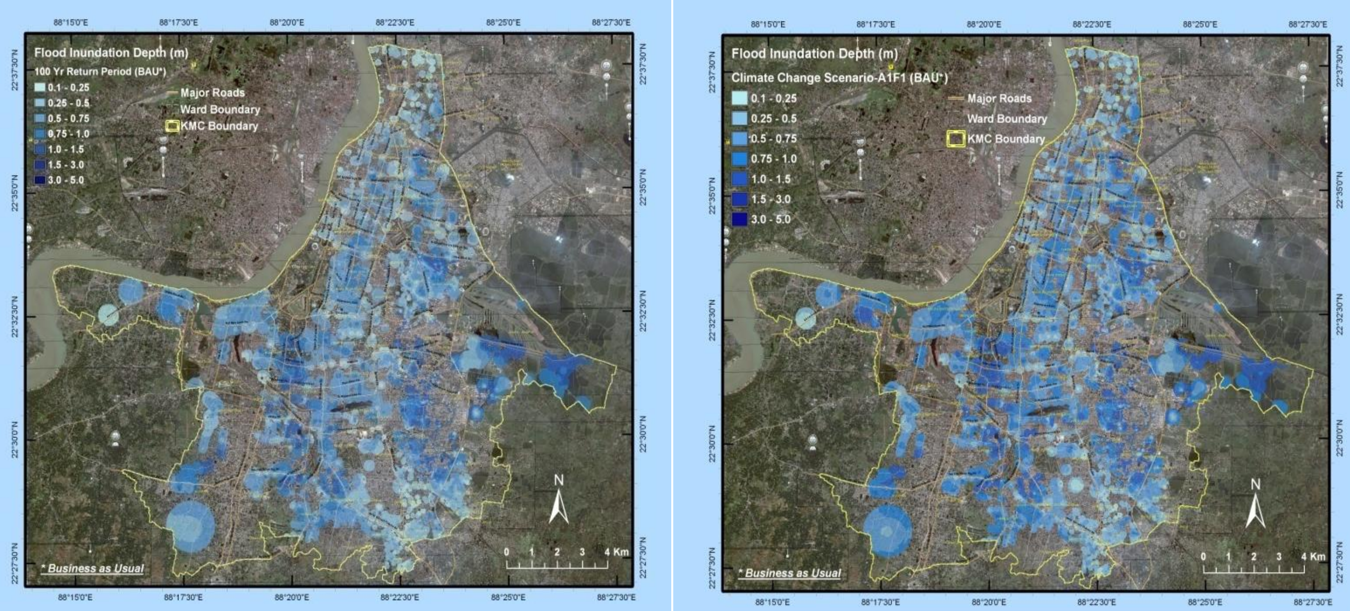
3.17 **The Percentage of area affected in KMC with different flood depths for various scenarios is shown in Table 3.4.** In KMC the largest affected area belongs to the two depth categories 0.25 – 0.50 m and 0.50 – 0.75 m for the baseline scenarios without the climate change. However when climate change effects are added for scenarios B1 and A1F1, the flooding depth goes up by one notch with the depth categories 0.50 – 0.75 m and 0.75 – 1.00 m accounting for the largest affected areas. This is in sharp contrast to the rest of KMA area where the percentage of area inundated in the two lowest depth categories were the highest. The depth of flooding in KMC is relatively more mainly due to its topography that prevents natural drainage. Figure 3.8 shows the inundation for the baseline and climate change scenarios. It provides a snapshot of how the area inundated and the depth of inundation changes in the KMC area.

Table 3.4 Percentage of area affected in KMC under different flood depths for all scenarios

	Storm return period scenarios				
Flood Depth Range (m)	**30yr**	**50yr**	**100yr**	**A1F1**(added to 100yr)	**B1** (added to 100yr)
< 0.1	0.72	0.51	0.29	0.22	0.22
0.10 - 0.25	4.79	3.88	2.79	1.92	2.18
0.25 - 0.50	16.51	14.02	10.43	7.62	8.07
0.50 - 0.75	11.17	14.14	15.47	13.87	15.07
0.75 - 1.00	3.40	4.61	7.22	11.06	10.03
1.00 - 1.50	2.05	2.71	4.12	5.89	5.25
1.5 - 3.0	0.74	1.00	1.97	2.20	2.08
> 3.0	0.01	0.02	0.16	0.37	0.32

Figure 3.7 Depth and spread of inundation in KMC for current climate 100 year flood and A1F1 climate 100 year flood

100 year return period	A1F1 – Climate Change Scenario

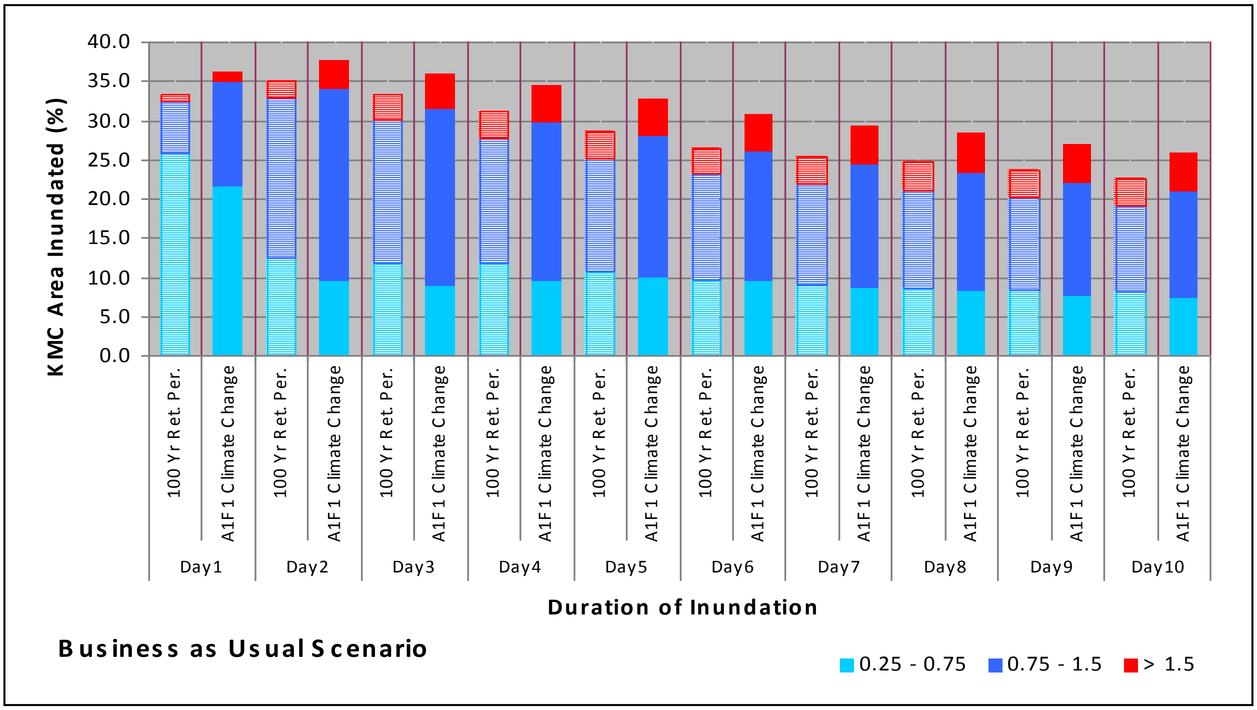


3.18 **A summary of the percentage of area and population affected in KMC with flood depths of 0.25 m and more under various scenarios** is presented in Table 3.5. The greater percentage of population affected by flooding in KMC compared to KMA is mainly a consequence of its higher population density. Figure 3.8 also provides a comparison of the duration of inundation of various depths between the 100 year return period without climate change effects and the A1F1 climate change scenario. It shows that flooding persists even after 10 days in large parts of the KMC. In addition, the difference in extent and depth of flooding between the 100 year return period and the A1F1 scenario continues even after 10 days.

Table 3.5 Percentage of flooded area (to the total of KMC) with flood depths of 0.25 m

	Storm return period scenarios				
	30yr	**50yr**	**100yr**	**A1F1(added to 100yr)**	**B1 (added to 100yr)**
Area affected	33.7%	36.4%	38.5%	41%	40.8%
Population affected (%)	38.9%	42.2%	44.9%	47.4%	47%

Figure 3.8 Duration of inundation of various depths in all of KMC for current climate 100 year flood and A1F1 climate 100 year flood



3.3.3 Land Subsidence

3.19 **Land subsidence in the KMA was not included in the present analysis because of inherent uncertainties about future changes.** Moreover, it was perceived to be a localized problem largely connected to the increasing pressure on ground water. However, there are specific locations in KMA which are undergoing considerable subsidence of land. This is primarily due to ground water extraction tapped by hand-pumps and heavy-duty tube wells installed by private industries, housing estates and high-rise apartment blocks. The driving force is the increasing population pressure that has led to the back swamp and marshy land in the eastern part of KMA, especially the Salt Lake and Rajarhat area, being encroached upon and becoming urbanized largely without planning (Nandy, 2007). Studies show a subsidence rate of 20.46 mm per year at Salt lake area where marsh lands were filled up.

3.20 **The literature indicates that some areas in KMC had also been undergoing subsidence ranging from 6.52 - 13.0 mm per year on average** for a period of 42 years from 1958 to 2000 (Chatterjee et al., 2006). If such subsidence continue over a longer period of time, land subsidence data input will become important as it may drastically increase extent of flooding both in KMC and rest of KMA. Land subsidence can therefore further exacerbate the flooding caused by climate change effects. In fact, a recent study shows that with an estimated land subsidence of 0.5 meters, the damage caused by water inundation in KMA by 2070 can be quite devastating (OECD, 2007).

Chapter 4. VULNERABILITY IMPACT ASSESSMENT

4.1 METHODOLOGY

4.1 The use of the hydrological, hydraulic and urban storm drainage models (as described in Chapter 3) provides the depth, duration, and extent of flooding in Kolkata due to climate change effects. However, even the same depth and duration of an inundation can have significantly differing impacts on the population and infrastructure depending on the vulnerability of the affected area. So, in this chapter a more detailed vulnerability impact assessment has been carried out using a number of indicators for the study area that can help explain such impact. However, the impact assessment has been restricted only to KMC instead of the whole KMA, since detailed data on population, infrastructure, and land use needed to do such analysis was available only for KMC.

4.2 **Looking at ward and sub-ward levels.** In order to evaluate the vulnerability to flooding in KMC, two separate exercises were carried out. In the first one, the vulnerability was assessed at a macro level by taking the ward as the smallest unit. This exercise helped identify the most vulnerable wards that require specific attention while designing adaptation strategies. The second exercise was designed to ascertain the vulnerability within each ward. The analysis was extended to the sub-ward level using spatial data.

4.3 **Three indices (flood, social and land-use) were developed to assess the vulnerability of Kolkata from flooding.** The outputs from the urban storm drainage model (Chapter 3) that quantified the depth and duration of flooding in KMC were used to build the flood vulnerability index[20]. Data and information on the socio-economic characteristics of the population and the existing infrastructure were combined to develop a *social vulnerability index*.[21] A l*and-use vulnerability index* was then developed based on the prevailing land-use pattern[22].

4.4 For each ward in KMC, the three indices (social, land-use, and flood) were separately determined based on data from each ward for the chosen indicators. Since the indicators had different units of measurements, they were first normalized and assigned values between 0 and 1 before they could be used to develop each index[23].

[20] The scenario considered is the 100 year return period

[21] Data used for social vulnerability index were taken from two major sources: Census 2001 data (Census of India, 2001) and Industrial data and Infrastructure data (WBPCB).

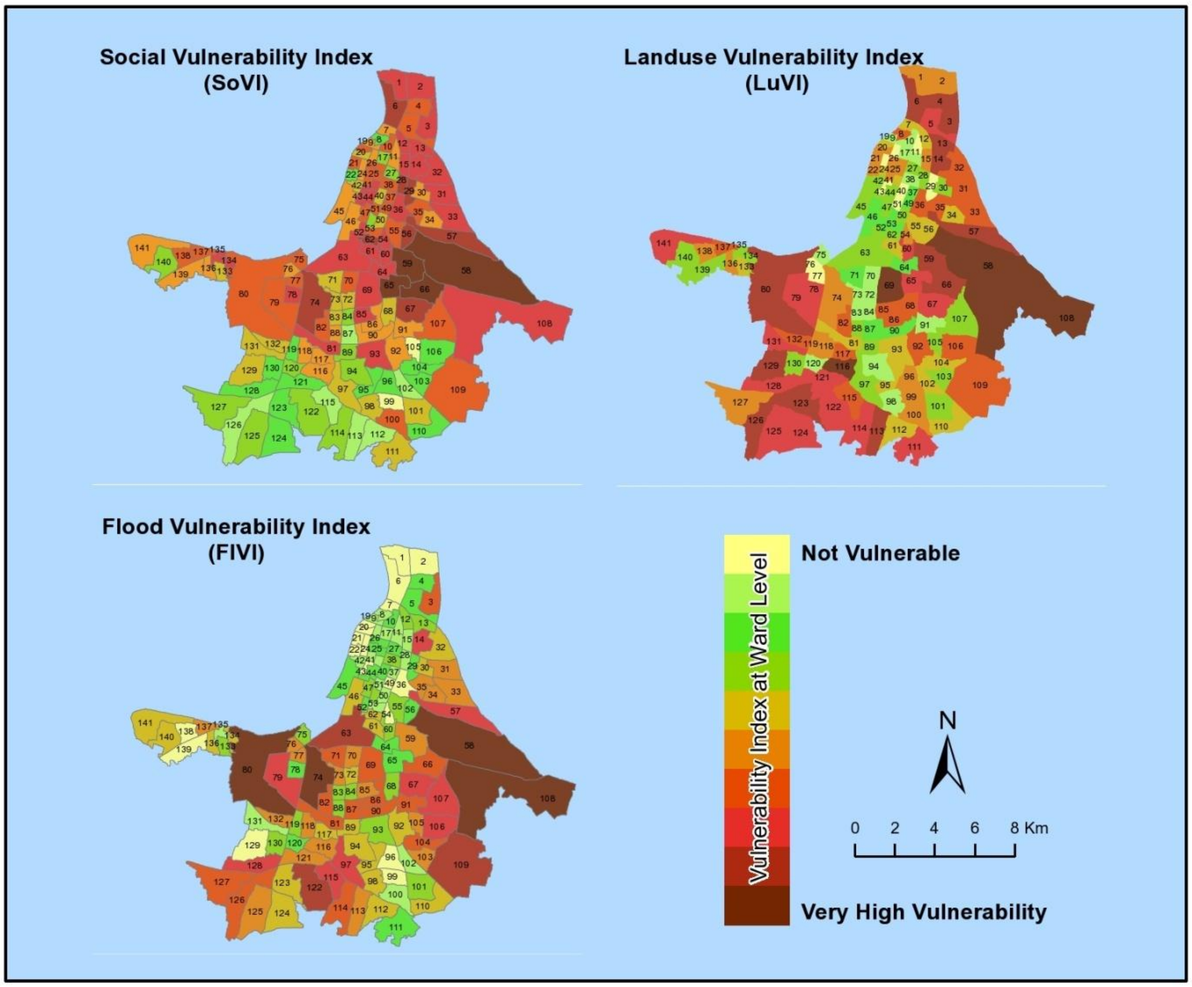
[22] Land-use vulnerability is based on data from NATMO (National Atlas & Thematic Mapping Organization, Kolkata) maps and Google Earth (earth.google.com).

[23] The details of the indicators and the methodology used to normalize the indicators are shown in Appendix C.

4.2 WARD LEVEL ANALYSIS

4.5 The extent of vulnerability ~~of~~ based on the three separate indices in each KMC ward are shown in Figure 4.1. The color coded graph ranks the wards by degree of vulnerability with ranks going from *not vulnerable* to *very high vulnerability*. The analysis reveals that some wards, especially on the eastern portion of KMC, have a very high vulnerability ranking under all three indices.

Figure 4.1 Vulnerability indices per wards in KMC



4.6 **Identifying the most vulnerable wards.** The top 20 wards based on Flood vulnerability were examined to ascertain those that also figure among the top 20 wards in terms of Social vulnerability and/or Land-use vulnerability. The most vulnerable wards based on that analysis are shown in Table 4.1.

