National Resilience Programme

Economic Impact of Waterlogging on Local Trade
The Case of Khatunganj, Chattogram

Programming Division
Planning Commission
Ministry of Planning
Government of the People's Republic of Bangladesh

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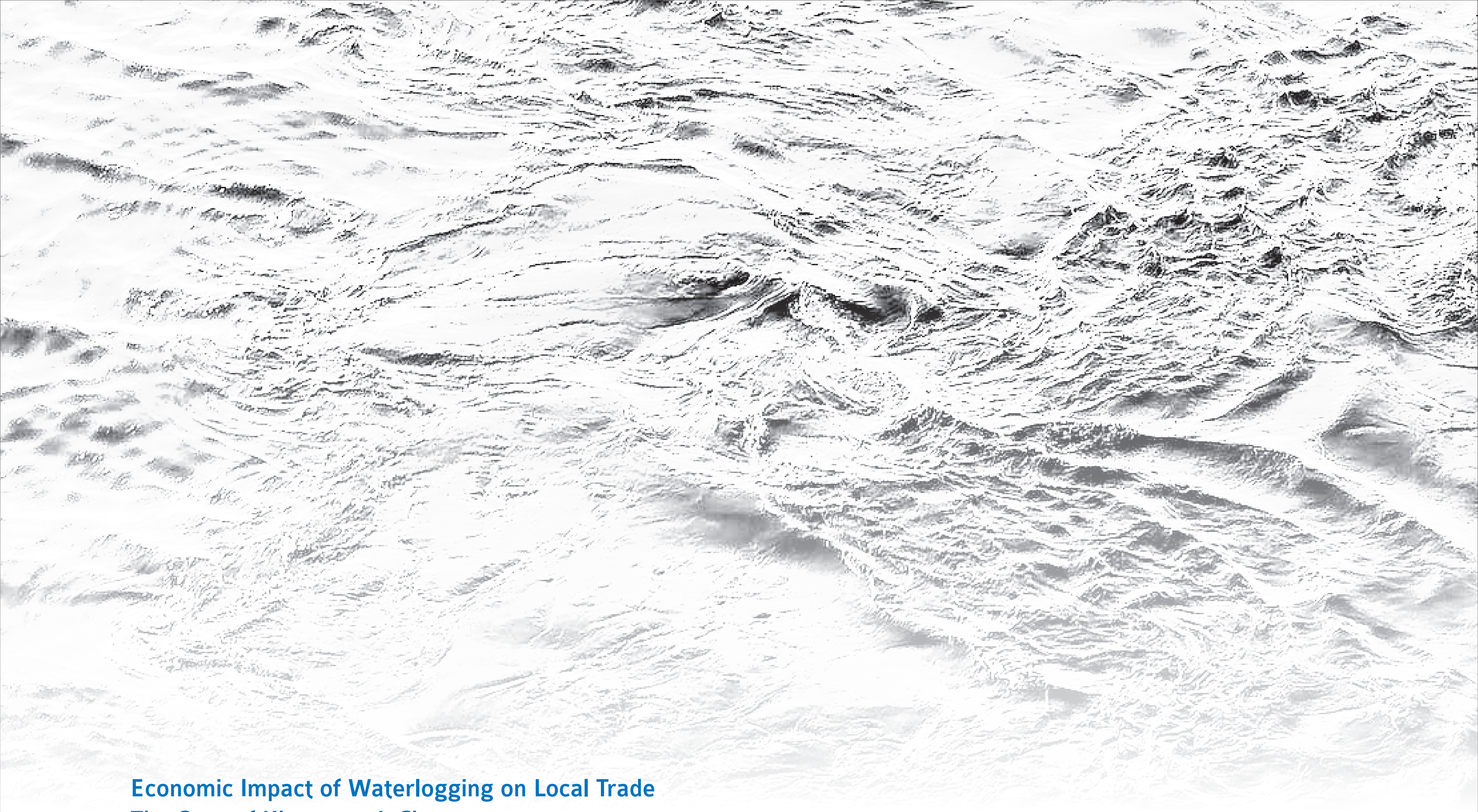

Economic Impact of Waterlogging on Local Trade
The Case of Khatunganj, Chattogram

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Message

Waterlogging in Chattogram is considered as a major hazard which creates suffering to citizen life and disrupt the economy and business. Though this is long term problem, yet there was no evidence based document regarding economic loss and the business community realized an in-depth situation analysis and comprehensive recommendations to overcome the situation. From this reality, the CCCI requested National Resilience Programme (NRP) under Programming Diviison of Planning Commission to conduct a study on "Economic Impact of Waterlogging on Local Trade : The Case of Khatunganj, Chattogram." We are very much happy that this report is going to be published by Programming Division with the support from National Resilience Programme (NRP)

This is very much encouraging that, the study has been completed having wider participation of stakeholders including the Chattogram City Corporation, Chittagong Development Authority and other Government and Non-Government organizations . Presence of newly elected Mayor of Chattogram City Corporation in dissemination workshop of study findings was very much encouraging and it shows the commitment of policy makers to address the issue with due importance.

We hope that implementation of the recommendations will be considered as priority work and the action matrix need to be transformed from thoughts to implication.

I appreciate the sincere efforts of the consultant team along with the NRP project team and Programming Division as host agency to support the study. We are grateful to the business community particularly the business persons of Khatunganj areas for their response, feedback and cordial cooperation to make the study informative and evidence based.

Looking forward to have coordinated efforts to overcome this long lasting problems and have better environment for resilient business.

Mahbubul Alam
President, CCCI

Foreword

I am really delighted to see the study report "Impact of waterlogging on Local Trade: The Case of Khatunganj, Chattogram" initiated by National Resilience Programme (NRP) being implemented by Programming Division of Planning Commission.

Resilience is considered from a wider perspective, where economic resilience is a big factor. Particularly waterlogging is a huge threat to urban resilience. For sustainable development interventions, evidence-based information is very important. This study disclosed that traders in Chattogram's Khatunganj incurred direct financial losses of around taka 514.38 crore last year solely for waterlogging. The damage occurred not only to stocks of the country's once top commodity trading centre and commercial hub but also through reduction in sales. The study suggests for regular dredging facilities for the Karnaphuli river and the Chaktai canal to ensure responsible waste management practices by the traders for getting rid of the problem.

The study was initiated having request from the Chittagong Chamber of Commerce and Industry. The newly elected Mayor of Chattogram City Corporation expressed his commitment for combined and coordinated efforts to overcome the problem considering the study findings and recommendations including action matrix.

Planning Commission encourages researchers for in-depth analysis of the situation and identifying possible remedies. I appreciate NRP initiatives for establishing institutional relationship with business community in Chattogram and supporting the research work for suggesting actions to the agencies responsible for city governance.

The consultant team also deserve appreciation and I look forward to see the implementation of recommendations by the state and non-state actors.

Mohammad Jainul Bari
Secretary, Planning Division
and Member, Programming Division

Preface

Economic resilience is considered as an important factor for sustainable investment. Global and local experience shows that, without resilient measures it is difficult to prevent economic loss. Considering this reality, National Resilience Programme (NRP) of Programming Division, Planning Commission is contributing towards enhancement of knowledge base on disaster risks in public and private sector investment and emphasizes on capacity development of business community to make the investment resilient.

Study on Economic Impact of Waterlogging on Local Trade of Khatunganj, Chattogram is an attempt to document evidence-based facts and figures for an assessment on economic loss having consultation with the stakeholders including the business community and local administration. The study report is knowledge product, which will contribute towards better planning for overcoming the long-lasting waterlogging and its negative impact on economy and livelihood. The NRP consultants engaged for this study concentrated on scientific analysis, historical data, local coping mechanism, community thoughts and also the expert opinion in identifying causes and the remedies.

We are very much encouraged for active response by the local business community and the cooperation from the Chittagong Chamber of Commerce and Industry (CCCI) for successful completion of this study. The inception of the study, draft sharing workshop and the dissemination workshop was well participated and widely covered by national and local dailies.

We acknowledge sincere contribution of all respondents, the consultant team and also the contribution of NRP Project Team, particularly dynamic role of the Project Director for managing such a good work.

We wish to see this port city as a resilient and smart city in this region.

Khandker Ahsan Hossain
Chief (Additional Secretary)
Programming Division

Acknowledgement

The study on Economic Impact of Waterlogging on Local Trade: The Case of Khatunganj, Chattogram is a joint initiative of Programming Division of Planning Commission and the Chittagong Chamber of Commerce and Industry (CCCI). This is the first time, that such a study focusing on the problem of waterlogging as a hydro-meteorological and planning issue by identifying natural, man-made, and planetary threats has been carried out which was a crying need of the local business community in Chattogram. Based on the scientific data and advanced modeling techniques the study showed that the economic impacts of waterlogging on the local trades of Khatunganj is a matter of great concern.

We acknowledge the active response and heartiest cooperation from local business community in Chattogram, officials of Chattogram City Corporation, Chittagong Development Authority, local administration, scientific and research organizations and also the non-state actors including the NGOs and civil society organization. A good number of architects and urban planners extended support to the study team.

We express thanks to CCCI for their cordial and sincere cooperation. Without the sincere support from the President Mr. Mahubul Alam, Mr. S. M Tanvir, Wasfi Tamim and other officials of CCCI, the study could not have progressed. We highly appreciate the active cooperation of electronic and print media in wide dissemination of study findings with due importance.

Special thanks to the study team: Dr. Abu Taib Mohammad Shahjahan, Professor Reaz Akter Mollick, and Dr. AK M Nazrul Islam for their sincere efforts to make the report comprehensive and informative. Thanks also goes to the NRP–PD team for its contribution to the study.

We are very grateful to Mr. Jainul Bari, Secretary of Planning Division and Member Programming Division for his guidance in completing the study and its publication. We are also grateful to Mr. Nurul Amin, Senior Secretary Planning Division who had encouraged us to undertake such a study in the problem area.

The study has provided a great learning experience for us on resilience of the business community. We hope that this study will make additional values in undertaking future action in overcoming this problem and strengthening urban resilience.

Dr. Nurun Nahar
Joint Chief, Programming Division
and Project Director, NRP-PD Part

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Acronyms

AAWL	Average Annual Waterlogging Loss
ADT	Alternating Decision Trees
AGNPS	Agricultural Non-Point Source Pollution Model
AHP	Analytical Hierarchy Process
AI	Artificial Intelligence
ANN	Artificial Neural Network
ASTER	Advanced Spaceborne Thermal Emission and Reflection Radiometer
AUROC	Area Under Receiver Operating Curve
BGI	Blue-Green Infrastructure
BMD	Bangladesh Metrological Department
CART	Classification and Regression tree
CCC	Chattogram City Corporation
CCCI	Chittagong Chamber of Commerce and Industries
CDA	Chittagong Development Authority
CRED	Centre for Research on the Epidemiology of Disasters
CVM	Contingent Valuation Method
CWASA	Chattogram Water and Sanitation Authority
DALY	Disability-Adjusted Life Year
DDM)	Department of Disaster Management
DEM	Digital Elevation Model
DOE	Department of Energy
DSM	Digital Surface Model
DT	Decision Tree
EPS	Ensemble Prediction System
FEMA	Federal Emergency Management organization
FR	Frequency Ratio
FLEMO	Flood Loss Estimation Model
GIS	Geographical Information System
GSSHA	Gridded Surface/Subsurface Hydrologic Analysis
HEC-HMS	Hydrologic Engineering Center's Hydraulic Modeling System
HEC-RAS	Hydrologic Engineering Center's River Analysis System
HYPE	Hydrological Predictions for the Environment
HPM	Hedonic Pricing Method
ICPR	International Commission for the Protection of the Rhine
IPCC	Intergovernmental Panel on Climate Change
KII	Key Informant Interview
LiDAR	Light Detection and Ranging
LfUG	Landesamt für Umwelt und Geologie
LMT	Logistic Model Trees
LR	logistic regression
ML	Machine Learning
MLP	Multilayer Perceptron
MTHs	Multimodal transport hubs
MURL	Ministerium für Umwelt, Raumordnung und Landwirtschaft des Landes Nordrhein-Westfalen (Ministry for the Environment, Regional Planning and Agriculture of the State of North Rhine-Westphalia)
NBT	Naïve Bayes Trees
NIBS	National Institute of Building Sciences
NDVI	Normalized Difference Vegetation Index
NRE	Department of Natural Resources and Environment, Victoria
NR&M	Department of Natural Resources and Mines, Queensland Government
NRP	National Resilience Programme
OECD	Organization of Economic Cooperation and Development
PRMS	Precipitation-Runoff Modeling System
RT	Regression tree
RF	Random Forest
REPT	Reduced Error Pruning Trees
SCS	Soil Conservation Service
SPI	Stream Power Index
SPARRSO	Space Research and Remote Sensing Organization
SVM	Support Vector Machine
SRTM	Shuttle Radar Topography Mission
SWAT	Soil & Water Assessment Tool
SWMM	Storm Water Management Model
TCM	Travel Cost Method
TIN	Triangulated Irregular Network
TWI	Topographic Wetness Index
UBGI	Urban Blue-Green Infrastructure
UMEP	Urban Multi-scale Environmental Predictor
UNDP	United Nation Development Programme
UNISDR	United Nations Office for Disaster Risk Reduction
VSL	Value of Statistical Life
WL	Waterlogging
WNN	Wavelet Neural Network
WMO	World Meteorological Organization
WetSpa	Water and Energy Transfer between Soil, Plants and Atmosphere

Executive Summary

Khatunganj was the main port of entry for international traders from historical time due to its suitable geographical location. Today's Chaktai *khal*, which was known as Chakoria *Nalla* in the past, was the connection of Khatunganj for international traders. According to the map of "Bengal, Bahar & c. (South)" by Robert Laurie & James Whittle (1794), the main port of the Islamabad (today's Chattogram) was Khatunganj. Another map, "Fragment of the Map of Chattogram (Bengal)" by John Cheape (1818), showed that there were approximately 10 to 11 foreign warehouses at the location of the present police station, which is precisely on the north part of today's Khatunganj. These documents prove the existence of today's Khatunganj as a business hub from historical time.

At present, Khatunganj has approximately 5000 warehouses and 250 wholesale shops. This area used to control 50% of the country's commodity market up to the year 2004, but later the control was taken over by other regions due to several reasons. "Only around 12 years ago, about 50% of the country's commodity market was controlled by Khatunganj businesses, but now the majority of that has been taken over by the businesses in Dhaka's Moulvibazar", as stated by Islam, (2018). The problems are multi-faceted, starting with seasonal waterlogging besides other issues like lack of proper management of infrastructure and road connectivity, which are constraining the daily business and reducing the robustness of the area (Illius, 2019). Every year the loss from the waterlogging alone amounts for about 50 crore taka in the Khatunganj area. This study is designed to support Chittagong Chamber of Commerce and Industry with quantification of economic losses and damages caused by waterlogging associated with future climate change phenomenon in the Khatunganj wholesale market area.

This study thus tried to investigate and analyse the entire problem scenario of waterlogging as a hydro-meteorological and planning problem by identifying natural, man-made, and planetary threats. For this purpose, the study considered all the available data related to the projects from different government, semi-government and private organizations besides collecting first-hand data using state-of-the-art techniques like a photogrammetric survey using an aerial drone.

For the first time, the study identified the economic impacts of waterlogging on the local trades of Khatunganj based on scientific data and advanced modeling techniques, which is expected to pave the way for a future comprehensive project to ameliorate the waterlogging condition of the area. Collected data to analyse economic impact were mostly done by applying descriptive analytical and quantitative tools. It is found that waterlogging had a direct economic cost of over taka 500 crore in Khatunganj wholesale market in the year 2020. A similar picture can also be observed from the estimated losses for the last ten years with a clear increasing trend. It is also understood that such direct impacts with time may increase many-folds if no viable solution to the problem of waterlogging is adopted immediately.

The study also developed a risk and vulnerability profile of Khatunganj in relation to waterlogging with climate change scenarios with proper and reproducible methodology. It is observed that a small rainfall results in inundation in the study area, and the consequences are huge economic losses to the commercial areas. To carry out such analysis, a hydrologic-hydrodynamic model was developed that gave an inundation scenario, and from the inundation scenario in combination with other factors, vulnerability of each structure was assessed. For hydrologic-hydraulic modeling purposes, a model was formulated on the SWMM model platform that gave discharge and water level at different points of the canal. Eight different scenarios on different rainfall events were simulated where an actual rainfall event was taken from the 5 July 2017 rain event, and the remaining scenarios were designed rainfall events.

It is found that a low rainfall (around 15 mm/hr) generates a WL of 2.5 m, whereas an average rainfall generates a WL of 3-3.2 m. Such WL results in the inundation of the Khatunganj main road. The level of the Khatunganj main road is about 2.9 to 3.1 m. An average rainfall creates water inundation about 6 inches to 1 foot over the main road. Heavy rainfall with climate change scenario gives around 4.1 m WL meaning around 1m depth of water inundation on the road. Using such an inundation pattern combining with three other factors, namely, proximity to canal, structure type, and land use type of the area, the vulnerability of the area was enumerated. The levels of vulnerability were classified into four classes – not vulnerable, low, medium and very vulnerable. With three rainfall cases (low, average, and high), the risk profile for the structures were also estimated. Majority of the structure on both sides of Khatunganj main road fall in the medium vulnerable class for all three rainfall cases. In the case of high rainfall, all the structures are shown to some extent vulnerable. Water retention options increase in canal capacity, and regular maintenance of the canal is extremely important for managing such a crisis.

Current field surveys and various news from different daily newspapers show a growing trend of location shifting for main trading offices at other commercial places from Khatunganj wholesale market area. Waterlogging problem has been reported as the principal reason behind this shifting. However, as Khatunganj had survived more than a century, only the waterlogging issue should not be the sole basis of this shifting tendency. The transportation network around Khatunganj grew over time incorporating the existing water transport network of the Chaktai canal. But after 2004, this water transport network could not survive any further due to a development project at Chaktai canal area by Chattogram City Corporation, which had created blockage for water transport. To analyse the influencing role of this blockage on the Khatunganj area which generates a blockage to the direct connection from Karnaphuli river with Chaktai canal, a Space Syntax analysis was performed focusing Khatunganj wholesale market area. Results from this analysis clearly show the water transport network of Chaktai canal was the sole reason behind the development and survival of the Khatunganj wholesale market area. The research also projected different future urban development scenarios for Khatunganj considering climate change risks and possible adaptation measures. Using the state-of-the-art Urban Multi-Scale Environmental Predictor (UMEP), the study identified an optimum ratio of water surface, built area, and green at approximately 52:46:2 for onsite storm water management.

Chapter 1

Introduction

1.1 Background

Bangladesh was listed in the 7th position according to the Global Climate Risk Index 2020 as the most affected country by climatic calamity from 1999 to 2019 (Germanwatch, January 2021). Within these 20 years, Bangladesh has lost 0.41% per unit GDP for 191 events (Germanwatch, December 2019). Keeping this reality in mind, the Government of Bangladesh has designed and undertaken several development projects and initiatives to deal with the changes in climatic conditions by the country. The National Resilience Programme (NRP) is one of the specially designed programmes adopted by the government.

Though Khatunganj is considered a local trade hub, in a broader sense the place holds international importance as most of the imported grocery items are stocked in this area. The importance of Khatunganj can be traced back to the 4th century BC with the growth of Chattogram as a port city (Ministry of Information, GoB, 1994). Later, this port city was mentioned as one of the most impressive ports in the East in Ptolemy's world map in the 2nd century (Mannan, 2012). Chaktai *khal* became a part of the major trade route of the Silk Route and during the 11th and 12th centuries (Rodrigue, 2020) Chattogram was described as the most famous and wealthy city of the Bengal kingdom by Portuguese chroniclers De Barros in 1552, as it served the connection to the eastern region (O'Malley, 1917). The Mughal Bengal contributed 40% of the then Dutch imports outside the European continent, and its contribution to the world GDP was 12% (Prakash, 2006). The eastern part of Bengal was the major exporter of silk and cotton textiles, steel, saltpeter, and agricultural and industrial produce in the world. The prominent industries were textile manufacturing and ship-building (Ray, 2011). This old glory of the land later got hindered with dependence on the motorized vehicle as a means of transport and development of land ports. Khatunganj was developed organically with time to serve as a business hub as it is situated on the bank of Chaktai *khal* (also known as Chakoria Nallah), which was the gateway to inner land from the Chattogram Port. The livability of Khatunganj is directly related to the survival of its water network.

However, Khatunganj has been facing severe waterlogging problem from about one and half decades and to date, very little has been done to conduct a scientific study on the economic impact of the current waterlogging scenario on the economy of Khatunganj wholesale market of Chattogram. This study made an attempt to provide the Chittagong Chamber of Commerce and Industry (CCCI) and Khatunganj Trade and Industries Association with evidence and actionable information about the root causes of water retention, policy gaps, and institutional capacity to raise awareness and policy advocacy for risk-informed business practices in the city.

Photo Credit: NRP

1.2 Problem Scenario

Before proceeding to elaborate on the problem scenario, it should be noted that waterlogging is the saturation of soil with water, which is not the case of the study area. The problem of the study area is an urban drainage problem, as there is no effective system in place for onsite water management from rainfall, upstream flow, and tidal floods. The city is a dynamic landscape characterized by natural (blue and green) and man-made (grey) elements (Galli et al., 2012). These elements, accumulated over time, shape the urban form, and influence the behavior of the residents. Over densification and unplanned urbanization leave little room for interaction among blue, green, and grey elements, and as a result, the natural elements (e.g., water, green space) and natural characteristics (e.g., topography) are reprioritized in many cities. One manifestation of this is that water which is a vital structuring element, can become a challenge for the urban environment during extreme weather events such as heavy rainfall. The compact urban fabric often does not possess porous surfaces for water permeability, causing historically unprecedented flooding events. The rapid process of urbanization in mega-cities resulted in an increasing frequency of disaster events including hydro-meteorological disasters that have threatened human lives and infrastructure. One of the most common water related disasters frequently affecting urban social life, particularly in the Asian region, is urban flooding (CRED-UNISDR, 2015). In this study, water retention in the city area is the aggressor, which is victimizing the economy, increasing operational costs and losses to the local traders. This scenario can be interpreted in three threads, namely, natural, man-made, and planetary threats. For this study, the technical interpretation of the above mentioned threats are as follows:

Natural Threats

- Flood, Rainfall
- Tidal Flooding

Manmade Threats

- Land reclamation/ encroachment
- Erosion/siltation Solid waste
- Black water drainage
- Soil permeability/ soak ability
- Hard engineering

Planetary Threats

- Excessive rainfall
- Sea level rise
- Heatwave

Natural Threats

i. Flood, Rainfall: In recent past low-lying areas in Chattogram city, such as Chawk Bazar, KB Aman Ali Road, DC Road, Muradpur, Bahaddarhat, Badurtola, Kapasgola, Sholashahar Gate-2, Proborttak Intersection, Agrabad, Halishahar, Shulak Bahar, Bibirhat, Chandgaon, Dewan Bazar, Chaktai, Khatunganj, Oxygen, Katalganj, Panchlaish residential area are reported to be under knee to waist deep water many times in the rainy season in the national dailies. Though rainfall in our context is a natural phenomenon, due to water drainage problems, it has become a threat for the businessmen and the city dwellers.