Table 4.1 The most vulnerable wards in KMC

Among the top 20 most vulnerable in all 3 indexes	Among the top 20 most vulnerable wards in Flood and either Social or Land-use Vulnerability Index
W_14, W_57, W_58, W_66	W_63, W_67 W_74, W_80, W_108

4.7 **Validating the results**. The vulnerability indices developed for each KMC ward were also compared with two other methods used to determine vulnerability indices: the *principal component analysis* and the *factor analysis*. The *principal component analysis* enabled computation of each of the three indices as the linear combination of the weighted normalized indicators in a ward with the weights obtained from the analysis itself. Similarly, the *factor analysis* was used to determine the weights and then develop the three vulnerability indices in each ward using those weights[24]. Table 4.2 compares the ranking of the most vulnerable wards found from the analysis with the rankings found from *principal component analysis* and *factor analysis*. The wards found most vulnerable with the analysis are also found to be among the most vulnerable under both the *principal component* and *factor analysis*. This shows the consistency in vulnerability rankings among the wards in KMC and supports the validity of the selected procedure used in vulnerability rankings.

Table 4.2 Comparison of most vulnerable wards in KMC under alternative analysis

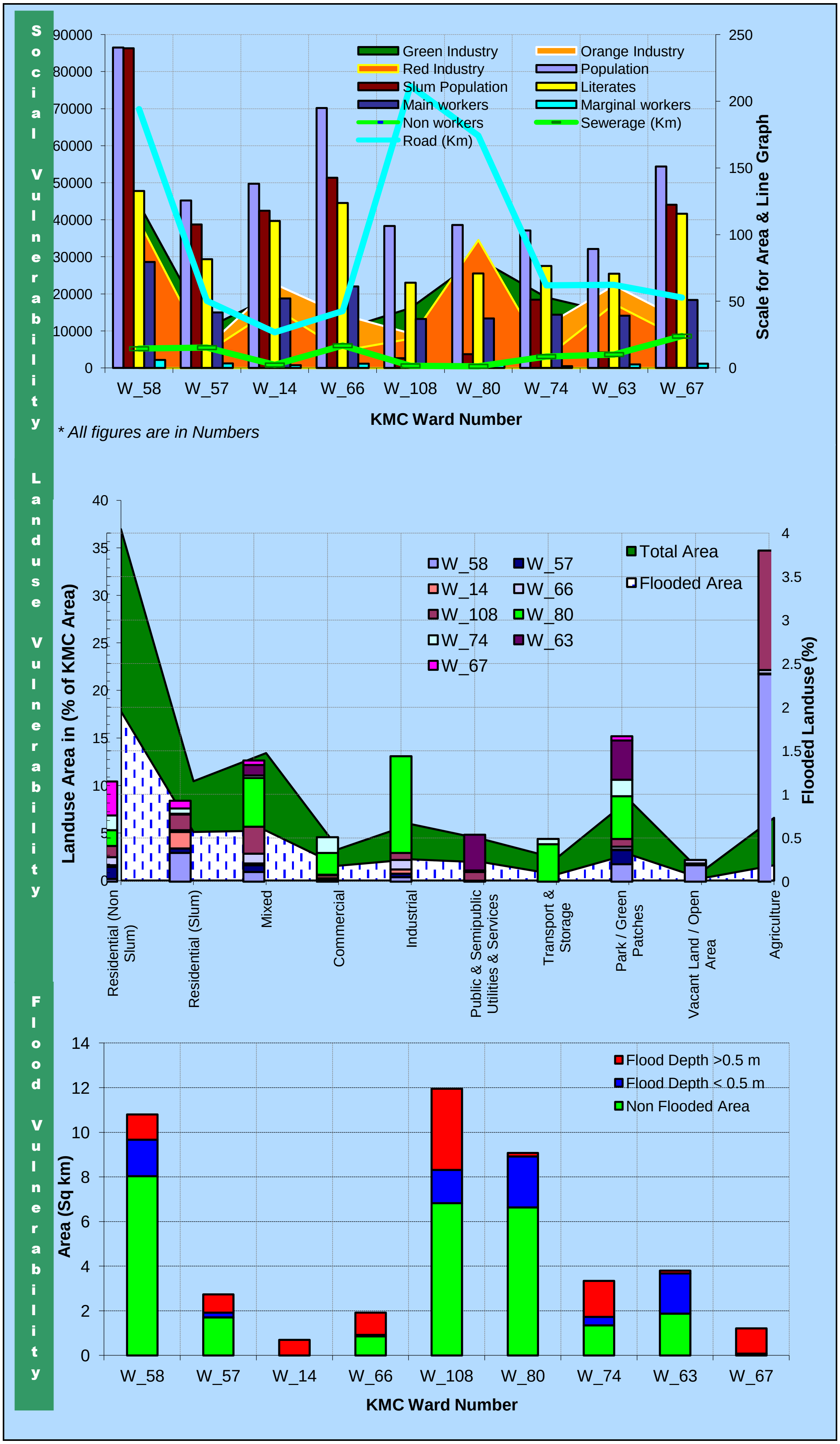
Ward Number	Vulnerability Index Analysis	Principle Component Analysis	Factor Analysis
W_14	Top 20 in all three	Top 20 in two	Top 20 in two
W_57	Top 20 in all three	Top 20 in all three	Top 20 in all three
W_58	Top 20 in all three	Top 20 in all three	Top 20 in all three
W_63	Top 20 in two	Top 20 in two	Top 20 in all three
W_66	Top 20 in all three	Top 20 in all three	Top 20 in all three
W_67	Top 20 in two	Top 20 in two	Top 20 in two
W_74	Top 20 in two	Top 20 in all three	Top 20 in two
W_80	Top 20 in two	Top 20 in all three	Top 20 in two
W_108	Top 20 in two	Top 20 in two	Top 20 in two

4.2.1 Characteristics of the 9 most vulnerable wards in KMC

4.8 A closer look at how each of the indicators stack up in the most vulnerable wards (Figure 4.2) enables a better understanding of why these wards happen to be more vulnerable than other wards in KMC. Of the most vulnerable wards, six wards (14, 57, 58, 66, 67, and 108) in the eastern part and ward 80 suffer from inadequate sewerage and infrastructure facilities and high slum population. As a result, these wards generally face higher social and flood vulnerability. Some of these wards also score high on the land-use vulnerability because of greater concentration of small scale industries. The other 2 wards (63 and 74) appear among the most vulnerable mainly because of their topography which makes them highly vulnerable to flood (and hence score high in flood vulnerability index).

[24] The details of the procedure followed for the *principal component analysis* and the *factor analysis* and the results obtained are provided in the Annex C.

Figure 4.2 Characteristics of the 9most vulnerable wards in KMC



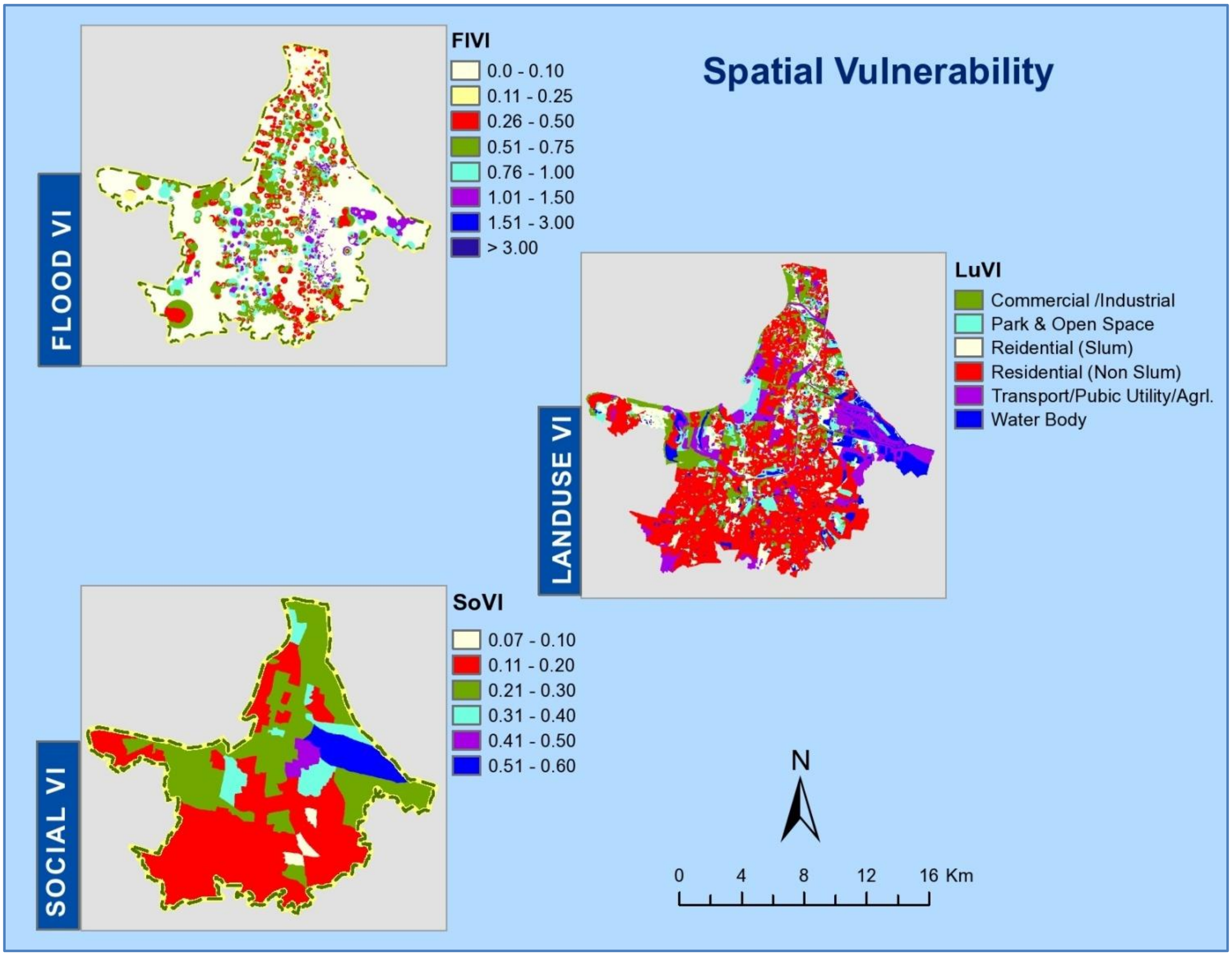
4.9 **Ward 58 is the most vulnerable of all.** A closer look at ward 58, the ward that tops the vulnerability rankings under all methodologies, clearly brings out the factors that make it so vulnerable. In this ward, almost the entire population (99.8 %) lives in slums and 44.8 % of the population is illiterate. These characteristics result in a very high ranking in the social vulnerability scale. In addition, although the state government took the initiative to shift all tanneries in Kolkata, many of which were located in Ward 58, quite a few have not yet shifted. According to a rough estimate, more than 5,000 big and small units are still operating in the area. This, in turn, makes ward 58 highly vulnerable as per the land-use vulnerability index as well. Ward 58 has considerable low lying areas and the sewer network is inadequate with poor maintenance. Some areas are below the full supply level of the storm water flow channel which flows through the ward. Though about 90% of the area under ward 58 has underground sewerage, most of the pipelines have inadequate carrying capacity, have been laid at a relatively flat slope, and are silted up. In addition, the conditions of the pipes have deteriorated due to industrial waste discharged into the pipes mainly from leather industries. As a result, the ward scores very high on the flood vulnerability index as well.

4.3 SUB WARD LEVEL ANALYSIS

4.10 In the analysis so far, the Ward had been taken as a single unit for assigning vulnerability depending on the characteristics of the ward as a whole in terms of the social and infrastructural set up and the extent of flooding. However, even in a ward with very high vulnerability index not all areas in the ward may be equally vulnerable. In contrast, some pockets in Wards found less vulnerable may face severe threats. To capture such details, another exercise was conducted in which the spatially distributed Geographical Information System (GIS) layers of land-use and flood depth and duration were used at the sub-ward level along with the social vulnerability index for the given ward.

4.11 Figure 4.3 shows how the three layers appear using the GIS overlay analysis**.** The result in the map was then color coded to show how the extent of vulnerability compares among the three vulnerability indices. This analysis determines the vulnerability of the KMC area based on the characteristics at a more granular level ignoring artificial boundaries imposed by the wards. It thus helps in identifying the actual pockets of vulnerable areas in the whole of KMC, especially in the eastern parts that were generally found to be more vulnerable.

Figure 4.3 Methodology: Spatial overlay analysis using GIS



4.12 The vulnerability indices based on socioeconomic characteristics of the population, infrastructure, land-use, and flooding provide a road map for future planning to minimize the effects arising out of climate change. These not only help identify the wards in KMC that may need greater attention while designing adaptation methods to cope with severe storms, but can also help in designing specific area based targeted schemes using the detailed spatial analysis of the vulnerability within each Ward. This issue of adaptation strategies is discussed in more detail in Chapter 6.

Chapter 5. DAMAGE ASSESSMENT

5.1 METHODOLOGY AND ASSUMPTIONS

5.1 **Flooding in an urban area like Kolkata can lead to widespread damage** resulting from submersion of building and property as well as disruption of livelihood among the flood affected population. The damage is further enhanced the longer the flooding persists. While impacts like damage to property and loss of income from flooding can be readily quantified, it is often difficult to assign monetary values to many other types of damages that lead to the dislocation of normal living through socio-economic, environmental, and health impacts. An effort has been made in this study to account for readily quantifiable monetary damages as well as to impute a monetary value wherever possible to other intangible damages.

5.2 **This analysis focuses on the impact from flooding that can occur due to climate change** effects on the affected population in Kolkata in the year 2050. Since detailed data was available only for the KMC area, the analysis is confined only to that area. The starting point of the analysis is to estimate the impact resulting from a 100 year flood occurring in 2050. The study then examines the additional damage that can arise if the effects of climate change, as envisaged in the A1F1 scenario, are added to that 100 year flood. In the analysis, all relevant data is projected to the likely population for Kolkata in the year 2050. Thus, the expected population size of Kolkata in 2050 is extrapolated based on the past decadal growth rates adjusted for likely future changes[25]. The valuation of property and income levels in 2050 are also estimated using the average per capita GDP growth rates in the recent past and projections for the future. To assess the damage in real terms, all data are based on 2009 prices and thus ignores any inflation that can occur by 2050. This is a commonly adopted practice in such damage assessments as it is difficult to make credible assumptions about inflation in the future[26].

5.3 **Both the *depth* and *duration* of a flood play a role in the damage it causes.** The *depth* of an inundation has more effect on the physical capital while the *extent* of a flooding, if it exceeds a critical depth, has greater impact on the day to day livelihood of the population. It is therefore more meaningful to separate the flood damage into two categories: the stock and the flow damage based on whether time is not (or is) a primary factor for the damage estimates. By definition the stock at a point of time is the accumulated resources during a given time period while flow is a continuous generation of resources throughout time. In this analysis, the stock damage is assessed on the loss to accumulated resources out of past flow while flow damage is assessed based on the loss of future flow of resources. This differentiation avoids duplication of damage estimates and also helps in developing a more realistic estimate of flood damage.

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[25] JNNURM, 2005

[26] Background paper prepared by P. Shyamsundar (2009) on estimating flood damage costs in the context of the coastal cities and climate change studies.

- **Stock Damage:** This loss is primarily concerned with the damage to physical capital arising out of water submersion. The *depth* of flooding is the primary determinant of such damage. However, the degree of damage can also increase with the duration of the flooding of a given depth. So, any analysis of stock damage has to start with the depth of flooding and then adjusted upward using the duration of flooding. Such physical resource damaged can be of various forms and involve both private and public property. The most common examples of damage to private resources are buildings and property. While households face damage to their residences and household goods, commercial establishments face damage to commercial buildings as well as goods for sale, and industries can face damage to factory buildings, machinery, and inventory. Other private property losses include damage suffered by owners of transport vehicles, and telecommunication and electric infrastructure. Stock damage will also occur to publicly owned infrastructure like roads, railways, port, water and sewerage facilities, hospitals, and government owned buildings and property.

- **Flow Damage:** The main determinant of such damage is the *duration* of the flooding above a certain depth that can lead to disruption of normal activity over a period of time. While majority of the loss in this category will occur during the flooding, some of the losses can continue even after water recedes. The most significant component of this loss arises from the loss of income due to the inability of people, businesses, and industries to carry out their normal economic activity. While presence of flood water may be a major reason for the cessation of normal economic activity, the loss of resources covered under stock damage can also prolong the total or partial loss of earning capacity even after the flood water recedes. Flow damage can also occur from the stock damage to roads and other communications infrastructure that lead to future disruption of economic activity. In the health sector such flow damage arises from additional health care costs and the effect on livelihood from increased morbidity.

5.4 **Severity of damage according to water depth.** Since the severity of damages are linked to the depth of water inundation, four water levels were identified and associated damage severity was derived (Table 5.1). It has been found that a depth level below 0.25 m produces little damage in most affected areas as people have learned to adapt to such level of flooding as a common occurrence every year. However, when the depth of flooding exceeds 0.25 m, some damages are unavoidable. For the *stock* effect, the extent of damage is mainly dependent upon the *depth* of flooding with: 0.25 – 0.75 m leading to a low impact; 0.75 – 1.50 m leading to a moderate impact, and > 1.50 m causing an extensive impact. Such damage levels also continue to rise the longer the flooding persists.

Table 5.1 Severity of damage according to various water depths

Depth of Water	Nature of Damage
0.0 – 0.25 m	No damage
0.25 – 0.75 m	Low
0.75 – 1.50 m	Moderate
> 1.50 m	High

5.5 **Severity of damage according to duration of flooding.** To examine the severity of flood damage, the extent of flooding above 0.25 m level is analyzed up to 10 days. The cut-off of 10 days was chosen as it was found that flood water recedes from most areas in Kolkata by that period even for the A1F1 scenario with the 100 year flood. The *flow* damage mainly depends on *how long* flooding exceeds the critical 0.25 m of depth.

5.2 DAMAGES BY KEY SECTORS

5.6 The list of important sectors where damage in the two categories can occur is shown in the table below.

Table 5.2 Damages by sectors

Sectors	**Stock damage**	**Flow damage**
Residential	Building, property	Loss of income
Commercial	Building, property	Loss of income
Industrial	Building, machinery	Loss of income
Health		Treatment costs, mortality & morbidity
Roads	Infrastructure	Travel dislocation
Transport	Vehicles	Loss of income
Electricity	Infrastructure	Loss of income

5.2.1 Residential buildings

5.7 **Type of residential buildings**. It is assumed that building damage will occur only at the first floor and not the upper floors in a multi-storied building. Damage to each building will depend on its floor space as well as the nature of the building. For this analysis, the residential buildings were divided into three broad categories of housing: Economically Weaker Sections (EWS), Middle Income Groups (MIG) and High Income Groups (HIG). Google Earth data were used to separate the composition of the city residential buildings into the three categories. The composition for 2050 was then assessed based on a percentage of EWS moving out of core city areas. The percentage of each type of building is shown in Table 5.3. Discussion with town planning authority in KMC suggested that the average floor areas for EWS, MIG and HIG were 25m^2, 75m^2, 150m^2, respectively. It was also assumed that on average, EWS are two storied, MIG are three storied, and the HIG are four storied buildings.

5.8 Damages to residential buildings due to inundation have been separated into repair costs and clean up costs arising out of flooding. The rest of this section explains how each type of damage was estimated in this analysis.

5.9 **Repair costs.** Repair costs are estimated as 6% of building construction costs. At 2009 prices the building construction costs in Kolkata per square meter of floor area were found to be: EWS (Rs. 7000 per m^2), MIG (Rs. 8133 per m^2), and HIG (Rs. 11200 per m^2) respectively based on the ACC Help Home Building Calculator[27]. Using the floor space for each category of residential building, the repair costs for EWS, MIG and HIG at 2009 prices was calculated. The building repair costs were then extrapolated to 2050 costs using an annual growth rate of 4%. The percentage of buildings that require repair costs is determined based on damage factors developed using the depth and duration of flooding in each ward of KMC. It is assumed that any inundation (of depth > 0.25 meter for more than a day) will cause a minimum threshold proportional damage requiring repair that varies with the type of building (Table 5.3). The minimum damage threshold differs because of the quality of building material used in construction of EWS, MIG and HIG bulidings. It is also assumed that any building submerged for 10 days or more (with inundation depth > 1.5 m) will always require repair. The proportion of buildings requiring repair decreases linearly for fewer days of inundation. For depths 0.75 m – 1.5 m and 0.25 m – 0.75 m, the proportion of damage were 75% and 50% respectively of the proportion for depth > 1.5 m. Since the depth of inundation keeps changing as water recedes from a given area, the proportion of building requiring repair in an area is the maximum proportion found from the inundation duration for the three different depths over a 10 day period.

The proportion of damaged buildings requiring repair is given by:

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

M_t = Minimum threshold per building type
D1 = Number of days of inundation depths of 0.25 m – 0.75 m
D2 = Number of days of inundation depths of 0.75 m – 1.5 m
D3 = Number of days of inundation depths > 1.5 m

5.10 **Clean up costs.** It is assumed that all inundated buildings not requiring repair will incur clean up costs. Clean up costs mainly include whitewash, fixed inventories, and labor and was assessed based on field surveys. These were found to be around Rs 500, Rs 2,000 and Rs 4,000 respectively for EWS, MIG, and HIG. Clean up costs were then extrapolated to 2050 costs using an annual growth rate of 4%.

Damage to residential building (D_{RB}) in each category is then given by

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

HH = Total number of household in affected area
I = Percentage of area inundated in the affected area
P = Percentage of composition of different categories
S = Proportion of total households in first floor
C_b = Building construction costs
R_f = Proportion of damaged buildings requiring repair costs
D_h = Damage factor of a building needing repair (assumed to be 0.06)
C_c = Cleanup cost

[27] http://www.acchelp.in/ALH_cost_calculator.asp

Table 5.3 Data for residential buildings

Type	Average floor area	Average no. of story per building	Percentage of building in each category	Proportion of Building floor area in first floor[28]	Building cost (Rs M)	Repair costs (Rs M) per building in 2050	Minimum Damage Threshold	Clean up costs (Rs M) per building in 2050
EWS	25m^2	2	22%	0.5	0.87	0.05	33%	0.0025
MIG	75m^2	3	57%	0.33	3.05	0.18	25%	0.01
HIG	150m^2	4	21%	0.25	8.39	0.50	20%	0.02

5.2.2 Residential property

5.11 **Extensive residential property damage is caused by flooding, especially if it is sudden and prolonged.** All such damage can be categorized as stock damage. All household property like vehicles, appliances, electronic goods, furniture, and other belongings can be damaged to varying degrees, especially if they can't be moved to upper floors. Since there is a direct correlation between household income and the value of household property owned, the estimate of residential property is made based on household income in KMC. These are then extrapolated using an average of 4% annual growth to arrive at 2050 income levels (Table 5.4) [29].

Table 5.4 Household data in KMC

	Income category (Rs '000)[30]					
	< 75	**75-150**	**150-300**	**300-500**	**500-1000**	**>1000**
Percentage of Household	7.9	25.2	26.4	27.4	8.0	5.0
Average income in 2050 (Rs million)	0.25	0.56	1.12	2.00	3.74	9.99
Savings rate	5%	7.5%	10%	15%	20%	25%
Proportion of household in first floor	0.5	0.33	0.33	0.25	0.25	0.25

5.12 **Damage to residential property** is estimated based on the total property exposed to inundation in the first floor times a property damage factor. The value of the property owned depends on the savings accumulated in each income category over a 5 year period (Table 5.4). The proportion of households that face property damage in a Ward is given by the maximum percentage of area flooded in that Ward. The formula used to estimate the residential property damage is:

[28] The estimate is based on average number of floors in each type of house.
[29] The midpoint in each income range is used as the average income in that range other than the first and the last range because of the skewed distribution in those two ranges
[30] Based on 2009 data

Damage to Residential Property (D_{RP}) in each income category is given by

D_{RP} = HH * Y* C *S* D_p*I

HH = Total number of household in each income category in the affected area
Y = Average income in a household income category in 2050
C = Savings rate in an income category for 5 years
S = Proportion of total households in first floor
D_p = Property damage factor
I = percentage of area inundated in the affected area

5.13 The property damage factor is based on the depth and duration of flooding. It is assumed that a maximum of 33% of household property will be damaged if these are submerged for 10 or more days with inundation depth > 1.5 m with proportional decrease for fewer days of inundation. The corresponding maximum damage for depths 0.75 m – 1.5 m and 0.25 m – 0.75 m are assumed to be 25% and 20% respectively. The final damage factor uses the maximum damage factor found from the inundation duration for the three different depths.

The property damage factor D_p is given by

D_p = MAX(D3*.033,D2*0.025,D1*0.02)

D1 = Number of days of inundation depths of 0.25 m – 0.75 m
D2 = Number of days of inundation depths of 0.75 m – 1.5 m
D3 = Number of days of inundation depths > 1.5 m

5.2.3 Residential income loss

5.15 **Income loss affects both residents and migrant workers**. Income losses are considered a *flow* damage category as they depend on the number of days for which such losses occur. Flooding in KMC affects the income of both KMC residents and daily migrant workers who commute to KMC for their livelihood. While the population of KMC is estimated at 4.6 million[31], another 6 million person are expected to commute to KMC daily for work. The population of Kolkata as well as the number of migrant workers is extrapolated to 2050 using estimated decadal population growth rate of 4%.

5.16 **Income loss from the organized sector is not computed.** Estimates of income loss exclude any income loss in the *organized* sector because of two reasons. Firstly, most workers in the organized sector are paid on a monthly basis (such as office workers and those working in the administration) and hence do not face loss in income from daily disruptions. Secondly, workers in the organized sector, which are paid on a daily basis are likely to face income loss, but this loss has already captured under the commerce and industry sectors. It is therefore not included here, to avoid any double counting.

[31] As per the 2001 Census

5.17 **Income loss for KMC residents in the unorganized sector**. Household income data is used to estimate income loss for KMC residents working in the unorganized sector (such as artisans or construction laborers). The income loss is based on the number of lost work days multiplied by the average income in each category. For the purpose of the analysis the following assumptions were made:

- 90% of households in the lowest annual household income bracket (< Rs 75,000) are employed in the unorganized sector;
- 50% of households in the medium household income bracket ((Rs 75,000- 150,000) are employed in the unorganized sector
- 10% of households in the higher household income bracket (Rs 150,000-300,000) are employed in the unorganized sector.
- Households in the income bracket above Rs 300,000 are all considered to be in the organized sector.

5.18 **Income loss of KMC migrant workers in the unorganized sector.** It is assumed that 25% of migrant workers coming daily to KMC are in the unorganized sector. Since workers in the unorganized sector tend to be lower skilled, it was further assumed that migrant workers in the unorganized sector earn 33% less on average than that for an average urban worker residing in KMC The income loss for migrant workers is computed based on the number of lost days of work (which is based on the average duration of flooding in all of KMC).

> **Income loss** D_I **in each income group** is given by:
> $D_I = I * D_T$
> I = Income per day in each income category
> D_T = Number of lost work days due to flooding in each ward for KMC residents and average for the whole of KMC area for migrant workers;

5.2.4 Commerce and Industry

5.19 **Commerce: stock damage**. The stock damage in the commercial sector is based on damage to building and merchandise. Damage factors based on depth and duration of flood are applied to the value of building and merchandise affected by flood to assess such total damage costs. The average cost of a building in a commercial establishment is determined using an average area of 50 m^2 and a construction cost[32] of Rs. 7000 per m^2. The stock of merchandise is based weekly merchandise sale. Since only commercial establishments located in the first floor will face flood damage, it is assumed that only 50% of them will face flood damage. All damage costs are then extrapolated to 2050 costs using a growth rate of 4% per year.

[32] Based on the ACC Building Calculator.

5.20 **Industry: stock damage**. The stock damage in the industrial sector is based on damage to building and machinery. Fixed capital is used as an estimate of the value of building and machinery. Damage factors based on depth and duration of flood are applied to the value of building and machinery affected by flood to assess total damage costs. All damage costs are then extrapolated to 2050 costs using a growth rate of 4% per year.

5.21 Damage factor for commerce and industry. In absence of ward wise distribution of commercial and industrial data, the damage factor is developed using the average extent of flooding for 10 days under various depths for the whole of KMC area. It is assumed that the extent of damage for depths 0.25 m – 0.75 m, 0.75 m – 1.5 m and > 1.5 m will be 3%, 6%, and 9% of the value of the assets respectively.

5.22 **Commerce and Industry: loss of income**. Loss of earnings is assessed as the difference in the daily net value added and the avoided variable costs for the number of days business is affected. The number of lost days of business is based on the extent of average flooding and its duration.

Formula used in each case for loss of income is

$D_{XF} = N * D_T$

N = (Net Value added – Avoided Variable Cost) per day

D_T = No. of lost days over 10 days of flooding = $[0.5*(F_L - F_M - F_H) + 0.67*(F_M - F_H) + F_H]/100*10$

where

F_L, = Average extent of flooding in KMC over 10 days of flooding for depth 0.25-0.75m

F_M, = Average extent of flooding in KMC over 10 days of flooding for depth 0.75-1.5m

F_H = Average extent of flooding in KMC over 10 days of flooding for depth > 1.5m

5.2.5 Health Sector

5.23 Flooding causes damages to hospital infrastructure and increases the incidence of water born diseases[33]. Due to limited data availability, the analysis did not include damage to health infrastructure. Increased incidences of water born diseases are evaluated by assessing both the additional treatment costs as well as the loss of productivity due to illness.

5.24 **Treatment costs.** As indicated in Table 5.5, annual incidence of major water born diseases total around 5.86%. While anecdotal evidence is available about the higher incidence of such disease due to increased extent of stagnant water from flooding, actual data to estimate the impacts of flooding is hard to come by. However, during the rainy season and its immediate aftermath it's observed that such incidence more than double. For the purpose of this analysis, a conservative estimate of doubling the incidence of water born disease (to 11%) in the flooded area is used for both the 100 Year flood and the A1F1 scenario. Average per capita health care costs for treating such water borne related disease are estimated around Rs 440 at 2009 prices.

[33] Mortality and morbidity that may occur due to extreme heat events as a result of higher average temperatures arising from climate change effects has not been included in the analysis.

Table 5.5 Incidence of water borne disease in KMC[34]

Disease Category	**Annual incidence rate**
Gastroenteritis, Cholera	3.46%
Hepatitis	0.05%
Typhoid	0.18%
Malaria, Chickengunya Dengue	2.17%
Total	**5.86%**

5.25 **Increased morbidity.** The increased incidence of diseases entails also a loss of productivity. Various illnesses are converted into one common indicator the Disability Adjusted Life Years (DALY) for ease of computation. In West Bengal, an estimated 171 DALYs per thousand urban population is estimated lost every year due to various diseases[35]. Current data indicates that about 17% of such DALYs are caused by infectious and parasitic disease[36]. More than half of such disease can be traced back to water borne causes. These data were projected to 2050 and it was estimated that around 14 DALY per thousand people is expected to be lost due water born disease in KMC in 2050. In order to factor in the impact of climate change, a doubling incidence of such disease in the flooded area is used for both the 100 Year flood and the A1F1 scenario.

5.26 **Valuing morbidity.** There are two approaches to value a DALY. The *human capital approach* values a DALY at the level of income per capita. That means that if one year of a person's life is lost due to disability, society loses at the very least the person's contribution to production. This method provides a lower bound of a person's worth. An alternative method is the *value of a statistical life,* which provides an upper bound monetary value of health damages. It uses rigorous econometric technique to disentangle the effect of risks to life on the prices paid for goods and serves and obtain in this way a monetary value of the risk. The VSL[37] is then divided by 25 to obtain the value of a life year. The value of 25 is the number of discounted years of life that are lost on average with the death of an adult. In this analysis, the average of the loss found from the human capital approach and the value of statistical life is used.