Rickshaws and a car negotiate a submerged street in Chattogram city's Probartak area following torrential rain. (Source: The Daily Star, 09 July, 2019)

ii. Tidal Flooding: This commodity hub of Khatunganj and Asadganj houses some 3,000 business establishments and more than 5,000 warehouses. It was reported in a daily newspaper on 24 July 2017 that tidal water entered the business hub damaging goods worth more than taka 100 crore. On that day, tidal waters entered the commodity hub at 6 am and flooded the area till 2 pm.

Traders at Khatunganj incur huge losses as tidal and rain waters enter shops and godowns in the country's largest wholesale commodity market (Source: The Independent, 24 July 2017).

Manmade Threats

i. Land Reclamation/Encroachment: Over the period, the Karnaphuli river has changed its location, but Chaktai *khal* remained at its original place. The black circle in Figure 3 is showing the position of Chaktai *khal*. Within 200 years of time frame, in terms of surface area, channels have reduced 10%, sub-channels 5%, and river 5%. Besides the natural process of siltation, all inland water channels have faced encroachment in the Chattogram city area. A comparative analysis of water channels is shown in Figure 3 and the original width of Chaktai *khal* before encroachment is shown in Figure 4.

According to a research by Mahmood et al. (2018) total peak run-off to Chaktai *khal* for five-year return period rainfall is found to be 132.7 mm, and for a ten-year return, the rainfall is 164.4 mm. According to the research, it has been found that Chaktai *khal* discharges more water to the Karnaphuli river than Rajakhali *khal* and thus more vital for drainage management.

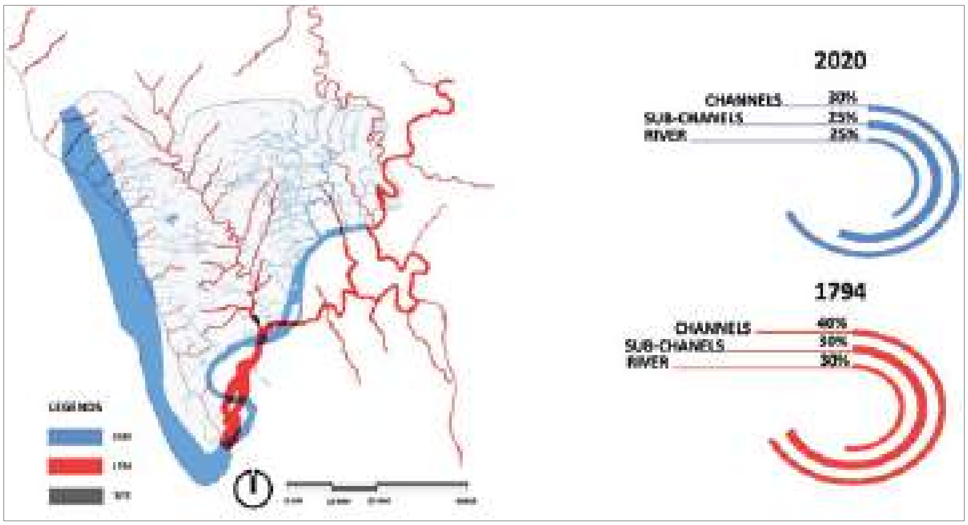


Figure 3: Locational change of Karnaphuli over 200 years (Source: Analysis done at Design Studio VII, Spring 2019-20, Architecture Department, AIUB, Studio Guide: Research team based on British Survey Map, 1794)

Figure 4: R.S. Map of Chaktai *khal* (Source: Ar. Planner Shahinur Islam Khan, Ar. Mahrina Jafrin, Transportation master plan of Chattogram city and an approach towards sustainable development, 13 August, 2014).

ii. Erosion/ Siltation: Unplanned urbanization in Chattogram is directly related to cutting hills, soil erosion, and landslides. Every year during the rainy season, landslide is a common problem in this hilly area. Soil erosion due to hill cutting creates siltation in water channels and blocks the natural flow system. The siltation problem gets triggered by solid waste disposal at water and drainage channels.

iii. Solid Waste and Black Water Drainage: Disposal of solid waste at drainage is a common phenomenon in Chattogram city area. As Chaktai *khal* is one of the city's main drainage channels, a considerable part of thrown away solid waste gets accumulated at the *khal* area. Besides, the disposal of organic waste from the Khatunganj area directly contributes to the siltation process. A national daily reported on the plastic waste problem at Chaktai *khal* in February 2020 (The Daily Star, 2020) which is depicted in Figure 6 below. From an initial field survey, it has been found that only 15% of the Chaktai *khal* areas are still free from pollution at Khatunganj, and 50% of the *khal* is heavily polluted.[1]

Figure 5: Landslide in Chattogram hilly area. (Source: Dhaka Tribune, 28 July, 2013)

Figure 6: Plastic accommodation at Chaktai *khal*, (Source: The Daily Star, February 16, 2020)

[1] Field survey and analysis done at Design Studio VII, Spring 2019-20, Architecture Department, AIUB.

The pollution map of Chaktai *khal* in the Khatunganj area is shown in Figure 7. According to Chattogram City Corporation (CCC), earth cutting during piling by the developers for high rise buildings in the city has also contributed to filling up the canals. Two different studies on waterbodies in Chattogram city by District Fisheries Department in 1991 (19250 waterbodies) and Chittagong Development Authority (CDA) during 2006–2007 (4523 waterbodies) mentioned Chattogram is losing 920 waterbodies per year.

iv. Soil Permeability/Soak Ability: Permeability of soil gets reduced when roads drain, and hard surfaces are built. Water that was supposed to be soaked by the earth turns out to be groundwater run-off as soon as hard surfaces are constructed. To keep pace with rapid urbanization of Chattogram, new roads, concrete drains, and pavements have been built in recent years. As most of these constructions are non-permeable, the amount of run-off water has been increased. Another study from Chattogram City Corporation (CCC) showed that Chattogram city lost 9% forest coverage and 8% of agricultural lands during 1990–2004 (Hashemi, 2006). This loss of land covered with vegetation and forest created a challenge for the existing hydrological cycle by reducing infiltration capacities, which resulted in excess water draining.

v. Hard Engineering: The Drainage Master Plan (Chattogram) was prepared in the year 1994 as part of the UNDP funded Chattogram Master Plan Project. The drainage master plans divided the city into twelve drainage zones, and the present study area Chaktai and Khatunganj are in the drainage zones 5a and 5b of the Drainage Master Plan. For the study area recommendation was the construction of abutment walls, the lining of side slopes, re-profiling of the downstream end of the Chaktai *khal*, and bed lowering up to the Karnaphuli river with a 21 m wide tidal regulator along with navigation gate at the mouth of Chaktai *khal* (Ashraf and Chowdhury, 2009). Later, it was found from a field survey that recommended abutment walls, the lining of side slopes was constructed without claiming the encroached area of Chaktai *khal*. Construction of foot bridges at points 1, 2, and 3 (Figure 8) also hindered boat movement in the canal area.

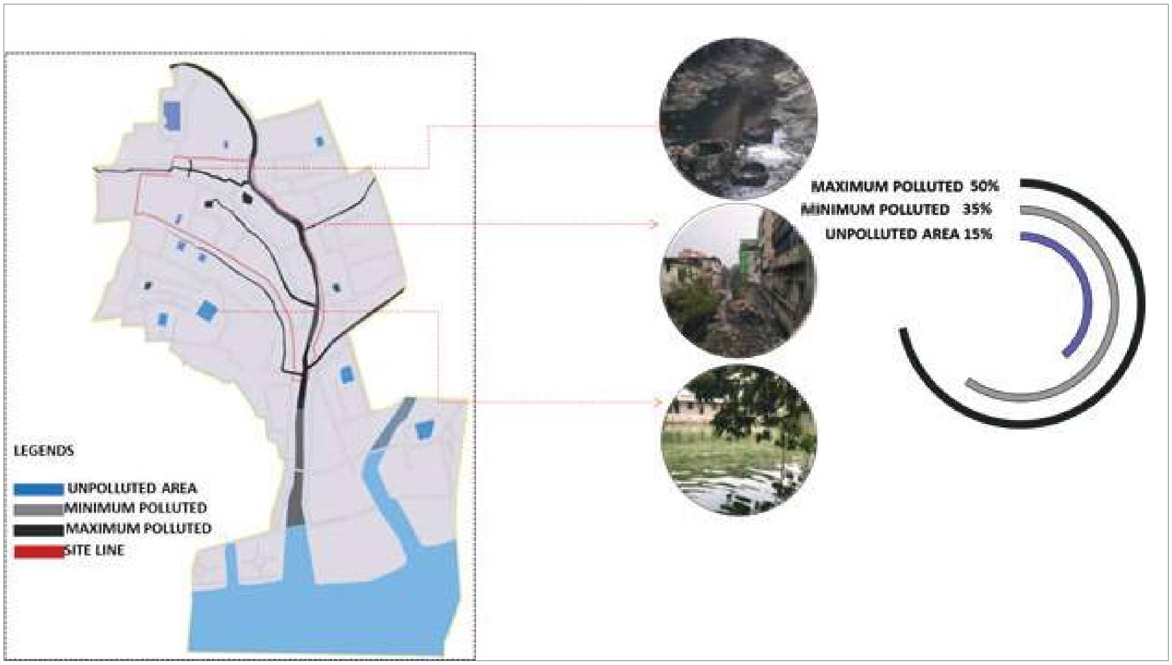


Figure 7: Pollution at Chaktai *khal* (Source: Analysis done at Design Studio VII, Spring 2019-20, Architecture Department, AIUB, Studio Guide: Research team)

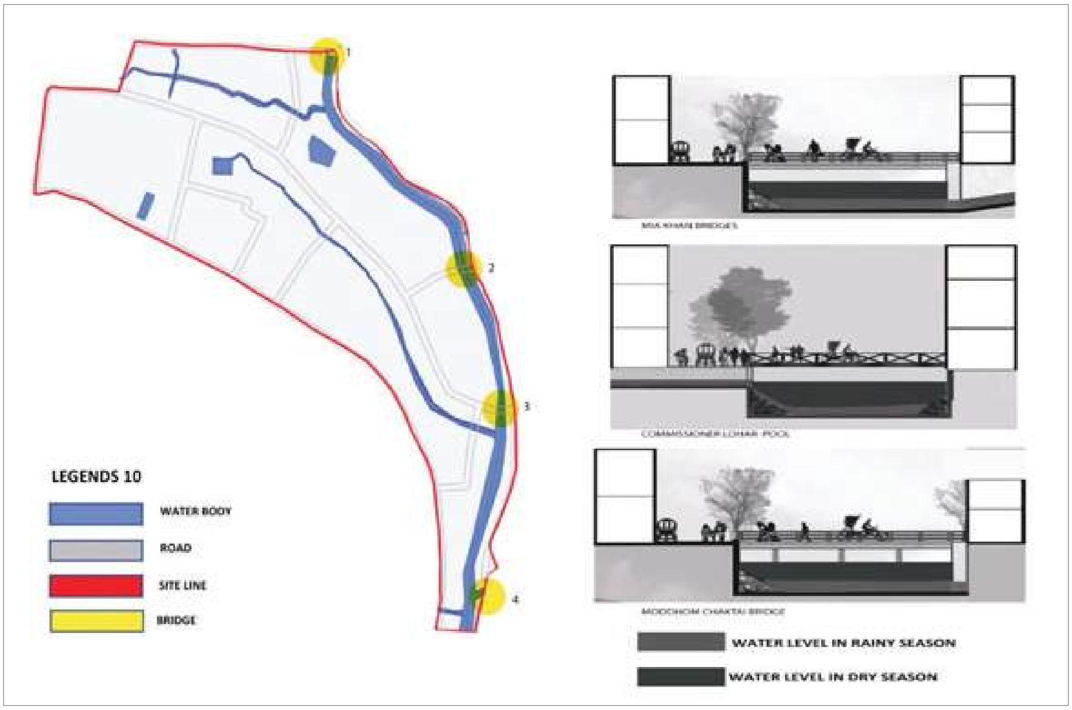


Figure 8: Hard engineering solution at Chaktai *khal* (Source: Urban studio VII, Spring-2019-20, Architecture Department, AIUB, Studio Guide: Research team)

Planetary Threats

i. Excessive Rainfall: Flash flood in the Chaktai area is a common scenario in the rainy season. Due to climate change, abrupt rain is becoming a new norm for the region. Figure 9 is showing the difference between flooded land areas beside Chaktai *khal* due to heavy rainfall in 2008 and comparatively less rainfall in 2011. The marked red area is Khatunganj in Figure 9.

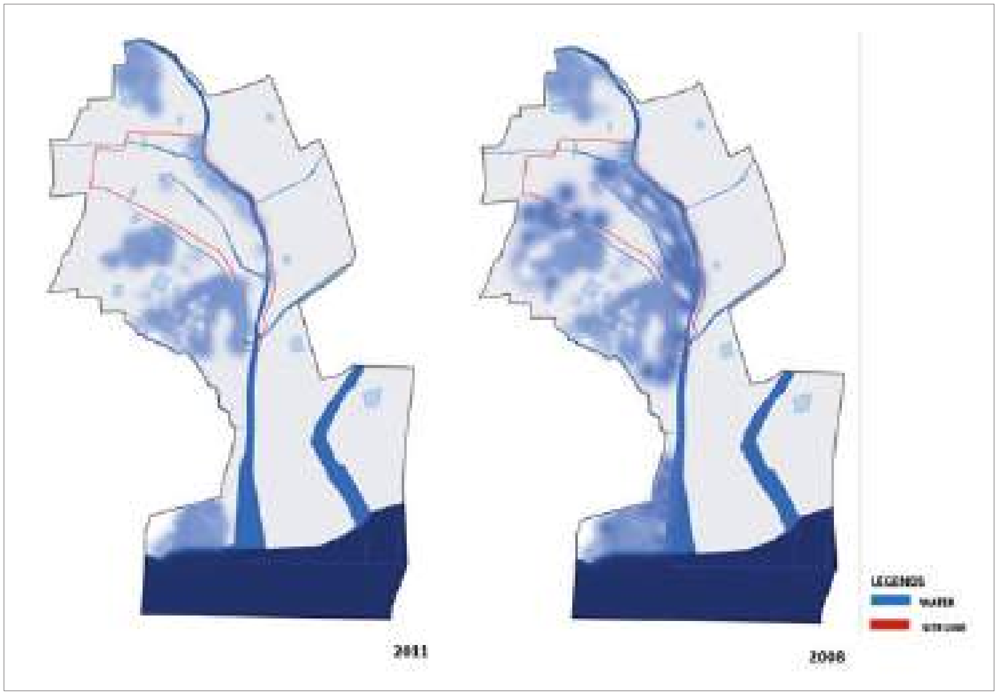


Figure 9: Flash flood at Chaktai *khal* area (Source: Analysis done at Design Studio VII, Spring 2019-20, Architecture Department, AIUB, Studio Guide: Research team)

In Figure 10, the graph is showing a comparison of meteorological data from 2008 to 2011. It is observed that in 2008, Chattogram had the most rainfall and passed the most humid time during that period.

ii. Sea Level Rise: In the global scenario, sea level rise has become an alarming threat to our country. According to a study by the Department of Environment (DoE), the tidal water level of the Ganges in the flood plains has been rising by 7-8 mm per year, 6-10 mm in the Meghna estuarine flood plain, and 11-21 mm in the Chattogram coastal areas (CCC, 2016), (Figure 11). Most of Khatunganj is located at 10.5m level, and the top contour level for this area is 13 m from the sea level (Figure 12). Sea level rise contributes to water retention at Chaktai *khal* and spillage of retained water at the Khatunganj area.

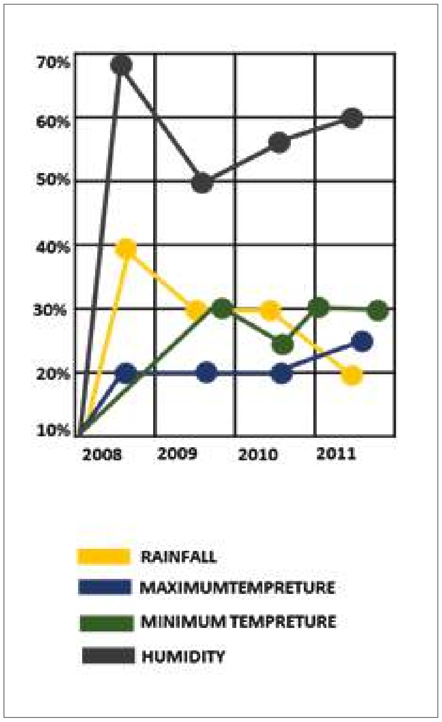


Figure 10: Comparison of meteorological data from the year 2008 to 2011 (Source: Bangladesh Metrological Department)

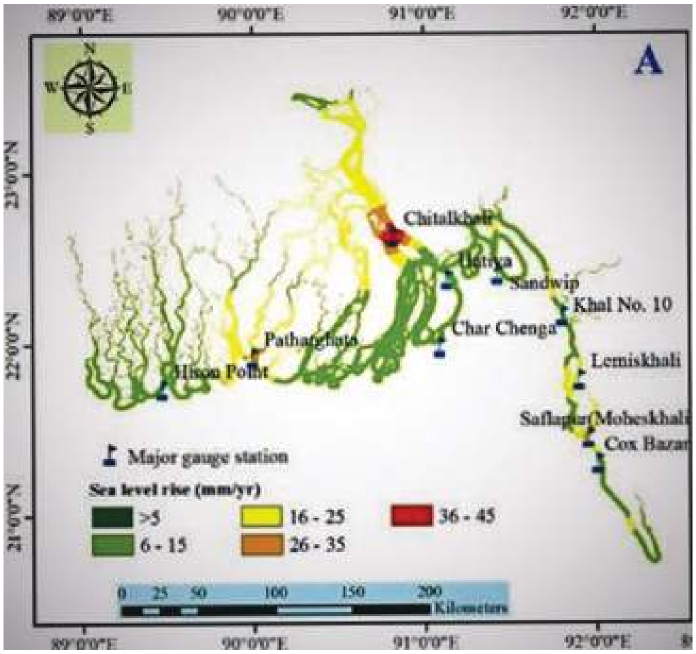


Figure 11: Sea level rise at coastal belts of Bangladesh (Source: Mullick, M. R. A., Tanim, A.H., Islam, S.M.S. 2019. Coastal vulnerability analysis of Bangladesh coast using fuzzy logic based geospatial techniques. Ocean & Coast. Management.)

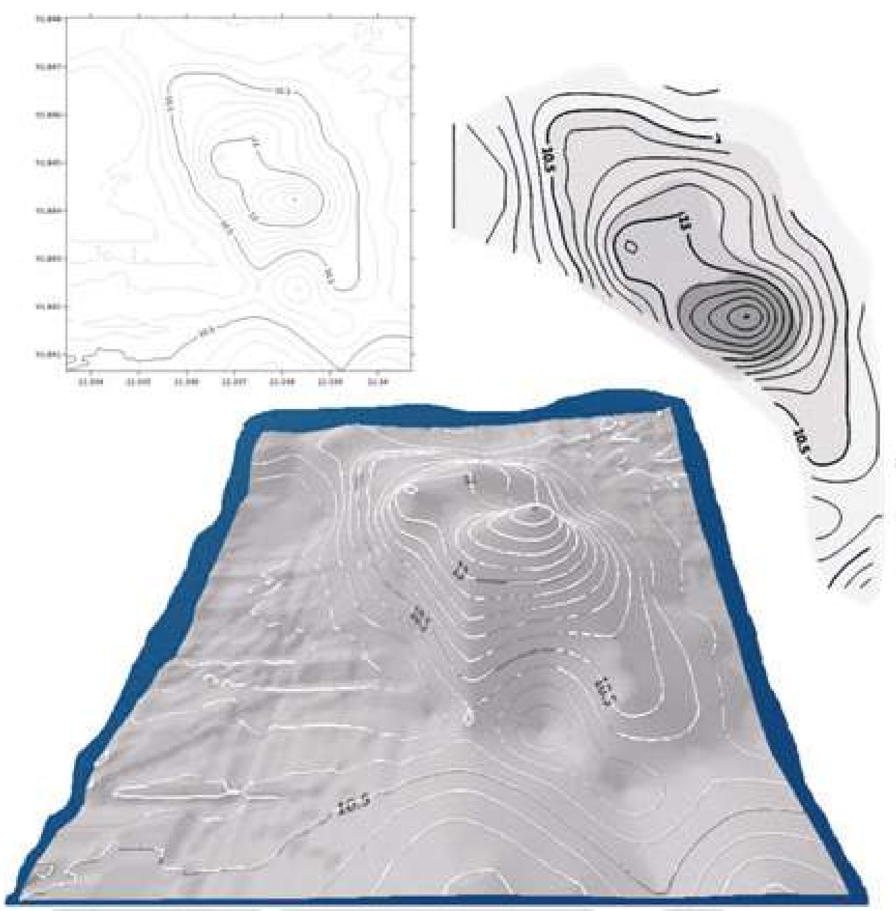


Figure 12: Contour level of Khatunganj (Source: Analysis done based on secondary data at Design Studio VII, Spring 2019-20, Architecture Department, AIUB, Studio Guide: Research team)

iii. Heatwave: During the last three decades (1982–2013), there had been an average increasing temperature trend almost every month compared to earlier years (Akter et al., 2017). In Chattogram, the rising temperature is also a global trend that cannot be overlooked.

1.3 Problem Statement and Research Questions

Within this context, one of the purposes of this research was to explore how the disruption in the urban blue-green network was creating urban flooding in the study area and how the urban blue-green infrastructure (UBGI) network can be part of a future urban development strategy for the Khatunganj area, to adapt against urban flooding. Against this backdrop, the study attempted to answer the following research questions:

a. What would be the urban flooding scenario of the study area regarding the present climate change scenario without any infrastructural intervention?

b. What could be the key policies and institutional arrangements in the public and private sectors to adapt to urban flooding?

c. How can the urban structure of the study area be adapted to mediate between the need to accommodate commercial growth and at the same time give room for water and green spaces to adapt against urban flooding?

1.4 Objectives of the Study

The specific objectives of the study include:

1. To identify the root causes of waterlogging in the study areas based on hard scientific evidence;
2. To assess the scale and intensity of the problem in quantitative measures;
3. To investigate the causal relationships of the prevailing scenario; and
4. To determine strategic interventions for the best possible future scenario.

1.5 Study Site

Khatunganj is situated at the east part of the Chattogram city by the side of the famous Chaktai canal. This is the place where the Chaktai canal opens to the Karnaphuli River. The geographic location of Khatunganj is at 22.33° N and 91.84° E. Khatunganj is located at the ward number 35 of Chattogram City Corporation. Figure 13 shows the location of Khatunganj.

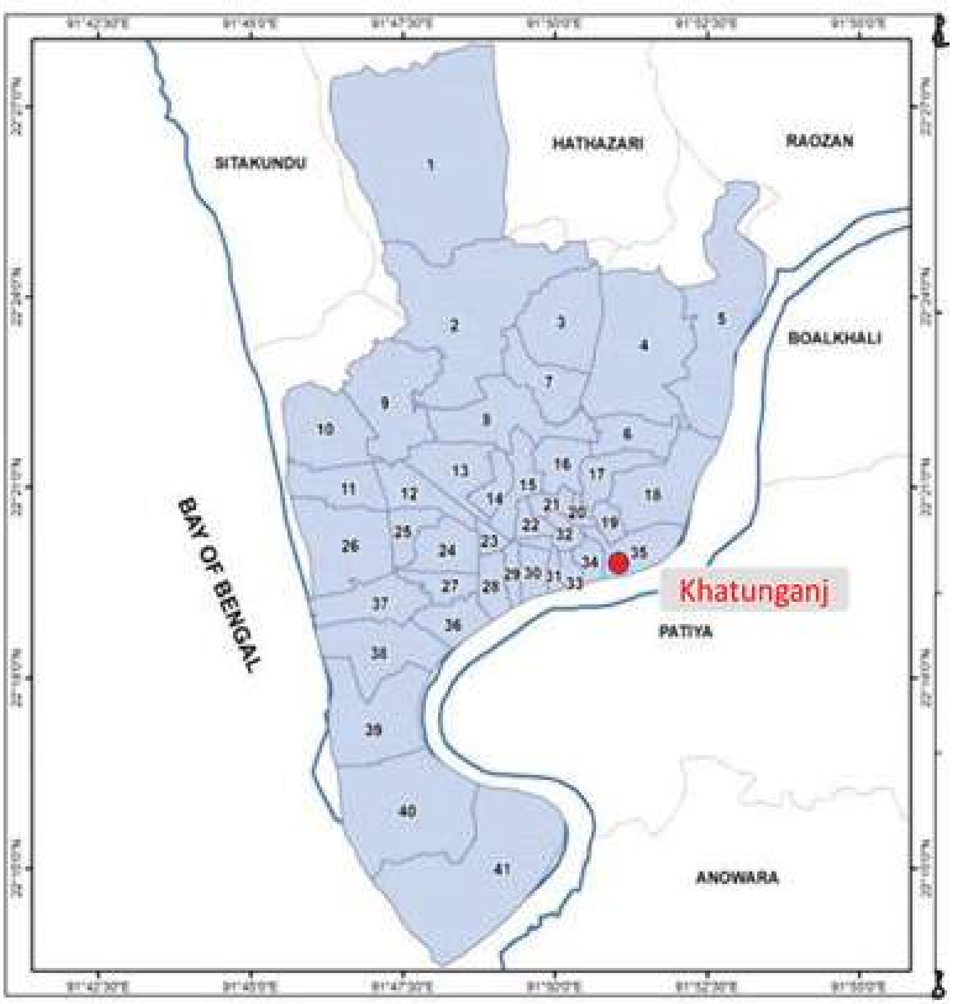


Figure 13: Location of Khatunganj in Chattogram city area (Figure drawn by Authors)

The place is vital for the economy of Chattogram city as well as for the entire country. This is the primary wholesale market for daily commodities. Once hundreds of boats used to enter the canal to offload products to this market, that glory is now lost, as land transportation has taken over maritime. However, water-based transportation is still regarded as the cheapest medium. About 3,000 firms, including 250 wholesale shops and 5,000 warehouses, are in Khatunganj (The Daily Star, 2020). Figure 14 shows some business activities at Khatunganj.

However, the business hub currently are suffering extremely from inundation problem. Khatunganj traders reported their sufferings with huge costs due to waterlogging as their stocks are destroyed. A very short duration rainfall results in waterlogging in all the alleys of this crowded market. Figure 15 portraits the waterlogged situation of some shops at Khatunganj. The economic problem and hardship of the traders due to the waterlogging in Khatunganj has been widely reported in the media to bring attention to the policy makers (Islam, 2018).

1.6 Structure of the Report

This report consists of the following sections:

Chapter One starts with the overview and background study of the problem. Then it continues with the research questions and objective of the study. Afterwards a detail description of the study site is provided. The chapter ends with the limitations of the current research.

Chapter Two describes the recent literatures relevant for the research.

Chapter Three details out the methodologies that were used to conduct the research.

Chapter Four includes result and analysis of the research.

Chapter Five provides a conclusion based on the findings of the research. It ends with an action matrix derived from the research.

Figure 14: Business activities at Khatunganj wholesale market, Chattogram (Source: Left: Business Insider Bangladesh, Right: Daily Ittefaq, 8 Sept, 2015)

Figure 15: Waterlogged shops at Khatunganj (Source: The Independent, 24 July 2017 & The Daily Star, 13 March 2020, respectively)

Chapter 2

Review of the Literature

2.1 Waterlogging and its Assessment

Waterlogging is a condition where the soil is completely saturated with water. The soil does not possess any more capacity to percolate water into the ground or drain. In urban areas, the ground surface is gradually becoming rigid by several imperforated layers that hinder the natural water percolation process and generate more runoff. Drainage congestion is often observed in the urban areas that hinder stormwater movement and create waterlogging. Due to rapid urbanization to cope with population growth, cities are losing open space that earlier acted as stormwater retention zones. Unplanned city development often acts in a synergistic way along this line. All these phenomena result in urban storm waterlogging. Urban flood problems in many cities of the developing countries occur in the form of pondage of surface runoff due to blockage of storm sewers and/or inadequate provision of drainage facilities for disposing of such runoff (Rasid, 1982). Waterlogging assessment includes waterlogging causes, prevention, and control strategy, waterlogging model, and risk assessment (Lin et al., 2018). Urban waterlogging assessment mainly focuses on the extent of waterlogging (1-D) and depth and extent of logging (2-D). Hydrologic and 2-D hydraulic model analyses result in the scenario of waterlogging of any place. The submerged area and depth of waterlogging due to various rain storms with different return periods are estimated and measured by building a model (Radmehr and Araghinejad, 2014). The risk analysis of urban rain storm led waterlogging impacting Tianjin city, including traffic conditions, by using methods of probability, investigation and numerical simulation was carried out in a study by Han (2006).

A fine-scale suitable Digital Elevation Model (DEM) is the first requisite for waterlogging study to delineate watershed. A DEM is a "bare" land surface model, supposedly free of trees, buildings, or other "nonground" objects. DEM can be obtained from ground surveys, airborne photogrammetric surveys, existing topographic map data, airborne laser scanning, automated stereoscopic based satellite imagery, radar-based satellite imagery, LiDAR-based satellite imagery, etc. For global-scale SPOT (30 m*30 m), SRTM (30 m*30 m), ASTER GDEM (90 m*90 m) etc. DEMs are widely used. SRTM and ASTER are freely available; however, the resolution is very coarse or low. For local scale, DEM production with higher resolution LiDAR data is used (Lakshmi & Yarrakula, 2018). A DSM is an elevation model that includes the tops of everything, including buildings, treetops, and the ground where there is nothing else on top of it. Therefore, DSM represents the top of the earth's surface, and it is developed by using terrain's elevation data. For local scale, LiDAR is again suitable to obtain the DSM at high resolution. LiDAR data and field-level information extracted for urban features (Priestnall et al., 2000) from DSM are used to predict flood inundation modeling.

In the next step for waterlogging assessment, a hydrological model and hydraulic model study are done. The hydrologic model estimates the runoff generated from the watershed and the hydraulic model features the inundation scenario of depth and extent. Dhami and Pandey (2013) developed nine hydrological modeling namely: AnnAGNPS, GSSHA, HYPE, HEC-HMS, MIKE-SHE, PRMS, SWAT, WetSpa, and WinSRM, which have been selected for the inter-comparison evaluation. Criteria used for the assessment are: I. Hydrological processes that the model can simulate, II. Governing equations used to simulate the hydrologic processes, III. Minimum data required to run the model, and IV. spatial and temporal scale of the model. They found HEC-HMS is a promising model for providing multiple options to simulate hydrologic processes. However, WinSRM is a robust, computationally efficient, and accurate model for simulating snow-dominated watersheds, and for continental or multi-basin simulation, HYPE is a better option. HEC-RAS. MIKE, SWMM, ANUGA, SOBEK, etc., are commonly used hydraulic modeling methods to simulate inundation scenarios. To integrate with hydrological modeling HEC-HMS, hydraulic model HEC-RAS is a better option.

2.2 Urban Flooding

The city is a dynamic landscape characterized by natural (blue and green) and man-made (grey) elements (Galli et al., 2012). These elements, accumulated over time, shape the urban form and influence the behavior of residents. Over densification and unplanned urbanization leave little room for interaction among blue, green and grey elements. As a result, the natural elements (e.g., water, green space) and natural characteristics (e.g., topography) are deprioritized in many cities. One manifestation is, water a vital structuring element can become a challenge for the urban environment during extreme weather events such as heavy rainfall. The compact urban fabric often does not possess porous surfaces for water permeability, causing historically unprecedented flooding events. The rapid urbanization process in megacities resulted in an increasing frequency of disaster events including hydro-meteorological disasters that have threatened human lives and infrastructure.

One of the most common water-related disasters frequently affecting urban social life, particularly in Asian regions, is flood (CRED-UNISDR, 2015). Urban blue-green infrastructure (BGI) network can be proposed both at macro and micro scales as part of a future urban development strategy for the megacities to mitigate the hydro-meteorological disasters. It combines the concept of green (including blue) networks and ecological networks (Jongman et al., 2004). BGI includes green and blue elements and processes besides man-made interventions, such as permeable pavements, bioswales, retention basins and constructed wetlands as an integrated way to perform multiple functions. These are mainly i. flood control, ii. water storage for irrigation and industry use, iii. wetland areas for wildlife habitat or water purification. (Ghofrani et al., 2016). BGI network helps for a greater recognition of an array of ecosystem services e.g., water purification, heat retention, as well as cultural and economic benefits, with a higher sensitivity towards human interventions. BGI can also help to create Biocapacity in the depleted urban areas. (Ahmed etl. 2019)

2.3 Climate Change Scenario of Bangladesh

Bangladesh is the country among the worst victim due to climate change (IPCC, 2007). Climate change impacts are felt on various aspects in Bangladesh, temperature, precipitation change, sea level rise, shifts in cyclone or tornado strength and others (Nishat and Mukherjee, 2013). The climate of Bangladesh is getting cooler and drier for winter, on the other hand, warmer and wetter for the rest of the year. On an annual basis, the trend is increasing with a value of 0.008°C/yr or 0.4°C in 50 years, having a significance level, $p < 0.05$. The trend of mean rainfall on an annual basis shows an increasing trend of 5.675 mm/yr. (Mullick et al., 2019). Climate change adaptation measures need to be in place to tackle the climate change induced natural disasters such as floods, cyclones, erratic rain etc. (Haque, 2013).

2.4 Vulnerability and Risk

2.4.1 Vulnerability

Vulnerability is considered to be the extent of harm expected under certain conditions of exposure, susceptibility, and resilience (Balica and Wright, 2009). Vulnerability is defined in terms of exposure, capacity, and potentiality. Accordingly, the perspective and normative response to vulnerability is to reduce exposure, enhance coping capacity, strengthen recovery potential and bolster damage control (i.e., minimize destructive consequences) via private and public means. Vulnerability also indicates a person's or group's features, ability to anticipate, cope, resist, and recover from the effect of a natural hazard. It includes a mixture of variables that determine the degree to which an event in nature or society puts a person's life and livelihood at risk (Wisner, Ben; Blaikie, Piers; Cannon, Terry; Davis, 2003).

2.4.2 Risk

Risk can be defined as the combination of the probability of an event and its adverse consequences (UNISDR, 2009). Risk is described as the anticipated losses (of life, injured individuals, damaged assets, and interrupted financial activity) owing to a specific area and reference period hazard. Risk is the result of hazard and vulnerability based on mathematical calculations (WMO, 1999). Mathematically risk is the product of hazard, vulnerability and exposure. Flood disaster risk assessment is a synthetic assessment and analysis of multiple variables. These variables include the stability of the disaster breeding environment, the risk of the disaster inducing environment, and the hazardous body's vulnerability (Kexue, 2004).

2.5 Risk and Vulnerability Assessment

Risk assessment is a method to evaluate the existence and magnitude of such risk by analyzing hazards and determining existing vulnerability conditions that together may potentially harm exposed individuals, properties, infrastructure, livelihoods and the environment they rely on. A thorough risk assessment assesses the severity and probability of future losses and offers a clear understanding of the causes and impacts of such losses. Therefore, risk assessment is an essential part of decision making and policy making processes and needs close collaboration between various parts of society (UNDP, 2010). Thus, vulnerability risk analysis is to determine the relationship between the expected consequences (i.e., physical damage, social interruption, economic loss, environmental degradation) and the harmful urban flood events.

The US Federal Emergency Management organization (FEMA) and the National Institute of Building Sciences (NIBS), has a very extensive module dealing with the inventory of exposure, such as buildings, population, and life lines, for the USA. It requires an enormous amount of detailed basic data input, often not available in developing countries. A GIS-based approach developed by (Yin et al., 2011) showed that the spatial exposure information for urban residential buildings could be simply extracted by overlaying the waterlogging extent map with the residential building codes. Various semi-quantitative multiple criteria evaluations (e.g., analytic hierarchy process, fuzzy comprehensive evaluation model, grey target model, principal component analysis, set pair analysis, the technique for order preference by similarity to an ideal solution, data envelopment analysis, variable sets method) have been widely used to reflect the vulnerability characteristics of receptors such as the urban system, population, households, and subways to urban flooding (Quan et al., 2011; Shi 2013; Yin et al., 2014; Wang et al., 2015). GIS based multi-criteria approach can help to identify areas of potential geo-technical and geo-environmental hazards that could impact the design and construction of buildings, allowing risk reduction measures at the early stages of the design process (Youssef et al., 2011 b). In a study in Greece showed that indexing the risk factor can help mapping of the flood hazard and its assessment (Stefanidis and Stathis, 2013).

2.6 Risk Profiling

A risk profile is an evaluation of an individual's willingness and ability to take risks. Organizations use a risk profile to mitigate potential risks and threats. The risk profile is a snapshot of all the risks a human target system is subject to within a given time frame. A simple risk profile includes a set of hazard scenarios, potential losses, and the probability of occurrence. A more comprehensive risk profile may have impacts of risk, categorization of risks, the relative priority of the risks, acceptable levels of risk, linkages between different levels of risks, ways of measuring the risk (qualitative and quantitative), key risk areas/hotspots, risk reduction measures, capacity for risk treatment, learning needs and tools, etc. (Hoogeveen et al., 2016). Victorine and Estuar (2014) used 'FloodPatrol' an android mobile phone application which allowed the crowd to report flood levels in various location. For the study purpose, the risk profile will identify potential risks for disaster preparedness and enhance capacity for business professionals for addressing disaster and climate change.

2.7 Economic Impacts of Urban Waterlogging

Waterlogging and flooding are common phenomena for many large cities across developing countries. The key sectors affected by floods include infrastructure, industry, trade and commerce, and utility services. These sectors cannot perform well during and after floods, thus increasing the vulnerability for city dwellers. Poor urban dwellers suffer health problems and loss of life and livelihoods (IPCC, 2007). The Impacts of waterlogging and flooding are diverse and sometimes can be quite severe. According to Subrina and Chowdhury (2017), waterlogging interrupts day-to-day life to the extent of severe damage to resources. In rural waterlogging or flooding, it may affect crops, bring changes in land-use patterns, damage fisheries, homesteads, and create obstacles for transportation and communication services. In the case of urban waterlogging and urban flooding, problems can be even more severe. Different sectors can be affected by urban flooding and urban waterlogging. The key sectors affected by floods include infrastructure, industry, trade and commerce, and utility services. These sectors cannot perform well during and after floods, thus increasing city dwellers' vulnerability (IPCC, 2007). Tareq, et al. (2016) observed that waterlogging has detrimental impacts on biodiversity and environment in the south-western region of Bangladesh.

The associated impacts of urban waterlogging, as per Subrina and Chowdhury (2017) include:

- Disruption of traffic flow- traffic congestion and traffic diversion often cause a severe traffic jam in many cities in the developing world
- Impairment of structures and infrastructure- prolonged waterlogging and water infiltration decreases the longevity of floors and walls, brick foundations and substructures of buildings in low lying areas of cities. It also causes the problem of subsidence, dampness, and other damage of infrastructure and impairs underground utility services such as water, gas, sewerage pipelines, etc.
- Contamination of water bodies and transmission of water-borne diseases-urban waterlogging and urban flooding often cause severe contamination of nearby water bodies like river, low depressions like beels (field), jheels, lakes, canals, etc. This can be a source of many water-borne diseases like diarrhea, cholera, typhoid fever, other types of fever, nausea, skin diseases, hepatitis A and E, etc.
- Urban waterlogging or urban flooding can also be a reason for damaging flora and fauna in the form of destructing their habitats and contaminating water and soil.

- Rise of construction and maintenance cost- another common problem of urban waterlogging or urban flooding is in the form of additional repair or maintenance cost urban authorities may need to incur for city's infrastructural facilities. Like after a flood, the city's roads can be damaged, and repairs need to be done. This may cause unplanned and additional costs on urban authority and
- Decrement of income potential- this may also cause loss of potential income by different parties. For example, transport service providers, traders and business people, and road vendors may be affected by their daily income earnings. It may also cause additional expenditure for many city dwellers in terms of additional transportation costs. Simultaneously, producers and business people may also need to face similar extra charges in repair and maintenance costs due to urban waterlogging.

In addition to these direct impacts of urban waterlogging, there can be many more indirect and secondary impacts of urban waterlogging. These can be psychological problems and mental stress; social problems like schools can be closed. Students may have to miss their schools, and mosquito breeding can be accelerated. Residents may face different health hazards and thus need to spend extra health costs and costs related to prevention and mitigation related concerns.

2.8 Urban Waterlogging and Business Interruption Costs

Waterlogging or floods can be a reason for the disruption of trade and commerce in any country. The losses from business interruption can sometimes be huge also. Such losses can be termed as the forgone value-added that is not created due to a flood (Vilier et al., 2014). The severity of impacts from urban waterlogging or flooding can intense on trade and commerce. Business interruptions take place, for example, if people are not able to carry out their work because their workplace is either destroyed or not accessible due to a hazard (Meyer et al., 2013). Often low-land areas of many cities go underwater for a few hours to several days and cause severe transportation and communication problems. Both flooding and waterlogging due to excessive rainfall cause severe damage in the trade and commercial sectors (Alam and Rabbani, 2007).

According to Hammond et al. (2015), there is a great emphasis in the literature on direct tangible flood damage, including damages to commercial and industrial properties. Ashraf and Chowdhury (2009) identified poor drainage and waterlogging as the major reasons behind the loss of importance of the Chaktai commercial area of Chattogram city. According to WB report (2014), waterlogging puts city dwellers and family assets, the urban built environment and vital public infrastructure at risk; in turn, industry and trade are harmed and daily wage earners and temporary workers lose employment and income. Komolafe et al. (2018) estimated different urban costs from flooding, including business and commercial costs and predicted the same might accelerate with increases in the climate-induced precipitations. A study by Khan et al. (2014) also showed that monsoon flooding in Malaysia's Kelantan state caused losses for the residents and businesses located in various areas located near the Kelantan River.

A flood or waterlogging not only affects regular trade and commerce activities of an inundated area due to direct business interruptions but can also cause losses for them through disruption in business processes (Meyer et al., 2013). Losses from the business interruption may include damages to stocks, loss of infrastructure and properties, high operation cost, reduction in investment returns, etc. Loss of production, particularly for business areas that are production hubs, is another major consequence that businesses may need to bear due to waterlogging. They are referred to as direct losses as they cause immediate effects from waterlogging (Kok et al., 2004). Expected business interruption losses refer to the loss of revenue from the reduction of the flow of services, economic output, or profit (Rose and Huyek, 2016). In addition to these costs and losses, the business may also have to face indirect impacts like additional investment required to ensure safety and security, shifting business operations from waterlogged area to a safer place, loss of market due to business interruptions in the long run, etc.

Waterlogging is a prevalent incident for cities like Dhaka and Chattogram. The parts of the Dhaka city under the jurisdiction of Rajdhani Unnayan Kartripakkah (Rajuk) had 100,937 acres of water bodies and lowlands nine years ago, but 22% of those (22,156 acres) have been filled up since then, significantly contributing to the perennial waterlogging issue (The Dhaka Tribune, 2019). According to a World Bank study published in November 2014, the potential damages from waterlogging between 2014 and 2050 will be taka 110 billion in Dhaka if climate change adaptation measure is not considered. In a changing climate with more intense rainfalls, the loss will be taka 13.9 billion between 2014 and 2050 (The Dhaka Tribune, 2017).