5.2.6 Road damage

5.27 Floods cause damage to the road network (*stock* damage) and disrupt economic activity due to delays, congestion and road closure (*flow* damage). Due to data constrain only damage to road infrastructure has been estimated in this analysis. Damage to road infrastructure was estimated based on repair costs. The depth of flooding over the road is a major factor that affects the extent of damage on the road. Kok's estimates of damage are used while determining the road repair costs per

[34] Personal communication with Secretary of Department of Health and Family Welfare, Government of West Bengal, March 2010
[35] KEIP, 2007
[36] Murray and Lopez, 1997
[37] The VSL used for this analysis is Rs 15 million. This has been computer through a survey among workers in Chennai and Mumbai by S. Madheswaran, 2007.

meter of inundation (Kok, 2001). Accordingly damage factors of 0.1, 0.225, and 0.4 respectively for water depths of 0.25-0.75 m, 0.75-1.5M, and > 1.5 m were used. The maximum extent of inundation in the KMC area over the 10 days of flooding under each depth of flood was used to determine the extent of damaged roads.

> **The length of damaged roads L_D** was given by:
> $L_D = L_T *[A_H*0.4 + (A_M - A_H)*0.225 + (A_L - A_M - A_H)*0.1]$
>
> L_T = Total length of roads
> A_L , A_M , and A_H are the maximum proportion of flooded area over 10 days under the three flood depths in increasing order.

5.28 **Road repair estimate.** Average road repair and rehabilitation cost of Rs 9 million per kilometer was used. This estimate was on based on World Bank transport data used in projects in India. This estimate was further validated using actual data from "Project-Special Road Repairing Works" of KMC[38]. The average road repair costs were extrapolated to 2050 for the final analysis. The road repair cost caused by flooding was then obtained by multiplying the length of damaged roads L_D by the per km road repair cost.

5.2.7 Transport

5.29 **Damage to vehicles.** The main *stock* damage age in the transport sector arise primarily from the damage to vehicles. All powered public transport vehicles including buses, taxis, auto-rickshaws, and goods vehicles were included in the analysis. The number of public transport vehicles in 2050 was estimated using the decadal growth rate of 4% for the population of KMC. To assess the repair cost for damaged vehicles due to flooding, data was obtained using sample surveys from auto repair shops. The average estimates ranged between Rs 10,000- 30,000 based on the depth of the water submersion and the type of the vehicle. To determine the proportion of vehicle damaged by flood, it was assumed that 50% in depth category > 1.5 m, 33% in depth category 0.75 m - 1.5 m, and 25% in depth category 0.25 m - 0.75 m will suffer damage.

> **T_p the transport damage factor** is given by
>
> $T_p = [0.25*(F_L- F_M – F_H)+ 0.33* (F_M – F_H) + 0.5* F_H]/100$
>
> F_L, F_M, and F_H are the average extent of flooding in the KMC area over the 10 days of flooding for the three depths in increasing order.

5.30 **Damage to railways and airport.** Due to data constraint damage to the railway network as well as airline infrastructure and disruption were not includes in the analysis. Although these impacts are not expected to be major, the analysis is likely to underestimate the overall impact for a flood event.

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[38] KMC (Roads Department): New Year's Resolution and Request- Keep Track of Our Progress toward a Better Kolkata, Today Episode-1. Today we give an account of Roads, Timeframe: January-December, 2006.

5.31 **Loss of income.** All revenue loss (*flow* damage) estimates in the road transport sector were made using data for annual traffic and revenue for vehicles owned by Calcutta State Transport Corporation (CSTC) for buses and Calcutta Tramways Corporation (CTC) for trams. The loss of income was calculated based on daily revenue loss offset by savings in variable costs. It is assumed that there can be no transport in areas where depth of flooding > 1.5m with the corresponding loss for the depths of 0.75 m – 1.5m and 0.25 m – 0.75 m being 67% and 50% respectively.

The number of lost days D_T over the 10 days of flooding is given by
$D_T = [0.5*(F_L - F_M - F_H) + 0.67*(F_M - F_H) + F_H]/100*10$
F_L, F_M, and F_H are the average extent of flooding in the KMC area over the 10 days of flooding for the three depths in increasing order.

The income loss L_T **in each transport category** is given by
$L_T = V_T * D_T$
V_T = (Net Earning Loss – Avoided Variable Cost) per day;

5.32 The net earning loss is computed based on the passenger-km traveled and the tariff charged by the various modes of transport. The passenger-km travel data was available for buses and for taxis, auto-rickshaws, and goods vehicles, the data for buses was used with proportional reduction for passenger carrying capacity. The revenue loss for goods vehicles were computed using half the distance traveled by buses along with per Km rates for transport. The losses to intercity trains were calculated using the average daily revenue loss derived based on annual revenue. The loss of revenue for Kolkata Port was also calculated using the average daily revenue and the number of days lost because of disruption caused by flooding.

5.2.8 Electricity

5.33 **Damage to physical assets from flooding,** especially if they are coal based. Such coal based power generating units face disruption due to flooding of coal handling plants and outages arising from flooding of machinery. While majority of current power generation in Kolkata is currently coal based, it is difficult to predict the likely scenario in 2050, especially because of the concern about global warming effects from coal based power plants. Moreover, due to their proximity to water bodies needed for cooling, power generating units take extra precaution for flooding. So, for this analysis, no *stock* damage of power plants from flooding is included.

5.34 **Loss of revenue**. The electric utilities are still susceptible to flow damage from the need to disconnect electric supply in severely submerged areas to prevent accidental electrocution. The loss of income from such effects is calculated using the revenue loss in the flooded areas which is offset by a factor to account for the savings in variable input costs.

5.2.9 Telecommunication, Water Supply and Other Public Sector Damage

5.35 **In the telecommunication sector**, flooding affects the landlines more than wireless. Since landlines are currently witnessing a decline being substituted by wireless, it is expected that most telecommunication service will be provided through wireless by 2050. So, the effect of flooding on telecommunication is assumed to be minimal.

5.36 **Any damage to water supply** and sewerage infrastructure from flooding is likely to be minor and difficult to assess. Since the water rates in KMC are based on the ferrule size of the water line and not metered, any disruption of water supply caused by flooding will not lead to any significant revenue loss as well.

5.37 **The increased flooding will also affect government buildings and other government owned property.** It will also have an impact on school and hospital buildings both private and government owned. Such losses, although substantial, are difficult to assess and are not included in the study.

5.3 DAMAGE ESTIMATES

5.3.1 Residential buildings and property damage and income loss

5.38 Faced with a 100 year flood in 2050, an estimated 14.2% of all household in KMC will face varying degrees of damages to their residential building (0.16 million out of total 1.13 million households). Adding the impact of climate change, under an A1F1 scenario, will increase this number to 15.2% of all households (or 0.17 million). Damages to residential buildings are estimated at Rs 24,700 million (under a 100 year flood) and at Rs 27,900 million (under the A1F1 scenario). In terms of household property losses, damages are estimated at Rs 34,000 million (for a 100 year flood) and at Rs 38,600 million (under the A1F1 scenario). The results are summarized in Table 5.9.

5.39 The total loss of income from the 100 year flood is estimated at Rs 4,300 million, of which the KMC residents will suffer a loss of Rs 1,200M while migrant workers will lose an income of Rs 3,100 M. Under the A1F1 scenario, the total income loss increases to Rs 5,000 million and the major share of that loss is faced by migrant workers amounting to Rs 3,700 million.

5.3.2 Commercial and industry damage

5.40 Losses in the commercial and industrial sectors from a 100 year flood and under A1F1 scenario is shown in Table 5.6. The majority of the losses arise from the damage to building and property in both sectors.

Table 5.6 Total losses to commerce and industry

In 2050 (Rs million)	100 Y Building & property	100Y Income loss	100Y Total	A1F1 Building & property	A1F1 Income loss	A1F1 Total
Commercial	6,600	1,200	7,800	7,800	1,500	9,300
Industry	1,700	900	2,600	2,100	900	3,000

5.3.3 Health loss

5.41 As explained earlier floods usually leads to increase the incidence of water born diseases generating a loss in productivity and additional treatment costs. The results of the estimates are shown in Table 5.7.

Table 5.7 Total losses in the health sector

In 2050 (Rs million)	100Year	A1F1
Treatment cost	600	700
Loss in productivity (estimated using DALYs)	16,500	17,700
Total	**17,200**	**18,400**

5.3.4 Roads

5.42 The total road repair cost amounts to Rs 2,100 million for the 100 year flood. This estimates increases to Rs 2,400 million under the A1F1 scenario. The results are presented in Table 5.9

5.3.5 Transport

5.43 Damages to the various modes of transport that arises from a flood event are shown in Table 5.8 below.

Table 5.8 Total losses in the transport sector

In 2050 (Rs million)	100Y Damage	100Y Income loss	100Y Total	A1F1 Damage	A1F1 Income loss	A1F1 Total
Bus, Tram	310	430	740	340	510	850
Taxi	380	90	470	420	110	530
Auto	110	20	30	120	20	140
Goods Vehicle	930	980	1,910	1,040	1,160	2,200
Trains	NA	70	70	NA	80	80
Port	NA	40	40	NA	50	50
Total	**1,720**	**1,630**	**3,250**	**1,920**	**1,930**	**3,850**

5.3.6 Electricity

5.44 Under the 100 Year flood, the total income loss amounts to Rs 300 millions in 2050 and it increases to Rs 400 million under the A1F1 scenario.

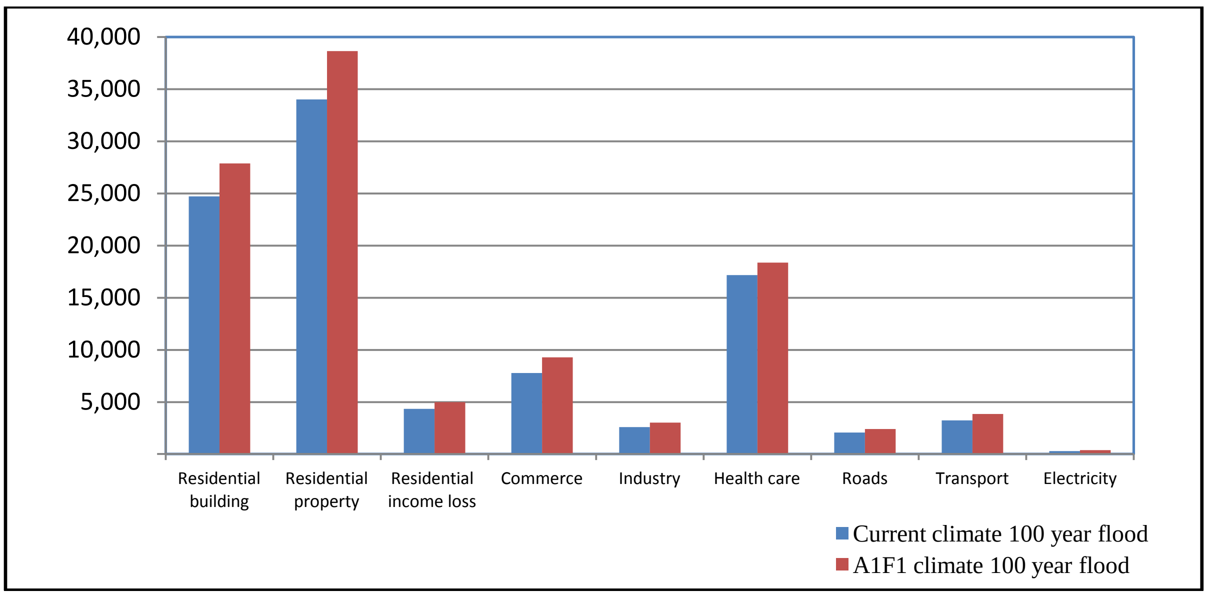
5.4 OVERALL DAMAGES

5.45 **The total loss** in each sector is calculated by combining the stock damage and the flow damage. The sector-wise break down of total losses is shown in Table 5.9 and Chart 5.1.

Table 5.9 Total losses in major sectors in KMC (in 2050)

	100 Year Flood	A1F1 Scenario	Only Climate Change
Residential building	24,700	27,900	3,200
Residential property	34,000	38,600	4,600
Residential income loss	4,300	5,000	600
Commerce	7,800	9,300	1,500
Industry	2,600	3,000	400
Health care	17,200	18,400	1,200
Roads	2,100	2,400	400
Transport	3,200	3,800	600
Electricity	300	400	100
Total (Rs. millions)	**96,200**	**108,800**	**12,600**

Chart 5.1 Total losses in major sectors in KMC (Rs million in 2050)

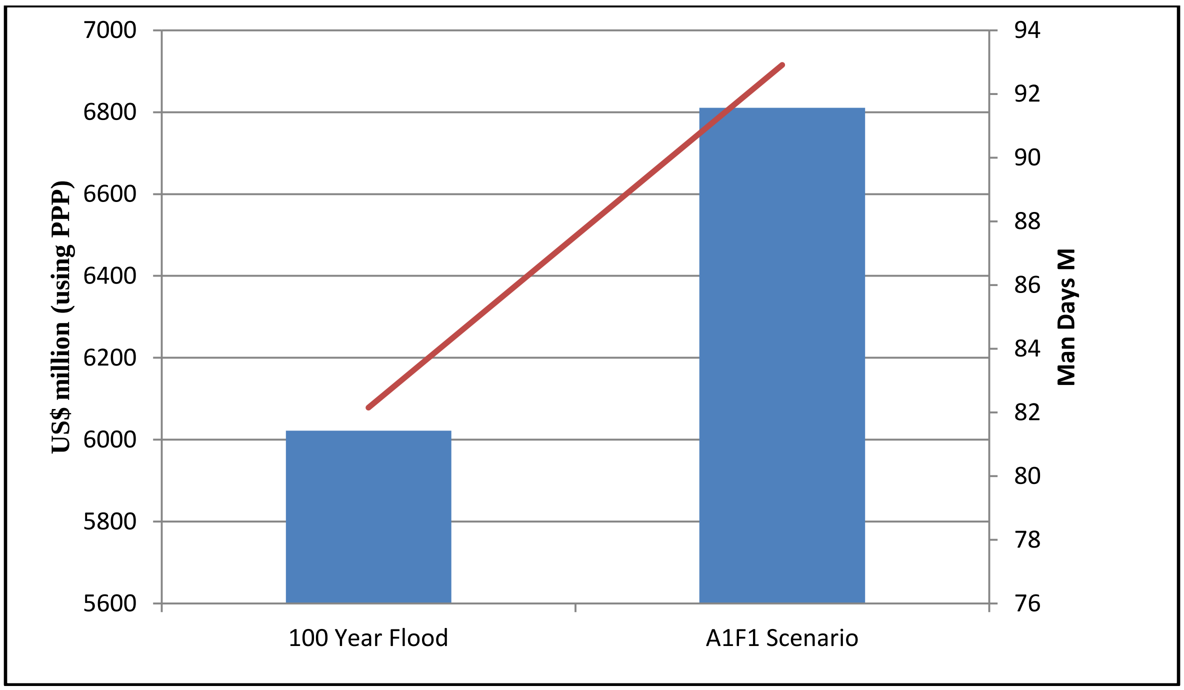


5.46 **Additional damage due to climate change**. The additional losses resulting from the A1F1 climate change scenario in 2050 was estimated to Rs 12,600 millionFor a meaningful comparison it is appropriate to convert the loss in local currency to US $ using the Purchase Power Parity index. Because of the uncertainty about the likely PPP index in 2050 and as the losses for 2050 are expressed in 2009 prices, the PPP adjustment is made based on the PPP index for India in 2009 of

2.88[39]. Using PPP US$, the additional loss from climate change effects under the A1F1 scenario in KMC area in 2050 amounts **to $790 million**.

5.47 Another useful way of assessing the extent of damage from climate change effects is to assess the number of man days needed to recover from the loss. This is based on the average daily wage of urban workers in Kolkata. For this comparison, the data for 2009 is projected to 2050 income levels using the per capita growth in GDP in the recent past. It is found that due to climate change effects under the A1F1 scenario in KMC area in 2050, total loss in terms of man days will amount to 10.8 million. The extent of losses with and without climate change effects using various comparison dimensions is shown in Chart 5.2.