2.9 Need for Assessing Economic Impacts of Urban Waterlogging

According to Seneviratne et al. (2018), the projected changes from both global and regional studies indicate that it is likely that the frequency of heavy precipitation or proportion of total rainfall from heavy falls will increase in the 21st century over many areas on the globe, especially in the high latitudes and tropical regions and northern mid-latitudes in winter. Heavy precipitation is projected to increase in some areas with projected decreases of total precipitation. Such changes can already be observed in many parts of the world, including Bangladesh. This is not only causing floods and droughts, but urban waterlogging can also be linked with these changes, although there are many other reasons behind the problem of urban waterlogging. For many cities across the developing world, it has gradually become a serious civic challenge. The intensity of precipitation is predicted to increase with time, which means such incidences may only get exacerbated and thus there is a need to deal with the challenge carefully. According to Sharma et al. (2016), estimation of economic loss due to floods and waterlogging, or any climate-induced event, can be an important process of understanding vulnerability and identifying those most badly affected economically. This can inform the subsequent adaptation strategy.

Addressing issues like urban waterlogging demands a well-coordinated and comprehensive plan. The issue of current challenges with future possibilities needs to be kept in mind while designing any plan to address the issue. This demands not only careful strategy and planning but also proper execution of the same. A real challenge for any developing country city like Chattogram is managing the required resources, including financial resources for carrying out necessary projects to develop required infrastructural facilities, excavating water channels for smooth flow of rainwater or city's wastewater, and developing regulatory frameworks. Considering resources have alternative uses and any development project where scare resource needs to be allocated demands a benefit-cost analysis. Understanding the economic impacts of non-action or business as the usual situation can help policymakers and all concerned understand the possible impacts of any ongoing problem like urban waterlogging. While it is also essential to assess the potential benefits that can be accruing from investing in dealing with the problem, i.e., the benefits an investment can generate is equally important to understand any careful investment from the economic point of view. The degree of economic impacts of urban waterlogging needs to be estimated and understood for undertaking their informed solutions.

2.10 Methods of Costing Economic Impacts of Urban Waterlogging

Waterlogging and floods cause various damages and losses for any area. According to Merz et al. (2010), flood or waterlogging risk assessment should comprise all damage dimensions, including adverse social, psychological, political and environmental consequences. The nature and extent of rural and urban waterlogging or flood can be different, given their exposure groups are different. Urban waterlogging or floods may cause direct and indirect impacts on public and private properties and infrastructure, business and commerce, transportation and other direct losses in the form of a reduction in earnings by service providers, etc. These effects can thus be classified into direct and indirect impacts. Similarly, waterlogging incidences can have immediate, medium-term, or long-term impacts, while their spatial scales can also be different. Thus, any assessment of damage from urban waterlogging demands understanding its dimension, type, and spatial nature.

2.10.1 Types of Damages & Assessment Methods

Just as comprehensive assessments that quantify the flood risk are essential for an efficient flood management (Kreibich and Dimitrova, 2010), similarly damage assessments for waterlogging is very important. Damages from floods and waterlogging are similar in nature. They can be categorized into direct and indirect damages while further divided into tangible and intangible ones. According to Merz et al. (2010), direct damages occur due to the physical contact of flood water with humans, property, or any other objects. Indirect damages are induced by the immediate impacts and occur – in space or time – outside the flood event. Based on whether the damage can be assessed in monetary terms or not, they are divided into tangible and intangible damages (Smith and Ward, 1998). Tangible damages are the losses of man-made capital assets or resource flows that can be easily specified in monetary terms. Intangible ones are not generally traded in a market and are challenging to transfer to monetary values (Merz et al., 2010; Radmehr and Araghinejad, 2014).

Table 2.1: Types and scales of damages applicable to floods and waterlogging

Types of Damages		Method of Estimation
Direct, tangible (market impacts)	Damage to private buildings and contents, direct livelihood losses (in terms of human days), evacuation and rescue measures, clean-up costs	For capital assets, the present value of income flow it generates over the rest of its life span or: the value of the asset as depreciated value or replacement cost. Use values of natural stocks other costs as actual
Direct, intangible (non-market impacts)	Injuries, psychological distress, damage to heritage, impacts on ecosystems	Contingent valuation of hedonic pricing method, indirect costs of ecosystems assets (e.g., biodiversity loss)
Indirect, tangible (market impacts)	Disruption of public service (electricity, water, transport, community hall), disruption in private services (access to daily need shops, communication, etc.)	Public services may often become a part of rescue operation or shelter (cost-benefit analysis) Private services – business losses to the service providers; consumption losses to urban dwellers opportunity cost for productivity (human labour)
Indirect, intangible	Trauma, loss of trust, interpersonal conflicts	Value of statistical life (VSL), disability-adjusted life years (DALYs), relative deprivations, cultural contexts, etc.
Scale of Assessments		**Method of Estimation**
Micro	Assessment based on single elements at risk, damages for each affected object	Household-level direct market estimations for assets Household-level indirect estimation of opportunity cost Firm-level estimation of losses
Meso	Spatially aggregated on land use units such as residential areas or administrative units	For the heterogeneous pattern of land use aggregation problems
Macro	Large-scale spatial units' analysis, such as municipalities, regions, or countries	Market-based macroeconomic output losses, sector-wise estimation; loss of production in climate-sensitive sectors

Source: Sharma et al. (2016)

Based on the scale, damages can be classified into three categories, i.e., micro-scale damages, meso-scale damages, and macro-scale damages. Sharma et al. (2016) defined micro-scale damages as those where an assessment is based on a single element at risk (Table 2.1). In the case of meso-scale, an assessment is based on spatial aggregation. For Macro-scale large-scale spatial units are the basis for damage estimation. On the other hand, the classification in micro-, meso- and macro-scale is related to the spatial extent of a damage assessment. There is also a methodological distinction among the three types of approaches: meso- and macro-scale approaches differ from micro-scale approaches in their need for aggregation. The latter does not need any aggregation, while others depend on aggregation to get their outcomes.

Table 2.2: Various components of impact parameters and resistance parameters

Parameters	Details
Impact Parameters	
Inundation depth	The higher depth and stronger buoyancy force will cause greater damage
Duration of inundation	Longer the duration, the more severe damage and longer time in recovery
Contamination	Greater clean-up costs, disinfection
Debris/sediments	Clean up
Frequency of inundation	Cumulative effects of damage (preparedness will reduce damage)
Timing	To undertake rescue measures
Resistance Parameters	
Use of the building	Preparedness quotient for manufacturing units would be higher than households or services sector
Building type	Single/multi-storey buildings
Building material	Construction material
Precaution	Elevated buildings
External response	Emergency measures
Early warning	Timings and comprehensibility of contents of the warning

Source: Sharma et al., (2016).

Impacts of a flood or waterlogging depend upon many factors and may vary from case to case, depending upon the variation in their parameters. According to Thieken et al. (2005), the factors influencing damage are identified as impact and resistance parameters. Impact parameters like water depth, flow velocity and contamination of a flood or waterlogging incidence show its characteristics, while resistance parameters like size, type, and structure of a building specify an object's capability to resist its impact (Sharma et al., 2016). The above table (Table 2.2) presents further details on impact parameters and resistance parameters in brief.

2.10.2 Classification of Elements at Risk

According to their economic sectors, the classification of elements at risk from a waterlogging or flood incidence can be done. Merz et al. (2010) thought that asset values depend on the type of elements at risk and vary in time and space. The variation in time can be attributed to economic trends like inflation, new investments, and innovation, while variation in space occurs because the same object type has a different asset value in one region than in another due to regional specifications or differences in material costs, wages, etc. The following table adapted from Merz et al. (2010) presents the classification of elements more clearly.

Table 2.3: Possible classification of elements at risk according to economic sectors

Sector	Examples	Remarks
Private households	Residential buildings including contents, garages, summer houses, etc., privately used vehicles	The majority of data sets and approaches exist for this sector. Variation of assets and susceptibility is rather low compared to other sectors.
Industry, manufacturing	Mining, metal processes, car, mechanical engineering industry, chemical industry, construction industry, installers workshop, carpentry, etc.	High variability and little data available. The transfer of asset values and damage functions within the sector is problematic. Booysen et al. (1999) argue that it is not possible to develop standard damage functions for industries and that questionnaires have to be provided for each industrial plant.
Services sector	Retail trade, wholesale trade, credit and insurance institutions, hotel and restaurant industry, lawyers, software companies, etc.	Rather high variability and little data available. Transfer of asset values and damage functions within the sector has to be done with care.
Public sector	Education and culture (schools, universities, theatres, etc.), recreation and sports (campsite, sports hall, etc.), administration, health care and social welfare (hospitals, nursing home, etc.), churches.	High variability and little data available. The transfer of asset values and damage functions within the sector is problematic.
Lifelines and infrastructure	Water supply, sewerage and drainage, gas supply, power supply, telecommunication, and transportation.	Little data were available. Transfer of asset values and damage functions possible within certain classes, e.g., unit values and damage functions for roads of certain characteristics.
Agriculture	Loss of crops, damage to buildings, contents, machinery; soil erosion, loss of livestock	Methods and data availability are comparatively good. Average values per element at risk might be suitable in countries where this sector has a small damage potential compared to other sectors.
Others	Damage to flood defense structures; clean-up costs, evacuation, and disaster management costs.	Little data are available. Average values are often used but do not hold in the context of multiple hazards.

Source: Merz et al., (2010).

2.10.3 Waterlogging Impact Assessment for Industrial Sector

The industrial sector, like the residential or infrastructural sector, may also get affected by urban waterlogging or floods. In the case of trade and commerce, the same can be real. However, the types of impacts can have some variations, like loss of tangible output production can be missing in trade and commerce. In contrast, the industrial sector may not have some trade-related variables. Unfortunately, no study is found to address the issue of waterlogging's impacts on trade and commerce separately, although many studies have taken the case of the industrial sector.

The two sectors have many issues in common with some dissimilarities. No specific study is found to consider the impacts on local trade and commerce from waterlogging or urban flooding. The methodological issues applied to assess the damages incurred by the industrial sector are discussed with care. The following table (table-2.4) presents a summary of the available methods used for different countries and the type of functions and parameters applied.

Table 2.4: Comparison of different damage models for the industrial sector

Models (references)	Country	Development	Functions	Parameters	Loss type
Anuflood (NR&M, 2002)	Australia	empirical	absolute	water depth, object size, total	total
RAM (NRE, 2000)	Australia	empirical	absolute	object size, object value, lead time, flood experience	total
FLEMOcs (Kreibich et al., 2010)	Germany	empirical	relative	water depth, contamination, business sector, number of employees, precaution	building and equipment and goods, products, stock
Model of MURL (MURL, 2000)	Germany	empirical	relative	water depth, building, and business sector	building and inventory
Model of Hydrotec (Emschergenossensc haft and Hydrotec, 2004)	Germany	empirical	relative	water depth, business sector	total
Model of ICPR (ICPR, 2001)	Germany	empirical	relative water	water depth, business sector	building and mobile and immobile inventory
Model of LfUG (LfUG, 2005)	Germany	empirical	relative	water depth or specific discharge, business sector	building and mobile and immobile inventory

Source: Modified from Kreibich et al., 2010.

2.11 Machine Learning (ML) Method for Urban Flood Prediction Models

Floods are highly complex to model natural disasters. (Mosavi et al., 2018). Appropriate use of flood prediction models resulted in reduced human life loss, property damage associated with floods, and generating policy suggestions for the relevant agency. Machine Learning (ML) methods provided better performance and cost-effective flood prediction solutions by simulating the complex mathematical expressions of floods' physical processes (Noymanee and Theeramunkong, 2019). Researchers discovered more accurate and efficient flood prediction models incorporating novel ML methods and hybrid methods based on the existing ones. Maier et al. (2010) identified several flood resource variables, "water level, rainfall-runoff, flash flood, urban flood, river flood, soil moisture, rainfall–discharge, precipitation, river inflow, river flow, rainfall, stream-flow, seasonal stream-flow, flood peak discharge, plain flood, groundwater level, rainfall stage, flood frequency analysis, flood quantiles, surge level, extreme flow, storm surge, etc." used in the applications in flood prediction. Rainfall and the hydrologic cycle's spatial examination had a unique role among flood resource variables in runoff and flood modeling. (Lafdani et al., 2013). Some Fundamental ML Algorithms such as Artificial Neural Networks (ANNs), Multilayer Perceptron (MLP), Support Vector Machine (SVM), Decision Tree (DT), Ensemble Prediction Systems (EPSs), etc. are widely used in the flood modeling (Kasiviswanathan, 2016; Radmehr and Araghinejad, 2014; Kar et al., 2010).

Rahman et al. (2019) proposed a new approach by integrating "statistical, machine learning and multi-criteria decision analysis, including artificial neural network (ANN), logistic regression (LR), frequency ratio (FR), and analytical hierarchy process (AHP)." In his work, independent variables (flood causative factors) and dependent (flood inventory) were prepared using the Mike-11 hydrological model, remote sensing data and secondary data from various sources. At the Haraz Watershed in the northern part of Iran, Khosravi et al. (2018) tested four decision trees-based machine learning models, such as Alternating Decision Trees (ADT), Logistic Model Trees (LMT), Naïve Bayes Trees (NBT) and Reduced Error Pruning Trees (REPT) for flash flood susceptibility mapping. In his work, a spatial database was constructed from eleven flood-influencing factors such as altitude, curvature, distance from river, ground slope, land use, lithology, Normalized Difference Vegetation Index (NDVI), rainfall, river density, Stream Power Index (SPI) and Topographic Wetness Index (TWI), together with 201 present and past flood locations. Ireland G et al. (2015) explored the ability of "regularized Kernel Fisher's discriminant analysis (rkFDA) and Support Vector Machines (SVMs) machine learning supervised classifiers in extracting flooded areas using optical Landsat TM imagery." The successful examples of SVM as an analysis technique in machine learning have been discussed by Hearst et al. (1998), Tehrany et al. (2014); Li Ma et al. (2016).

In the Damansara River catchment of Malaysia, Mojaddadi et al. (2017) demonstrated "efficiency in GIS-based flood modeling and created flood probability indices using an ensemble method." He combined "the frequency ratio (FR) approach with a SVM using a radial basis function kernel to estimate flood probability." Also, thirteen flood conditioning parameters, such as altitude, aspect, curvature, distance from the river, geology, land use/cover (LULC), soil, surface runoff, stream power index, sediment transport index, slope, topographic roughness index and topographic wetness index were selected for the study. Similar application of GIS for flood area susceptibility mapping can be found in the study by Lee Kang et al. (2012), Papaioannou (2015) and Pradhan (2010). The ensemble frameworks have been used for flood susceptibility mapping and also for improved prediction performances of rainfall induced landslide models in Vietnam in the studies by Tien et al. (2016) and Tien et al. (2016a) respectively.

2.12 Urban Multi-Scale Environmental Predictor (UMEP)

As given in the documentation of the UMEP (Urban Multi-scale Environmental Predictor), "it is a city-based climate service tool, combines models and tools essential for climate simulations. Applications are presented to illustrate UMEP's potential in identifying heat waves and cold waves, the impact of green infrastructure on runoff; the effects of buildings on human thermal stress; solar energy production; and the impact of human activities on heat emissions. UMEP has broad utility for applications related to outdoor thermal comfort, wind, urban energy consumption, and climate change mitigation. It includes tools to enable users to input atmospheric and surface data from multiple sources, characterize the urban environment, prepare meteorological data for use in cities, undertake simulations and consider scenarios and compare and visualize different combinations of climate indicators. As an open-source tool, UMEP is designed to be easily updated as new data and tools are developed and to be accessible to researchers, decision-makers and practitioners" (Lindberg et al., 2018). One of its significant features is users' ability to interact with spatial information to determine model parameters and edit, map and visualize inputs and results. For this reason, the software is written as a plug-in to QGIS, a cross-platform, free and open-source desktop geographic information system (GIS) application.

2.13: Waterlogging Risk Reduction into Planning and Budgeting

The target in the 7th FYP was to reduce waterlogged areas in the country from existing 2.5 percent to 0.5 percent of the coastal area. Parts of southwest Bangladesh, experienced persistent waterlogging for two to six months during monsoon season for the last 20-30 years. To address waterlogging problem a series of engineering interventions are required with re-excavation of rivers and canals to improve the flow of drainage. While physical interventions are important, institutional bottlenecks in addressing the problem have often been overlooked.

A scoping study, led by the Planning Commission (Programming Division, Bangladesh Planning Commission and UNDP, 2018) developed a proposal for better institutional coordination at national and local levels: strong vertical linkages between agencies and their ministries following sectoral approach, and the horizontal integration at a regional scale. About 574 projects were implemented in the three districts from FY 2001-02 to FY 2015-16 with a total allocation of Tk 4107 crore, increasing at an average rate of 5.5 percent per year, to address different aspects of waterlogging problem. ADP allocation for waterlogging in the three districts is estimated as less than one percent (0.73%) of development budget and only 0.03 percent of GDP. The study recommends that a multi-layered and multi-sectoral institutional coordination framework both at the national and local level is a needed to reduce risks from waterlogging for now and for years to come.

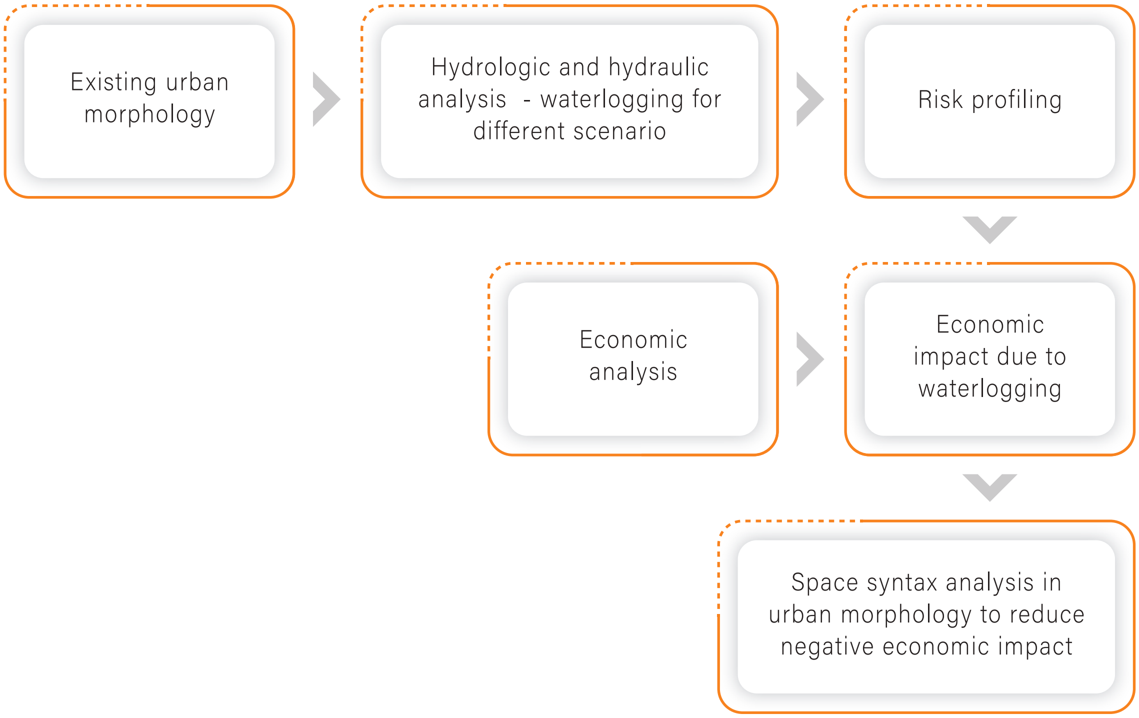
Chapter 3

Methodology

3.1 Data and Method for Economic Impact Study

The methodology for the study was divided into three components, namely, Economic, Hydrology, and Urban design and planning in an integrated manner. The conceptual model for analysis the problem is presented in Figure 16.

Figure 16: Conceptual model for the study of economic impact of waterlogging on local trade at Khatunganj



3.1.1 Data Requirements and Methods of Data Collection

The Khatunganj commodity market's waterlogging problem and its adjacent areas mainly cause problems for traders, producers and service providers, including transport services and laborers. This also affects buyers and those who supply commodities across different parts of the country.

Table 3.1: List of variables, data types and collection methods

Variable	Data type	Data Collection Method
a. Direct Tangible Impacts (market impacts)		
Damages to private properties	Quantitative	Questionnaire Survey
Damages to stocks	Quantitative	Questionnaire Survey
Additional investment made on infrastructure by traders, producers, etc. (raising floor height, creating walls to prevent water from entering, etc.)	Quantitative	Questionnaire Survey
Additional operation costs incurred by traders and buyers	Quantitative	Questionnaire Survey
b. Indirect Tangible Impacts		
Loss of income from the reduction in sales by traders	Quantitative	Questionnaire Survey
Loss of income from the reduction in trade by buyers (retailers, traders)	Quantitative	Questionnaire Survey
Relocation expenditures by businesses that have left the Khatunganj market	Quantitative	Questionnaire Survey

Often shops and warehouses get flooded with water and thus damage stocks and inventories. Many traders have shifted their businesses to other parts of the city or safer places to address the waterlogging problem. In contrast, many have invested in raising the floors of their business complexes and make barriers to stop water from entering their shops and warehouses. The Chattogram City Corporation (CCC) and Chittagong Development Authority (CDA) have invested in infrastructure development and maintenance and repair. Due to the reduction in trade and commerce activities, sellers and buyers both lose their revenue earnings due to reduced trade and commerce activities. At the same time, consumers often must purchase their daily essentials at higher prices due to insufficient supply from Khatunganj.

Any study estimate economic damages and losses from waterlogging in any marketplace like the Khatunganj commodity market must identify the major affected parties and types of losses and damages. Considering Khatunganj does not maintain a proper record of total damages of all types, nor is any scientific study found to address the issue from economic point of view, the present study plans to use mostly primary data to be collected from affected parties. This required designing a survey questionnaire and used the same for primary data collection. For this purpose, the major respondent group was identified as the area's traders (sellers). A semi-structured questionnaire (Please see Annex 1) was designed for primary data collection. Besides, key informant interviews (KIIs) were also conducted among the major stakeholders, including trade bodies, municipal authority, CCC, CDA and experts (academicians, researchers, etc.). In addition, secondary literature in the form of published reports, articles and unpublished data from relevant authorities were also collected for analysis.

3.1.2 Sampling Technique and Sample Size

For field data collection, trained enumerators were employed to visit traders (business enterprises) for data collection. The study used a convenience sampling technique[2] for choosing respondent enterprises among all the business enterprises. It is reported that the primary Khatunganj wholesale market [shops and enterprises on both sides of the Khatunganj road] has a total of 1000 to 1200 business enterprisers of all types comprising: i. traders of onion, garlic, and ginger; ii. traders of spices; iii. traders of lentils; iv. traders of rice; and v. aratdars. The entire waterlogged areas in and around the Khatunganj wholesale market, including Khatunganj wholesale market, Asadganj, Chaktai and Korbaniganj areas considered as part of the Khatunganj market by the traders. It is learned that the site has 4500 to 5000 traders, who suffers from waterlogging in the area. Against this backdrop, the present study collected data from 65 enterprises. However, 59 were found to be useful for analysis, and another six had to be dropped out due to data deficiency and doubtfulness about the authenticity of data.

3.1.3 Method of Data Analysis

The method of data analysis comprised using both quantitative and qualitative techniques. In the present case, the quantitative analytical tool was the estimation of direct monetary losses by summing up the money needed as a coping mechanism and monetary value (replacement cost) of the items lost and damaged from waterlogging. Besides, the qualitative analysis also made to understand the nature and extent of the waterlogging problem, the exposure groups and their level of exposures, change in the extent of losses and damages over year, and profiling the affected parties and their coping mechanisms.

The present economic impact assessment study had three specific objectives to be fulfilled. In the following section, the method of analysis for each of them are discussed:

Economic Impact Study Objective-1

Identify the current economic impact of waterlogging and future risks associated with climate change:

This demands two step-estimation of economic impacts. First, an assessment of current economic impacts of waterlogging in the Khatunganj wholesale market; this study estimated existing economic losses and damages associated with waterlogging for traders and buyers along with additional investment requirements for concerned authorities. Second, the estimated data used to forecast future economic losses and damages against the changed climatic scenario.

Economic Impact Study Objective-2

Conduct an economic assessment of both direct impacts of waterlogging to commodity markets and collateral impacts:

As mentioned above, to estimate direct losses and damages and other collateral impacts of waterlogging on traders, buyers, service providers, trade bodies and government authorities, this study applied the following methods of analysis:

[2] It was almost impossible to use a random sampling technique due to the outbreak of coronavirus. In addition to temporary shut-down of many enterprises, many respondents were found to refuse cooperating with the survey team for conducting the survey due to health risk posing by the pandemic. That was a major reason why the study finally adopted a convenience sampling technique for conducting the survey.

Estimation of Direct Economic Impacts

Direct economic impacts from waterlogging were estimated by summing up the money needed as a coping mechanism and monetary values (replacement costs) of the items lost and damaged in every incidence of waterlogging. The estimated present annual amount of direct loss was calculated by summing up losses incurred in waterlogging incidences in the last one year. Further, the study also estimated the volume of losses incurred by all parties involved in the Khatunganj wholesale market over the previous ten years. Future projections were also made based on current and prior losses and damages. Data from earlier years were collected from respondents by using the recall method. Besides, data collected through KIIs were used as supplementary information from related informant groups. These were analysed mostly by applying descriptive analytical techniques. It is expected that data from KIIs strengthened the supports for findings from the quantitative analysis.

Economic Impact Study Objective-3

Identify key policy gaps, institutional arrangement, and actions for the public and private sector to strengthen the resilience of Khatunganj wholesale commodity market to waterlogging risks:

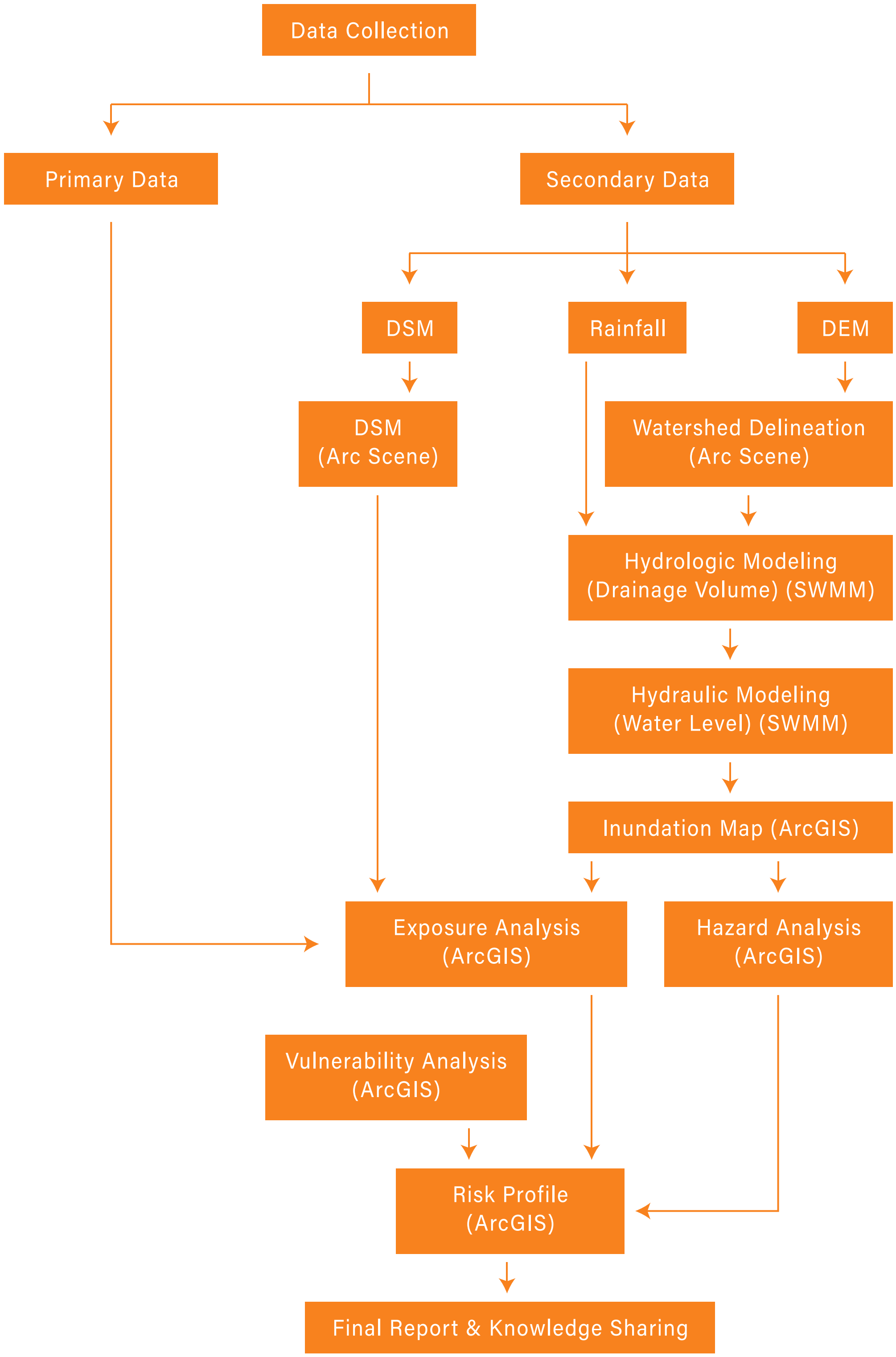
The final objective under this assignment was met by analyzing findings from the primary and secondary data analysis, KIIs and secondary literature survey. Current policies and institutional arrangements were scrutinized to identify their strengths and weaknesses. This helped to propose suitable policy guidelines that policymakers can apply to strengthen the Khatunganj wholesale market's resilience capacity to address waterlogging and its consequences.

3.2 Data and Method for Hydrological Study

To find the waterlogging scenario, the site's digital elevation model (DEM) was prepared. Data from field surveys and DEM data were used to get the digital surface model. Watershed analysis were conducted to identify the surrounding catchment area. To determine the drainage volume due to a specific rainfall, a hydrological model was run for the catchment. To estimate the extent and depth of inundation due to a particular storm, a hydrodynamic modeling was used. Finally, the vulnerability assessment resulted in a risk map and that was also used to identify the vulnerable areas due to waterlogging.

Figure 17 overleaf represents the complete methodological framework for the hydrological study and risk profiling that has been followed by the authors based on the objectives for risk assessment.

Figure 17: Methodological framework for the hydrological study and risk profiling



3.2.1 Preparation of Digital Elevation Model

The use of distributed watershed models commonly investigates the hydrologic process and water resource issues. These watershed models require physiographic information such as the channel network configuration, location of drainage divides, channel length and slope, and sub-catchment geometric properties. These parameters are usually gathered from the maps or field surveys. During the last two decades, this knowledge has been acquired directly from digital topographic representation. The topography's digital representation is called a Digital Elevation Model (DEM) (Jenson & Domingue, 1988).

Automated topographic watershed data derivation from DEMs is easier, less arbitrary and offers more reproducible measurements than conventional topographic maps prepared from manual techniques. Digital data generated by this approach also has the advantage that Geographic Information Systems (GIS) can easily import and analyse these data. The technical advancements made by GIS and the growing availability and quality of DEMs have greatly expanded the scope for application of DEMs to many hydrologic, hydraulic, water resources and environmental research (Jenson & Domingue, 1988).

Since the study site is not very large, a fine-scale LiDAR (Light Detection and Ranging) generated DEM, preferably 0.5 m x 0.5 m, was used in this study. LiDAR is an active mode of remote sensing not involving with electromagnetic radiation; its records laser pulses that hit the target and return to the sensor. LiDAR calculates the distance between the sensor and the target by setting the time between the release of the laser pulse and the reception of the reflected pulse. Multiplying this time by light speed and dividing it by two would then give the distance between the sensor and the target. LiDAR uses a near infrared laser (900–1064 nanometers) and green light (532 nanometers) for the measurement of water for terrestrial applications. ArcGIS 3D analyst tools and Spatial analyst tools were used to run the digital elevation model to create Triangulated Irregular Network (TIN). ArcScene was used for the visualization of the TIN in 3D.

3.2.2 Preparation of Digital Surface Model

Digital Elevation Models (DEMs) have diverse and well-documented applications, including visual impact assessment, hydrological modeling, flood prediction and site suitability analysis. Automated elevation model creation from remotely sensed data were expected to provide a representation of both the ground surface and the objects on that surface (Burrough et al., 1998). Digital Surface Models (DSMs) provide the option of extracting surface elevations to leave the surface DEM on the ground. This separation of over surface feature information from ground information can provide a useful combination of data sets for many applications in the urban world. For example, comprehensive knowledge of ground surface elevation is necessary to predict flood inundation and the possible effects of sea level rise, whereas a comprehensive model of man-made structures is important for landowners, planning authorities and insurance companies. Since the study site is not very large, a fine-scale LiDAR generated DSM, preferably 0.5 m x 0.5 m, was required and used in this study.

3.2.3 Watershed Analysis

A watershed is the area of land where all the water falling into it and flowing away from it falls into the same place or common outlet. Topographic distinctions between two or more neighboring catchment basins, such as a ridge or a crest, often describe a watershed. In simple words, a watershed is a region of land where water flows into a designated body, such as a river, lake, sea, ocean, or a drainage basin.

At first hydrologic terrain, analysis is done. Then “fill”, “flow direction analysis,” “flow accumulation”, "stream threshold" tools are used on the raster image. Finally, raster data is converted to vector data and overlaid on satellite images for verification.

3.2.4 Hydrologic and Hydraulic Modeling

A hydrological model can be described as a set of equations that help estimate runoff as a function of the various parameters used to describe the watershed characteristics. Data on rainfall and drainage area are the two important inputs needed for all models. In addition, watershed properties such as soil properties, vegetation cover, watershed topography, soil moisture content, groundwater and aquifer characteristics are also considered (Devia et al., 2015).

Rainfall, basin characteristics, losses, calibration data and different human effects are regarded as the data required for hydrological modeling. To estimate the extent and depth of inundation due to a specific storm, hydrodynamic modeling is required. Using SWMM 5.1, the hydrodynamic modeling was performed, showed the extent of flooding expected spatially over a given area for different water heights. The required data were obtained mainly from CEGIS, but on a very small scale. Cross-section of Chaktai *khal* at 89 points, the water level of Chaktai outfall for the year 2017 and discharge of Chaktai outfall for three months (June, July, and August) of 1983 were also collected. Last 25 years' rainfall data for Chattogram were obtained from the Bangladesh Meteorological Department (BMD). Several scenarios with other critical design storms based on IDF analysis were generated using the equation obtained from the literature. The following scenarios were considered:

Scenario 1: Max rainfall event in 2017 (Actual Scenario)

Scenario 2: 2-hour 20-year return period rainfall (High Tide)

Scenario 3: 2-hour 50-year return period rainfall (High Tide)

Scenario 4: 2-hour 50-year return period rainfall (Low Tide)

Scenario 5: 2-hour 50-year return period rainfall (considering 50% rainfall decrease) (High Tide)

Scenario 6: 2-hour 50-year return period rainfall (considering 50% rainfall decrease) (Low Tide)

Scenario 7: 6-hour 50 years return period rainfall (High Tide)

Scenario 8: 2-hour 50-year return period rainfall (considering Climate change 11% rainfall increment)

Using DEM, DSM with the combination of hydrologic and hydraulic modeling resulted in an inundation map for the specific site.

3.2.5 Vulnerability and Risk Assessment

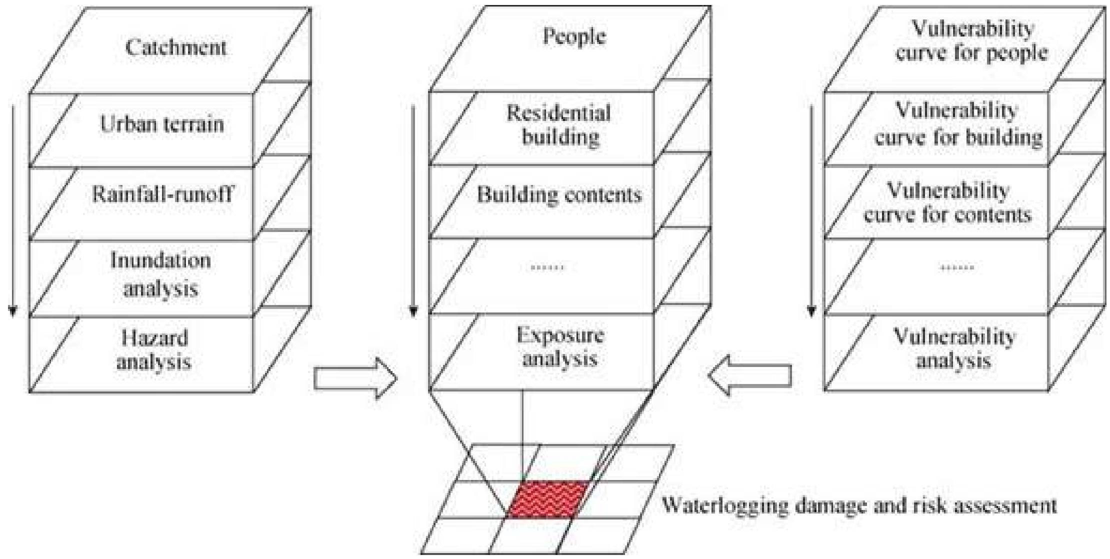
Under different hypothetic precipitation scenarios, the risk potential in the Khatunganj is simulated using GIS. According to the local conditions, stage-damage curves are developed for the commercial buildings and the commercial building contents using the information collected through interviews, which are further applied to analyse the vulnerability, exposure and damage of waterlogging. Finally, the loss maps of different return periods, the risk curve and Average Annual Waterlogging Loss (AAWL) are taken to express waterlogging risk.

$$AAWL = \int x f(x) dx$$

where, x is the occurrence probability of a waterlogging event and f (x) is the loss of x (Yin et al., 2011).

The schematic view for risk assessment is presented in Figure 18.

Figure 18: Framework of rainstorm waterlogging risk assessment based on a GIS-grid



3.3 Data and Method for Urban Planning Study

3.3.1 Method for Urban Planning Study

1. Analysing Spatial Morphology using Space Syntax: By using Space Syntax methodology the current condition of road network integration and its economic relation with land use has been analysed. Also, using the same method what may happen to the land value if the water network is activated with existing road network system has been analysed

2. GIS-based stream delineation model to identify the hidden streams that are buried under current development (e.g., buildings, streets, other impervious features) and locate bypass stream

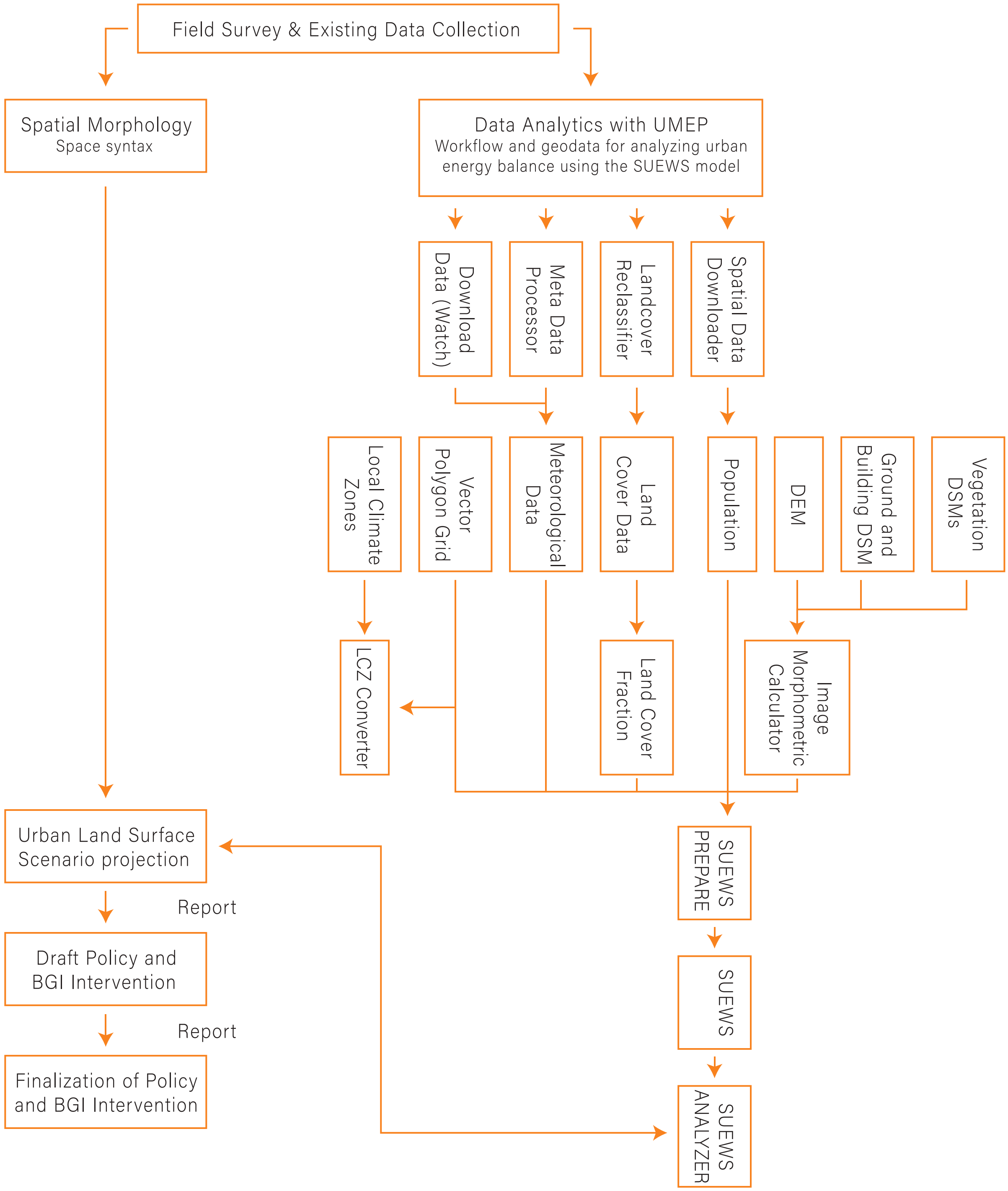
3. Analysis of urban water and energy cycle for the site with Urban Multi-scale Environmental Predictor (UMEP) (a climate service tool, presented as a plugin for QGIS). This tool would be used for different purposes related to Urban Flooding and climate change adaptation etc.

4. Urban land cover scenario projection hydro-meteorological: present trend (business as usual) Vs. Urban Hydro-meteorological (UHM) intervention with BGI.

3.3.2 Data Source

Data was gathered from different secondary sources as well as from primary survey. The GIS map and information on administrative boundaries, parcel boundaries, building footprints, building heights, number of stories per building was taken from LGED, Chattogram City Corporation and Chittagong Development Authority. Meteorological Data such as air temperature, relative humidity, wind speed, wind direction, rainfall, and solar radiation for the stations of Ambagan, Chattogram; Patenga, Chattogram and Agargaon, Dhaka were taken from Bangladesh Meteorological Department for the period of 1990-2019. Meteorological Data was also gathered from Copernicus_Climate_Change_ Service (EU). All the hydrological data on rivers and waterways, wetlands, topography, and flood plains were taken from different Government and private agencies. High and medium resolution remote sensing data from satellite was downloaded for DEM preparation. However, photogrammetric survey was also conducted to gather the actual land and building elevation and building position. Demographics and economic data were taken by field survey. Figure 19 shows the methodological framework for the urban planning study.

Figure 19: Methodological framework for the urban planning study



3.4 Limitation of the Study

Although the research has followed the methodological steps in a scientific way, but there are some limitations in the study which are explained below:

a. A partial analysis of the waterlogging scenario for Khatunganj wholesale market might have presented a snapshot of the gravity of the problem of waterlogging for Chattogram city and its economic activities, but a comprehensive analysis for the entire city could have given a better picture.

b. Economic impacts of waterlogging can have both local, regional and national-levels effects, while such effects can also be both direct and indirect in nature and short and long term based on time dimension. The present study only considered direct and local effects of waterlogging.

c. In addition to economic and financial losses, waterlogging can also have other types of non-economic and non-financial losses like psychological and mental trauma, loss of business motivation, loss of reputation, etc. But for this study only considered direct economic losses and effects.

d. Due to limitation of time, all data from secondary sources was used. There was scarcity of data in particular the data on canal discharge and canal section, which might affect hydrological model calibration and validation.

e. Due to the lack of time series data, it was not possible to do analysis with Machine Learning technique for future scenario projection of urban flooding. However, the relevant literature for this technique is included for further research.