Chart 5.2 Total Losses using PPP and Man Days



5.48 The estimated additional loss of $790 million in KMC from climate change effects is based only on damage resulting from increased flooding and leaves out impacts from other weather related incidents like increased wind damage. Land subsidence was also not included in the analysis as it was considered a second order effect in connection with the increased damage from climate change. In addition, the damage estimates are based on a partial equilibrium analysis and do not include losses in consumer surplus. It is important to note that this estimate is likely to underestimate to total damage due to climate change because many impacts were not quantified in this analysis due to data constraints. Thus the estimated loss of $790 million represents a **lower bound** and actual damage is likely to be even higher. .

[39] IMF, 2009

Chapter 6. ADAPTATION STRATEGY

6.1 INTRODUCTION

6.1 **Urban flooding is the most critical climate related hazard in Kolkata.** Urban flooding is a recurring phenomenon that Kolkata faces every year during the monsoon period. The reasons for such flooding are partly natural and partly anthropogenic. Whenever high intensity rainfall had synchronized with high tide in the Hugli river, the consequence had been disastrous. The excess water released from Damodar Valley Corporation and other reservoirs aggravated the situation even further. From such experience the local population has also learned to adapt by developing a number of coping strategies for facing such periodic episodes of flooding. However, as discussed in chapter 3, climate change is likely to intensify this problem through a combination of more intense local precipitation, riverine flooding in the Hooghly and coastal storm surges. In addition, if such intense precipitation is accompanied by extreme weather events such as cyclones, it can lead to widespread and severe flooding that can bring the city to a standstill for a few days.

6.2 **As discussed in Chapters 4 and 5, the economic, social and environmental costs of such intense flooding can be quite high**. These impacts will only grow in the time horizon of 2050 as the city population rises and with it comes increasing development and urbanization in a metropolis which has already grown and sprawled, largely in an unplanned way. Since 1970s the northward and southward expansion of Kolkata has slowed down and the main growth has been towards the east. This has led to the shrinkage of the wetlands located in the east that may worsen the flood incidence in the future.

6.3 **A major cause of such periodic flooding during the rainy season is the 'Adaptation Deficit' that Kolkata faces** at present to cope with such events. This arises not only from deficiencies in physical infrastructure that lead to flooding but also from problems with land-use and socio-economic and environmental factors that can aggravate the impact of such flooding. This chapter first identifies the causes that contribute to urban flooding in an area like Kolkata to help determine the possible adaptation strategies to mitigate such problems. The current major adaptation deficits in Kolkata are then analyzed and steps that may be needed to bridge those gaps are discussed. The analysis also takes into account the modifications needed to cope with the increased impact resulting from climate change effects. Since investment in infrastructure to fully prevent flooding under the most severe weather related scenarios arising from climate change may not be economically justifiable, other ways of minimizing damage from such flooding are also explored. These include preparedness *before* and *during* the event as well as *post*-event rehabilitation strategies.

6.2 CAUSES FOR URBAN FLOOD

6.4 **Current literature list some common factors that contribute to urban flooding** (Table 6.1). Among these, while it may be difficult to control the meteorological factors, any adaptation strategy need to address the hydrological causes as well as the human factors.

Table 6.10 Factors Contributing to Urban Flooding

Meteorological Factors	Hydrological Factors	Human Factors Aggravating Natural Flood Hazards
▪ Rainfall ▪ Cyclonic storms ▪ Small-scale storms ▪ Temperature ▪ Snowfall and snowmelt	▪ Soil moisture level ▪ Ground water level prior to storm ▪ Natural surface infiltration rate ▪ Presence of impervious covered surface layers ▪ Channel cross-sectional shape and roughness ▪ Presence or absence of over bank flow, channel network ▪ Synchronization of run-off from various parts of urban watershed ▪ High tide impeding drainage	▪ Land-use changes (e.g., surface sealing due to urbanization, deforestation) increase run-off and may be sedimentation ▪ Occupation of the flood plain obstructing drainage and flows ▪ Inefficiency or non-maintenance of infrastructure ▪ Too efficient drainage of upstream areas increases flood peaks ▪ Climate change affects magnitude and frequency of precipitations and floods ▪ Urban microclimate may enforce precipitation events
Adopted from WMO (2008)		

6.5 In a **coastal city like Kolkata, floods are mainly caused by a combination of local, riverine, and coastal factors.** Chapter 3 of the report examined in detail the causes for flooding from these factors in Kolkata. However, one important factor that contributes to local floods is the extent of absorption and percolation of water in the soil. Urbanization in general leads to decreased rates of infiltration and increased surface runoff as shown in Table 6.2. If the surface runoff generated exceeds the drainage capacity of the local storm-water drainage system then the area is flooded. Many a times, urban drainage facilities are either not in good shape or altogether missing which also reduces the drainage capacity of the area and cause flooding.

Table 11 Effect of Urbanization on Infiltration and Surface Runoff

Types of Surface	Evaporation	Shallow Infiltration	Deep Infiltration	Surface Run-off
Natural Ground Cover	40%	25%	25%	10%
10-20% Impervious Surface	38%	21%	21%	20%
35-50% Impervious Surface	35%	20%	15%	30%
75-100% Impervious Surface	30%	10%	5%	55%
(Source: WMO, 2008)				

6.3 URBAN FLOOD MITIGATION OPTIONS

6.6 **Given the causes for urban flooding in general**, experience reveals that complete flood protection in any urban setting is neither feasible nor justifiable. So, flood protection and management should involve a spectrum of activities aimed at reducing harmful impacts of floods on people, environment and economy of the area (Andjelkovic, 2001). The major limitation of present flood management methodologies is that these are mostly oriented towards the economic impacts and does not address the environmental and social impacts.

6.7 **According to the UNESCO guidelines** (Andjelkovic, 2001) identification of problems, opportunities and constraints, the setting of goals and objectives, the establishment of policies and priorities that govern overall effort, and finally the development of criteria and standards for evaluating system's performance under future development scenarios should lie at the heart of any master planning for flood management. The emphasis should be to have a unified program for storm water drainage and flood control.

6.8 **Since every urban basin is unique**, each urban area needs to be analyzed to identify drainage problems under present hydrologic conditions. The basin hydrology should then be analyzed with full development of the basin so as to identify the improvements necessary to serve future developments.

6.9 **An integrated approach is recommended** that recognizes drainage system complexity and interconnectivity of its elements such as storm water drainage, water supply, wastewater, water pollution control, water reuse, soil erosion, solid waste management, etc. The approach should also be sustainable which means that the present human needs should be met without undermining the resource and ecological base of the future generations.

6.10 **The flood management methodologies** need to be based on mathematical modeling rather than statistical and probabilistic analyses because the floods are dependent on hydrological conditions in as much as that two identical rain storms may produce different runoff dependent on the antecedent condition of the catchment. The effective implementation of mathematical models need the basic data on precipitation, terrain characteristics, landuse, urban infrastructure and other associated entities.

6.11 **The climate change has added another dimension to the whole problem** of urban flooding. Most climate change models predict much higher intensities of precipitation in future thereby rendering many of the drainage infrastructures inadequate to safely drain the storm waters and thereby causing higher levels of floods and consequent damages. These concerns have to taken into account in any future flood management plans.

6.4 URBAN FLOOD MANAGEMENT STRATEGY

6.12 **Experience with urban flood mitigation strategy in general** reveal that a sustainable urban drainage system should essentially aim for adequate drainage (buffer drainage channels) in order to mitigate local floods, without creating flooding downstream. A number of so-called "source control measures" which are meant to either retain storm water or reduce storm-water runoff in order to prevent the exceeding of the drainage system capacity and to mitigate the generation of flood hazards downstream are to be appropriately designed and employed.

6.13 **The reduction of surface runoff in absolute terms can only be achieved** by a variety of measures that potentially increase infiltration, evaporation and/or transpiration from the catchment areas that contribute to local flooding. The easiest way to do so is to preserve all mandatorily designated green areas in the city (30-50% as per the town planning laws). Such spaces are meant for multifunctional purposes such as

i) Reduce surface runoff by increasing infiltration and evapotranspiration

ii) Retain water through interception

iii) Filter the percolating water

iv) Recharge groundwater resources directly

v) Reduce air pollution and improve the urban microclimate and

vi) Develop parks and gardens with rain water harvesting systems.

6.14 **Since the availability of space is highly limited in cities**, less extensive measures that enable effective in-town infiltration can also be used. Among them are infiltration trenches, soak-aways, and measures that increase the permeability of larger surfaces. Infiltration trenches and soak-aways consist of a trench or a pit filled with a top layer of permeable material like crushed stones or gravel and a bottom layer of sand. Ideally, they are surrounded by filter fabrics. Parking surfaces can also be made of permeable materials that can contribute significantly to the reduction of runoff.

6.15 **Wherever potential options for infiltration and evapotranspiration** within the city are limited, especially where convective precipitation and non-absorptive soils prevail, measures of storm-water retention are vital for the mitigation of urban floods as well as for the prevention of downstream floods. Storm-water retention can be achieved or facilitated by constructing basins or ponds that temporarily store surface runoff and release it subsequently at a controlled rate. A variety of retention basins and ponds - open or covered, wet or dry – are in use that may serve various purposes. The advantage of multipurpose dry ponds is the maximization of land use (WMO, 2008). They also contribute to infiltration and to the removal of pollutants. Further, many creative possibilities exist to use the same space for everyday activities as well as for occasional flooding. Wet ponds in the form of artificial lakes can be of aesthetic value. Temporary storm-water retention can be made in sport courts, parking sites, playgrounds etc. In all these cases sedimentation has to be considered a likely problem.

6.16 **A complementary multipurpose retention strategy is storm-water storage** as a source of water supply, so-called "rainwater harvesting". Considering economic and environmental advantages and its potential for mitigation of urban floods, rainwater harvesting constitutes a reasonable measure in almost all cities. Although unfiltered storm-water is normally not of drinking water quality, it is amenable for non-potable purposes such as washing, irrigation, toilet flushing etc. Storm-water is usually collected from roofs and stored in underground tanks.

6.17 **A major concern in many cities with sub-optimal solid waste disposal systems** is the clogging of drainage facilities with solid waste that reduces the carrying capacity of the drainage systems. Open channels in cities with no effective waste management or drainage systems that are only intermittently used for carrying discharge, are particularly affected by this problem. Establishing an appropriate waste disposal system becomes an essential part of flood risk management strategy. Cleaning and maintenance of drainage facilities is essential to the operational reliability of such drainage systems. The same applies to watercourses that have high rates of natural sedimentation for which dredging or widening may be necessary to maintain discharge capacity.

6.18 **Controlling the storm-water quality** also constitutes a major challenge in urban flood risk management. One of the most severe post flood problems in many urban areas is the polluted flood waters. Some of the most common sources of contamination are sewer overflows, inundated waste disposals and sewage treatment plants, flooded open drainage systems, and dissolved chemicals, oils, etc., from industrial as well as domestic sources. Thus, reducing the potential for flood water contamination is crucial for hazard mitigation. WMO (2008) suggests the following steps for avoiding the water contamination by:

- Strictly separating sewage and storm-water drainage systems and by equipping them with adequate capacities
- Protecting sewage treatment plants against floods
- Improving the sanitation of liquid wastes and the collection of solid wastes
- Placing waste disposals at safe locations
- Enforcing regulations for the storage of dangerous substances

- Prohibiting the storage of dangerous substances in the most flood prone areas.

The various possible strategies to manage urban flood risks due to local flooding are summarized in BOX-6.1.

BOX-6.1 Mitigating Hazards of Local Floods

Reducing local floods by inducing infiltration through:

- preservation of unsealed areas,
- preservation of natural ponds,
- inducing groundwater recharge and greening of unsealed areas,
- introducing permeable pavings,
- provision of infiltration trenches, soak-aways

Retaining/ transferring local floods:

- minor and major urban drainage system (storm water channels, gutters, culverts, pumps etc.)
- preventing clogging of drainage facilities (cleaning, dredging, solid waste collection etc.)
- detention and retention basins
- rainwater harvesting

Preventing storm water contamination:

- strict separation of sewage and storm water drainage
- protection of potential contamination sources (sewage plants, landfills, patrol stations etc.) against floods

(Source: WMO, 2008)

6.5 ADAPTATION DEFICIT IN KMC

6.19 **Most of the problems discussed that lead to local urban flooding** exist in KMC area and are causes for the adaptation deficit. The following briefly lays out the main reasons underlying the current adaptation deficit faced by KMC that is causing recurrent flooding during the rainy season.

6.5.1 Deficit in sewerage network and treatment infrastructure

6.20 **The *urban storm drainange* (or SWMM) modeling** and subsequent analysis in Chapter 3 and 4 helped identify areas in KMC that are currently facing the most adaptation deficit. These are primarily areas that have inadequate drainage and sewerage infrastructure and high slum population (such as wards 14, 57, 58, 66, 67, 80, and 108) and some other pockets in KMC (such as wards 63 and 74) that have either remained vulnerable due to their topography or have become more vulnerable due to developmental activities in recent times and inadequate maintenance of infrastructure.

6.21 **Areas added to KMC.** Before their inclusion in KMC, the added wards from the Municipalities of South Suburban, Garden Reach and Jadavpur suffered from inadequate infrastructure, unplanned land-use, socio-economic and environmental vulnerability. Even after becoming part of KMC, not enough investments were made to make up for the earlier shortfalls in infrastructure and improve the socio-economic and environmental conditions. The infrastructural problems are getting even worse in recent times with increased building activity as these areas have become attractive to developers after becoming part of KMC. A number of new residential high rise apartments and commercial complexes are springing up in the added areas without adequate increase in sewerage facilities. The streets in these areas are generally narrow with insufficient room for separate wastewater and drainage systems. This has caused increased difficulties in constructing sewer networks in such highly congested and unplanned neighborhoods.

6.22 **Original areas in KMC.** In many places of the older KMC area the capacity of the sewerage systems have not kept pace with the changes in population as the city has evolved. These have been further aggravated by inadequate maintenance as well as the siltation of the existing trunk sewer systems that has considerably reduced their carrying capacity. While the sewer networks in KMC under such partially silted condition still provide reasonable hydraulic capacity for carrying the Dry Weather Flow (DWF), they prove highly inadequate for carrying the Storm Weather Flow (SWF) even with normal precipitation during the rainy season. As a result, there are pockets within the erstwhile KMC areas that face regular inundation during the rainy season. In addition, the construction of the Metro system also affected the existing sewerage systems in some areas of KMC that have caused some localized problems.

6.23 **Sewage treatment.** To avoid polluting the Hooghly River, the majority of the sewage from the core inner city area - about 1,100 million liter per day without formal treatment- is discharged via the DWF canal to the Kulti River after traveling a distance of 36 km. Although, this sewage receives partial natural treatment as it passes through the East Kolkata Wetland fisheries before being discharged to the Kulti river, it still poses environmental and health issues to areas along the DWF canal and in the Kulti river basin. In addition, during storms, the SWF mixes with DWF and this polluted water gets partially discharged into the Hooghly River instead of being fully transported to the Kulti river. Studies show that such discharge damages the water quality of the Hooghly River.

6.5.2 Deficit in drainage infrastructure

6.24 **The major issues with the drainage system in KMC** are (i) that almost all major pumping stations operate at much less than their rated capacity. This arises mainly from inadequate maintenance and renovation of equipment and buildings; and (ii) that the hydraulic capacity of the outfall canal system has been reduced due to siltation and deposition of solid waste. There has been no regular maintenance as the DWF canal was last maintained in 1999 and the SWF canal was last maintained in 2003-04.

6.5.3 Deficit in financial resources and institutional capacity

6.25 **Financial resources**. A major reason for inadequate maintenance and renovation of the sewerage/drainage system and other infrastructure in KMC is the inadequate availability of resources. The user charges for municipal services meet only a fraction of the cost involved and this is true even for the service charge recovery from institutional, commercial and industrial users

6.26 **Institutional capacity.** Due to the absence of a commercial approach there is lack of professionalism in operations in KMC with a consequent decrease in efficiency of utilization of both physical and manpower resources. There is also little private sector participation in improving the day to day functioning. In addition, the multiplicity of government agencies that are responsible for maintaining the system, many of which are not under the direct administrative jurisdiction of KMC cause coordination problems leading to operational inefficiencies.

6.5.4 The poor are the most affected

6.27 **Water logging and flooding along with sewer back up** poses a health threat to people who come into contact with the contaminated water. *Homeless people*, *street dwellers* and people living in informal settlements in low-lying areas are especially prone to contact with the backed-up sewage/storm water mixture. The untreated wastewater being conveyed in the DWF and SWF canals and in Tolly's Nullah, the Chetla Boat Canal, and the Circular Canal pose health hazards to *people who squat on the banks* of these canals and use the canal waters for bathing and washing. In addition, the untreated DWF and SWF are used for irrigation by *farmers* and use of such contaminated water for vegetable crops is known to spread typhoid, cholera and dysentery.

6.6 ADAPTATION STRATEGY IN KMC

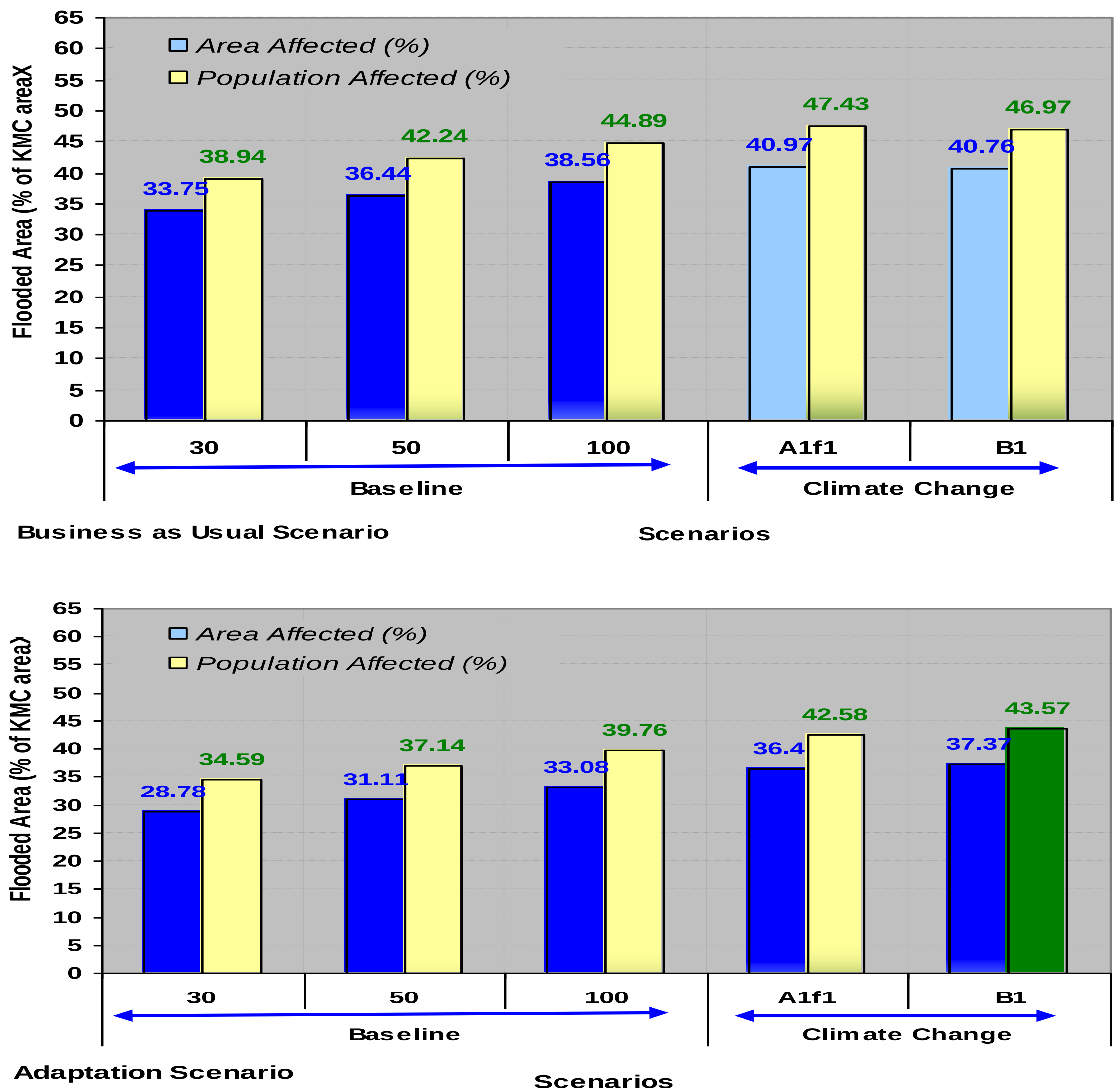
6.28 **What is needed is a comprehensive and effective strategy** that invests in both soft and hard infrastructure to tackle flooding problems in Kolkata. The goal of this strategy is to (i) reduce the percentage of people affected by flooding impact and sewage related diseases in KMC; and (ii) target the most vulnerable areas.

6.6.1 Investing in hard infrastructure

6.6.1.1 Investing in the Sewerage System

6.29 **De-silting of trunk sewers.** De-siltation of the trunk sewers both in the town and suburban systems is needed to increase the hydraulic capacity and minimize flooding in the core area. The results from the SWMM show the changes in inundation under various storm scenarios between a Business as Usual Scenario (30% silting) and an Adaptation Scenario (0% silting) (Figure 6.1). The findings indicate that this simple investment can reduce the area affected by a flood by 4% per cent and the population affected by floods by at least 5%.

Figure 6.1 Area and population affected by flooding with and without de-silting



6.30 **Construction of additional trunk sewers.** The results from the SWMM model also revealed that even if the existing sewer systems was completely de-silted, it will be still be insufficient to cope with a usual storm during the rainy season. Given that the *town system* was designed for 6 mm/hour constant rainfall and the *suburban system* for 4 mm/hour; the size of the entire trunk, primary and secondary sewerage laterals is undersized even for a normal storm. So, there is a need for augmenting the capacity of the trunk sewers in both the *town* and the *suburban* systems. Detailed hydrological modeling along with cost benefit analysis is needed to identify the optimal capacity augmentation.

6.31 **Extend sewerage system to un-served areas.** The greatest reduction in flooding in KMC can be attained by improving and extending sewerage and drainage facilities in the Cossipore - Chitpur area (Borough I) and the areas which were added to KMC limit in 1984 (Boroughs XI to XV). This will not only arrest the environmental degradation in these areas, but it will also have an indirect beneficial spillover impact on the core area where a sewerage and drainage system currently exists. In view of constraints with land availability, the proposed system may be developed essentially as a combined network to carry both DWF and SWF generated within the catchment area.

6.32 **Pumping stations.** Construction of deep pump sumps and/or rehabilitation of pump as well as changes to shape of existing sewers (gradation) have to be undertaken to improve the hydraulics of the major sewers approaching the major pumping stations and increase the flow velocities in the sewers during flood conditions. Critical investments are also needed to construct pumping stations in KMC and in highly populated areas of KMA, where they do not exist at present.

6.33 **Sewage treatment.** Sewage treatment is needed to improve environmental conditions both during the dry and the rainy season. *In the long run,* all sewage from the city area should receive full secondary treatment to meet the receiving water discharge standards for surface water set by the Central Pollution Control Board. However, on an *immediate basis* any discharge of DWF to tributaries of Hooghly, including Tolly's Nullah and Circular Canal, should be completely treated. *On an interim basis,* the DWF flow to East Kolkata Wetland fisheries should be treated to ensure reduction in BOD5 and Fecal Coliform levels in the sewage used for pisciculture. Industrial wastewater discharges must be either controlled at their source or at a central treatment facility. Any industrial discharges with concentrations of heavy metals to East Kolkata Wetland fisheries should be fully prevented. To prevent mixing together of sewage with storm water during the rainy season, the DWF and the SWF canals should be separated upstream of the Bantala Lock.

6.6.1.2 Investing in Storm Water Drainage System

6.34 **Storm water drainage.** There is a need for an overall improvement in the storm water drainage system from the core KMC which is channeled through the dry and storm weather channels leading to the Kulti river. This requires the rehabilitation of the outflow (DWF, SWF) channels to separate the channels before entry into the receiving water body and to control the growth of aquatic vegetation in the canals. Full secondary treatment of all wastewater in DWF is also necessary.

6.35 **Canals.** The renovation and rehabilitation of the canal system require the following:

- The implementation of an institutional arrangement that guarantees that the whole canal system is regularly maintained by all municipalities using them;
- The completion of the canal de-silting program;
- Monitoring the conditions of the canal embankments and raising them at vulnerable points to reduce future risk of overtopping;
- The rehabilitation of sluice gates and lock gates;
- The resettlement of informal dwellers living on canal banks;
- The separation of the dry and storm weather flow canals to prevent mixing together upstream of Bantala Lock; and
- Examining the need for dredging of Kulti River

6.6.1.3 Other Infrastructure

6.36. **Rain water harvesting** should also be promoted as a complementary multipurpose retention strategy as it allows storage of storm-water and also acts as a source of water supply. Although unfiltered storm-water is normally not of drinking water quality, it is amenable for non-potable purposes such as washing, irrigation, toilets etc. Storm-water can be collected from roofs and stored in underground tanks. Considering the growing demand for water, increased pressure for groundwater extraction, and poor infrastructure and network for water supply incorporation of rainwater harvesting structures into all major constructions both residential and commercial would lessen water demand and at the same time reduce storm water runoffs.

6.37 **Other public infrastructure.** Any adaptive strategy would be incomplete without complementary investments that improve the quality of life and thereby reduce the impact of flooding. So, investments are needed in *solid waste management* services (collection, disposal, improvements in landfill locations and designs, etc.), *water supply* (expansion of piped water supply services and improvement in water quality); *transport* (improvement of roads and maintenance of roads post flood events); *public health* (public clinics, mobile service providers, immunization campaigns, distribution of medicines in slums etc.). One of the critical civic infrastructures of Kolkata is road space which is only 6% of city area. During flooding the roads get fragmented into smaller stretches due to local inundation. As a result accessing critical infrastructures like hospitals during natural disasters become difficult. One adaptation strategy would be building all weather roads connecting critical infrastructure.

6.6.2 Investing in soft infrastructure

6.38 A number of soft measures are critical in ensuring the effectiveness of the capital investments in preventing flooding and also in ensuring longer term financial, institutional and environmental sustainability.

6.39 **A comprehensive approach to planning is needed**. One that recognizes drainage system complexity and interconnectivity of its elements such as storm water drainage, water supply, wastewater, water pollution control, water reuse, soil erosion, and solid waste management. The planning should encompass all major urban services including roads, traffic, water supply, electricity, telecommunications, open space, and green areas to provide a lasting improvement in the standard of sewerage and drainage in Kolkata. Such updated urban plan should also incorporate climate risk factors by clearly spelling out the climate risks and mitigating factors needed in operational plans for key relevant agencies.

6.40 **Institutional changes.** Particular institutional goals include the following:

- KMC to become a proficient and autonomous civic body and to operate sewerage and drainage systems on corporate principles with responsibilities;
- Role of Kolkata Metropolitan Development Authority (KMDA), Kolkata Metropolitan Water and Sanitation Authority (KMWSA), and the Irrigation and Waterways Department should be clearly defined and agreed upon;
- Maintenance of DWF/SWF canals to be taken over by KMC or Department of Municipal Affairs;
- Private sector participation introduced for trunk sewer and canal maintenance throughout KMC area; and
- Transfer of KMDA and KMWSA assets to KMC.

6.41 **Watershed management.** A key part of any adaptation strategy from flooding in Kolkata would be to support a natural resources conservation plan that ensures proper balance of the ecosystem. Investments to maintain and strength culverts retain structures and road design that mitigates pooling will have made in priority water logged areas. This would include the constructing storm water retention infrastructure and interlinking of ponds and parks in the drainage network to reduce flooding. Storm-water retention should be achieved or facilitated by constructing basins or ponds and buffer drainage channels that temporarily store surface runoff and release it subsequently at a controlled rate to prevent downstream urban floods. Retention structures may not only act as storage but also contribute to infiltration and to the removal of pollutants. Wet ponds in the form of artificial lakes can be of aesthetic and ecological value. Construction of less space intensive measures to enable effective infiltration (where space is highly limited) such as trenches, soak-away, permeable large surfaces (parking lots made of permeable material) that can contribute significantly to the reduction of runoff has also to be explored.

6.42 **Strengthening disaster management and preparedness** for both pre and post disaster situations. Under *pre-disaster* this would include public awareness and education that emphasize prevention and risk reduction, putting in place effective Early Warning Systems, networking with other regional and international Disaster Management Networks to enhance capacity and mobilize technical assistance, develop community-centered approaches for planning, preparedness and communication, and strengthen coordination, information sharing and management across agencies. For *post-disaster* preparedness it should include conducting accurate damage assessments (including damage costs) and focus on livelihood rehabilitation activities.

6.43 **Strengthening regulatory and enforcement process** including improving institutional management and accountability. This will entail a review of the KMC act and other regulatory frameworks to strengthen application of KMC's planning and regulatory roles, ensure coordination among disparate agencies and clarify institutional responsibilities in a way that allows for effective service delivery and regulation and defines accountability. The following two regulatory frameworks will need to be given priority:

- *Strengthening land use and building codes* to reduce obstruction and encroachments of floodplains and environmentally sensitive areas such as canal banks and wetlands and to prevent conversion of green spaces and natural areas that can act as retaining zones during flooding to delay runoffs or reduces their volume through infiltration.
- *Strengthening the pollution management framework* including the introduction of incentives and disincentives for enforcing regulations. A special attention should be paid towards regulating storage of dangerous substances and prohibiting the storage of dangerous substances in the most flood prone areas.

6.44 **Introducing sustainable financing** for infrastructure investment and maintenance from two angles: cost reduction and cost recovery. The former would relate to using appropriate technologies for Kolkata and reducing non-productive cost centers. The latter relates to improving the pricing of service delivery and realistic cost recovery. This would involve (i) to shift towards effective service delivery and associated pricing (including peak and off-peak pricing and flat annual tax for capital expenditures) and (ii) to put in place appropriate incentives (subsidies, taxation) to encourage adaptive behavior by both public and private entities. In addition it should include:

- *A budget expansion for sewerage and drainage maintenance* and an increase in allocation of removal of silt and mechanical sewer cleaning; and
- *The widespread adoption of flood insurance* that incorporate suitable incentives for adaptation that minimize flood damage

6.7 PROJECTS UNDER IMPLEMENTATION IN KOLKATA

6.45 **KMC has taken-up the Kolkata Environmental Improvement Project** (KEIP) a multi-agency endeavor to arrest environmental degradation and improve the quality of life in Kolkata by implementing a sewerage and drainage infrastructure improvement project in parts of Kolkata. Its work is mainly in the outer areas of the city where such infrastructure is grossly inadequate and the drainage canals are choked by silt. KEIP's objective is to provide a roadmap for sewerage and drainage for the KMC area for the project horizon of year 2035, to prepare recommendations for sustainable management of urban environmental waste, and to improve and protect the environment from adverse impacts arising from flooding.

6.46 **The project is implementing the following measures** to alleviate the problems of urban flooding:

- Release of excess storm runoff load into the surrounding water bodies (the Hooghly River, the Tolly's Nullah, the Circular Canal and the Chetla Boat canal) by gravitational means, or if needed due to tidal blocking by adequate pumping capacity
- Augment pumping capacity at the main pumping stations viz. Palmer's Bridge and Ballygunge to meet the maximum delivery capacity of the network and deepening of the sumps to keep low levels at all pumping stations
- Upgrade the hydraulic connections between the Town system and Suburban System
- Provide storm drains parallel to the existing combined sewers
- Interconnect the neighboring upstream ends of the dendritic network into a looped, self-adaptive network structure
- Replace undersized trunk sewers
- Replace undersized secondary sewers
- Adjust available pumping capacity and pumping regimes to the modified network performance
- Improve street intake capacity
- Install SCADA (Supervisory Control and Data Acquisition) system for the remote system operation supervision and control.

The estimated cost of implementing the above interventions for Sewerage and Drainage Master Plan is given in the Table 6.3.