Chapter 4

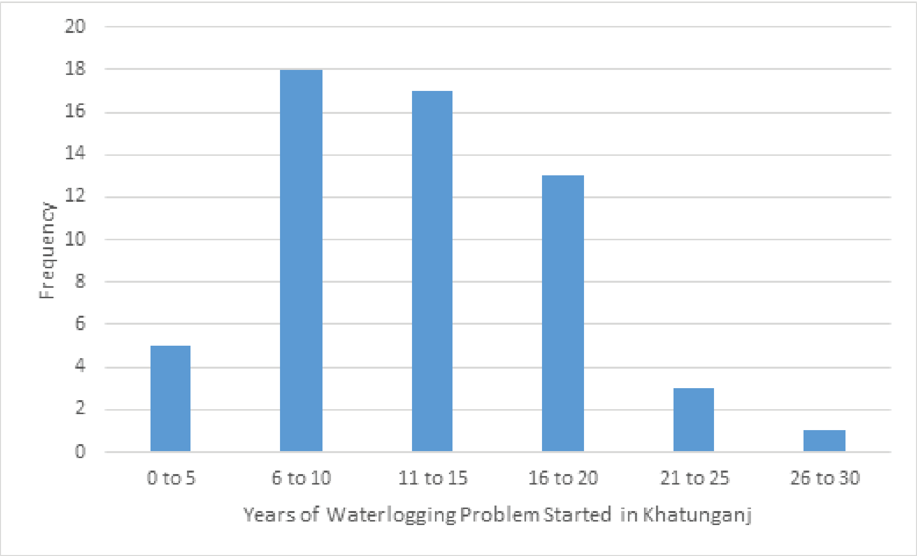
Analysis and Results

4.1 Direct Economic Impacts of Waterlogging on Khatunganj

4.1.1 Traders' Views on the Problem of Waterlogging in Khatunganj

The survey outcomes on the enterprises in Khatunganj wholesale market also supported the views of the business community and media reports on the problem of waterlogging and its economic impacts borne by the traders from the point of time. Tracing the time since when the problem was originated, it is found that some of the businessmen have been facing the problem for the last 20 years or so, while there are also traders who opined to facing the problem only from recent years. The average years of the time period since the problem was estimated to be 14.33 years in the Khatunganj wholesale market (Figure 20). This indicates that all business enterprises in the Khatunganj market have not been facing waterlogging related problems simultaneously. Although the entire area is exposed to tidal flooding and waterlogging from heavy rainwater that has increasingly become a common problem in recent years, some lanes and by-lanes are relatively less exposed to such incidences. It is also noticeable that most of the aged warehouses are having low floor heights, often lower than that of the road heights, and thus are exposed to rainwater or tidal flooding. Businessmen are often bound to create barriers at their shops' entrance to stop water from entering the shops from roads. Many business people have raised their warehouses floor heights to save stocks from damage. Most newly constructed buildings and enterprises generally do not face such problems as they take care of the situation by raising the floor above roads to stop water from entering.

Figure 20: Traders' views on the time since when the problem of waterlogging has been started at Khatunganj



Also all surveyed traders are found to have a similar opinion of getting affected due to waterlogging. Of the surveyed enterprises, 66% are severely affected, while the rest are found to be affected moderately (Figure 21). This implies that waterlogging has been a major concern for the market, for all traders, despite having variations in the level of consequences. This speaks the volume of the importance of solving the problem on an emergency basis to avoid further losses and suffering.

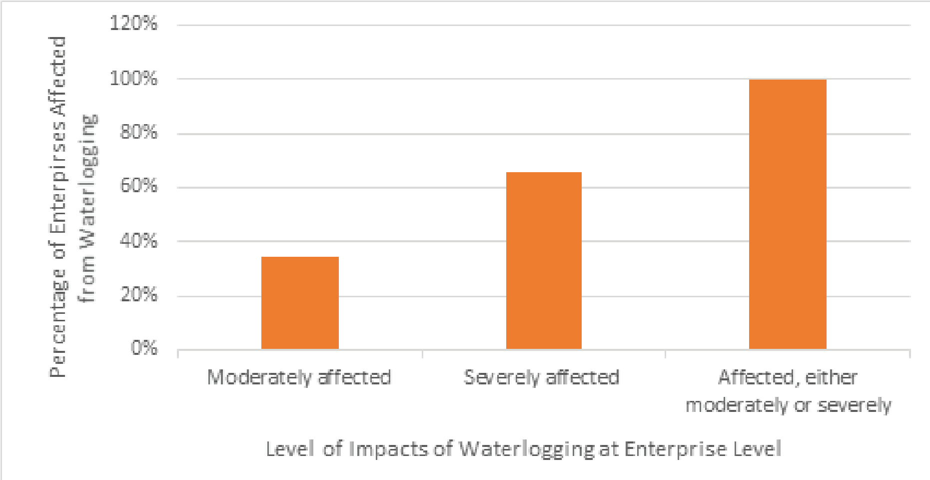


Figure 21: Traders' views on the extent of sufferings due to the problems of waterlogging at the Khatunganj wholesale market

In response to a question on the reasons behind the increasing waterlogging related problem in the Khatunganj market, most of the traders tried to relate the problem with high tides. They believed that tidal waves are getting higher with time and it is the primary reason for waterlogging in this market. Some respondents identified increasing rainfall patterns, siltation on the Karnaphuli River and Chaktai canal-beds and blockage of canals and drain due to waste dumping as some possible reasons behind these devastating incidences (Figure 22).

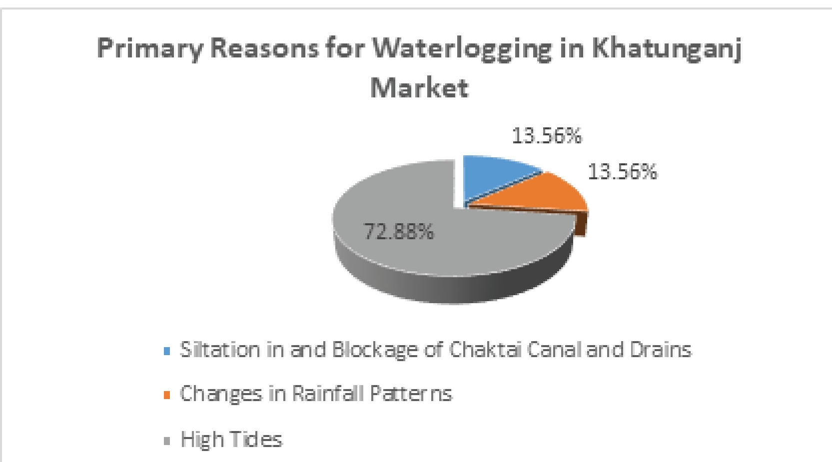


Figure 22: Traders perceptions on the causes of waterlogging in Khatunganj wholesale market

4.1.2 Impacts of Waterlogging on Local Trade at Khatunganj

It is found that 100% of the surveyed enterprises incurred both financial and non-financial losses due to waterlogging, particularly in recent years. Financial loss comprised damages of stocks, loss from reduced sales at the time of waterlogging, additional transportation costs, repairment and replacement cost, loss of capital assets, etc. (Figure 23). Such costs are not found to be similar in nature for all the surveyed enterprises considering their different levels of exposure. But with time, things are getting similar, particularly for most of the low-floor and aged warehouses, while the ones housed in newly constructed buildings are found to take care of the waterlogging problem by raising floor heights. Despite this, costs in terms of reduced sales at the time of waterlogging and the additional cost of transportation are some associated costs that can hardly be avoided by the traders.

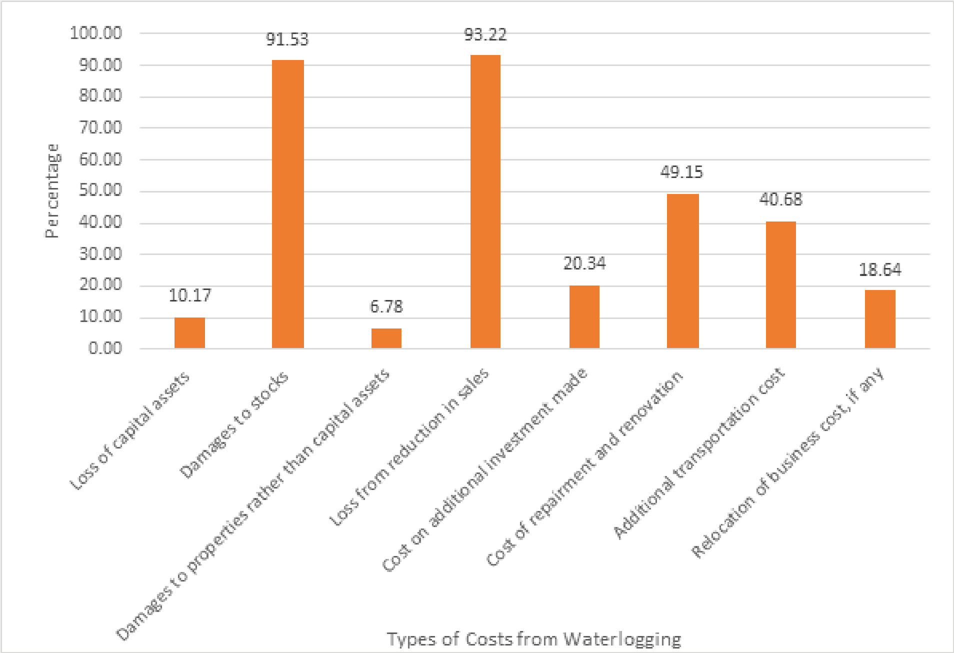
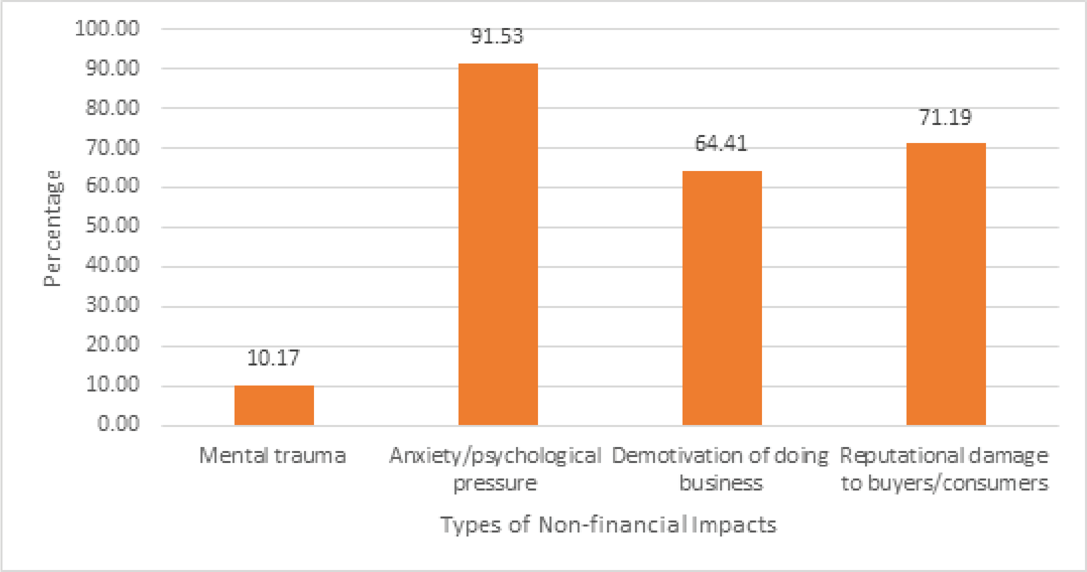


Figure 23: Percentage of traders on different types of financial losses incurred in 2020 due to waterlogging

In addition to the above-mentioned financial losses, traders also had to bear various types of non-financial losses from waterlogging. It includes mental trauma, anxiety or psychological pressure, demotivation of doing business and loss of trust by buyers and reputational concerns. Although the exact levels of such losses cannot be figured out directly in quantity terms, they can have high indirect costs and long term profitability consequences.

Figure 24: Percentage of traders on different types of non-financial losses incurred in 2020 due to waterlogging



The nature of economic cost and loss from waterlogging can further be classified between direct financial and indirect financial costs and losses. Direct costs and losses are immediate and primary costs, including damages of stocks, loss from reduced sales at the time of waterlogging, the additional cost of transportation, repairment and replacement cost, loss of capital assets, etc. On the contrary, indirect financial cost and loss are mostly secondary and medium to long term ones, including higher prices at the consumer level, reduction or cutting down of consumption of much essential food and non-food items particularly by low-income households, and associated health costs and loss of productivity due to poor health and preventive expenditures, inflationary pressure at the consumer level, reduction of household budgets on education, health and other non-essential items particularly by the low income-earning families, etc. In many cases, waterlogging also have ecological and environmental consequences. Loss of aquatic ecosystems and water pollution borne other environmental hazards are some common problems that can also be linked to waterlogging (Figure 24).

The estimated direct economic cost and losses of waterlogging on local trade at the Khatunganj wholesale market indicate a clear gradual increasing trend from the last decade. Although the changes in the figures in absolute terms for most years show no drastic jumps, 2017 and 2020 were found to be exceptionally higher (Table 4.1 and Figure 25). Devastating waterlogging incidences are recorded in both the years, and many traders had to bear huge direct losses, mostly in terms of losses of stocks and reduction in sales. It is clear from the findings that a rising trend of consequences can be observed despite traders taking more preventive measures to protect their business interests from waterlogging.

Table 4.1: Estimated direct economic losses and costs incurred by traders in the Khatunganj wholesale market in the last ten years (in crore taka)

Year	Estimated Direct Economic Loss (Number of Business Enterprises = 1,000)	Estimated Direct Economic Loss (Number of Business Enterprises = 1,200)
2011	34.96	41.95
2012	36.49	43.79
2013	36.67	44.00
2014	37.84	45.40
2015	41.55	49.86
2016	39.31	47.18
2017	80.46	96.55
2018	45.75	54.90
2019	47.46	56.95
2020	102.88	123.45

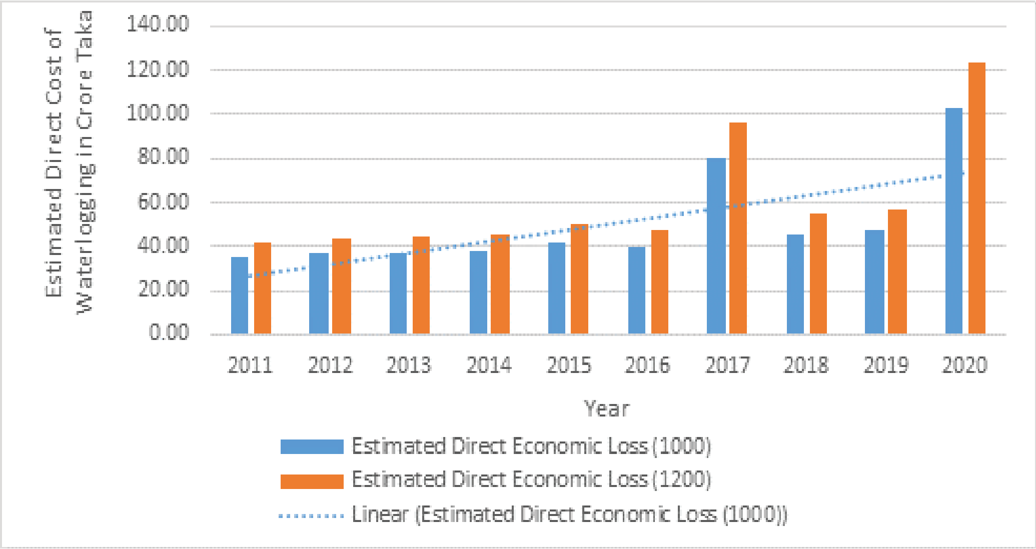


Figure 25: Estimated direct economic costs and losses due to waterlogging in Khatunganj wholesale market in the last ten years

The above trend line indicates increasing trend of costs of waterlogging with time (Figure 25). It is also expected that due to changes in rainfall patterns and if effective measures are not taken to dredge the Karnaphuli River and keep the Chaktai canal and drainage systems of the surrounding areas clean on a regular basis, then these costs may increase many folds in the near future.

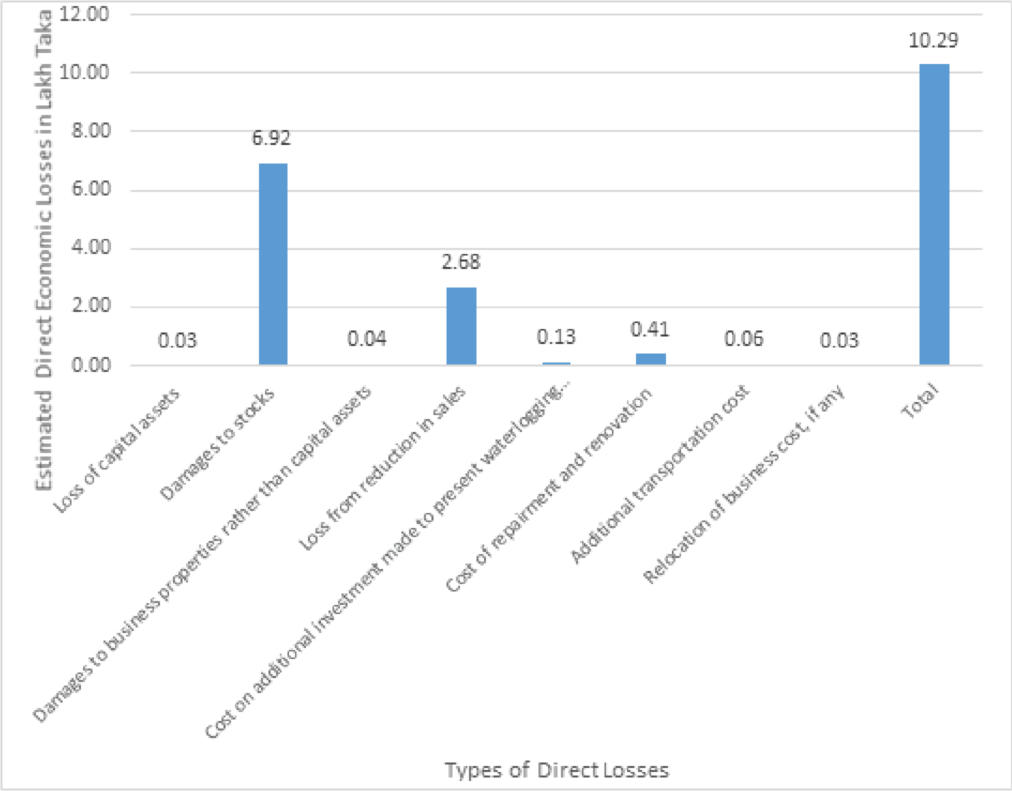


Figure 26: Estimated direct average economic costs and losses from waterlogging incurred at the enterprise-level in Khatunganj wholesale market in 2020

The above Figure 26 shows the estimated direct economic costs and losses on local trade due to waterlogging incurred by an average enterprise indicates that damages to stocks are the severe cost incurred by the traders as intrusion of water into warehouses damage their stocks. They are most common in the case of aged and low floor warehouses. Damaged stocks are sometimes dried up and sold at low prices. But this reduces not only potential revenues for trader but also demands incurring additional costs of labour for drying up and transportation. Severely damaged products are often thrown, which also demands paying labour and transportation costs. It is also understood that reducing sales due to waterlogging is another vital source of direct costs traders need to bear from waterlogging. It is found that, on average, over a million costs are incurred by each trader due to waterlogging in 2020.

If we look at the following table (Table 4.2 and Figure 27) on the direct economic costs and losses from waterlogging in Khatunganj and its neighborhood areas including Chaktai, Asadganj, Qurbaniganj, which are often treated as an inseparable market for common consumer items like onion, garlic, ginger, lentils, spices, etc. for the last one decade, the figures can help us understand the gravity of the problem. The estimated values of annual direct costs and losses ranging from 157.33 to 514.38 crore taka indicate a rising trend in values with time with some exceptional incidences of higher consequences.

Table 4.2: Estimated direct economic costs and losses incurred by traders in Khatunganj wholesale market and its neighborhood areas (Chaktai, Asadganj, Qurbaniganj) in the last ten years (in crore taka)

Year	Estimated Direct Economic Costs and Losses (Number of Business Enterprises = 4,500)	Estimated Direct Economic Costs and Losses (Number of Business Enterprises = 5,000)
2011	157.33	174.81
2012	164.20	182.44
2013	165.00	183.33
2014	170.27	189.19
2015	186.98	207.76
2016	176.91	196.56
2017	362.06	402.29
2018	205.88	228.75
2019	213.55	237.28
2020	462.94	514.38

Figure 27 present the findings of the above table (Table 4.2) graphically with trend analysis. This indicates a clear increasing trend in estimated direct costs and losses enterprises have been incurring. It is also predictable that if this trend continues uninterrupted, costs on the parts of the traders may increase many folds in the near future. The reason can be traced to changing rainfall and tidal patterns and the nature of business operations and its associated risks, which may increase further if no viable solution to the problem of waterlogging is undertaken.