Table 6.12 Summarized Cost Estimates for Sewerage and Drainage Master Plan under KEIP

Item	**Cost in Rs Million**	**Cost in US$ Million**
Desilting and Rehabilitation of Trunk Sewers	49,290	1,069
Pumping Station Upgradation	3,418	74
Outfall Canals Upgradation	6,883	149
Trunk Sewer Upgrades including Immediate Action	6,534	142
Provide Additional Gully Pits	108	2
Extension of Sewerage System in Non-sewered Areas	37,610	816
Tolly's Nullah Lock Gate and Pumping Station	1,130	25
Wastewater Treatment Plant	5,500	119
Storm Drainage Tunnel	12,051	261
Intervention Studies	88	2
Grand Total	**122,612**	**2,660**
Kolkata Environmental Improvement Project,: Sewerage and Drainage Master Plan for Kolkata City		

6.47 **In addition to these structural measures**, some additional adaptation options that are considered a part of City Development Plan include

- Conservation of wetlands and other natural water bodies
- Rain water harvesting
- Strengthening and regular maintenance of sewer network
- Restricting encroachment by settlements on canal banks
- Control of growth of aquatic vegetation which decreases the carrying capacity of canals
- Proper maintenance of the old pumps, increase the hydraulic capacity of sewerage system and discharge canal system by de-silting
- Use of state of the art technologies for integrated data management, information gathering, sharing, dissemination
- Use of modern technology including satellite remote sensing and Geographic Information System (GIS), and modeling tools to assist in developing and assessing alternative decision making options.

6.48 **Since poor management of solid waste** leads to problems with drainage solid waste management schemes have been proposed at a number of locations. In addition 75,000 numbers of Septic Tank/Pour Flush Latrines of capacity 10 users have been proposed for use by people who do not have such facilities.

6.49 **Emphasis has been placed on integrating environmental projects** starting from water and air quality monitoring at one end to Preservation & Conservation of Heritage Buildings and Monuments at the other extreme. Development of parks and play grounds and other landuse that can reduce the extent of paved impervious area and thus can reduce the runoff volume are being taken up. Restoration and management of wetlands has also been given due importance for its important role in managing floods. The activity of rainwater harvesting, is being promoted to reduce water run-off. The local organizations are being involved in the project implementation to improve the local understanding and recognition about the integrated flood management issues.

6.8 FUTURE ADAPTATION NEEDS FOR KOLKATA WITH CLIMATE CHANGE

6.50 **The projects currently being implemented** or in the pipeline in KMC were selected based on identification of future needs using current weather related data. Increased storm frequency and intensity due to climate change may exacerbate local flooding caused by increased runoff from hard surfaces, inadequate waste management and silted-up drainage. While the range of activities shall remain similar to what has already been described above, the design aspects of these interventions shall have to re-looked into in accordance with the changed requirements. For example, number or size of the pumps required to drain the areas may be higher under the climate change situation for reducing the impacts of flooding. Consequently the financial implications of incorporating the adaptation measures to cope with the climate change impacts may be higher.

6.51 **One aspect that needs closer scrutiny** is the implication of climate change on the requirement of strengthening and raising of embankments on the Hooghly river. In the study hydraulic modeling was used to route the flood hydrographs corresponding to 100 year return period under the A1F1 scenario with and without tide effect. This exercise has helped quantify the extent of strengthening needed for embankments to ensure that there is no over topping from increased river flow.

6.52 These climate change effects may therefore necessitate a re-examination of what modifications may be needed in the KEIP and other ongoing KMC projects. The next review of the KEIP will be a good opportunity to make suitable adjustments in the forecasts used to draw up the long term intervention programs incorporating the climate change effects.

6.53 **Selection of projects currently being implemented** or in the pipeline in KMC have been made using cost benefit analysis based on impact estimates from current weather related data. The impact from climate change were however not included in such analysis. Due to the increased flooding and damage caused by climate change, it is likely that use of cost benefit analysis that takes into account climate change effects will increase the viability of many projects not found viable earlier with only current weather data. Hence, there is a need for making climate change effects an integral part in all future planning for adaptation in Kolkata.

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ANNEX A KOLKATA A PROFILE

Table A.1 Distribution of area, population, density and growth rate of KMA (1991-2001)

Districts	Status	No. of units	Area sq km	Population (2001)	Pop % to KMA	Density (pop/sq.km)	Growth 1991-2001
Kolkata	MC	1	187	4,580,544	31.07	24,451	3.93
Sub total			*187*	*4,580,544*	*31.07*	*24,451*	*3.93*
Hooghly	CT	21	59.5	234,123	1.59	3932	26.71
	M	9	87.4	1,125,866	7.65	12876	18.36
	MC	1	22.0	162,187	1.1	7362	15.59
	OG	4	4.13	5,369	0.04	1300	-14.62
	R	128	225.6	360,227	2.45	1597	16.43
Sub total			*398.7*	*1,887,772*	*12.83*	*4734*	*18.58*
Howrah	CT	40	97.93	584,507	3.97	5969	24.55
	M	2	45.53	463,041	3.15	10170	28.82
	MC	1	51.74	1,007,532	6.85	19473	6.01
	OG	2	3.26	13,270	0.09	4071	12
	R	45	64.01	190,069	1.29	2969	19.67
Sub total			*262.47*	*225,8419*	*15.34*	*8604*	*15.82*
Nadia	M	2	52.56	137,183	0.93	2610	27.33
	OG	1	1.39	3,368	0.02	2423	62.78
	R	17	31.83	5,3005	0.36	1665	22.98
Sub total			*85.78*	*193,556*	*1.32*	*2256*	*26.58*
North 24par	CT	12	28.54	119,630	0.81	4192	22.69
	M	20	301.26	4,030,748	27.39	13380	26.91
	OG	7	6.31	35,073	0.24	5558	52.94
	R	83	133.3	220,084	1.5	1651	19.36
Sub total			*469.41*	*4,405,535*	*29.93*	*9385*	*26.57*
South 24par	CT	4	14.09	45,784	0.31	3249	17.68
	M	5	128.7	87,6275	5.95	6809	32.03
	OG	2	3.1	13,693	0.09	4417	34.22
	R	172	291.59	464,527	3.16	1593	32.65
Sub total			*437.48*	*1,400,279*	*9.51*	*3201*	*31.73*

Source: jnnurm.nic.in/nurmudweb/toolkit/KolkataCdp/CH-I.pdf

Table A.2 Population and global ranking Mumbai, Delhi and Kolkata

Agglomeration	Population (millions)			Global Rank			Average annual rate of change (%)		Population residing in agglomeration, 2005, as % of	
	1975	2005	2015	1975	2005	2015	2000-2005	2010-2015	Total pop.	Urban pop
Mumbai	7.1	18.2	21.9	15	5	2	2.5	1.8	1.6	5.7
Delhi	4.4	15.0	18.6	23	6	6	3.8	1.8	1.4	4.7
Kolkata	7.9	14.8	20.6	9	8	8	1.7	1.9	1.3	4.3

Source: United Nations, Department of Economic and Social Affairs, Population Division (2006). World Urbanization Prospects: The 2005 Revision. Working Paper No. ESA/P/WP/200.

Table A.3 Wards with the largest number of slums in KMC in 2001

Ward	Total Population	Slum Population	% of slum pop to total pop
Ward-58 Tangra, Tiljala	86,618	86,605	99.98
Ward-29 Narkeldanga	46,814	46,251	98.80
Ward-137 Metiaburz	20,041	19,710	98.35
Ward-134 Garden reach West Port	36,625	35,836	97.85
Ward-65	80,255	73,810	91.97
Ward-135	31,733	28,654	90.30

Source: Census of India, 2001

Table A.4 Percentage distribution of municipal population in West Bengal

Groups of municipal /urban local bodies	1951	1961	1971	1981	1991	2001
All municipal bodies	100	100	100	100	100	100
Non-KMA municipal bodies	22	25	28	30	36	53
KMA-municipal bodies	78	75	72	70	64	47
Kolkata	45	39	33	28	29	32
Howrah	8	7	8	6	6	7

Sources: Census of India, 1951,1961,1971,1981 1991 and 2001

Table A.5 Drainage basins and sewerage zones of KMA

Drainage Basins (25)	
East Bank	**West Bank**
Bager, Nowai, Ichapur, Khardah, Bagjola,	North West Reparian,
Sunti, Kolkata, Northern Salt Lake,	Ghia-Kunti, Dankuni,
Manicktola, Boinchita, Southern Salt Lake	Konnagar, Howrah,
Tollygunge-Panchannagram,	Barajola, Rajapur
Tolly's Nullah, Monikhali, Churial, Keorapukur,	
Mograhat, Sonarpur-Arapanch	
Sewerage Zones (20)	
Kalyani, Bhatpara, Barrackpur, Titarah	Bansberia,
Khardah, Barasat, Dum Dum, Manicktala/Sarampur	Chandannagar,
Salt Lake, Kolkata, Tollygunge, Rajpur,	Serampur, Konnagar,
Garden Reach, Budge Budge	Howrah, Uluberia

ANNEX B MODELING CLIMATE CHANGE

B.1 Weather related variables used in models

Precipitation was the main variable used in the study. The other key weather variables of minimum and maximum temperature, solar radiation, relative humidity and wind speed were considered in the SWAT model for computing first the Potential Evapotranspiration (ET), which is the maximum evapotranspiration that can take place at a location. The Potential ET is governed by the driving force of the weather variables of minimum & maximum temperature, solar radiation, relative humidity and wind speed. However the Actual Evapotranspiration that is effective at a specific location further depends on the opportunity that is prevalent at the location. Such opportunity is mainly dependent on the moisture availability in the soil at that time along with other factors such as the crop species. If the moisture in the soil is close to a level that can allow uninterrupted extraction of moisture by the root system of the crops/plants supporting the land mass then the Actual ET shall be very close to the Potential ET. However, such condition only last for a very short period, typically immediately after a natural rainfall event or an irrigation application. For majority of the period the soil moisture status is below this desirable level and thereby allows an actual amount of ET that is considerably less than the potential value.

The hydrological model takes care of all these dynamics on a regular basis at a daily interval and thus tries to represent the actual conditions prevalent at a location by using the daily variations of these variables, local characteristics of soil type, terrain, land use as well as the simulated status of the wetness/dryness of these local areas through continuous simulation.

B.2 Data used for the study in various models

1. Climate Change SWAT Runs:

- IPCC SRES Baseline (1961-1990), A2, B2 scenarios (2071-2100) from PRECIS UK Hadley Center RCM (at 50 km x 50 km spatial resolution) and at daily temporal resolution were used to run SWAT for 30 years of simulation.
- Results of these runs were used to quantify the change in water balance components of Average rain fall (change from Baseline to A2, B2 scenarios) and corresponding Stream discharge
- The climate change impact on rainfall for this area was provided to us for the A1F1 and B1 scenarios by JICA as a single point in the form of proportion increase for rainfall and temperature. For the modeling purpose we needed the spatial and temporal variability of the input data. Since we had access to HadRM3 data with spatial and temporal variability but with slightly different scenarios (A2 and B2), it was decided to use this elaborate data for converting the A2, B2 discharge to the A1F and B1 discharge by using appropriate extrapolation (assuming that A2 is proxy for A1F and B2 is proxy for B1). It was found that 1% change in rainfall produces 1.17 % changes in Stream Discharge for A2 and 1.1177 % for B2. Therefore the 16% increase in Rainfall as predicted by JBIC (A1F1) should amount to 17.12 % increase in stream flow. Similarly, 11% increase in Rainfall for (B1) should result in 11.77 increase in the stream flow. Furthermore, since these scenarios also belong to end-century, further extrapolation was done to bring the stream discharge of A1F1 and B1 to 2050 level as was required for HECRAS, Hooghly River flood modeling.

2. SWMM Urban flood modeling

- The climate change effects for urban flooding were modelled by multiplying the precipitation by a factor provided by JBIC (JBIC, 2008. "Interim Report, Study on Climate Impact Adaptation and Mitigation in Asian Coastal Mega Cities" prepared by the Integrated Research System for Sustainability Science, University of Tokyo) for the A1FI and the B1 scenarios respectively on the baseline extreme event. As the baseline flood the distribution pattern and the extreme event of 1978 flood was used.

B.3 Basin hydrology using models

The behavior of the hydrological regime of the basin was captured in a composite manner using a combination of Hydrological-Hydraulic-Urban Storm drainage models. The following specific models (all of them in the public domain) under these categories are used.

1. Hydrological model (SWAT) – to simulate the Hooghly River flows:

The Soil and Water Assessment Tool (SWAT) model is a distributed parameter and continuous time simulation model. The SWAT model has been developed to predict the response to natural inputs as well as the manmade interventions on water and sediment yields in un-gauged catchments. The model (a) is physically based; (b) uses readily available inputs; (c) is computationally efficient to operate and (d) is continuous time and capable of simulating long periods for computing the effects of management changes. The major advantage of the SWAT model is that unlike the other conventional conceptual simulation models it does not require much calibration and therefore can be used on ungauged watersheds (in fact the usual situation). The SWAT model is a long-term, continuous model for watershed simulation. It operates on a daily time step and is designed to predict the impact of management on water, sediment, and agricultural chemical yields. The model is physically based, computationally efficient, and capable of simulating a high level of spatial details by allowing the watershed to be divided into a large number of sub-watersheds. Major model components include weather, hydrology, soil temperature, plant growth, nutrients, pesticides, and land management. The model has been validated for several watersheds.

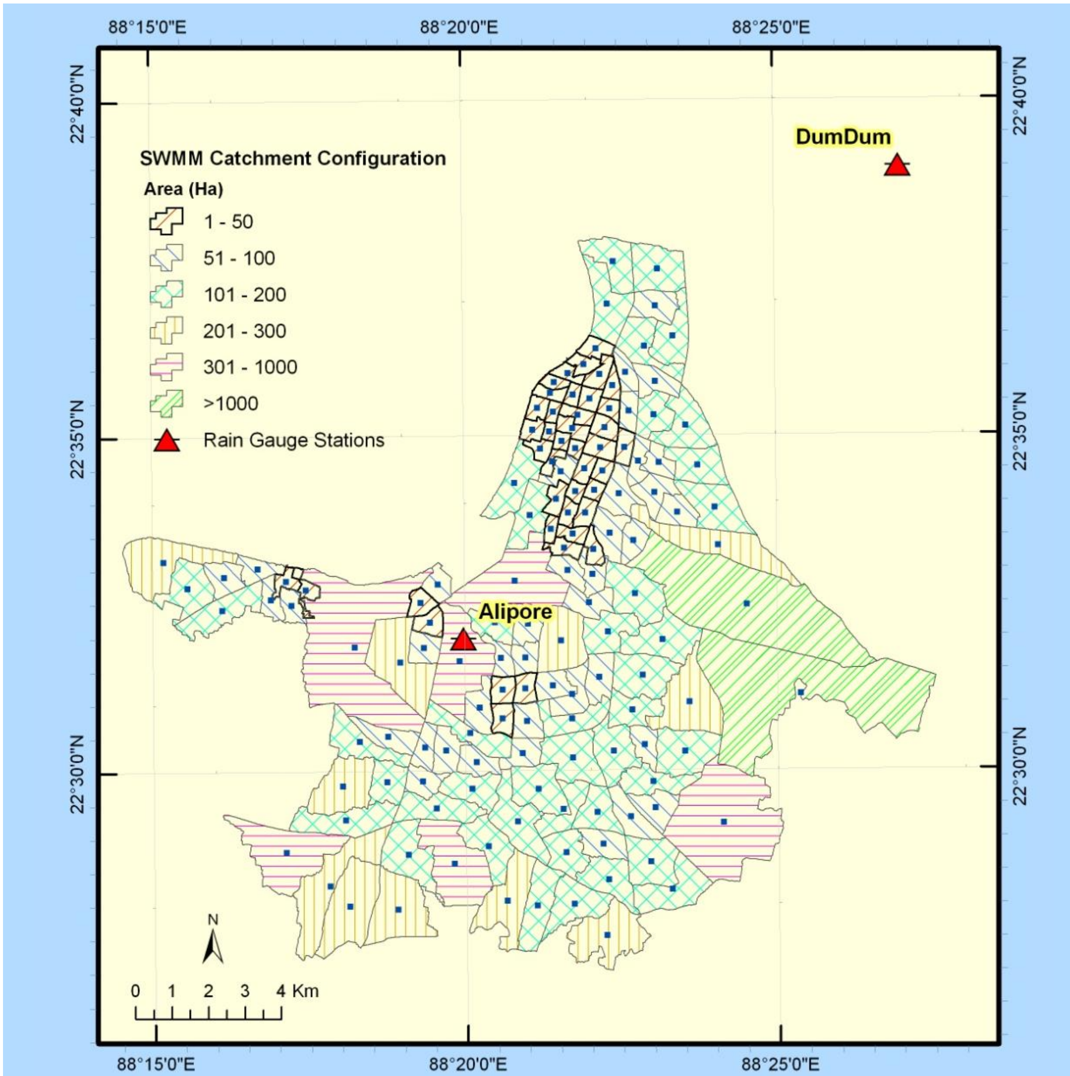
2. Hydraulic model (HEC-RAS) – for flood wave translation and inundation:

HEC-RAS is a one-dimensional steady and unsteady flow hydraulic model developed by the U.S. Army Corps of Engineers. The HEC-RAS hydraulic model takes the analysis further by translating the flood hydrograph through the river channel and providing the water surface profiles along the stretch. These flood waves cause inundation when the carrying capacity of the channel is exceeded by the volume of the passing flood wave. The output of the model provides the water surface profiles all along the river along with its temporal variation (change in flow depth during the flood period).