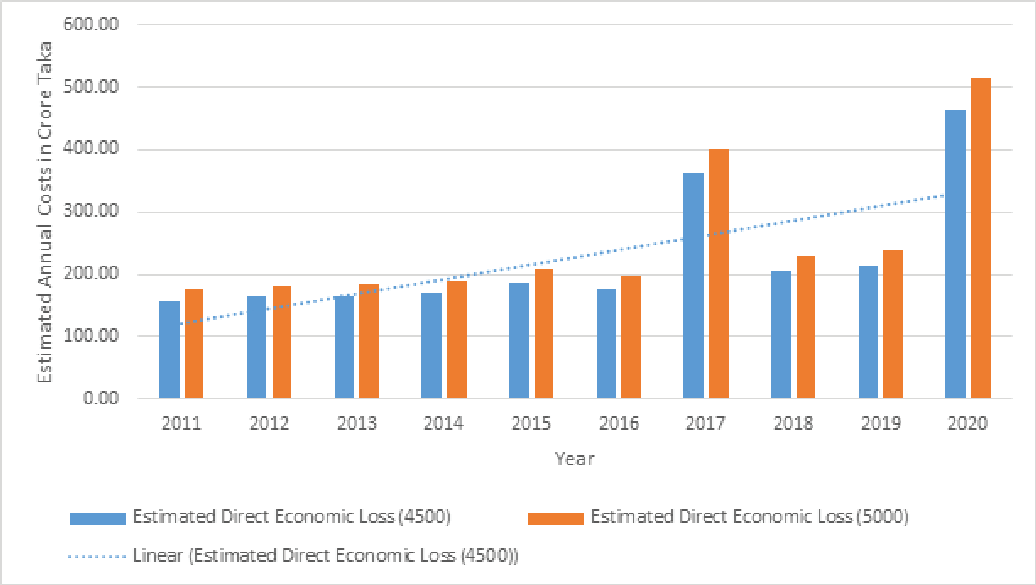


Figure 27: Direct economic costs and losses incurred by traders in Khatunganj wholesale market and its neighborhood areas (Chaktai, Asadganj, Qurbaniganj) in the last ten years

4.1.3 Traders' views on Possible Solutions of Waterlogging in Khatunganj

The rising trend of indirect economic costs and losses of waterlogging in Khatunganj and its neighboring markets of Chattogram, as seen above, demands an immediate solution to the problem to avoid further losses in the coming years. It is also predictable that with changes in climatic conditions, things can even be more complicated with time. Against this backdrop, maintenance of proper drainage system and changes in waste dumping behavior by traders and availability of timely dredging facility are opined to be the most viable solutions to the ongoing problem of waterlogging in the area.

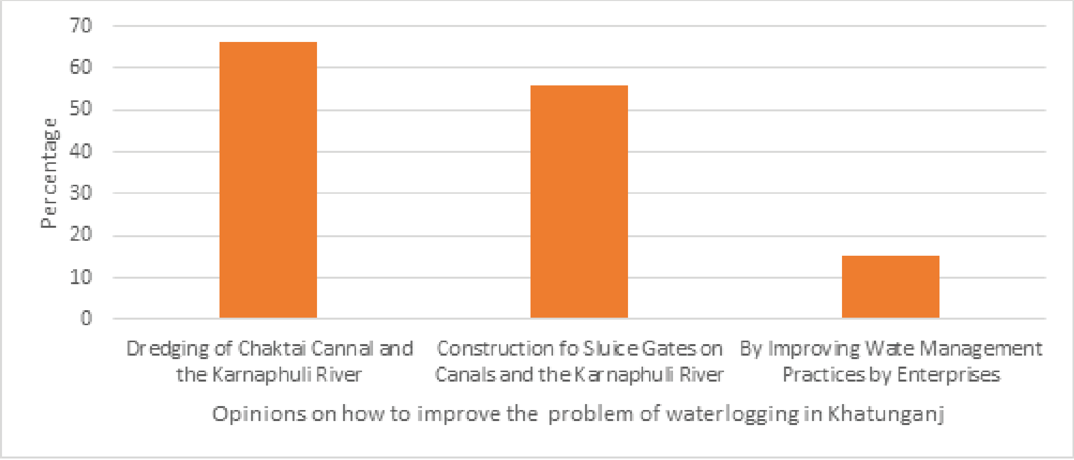


Figure 28: Traders' views on possible solutions to the problem of waterlogging in Khatunganj market and its neighborhood areas

Figure 28 presents the views of the respondents on possible solutions to the problem of waterlogging in the Khatunganj market and its neighborhood areas in a percentage format. It is clearly evident from the figure that the highest percentage of respondents consider regular dredging of the Karnaphuli river and cleaning of the Chaktai canal as the most important solution to the problem. As water can not flow downwards properly after rain or tidal flooding due to blockage in the channels, it creates waterlogging in the area. It is thus very important to ensure that water flows downward without any interruption. It is observed that respondents also considered the construction of sluice gates as a viable solution to waterlogging for the Khatunganj market. However, its relevancy and effectiveness are often questioned by experts. Some respondents also considerd rampant waste dumping, particularly by the traders, a big concern. Waste is often dumped in the drains, and due to rainwater or tidal flooding, they create blockages in the canal and channels.

4.2 Analyses and Results from Hydrological Study

4.2.1 Catchment Delineation

Khatunganj falls in a downstream portion of the catchment area composed of the Muradpur-Chawkbazar basin. Chaktai canal is the main drainage channel that conveys the drainage water from this basin to the Karnaphuli River. At first, the drainage network was identified from field visits to the study area and its vicinity for delineation of the catchment boundaries. The drainage network was then drawn in ArcGIS and was used to manipulate the Aster 30 m DEM obtained from earthexplorer.usgs.gov. Figure 29 shows the catchment boundary with its divides. Thirty-two sub-basins are identified in this Mudarpur-Chawkbzar basin. Since drainage water from these sub-basins contribute to the Chaktai Canal and also affects the waterlogging scenario at Khatunganj, all these sub-catchments were considered in the hydrologic model.

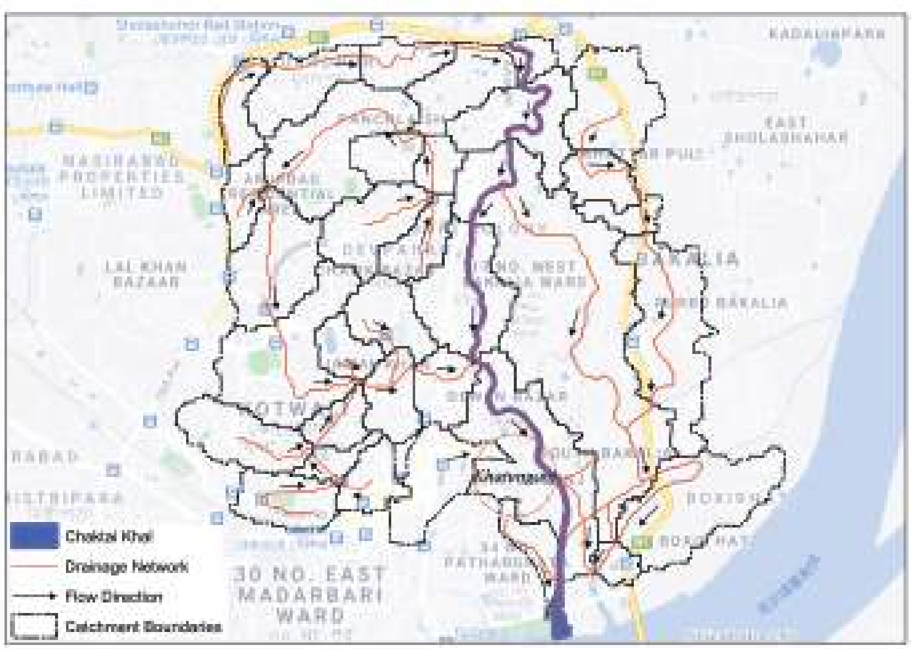


Figure 29: Catchment area map adjacent to Chaktai (Source: Authors)

4.2.2 Hydrologic Model Setup

SWMM model was used to simulate the rainfall-runoff scenario. The SCS (soil conservation service) curve number method was used for infiltration loss. The curve number of each basin was collected from the chart according to the relevant soil group, as presented in Figure 30, and land use classification (Figure 31). The SCS unit hydrograph was used to transform precipitation excess to direct run-off. In this regard, lag time (min) was required for the transform method, and the following equation was used to calculate the lag time (min):

$$\text{Lag time (h)} = \frac{2.587 \times L^{0.8} \times \left(\frac{1000}{CN} - 9\right)^{0.7}}{1900 \times H^{0.5}} \quad \text{Eq.(1)}$$

Where,

L= Hydraulic watershed length in meter = 110 x $A^{0.6}$, A = Sub-catchment area in hectare, CN = Curve number, H = Average sub-catchment land slope in percentage

The average sub-catchment land slope was calculated from DEM using the GIS interface. Due to lack of data availability, the base flow was not used. Since most of the areas in the basins are urbanized and impervious, interception and surface methods were also not used. Since the duration of the rainfall and resulting runoff events were relatively short and the events mostly happen in the rainy season with the highly humid condition, evaporation losses are considered very low, and it is considered negligible.

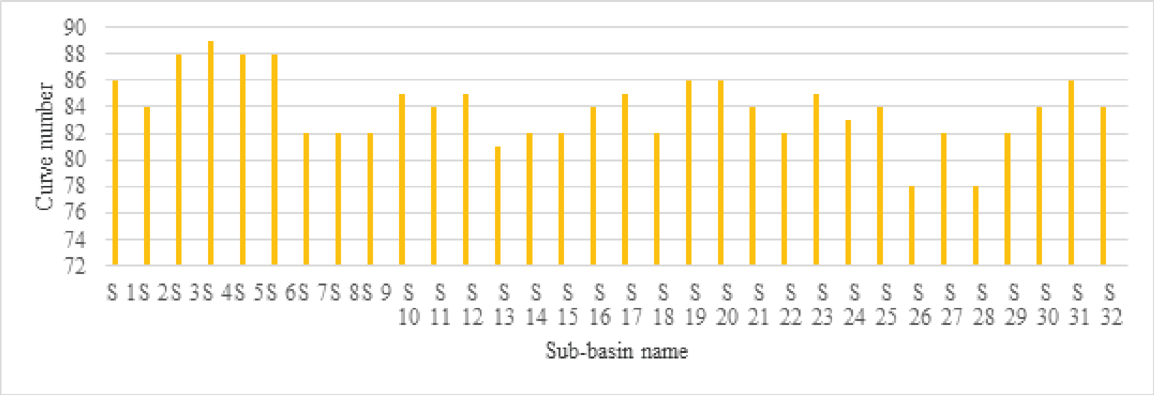


Figure 30: Curve number of Muradpur-Chawkbazar basin

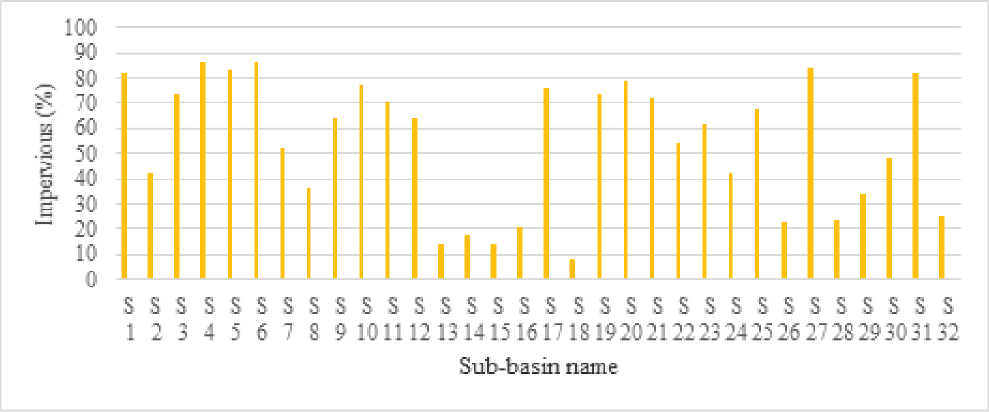


Figure 31: Percentage of impervious of Muradpur-Chawkbazar basin

4.2.3 Hydrodynamic Model Setup

Both the hydrologic and hydrodynamic models can be simulated simultaneously using SWMM. The resulting runoff from the hydrologic model from various sub-catchments was routed through the nodes and conduits added in the SWMM model. The cross-section properties of the conduits were selected as irregular shaped and relevant data obtained from the bathymetric survey conducted by CEGIS were given as input. Dynamic wave routing and unsteady flow equations were used in simulating the hydrodynamic model. The manning's roughness coefficient, n-value, was taken as 0.01. At the outlet, the boundary condition was set as 4.25 m water level, based on the highest tide WL in the year 2017 since only for the year 2017, water level data is available. To incorporate the climate change-induced sea level rise scenario, a 0.60 m rise was estimated (MOFC, 2018), and 4.85 m WL was used to include the climate change scenario.

The Chakbazar-Muradpur catchment drains off stormwater to the Chaktai *khal*. The sub-catchments are named respectively as S0, S1, S2 to S34. Cross-section properties of Chaktai *khal* at 89 points are given as nodes with an average 50m interval. The nodes were named respectively as J1, J2, J3 to J89, as shown in Figure 32. The nodes started from Muradpur Arakan road, and the last node is at the Karnaphuli river outfall. Nodes named J69, J70, J71, J72 are in the vicinity of the Khatunganj area.

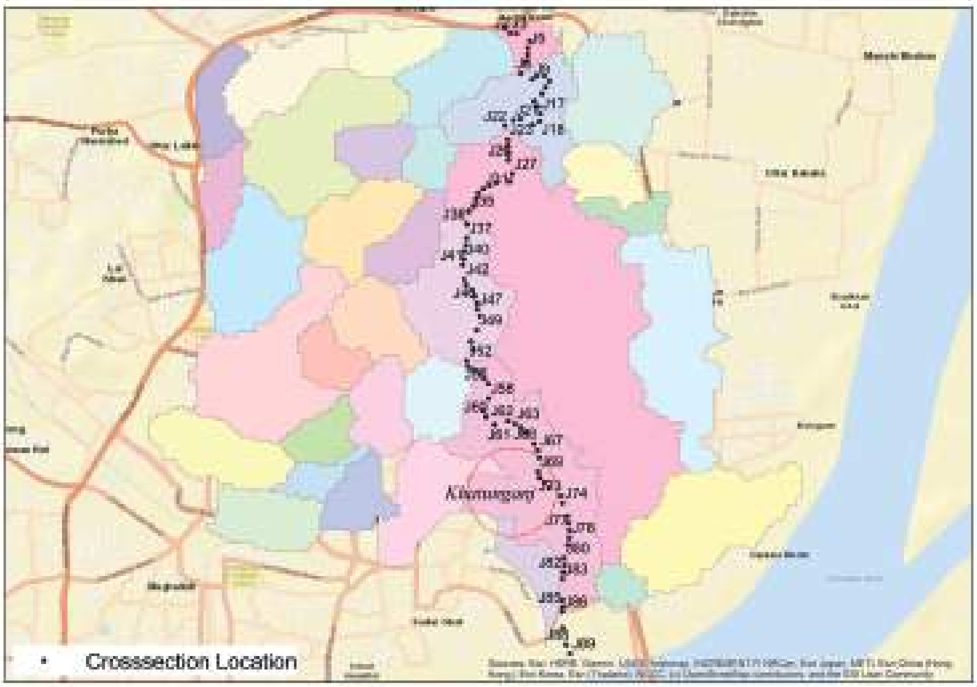


Figure 32: SWMM model setup showing the nodes and junctions (Source: Model setup by Authors)

4.2.4 Validation of SWMM Model

The model was run for the maximum rainfall as observed in the year 2017 since water level data for 2017 is only available. Corresponding inundation pattern was simulated using ArcGIS. Since no other data is available to calibrate and validate the model, an indirect validation approach was used using a satellite image. The simulated water inundation vicinity to the Khatunganj area was compared with the actual flood inundation extent obtained from the satellite image of Sentinel-1. Sentinel -1 images are 10 mx10 m resolution and perform well in case of inundation mapping in the cloudy environment (Tanim & Mullick, 2017).

With a known and actual rainfall event on 5 July 2017, the model was run and the extent of inundation was estimated, which has been compared with a satellite image. 32.35% of the study area was found as inundated on the same day as extracted from the satellite image analysis, whereas the simulation study results in an inundation of around 39.11% of the area. The obtained results are quite compatible, and the model is considered as calibrated. Figure 33 presented the actual inundation as obtained from the satellite and simulated inundation from the actual rainfall on 5 July in 2017.

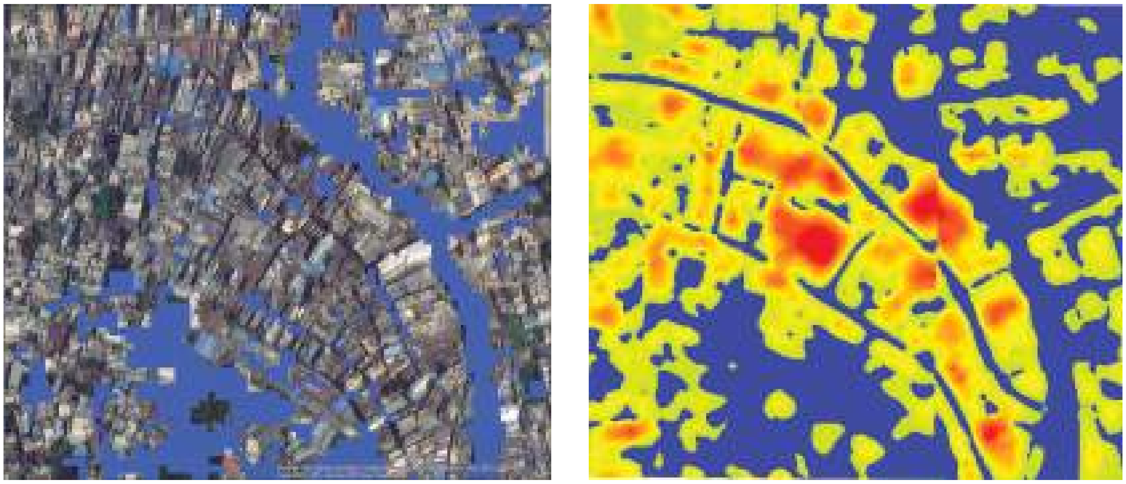


Figure 33: Actual flood scenario obtained from satellite and simulated flood scenario

4.2.5 Inundation from the Model Outputs

4.2.5.1 Actual Rainfall and Design Rainfall

The model was run with an actual rainfall, i.e., the maximum rainfall event in 2017 on 5th July as well as the model was simulated with a number of design rainfall events. The following IDF relationship (Figure 34) was used to extract the design rainfall events (Rimi and Matin, 2016). IDF equation is based on the rainfall for the years 1980-2014 in Chattogram and follows equation 2.

$$\text{Rainfall intensity (mm/hr.)} = \frac{776.24 \text{x} Tr^{0.217}}{Td^{0.563}} \quad \text{Eq.(2)}$$

Where, T_r = Return period in year, T_d = Rainfall event duration in hour.

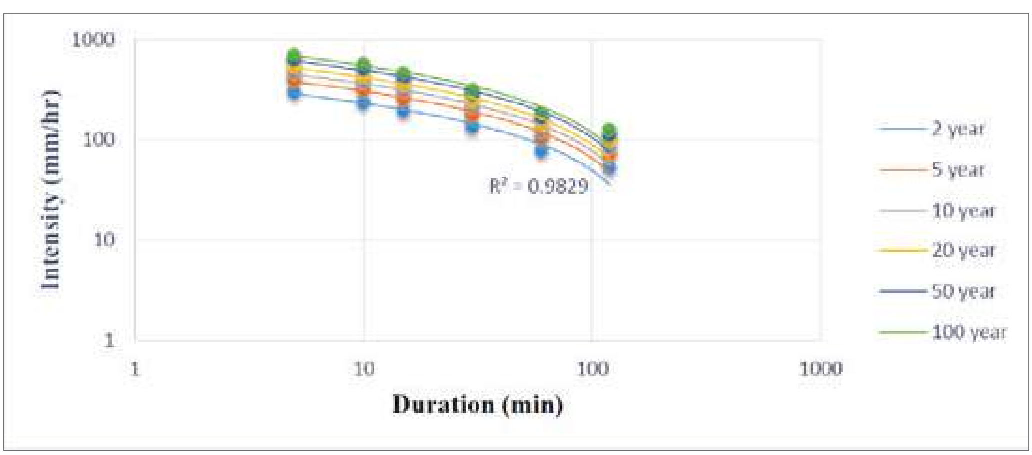


Figure 34: IDF curve of Chattogram city by hershfield method (Source: Rimi and Matin, 2016)

Table 4.3 presents the rainfall values that have been considered for modeling in different scenarios.

Table 4.3: Rainfall values considered for different scenarios

Scenario SL number	Scenario description	Rainfall value
S-1	Max rainfall event in 2017 (Actual Scenario)	222 mm
S-2	2-hour 20-year return period rainfall (High Tide)	200.80 mm
S-3	2-hour 50-year return period rainfall (High Tide)	244.98 mm
S-4	2-hour 50-year return period rainfall (Low Tide)	244.98 mm
S-5	2-hour 50-year return period rainfall (considering 50% rainfall decrease) (High Tide)	122.49 mm
S-6	2-hour 50-year return period rainfall (considering 50% rainfall decrease) (Low Tide)	122.49 mm
S-7	6-hour 50-year return period rainfall (High Tide)	395.94 mm
S-8	2-hour 50-year return period rainfall (considering Climate change 11% rainfall increment)	271.92 mm

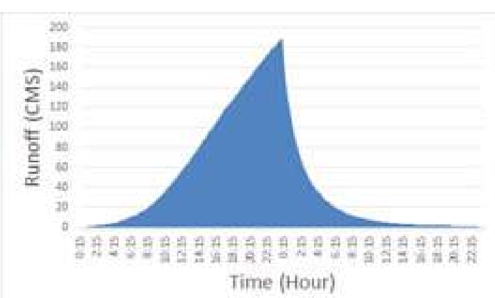
4.2.5.2 Upstream and Downstream Boundary Condition

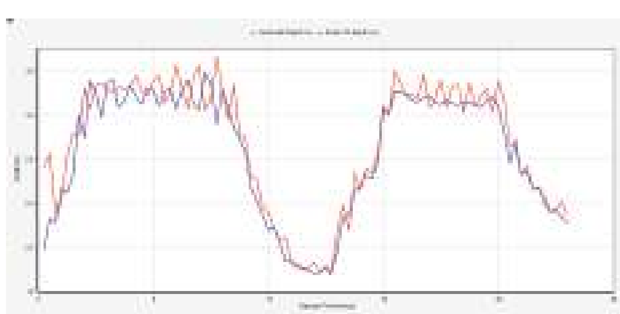
The entire catchment has been considered for hydrological modeling. No boundary condition was imposed on the model; however, the water level at the outfall of Chaktai has been used as the downstream boundary condition. The high and low tide condition water levels at the Chaktai outfall are considered as maximum and minimum boundary level. The water level is taken as 4.5 m and 1.5 m for the high and low tide conditions based on the tide chart as published by the chittagong Port Authority.

4.2.5.3 Discharge and Water Level

In different scenarios, the discharges (hydrograph) and water levels at the nodes (node 69 & 70) near Khatunganj are considered for the study and presented in Figure 35. For each scenario, the maximum discharge and water level have been reported.