3. Storm drainage model (SWMM) – for localized flooding due to intense rainfall:

The SWMM has been deployed to simulate the flooding due to the local rainfall by incorporating the prevailing urban characteristics of the area as well as the other specific structures such as lock gates, etc. SWMM is a dynamic rainfall-runoff simulation model used for single event or long-term (continuous) simulation of runoff quantity from primarily urban areas and is used for simulation of hydrologic and hydraulic conditions of the area. This model can be used to evaluate the impact of a single-event storms, such as the 2-year 24-hour storm event. A schematic diagram used is shown in Figure 1.

Figure B.1 Schematic diagram of catchment areas in SWMM -for KMC



ANNEX C VULNERABILITY IMPACT ASSESSMENT

Development of Indices

The factors used in developing the Social Vulnerability Index were the data from Demographics like population density, percentage of slum population, percentage of illiterates, percentage of marginal workers and Infrastructure data like sewerage, roads, schools, hospitals as well as Environmental data like number of red industries. The Land-use Vulnerability Index was developed using data on residential, commercial, and industrial land as well as vacant land and open areas in the identified area. The Flood Vulnerability Index was obtained using the depth and duration of flooding produced by the models.

To develop a unitless index of vulnerability, the individual factors included in each index had to be normalized and made unitless as well. The Box 4.1 explains how each factor was normalized to a value between 0 and 1 before they were combined to arrive at each of the index of vulnerability.

Box C.1. The normalized value Y_{ij} for indicator *i* in ward *j* was calculated using the formula below, where X_{ij} is the indicator *i* for the ward *j*.

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

The social, land-use and flood indices for each ward were determined separately by combining the normalized values of indicators included under each type of vulnerability. $\bar{Y}_{j\,k}$, the vulnerability index of type *k* in Ward *j* was computed as the weighted sum of all the normalized values of the indicators included in index *k* for that Ward and given by:

$$\bar{Y}_{jk} = \sum_{i=1}^{N} w_i Y_{ij}$$

where w_i is the weight for the indicator *i* and *N* is the number of indicators in index of type *k*. The weights were assigned based on the variability of each indicator among all the Wards in KMC since a greater variability poses higher risk. To ensure that the weights added to 1 the weights were defined as

$$w_i = k\sqrt{Var(Yi)} \quad where \quad k = \frac{1}{\sum_{i=1}^{N}\sqrt{Var(Yi)}}$$

where $Var(Y_i)$ is the Variance of indicator *i* normalized values among all the KMC Wards.

Alternative analysis of vulnerability

1. Principle Component Analysis (PCA)

A principal component is a linear combination of weighted observed variables. The method of principal components enables us to extract from the large matrix of indicator variables, an eigenvector which best captured the common information. This gives us the weights for each of the indicators, with the help of which the composite social/landuse/flood index was defined. For ward i, the relevant index Ai is given by:

$$A_i = f_1 * \frac{(a_{i1} - a_1)}{s_1} + ... + f_N * \frac{(a_{iN} - a_N)}{s_N}$$

where f1 is the individual weight of the first indicator variables, ai1 is the ward's value of the asset, and a1, s1 are the mean and standard deviation of the first indicator variable. The first principal component identified accounts for most of the variance in the data. Eigenvalues indicate the amount of variance explained by each component. Eigenvectors are the weights used to calculate components scores (generally the first eigenvector is used); eg. for social index:

$$A_i = -0{:}1223popdensity + 0{:}384ilit + 0{:}367Mainwork + :::$$

2. Factor Analysis (FA)

Mathematically, factor analysis is very similar to principal components analysis but instead of analyzing a correlation matrix the ones on the diagonal are replaced with communalities and initial estimates of the communalities must be specified. Typically the squared multiple correlation of each variable with all other variables is used as the initial communality estimate. A communality refers to the percent of variance in an observed variable that is accounted for by the retained components (or factors).

In factor analysis, observed variables are a linear combination of the underlying factors (estimated factor and a unique factor). Here unique factor weight (parameter estimate) is equal to the square root of the percentage variance accounted for by the unique factor.

3. Objective Vulnerability Analysis

The objective method evaluates the structure of indicator matrix representing the values Xij or their normalized values Yij to calculate the weights. Since the indicators have different units of measurements, these have been normalized to assign the values from 0 to 1. The scaled data matrix Yij has been obtained using the formula:

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

where Yij is the scaled indicator i for the ward j, Xij is the indicator i for the ward j. Overall Ward vulnerability index for each source of vulnerability (social, landuse and flood) has been obtained as the weighted sum of all the scaled indicators as:

$$\overline{Y}_j = \sum_{i=1}^{N} w_i Y_{ij}$$

Where wi is the weight for the ith indicator and its weight determined by

$$w_i = \frac{k}{\sqrt{Var(Y_i)}} \quad and \quad k = \sum_{i=1}^{w} \frac{1}{\sqrt{Var(Y_i)}}$$

Sum of the weights across all indictors will be equal to 1. The assignment of the weights ensures that large variation in any one of the indicators will not unduly dominate the contribution of the rest of the indicators and distort inter-ward comparisons.

ANNEX D EFFECT OF CYCLONE IN A CHANGING CLIMATE

The present study has examined only the likely damage caused by increased precipitation in Kolkata resulting from climate change effects. As mentioned in the report, any possible damage from cyclones has not been included in the analysis. Since climate change is also likely to impact cyclonic activity in the study area, to get a complete damage estimate from climate change effects, we have to include both the impacts from increased precipitation as well as alterations in cyclone intensity.

Cyclones get their power from the difference between temperatures at the ocean surface and in the upper atmosphere. Scientific evidence indicates an increase in sea surface temperature at all latitudes and in almost all ocean areas. If global warming increases temperatures at the earth's surface but not the upper atmosphere, it is likely to provide tropical cyclones with more power (Emmanuel et al 2008). A sea-surface temperature of 28^{o} C is considered an important threshold for the development of major hurricanes of categories 3, 4 and 5 (Michaels et al, 2005, Knutson and Tuleya, 2004).

Any increased sea surface temperature with climate change is thus expected to intensify cyclone activity. This increased intensity will be felt on *Storm surge* which refers to the temporary increase, at a particular locality, in the height of the sea due to extreme meteorological conditions: low atmospheric pressure and/or strong winds (IWTC 2006; IPCC 2007; see also Woodworth and Blackman 2004; Pielke et al. 2005; Woth, Weisse, and von Storch 2006; and Emanuel et al. 2008).

The storm surge due to climate change has to take into account another impact as well. Climate change is likely to result in a rising sea level due to thermal expansion of the oceans and increase in the volume of water as ice cap(s) continue to melt (Nicholls et al. 2007; Dasgupta et al. 2011). The rising sea levels due to climate change are expected to elevate storm surge activity even more.

Such larger storm surges threaten greater future destruction from increased depth of inundation and due to larger areas getting inundated as the surges move further inland. The destructive impact of storm surges will generally be greater when the surges are accompanied by strong winds and large onshore waves. In addition, the flooding caused by increased precipitation that generally accompany cyclones, will increase the depth and duration of inundation in the affected area.

These impacts from increased cyclone intensity from climate change will be felt not only in Kolkata but also throughout the coastal areas in West Bengal near Kolkata. Disaster preparedness from such climate change effects therefore calls for an examination of the impacts throughout the adjacent coast of West Bengal.

This study could not include the damage estimates from cyclone since cyclone modeling requires a different modeling process compared to the modeling done in the study to estimate damage caused by increased precipitation. This is because damage from a cyclone results from three separate factors: (i) storm surge, (ii) high wind, and (iii) intense rainfall. Of these, historical records show, that the maximum damage results from the inundation caused by storm surge. But all three impacts need to be examined to get a full extent of the damage caused by a cyclone.

Among the three factors, the storm surge modeling has to take into account the bathymetry of the sea in the coastal regions and then use the wind speed during a cyclone to estimate the rise of the sea level. Climate change can impact the storm surge effects as a result of additional intensification of the wind speed and its duration. In addition, the estimated sea level rise from climate change over a period can further add to the height of the storm surge. Moreover, any analysis of potential storm surge has to distinguish between two scenarios: (i) cyclones making a landfall during high tide and (ii) cyclones making a landfall during low tide.

In addition to the damage caused by inundation resulting from the storm surge, the modeling for cyclone damage has to include also the effects of high wind in the path of the cyclone and the additional rainfall in the affected area from the cyclone. This requires estimating the path of cyclones based on past history of their landfall.

Any modeling for determination of inundation zone and location-specific surge height/ inundation depth caused by cyclones will therefore require

a) bathymetric data in the Bay of Bengal adjacent to the West Bengal cost,
b) high resolution digital elevation data for coastal West Bengal including information on coastal dykes
c) past landfall of cyclones during high/ low tide and sea level - using the best fitting tide (hydrodynamic) and storm surge model
d) inundation zones and GIS maps based on the height of storm surge for alternative scenarios of cyclonic wind speed based on historical data
e) inundation zones and GIS maps based on the height of storm surge for likely sea level rise and intensification of cyclones from climate change

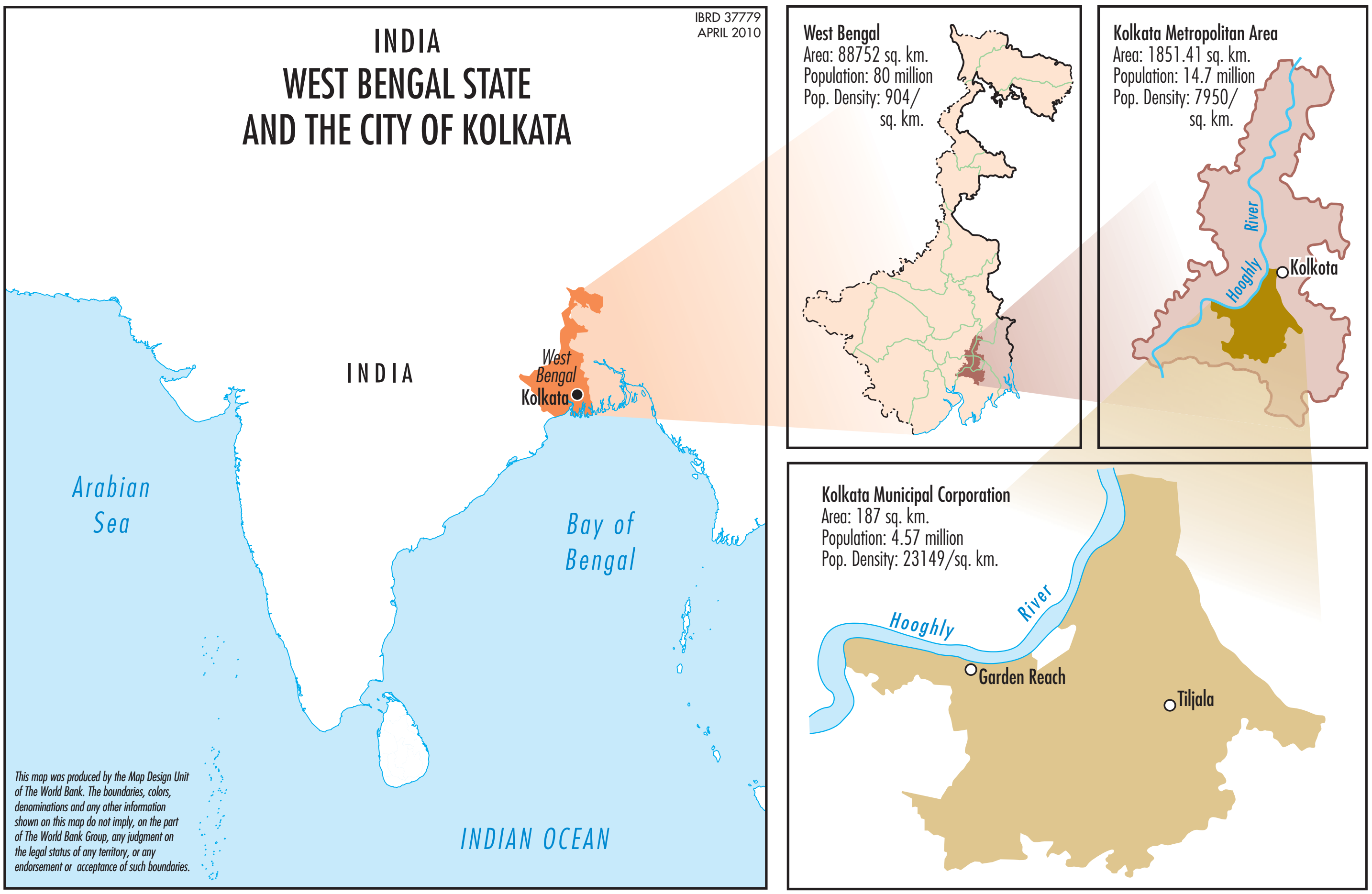
Based on the inundation, wind speed, and extra rainfall arising from a cyclone in the geographic area, the physical damage can be estimated using GIS overlays that identify "Critical Impact Elements" from secondary sub-national geo-coded data on coastal human settlements, assets and activities. Critical impact elements would include (but not limited to) human settlement, poverty map, land use, economic activity, production pattern, infrastructure (Roads, Bridges, Power plants, Power transmission lines, Deep Tubewell, Drinking water sources, Schools, Religious places, Growth Centers, Mill/ factory (large scale), Food Godowns, Historical Places, Tourist Destinations, Housing), and biodiversity.

Total damages suffered have been estimated in the present report but based only on the inundation arising from increased precipitation. This is only a partial estimate of such damages caused by climate change since any additional inundation likely from cyclone activity can cause an exponential increase in damage. Hence inclusion of cyclone damage can be an important consideration to be taken into account for making adaptation plans to face impacts arising from climate change effects.

The modeling for cyclone change requires additional data and analysis that are not part of the current study. In addition such study has also to take into account the impact on the coastal areas of West Bengal adjacent to Kolkata to get a fuller understanding of the damage caused by cyclones in the study area. Therefore the inclusion of the impacts caused by cyclones in coastal West Bengal can be critical to determine the effects in Kolkata arising from climate change and what adaptation measures may be needed to cope with such impacts.

A separate study on the effect of cyclones with climate change in the coastal areas of West Bengal is therefore proposed as a follow up to complement the current study based only on increased precipitation in Kolkata. For the cyclone study, the present study can serve as a relevant starting point and help to get a fuller picture of the impact of climate change effects in the study area and the preparedness that may be needed to minimize the impact from such changes.

MAP SECTION


IBRD 37779
APRIL 2010
INDIA
WEST BENGAL STATE
AND THE CITY OF KOLKATA
INDIA
West Bengal
Kolkata
Arabian Sea
Bay of Bengal
INDIAN OCEAN
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West Bengal
Area: 88752 sq. km.
Population: 80 million
Pop. Density: 904/ sq. km.
Kolkata Metropolitan Area
Area: 1851.41 sq. km.
Population: 14.7 million
Pop. Density: 7950/ sq. km.
Hooghly River
Kolkota
Kolkata Municipal Corporation
Area: 187 sq. km.
Population: 4.57 million
Pop. Density: 23149/sq. km.
Hooghly River
Garden Reach
Tiljala