Scenario S-1 — Max rainfall event in 2017 (Actual Scenario)



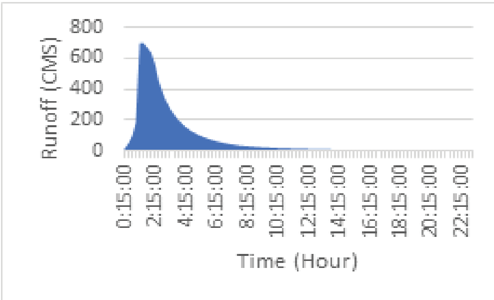


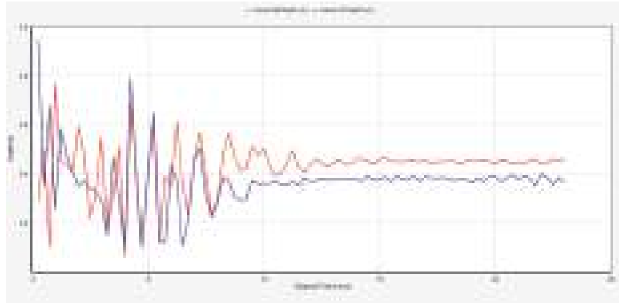
Maximum Q = 179.48 CMS

Maximum WL (m) at Node 69 = 3.73

Scenario S-2

2-hour 20-year return period rainfall (High Tide)



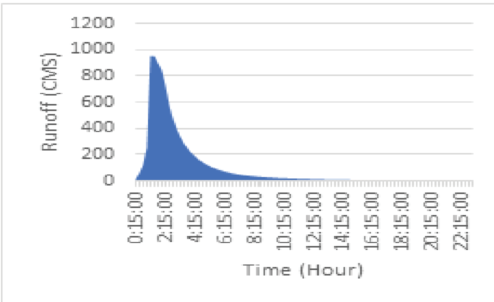


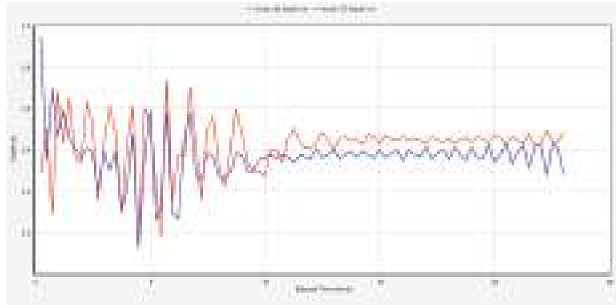
Maximum Q = 700.34 CMS

Maximum WL (m) at Node 70 = 3.94

Scenario S-3

2-hour 50-year return period rainfall (High Tide)



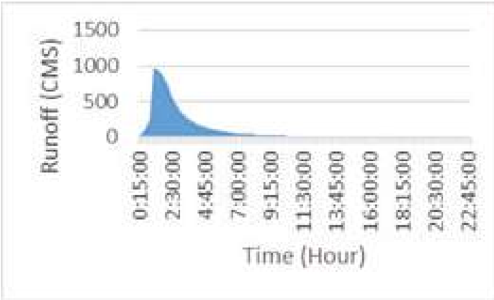


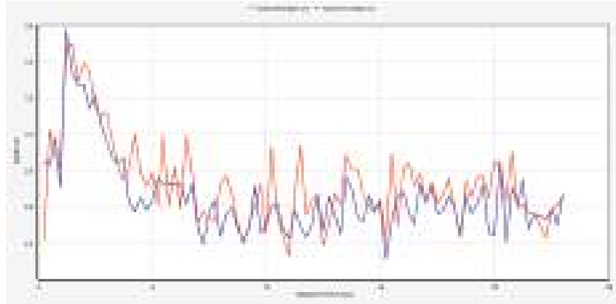
Maximum Q = 955.52 CMS

Maximum WL (m) at Node 70 = 3.94

Scenario S-4

2-hour 50-year return period rainfall (Low Tide)



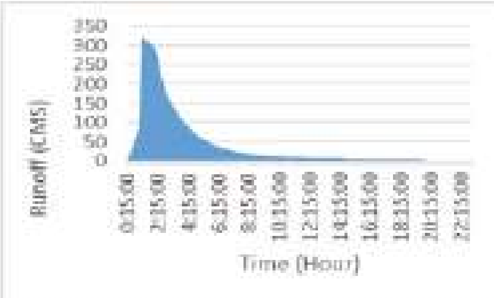


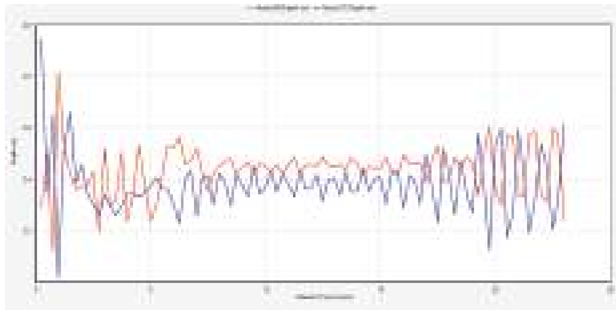
Maximum Q = 923.51 CMS

Maximum WL (m) at Node 70: 3.58

Scenario S-5

2-hour 50-year return period rainfall (considering 50% rainfall decrease) (High Tide)



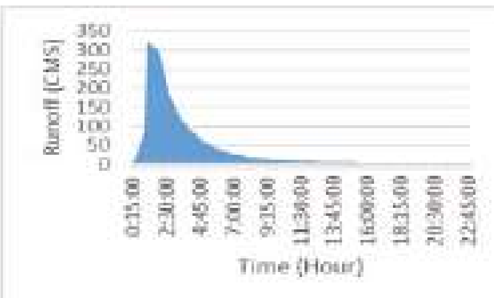


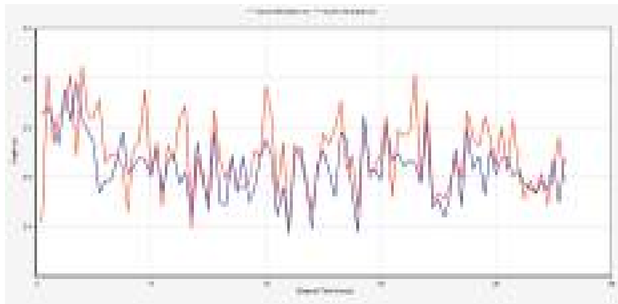
Maximum Q = 323.51 CMS

Maximum WL (m) at Node 70: 3.94

Scenario S-6

2-hour 50-year return period rainfall (considering 50% rainfall decrease) (Low Tide)



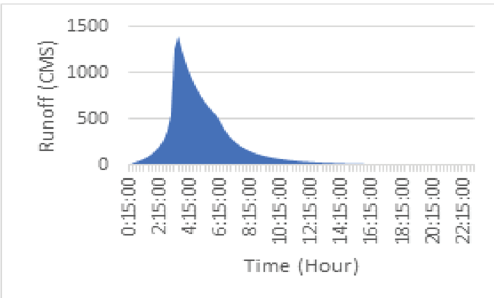


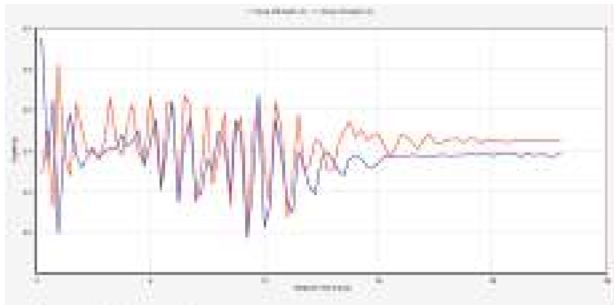
Maximum Q = 323.51 CMS

Maximum WL (m) at Node 69: 3.05

Scenario S-7

6-hour 50-year return period rainfall (High Tide)





Maximum Q = 1394.27 CMS

Maximum WL (m) at Node 70: 3.94

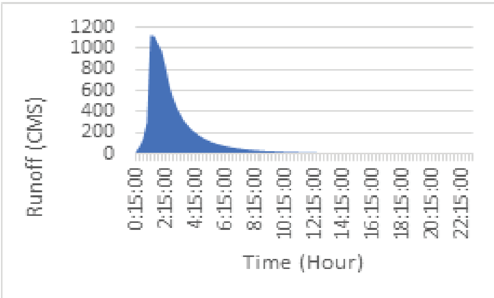
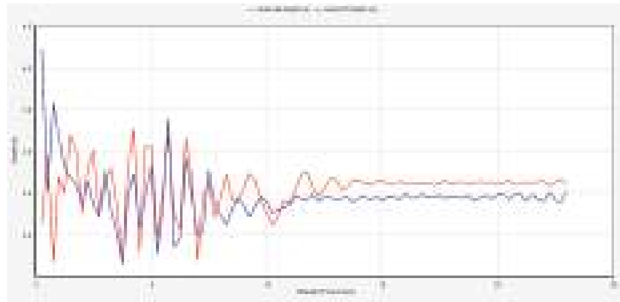
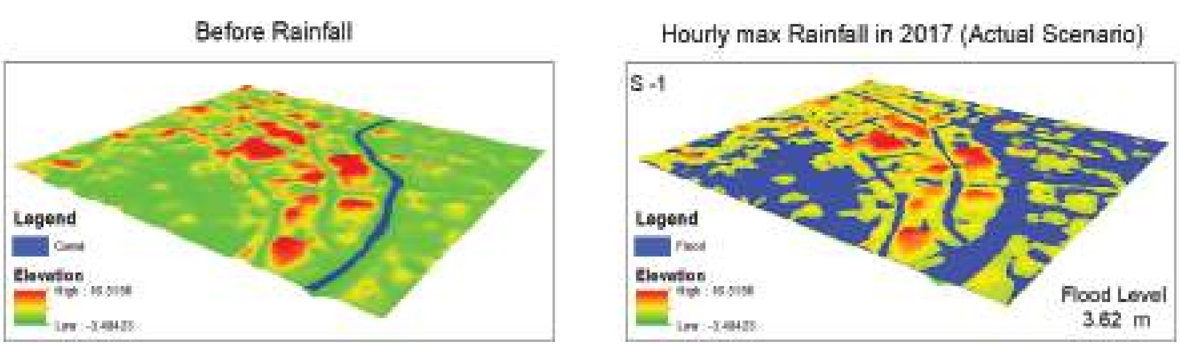
Scenario S-8	2-hour 50-year return period rainfall (considering Climate change 11% rainfall increment)
	
Maximum Q = 1123.87 CMS	Maximum WL (m) at Node 70 = 4.09

Figure 35: Discharge and water level for different scenario analysed (Source: Authors)

4.2.5.4 Inundation

The inundation patterns as obtained from the model and for the different scenarios are shown in Figure 36. Analyses show that in all the scenarios, the water level exceeds 3 m, where the existing road level is around 3 m. Road level actually varies between 2.9 m to 3.05 m. So, for any average to heavy rainfall case, the Chaktai *khal* became overtopped, and the adjacent area becomes flooded. The structures on both sides of Khatunganj road have three types of plinth levels, namely, plinth elevation near to road level, below road level and above road level. The majority of the structure is very old; on the other hand, the city authority upgraded the road level time to time, that resulted in structures level to be lowered than road level. However, the plinth level of the new structures is slightly high even 3 feet higher than the existing road level.

Such an inundation pattern generates three types of flooding scenarios. Low rainfall, when Chaktai *khal* overflows a little, average rainfall that generates around 3.1 m WL at the *khal* and very heavy rainfall that gives more than 4.0 m WL. Vulnerability and risk profiling further followed these three types of scenarios.



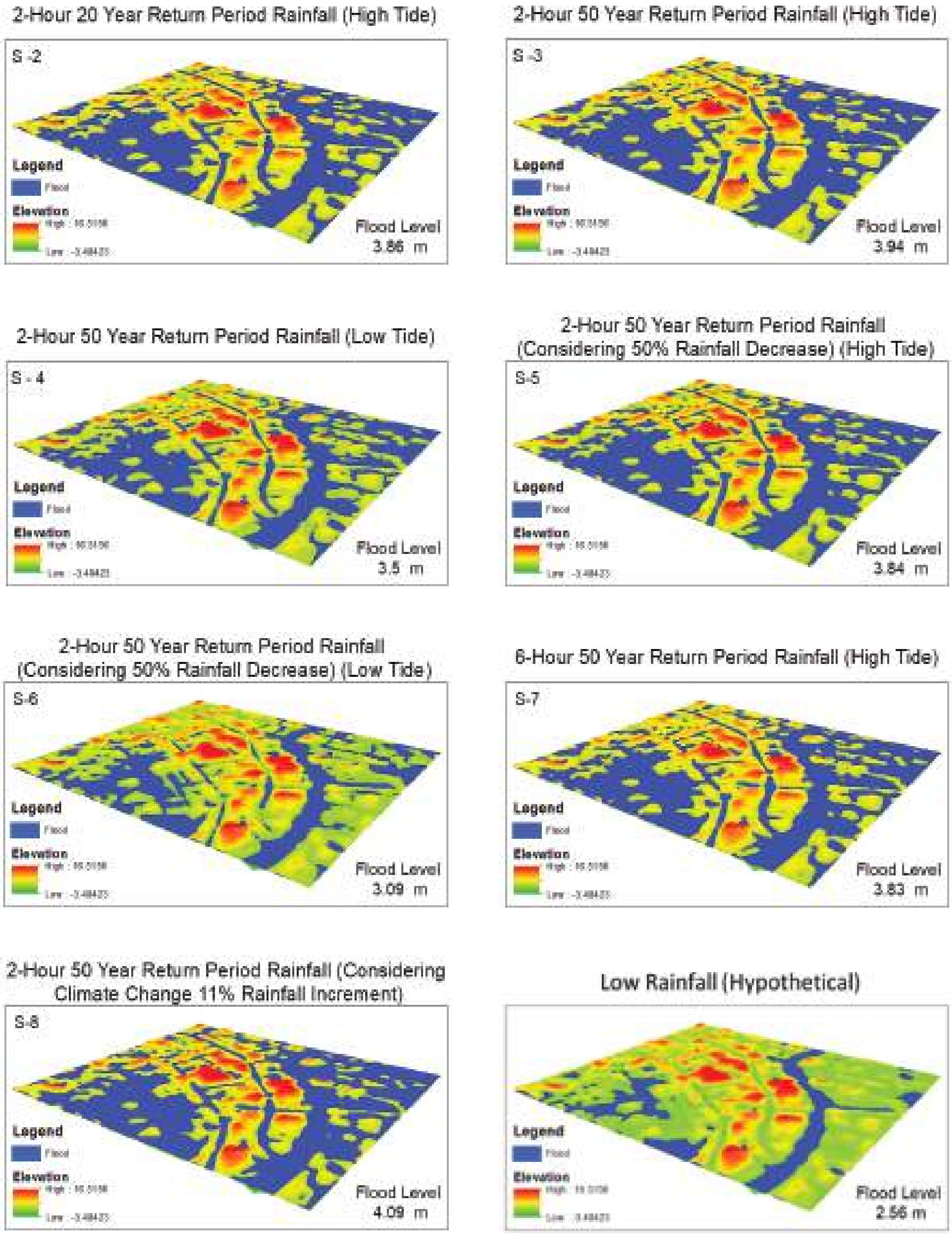


Figure 36: Inundation pattern as obtained from the model for different scenarios
(Source: Model output as calculated by the authors)

4.2.6 Vulnerability and Risk Analysis:

Four criteria are chosen to determine the vulnerability of the Khatunganj due to the flooding caused by different rainfall scenarios. The four criteria are namely, plinth level of the structure, proximity to Chaktai *khal*, structure type (*kacha*, *pacca* or semi-*pacca*), and land use pattern. Figure 37, 38, 39, and 40 represents the structure and area classification based on four criteria, respectively.

Khatunganj is a very historical and old area. Some buildings are caring for the legacy of a hundred years. As time goes by, the flood level increases due to several changes. But on the contrary, the plinth of the buildings does not get higher and remains at the old level. Many shops have a ground floor is road level. A few of the new structures, especially the commercial banks, have a higher plinth.

In the case of proximity analysis, the more the structure is near to the canal, the more it is considered vulnerable because the main reason for flooding is overflow of Chaktai. Therefore, if a structure is close to Chaktai, it is considered vulnerable but with a factor of 80%.

Khatunganj is the biggest commercial hub of Chattogram. Wholesale shops are seen in both sides of the roads. The warehouse is normally situated behind the front shop place. Presently, the majority of the buildings are *pacca*. However, semi-*pacca* and tin shed buildings are also available at the site. Based on the structure type, the vulnerability has been considered.

The vulnerability of the commercial and service activity is higher than that of the residential one due to flood, and therefore land use pattern has also been considered in vulnerability estimation. Figure 39 shows the areal classification based on the land use pattern.

Figure 37: Area classification based on plint of the structures

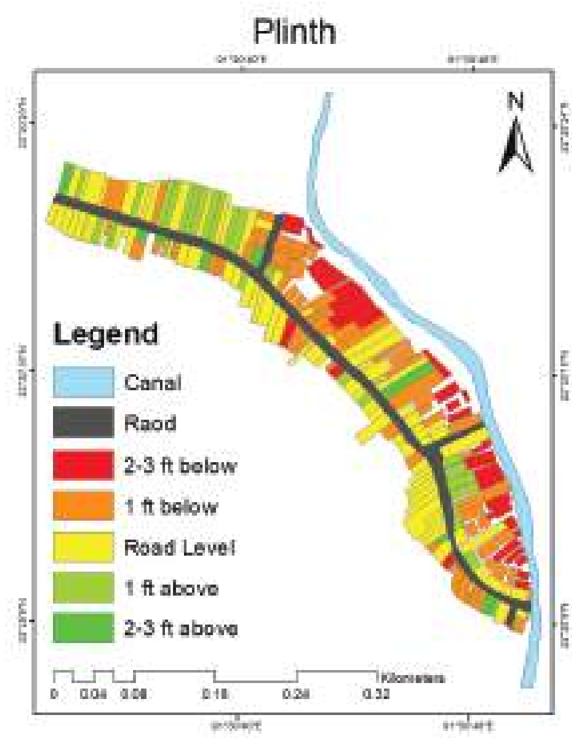
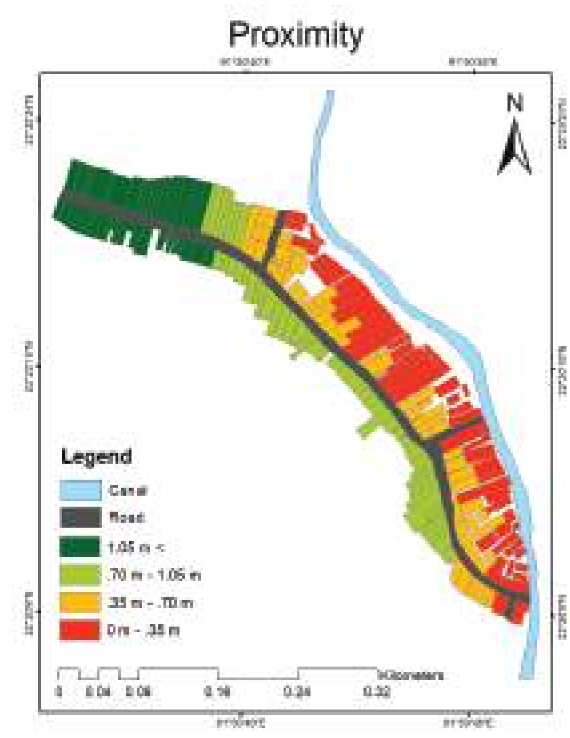


Figure 38: Area classification based on proximity to Chaktai



Source: Model output as calculated by the authors

Figure 39: Area classification based on structure type

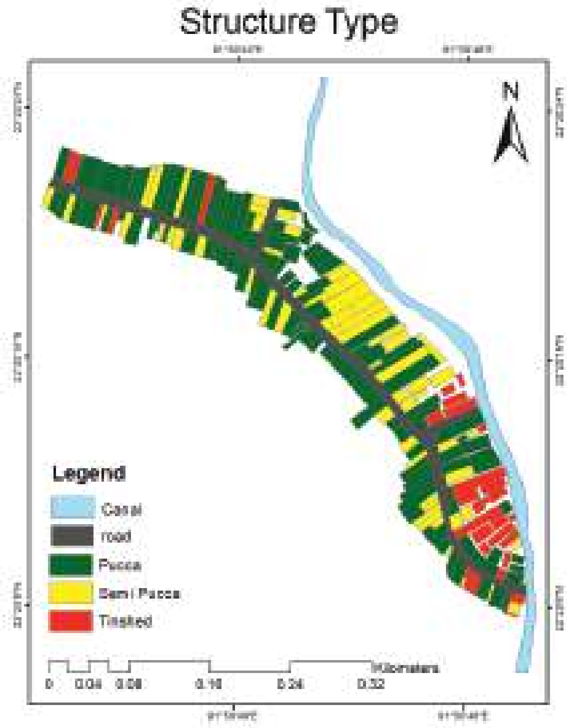
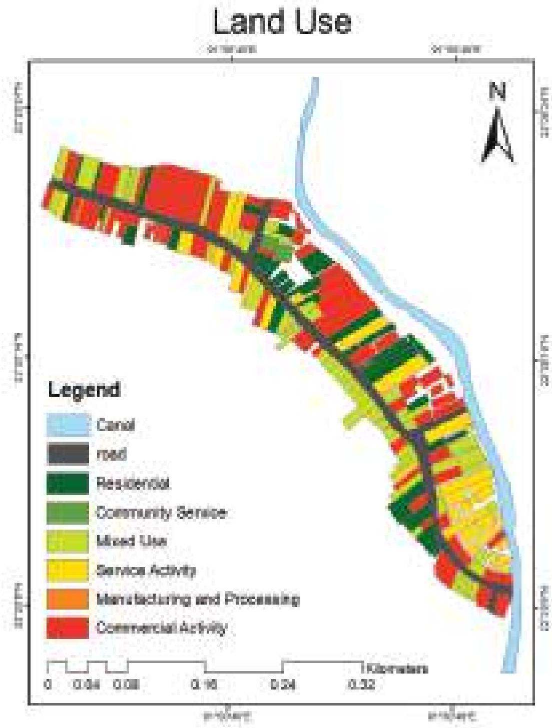


Figure 40: Area classification based on land use



Vulnerability due to flooding is then estimated using equation 3.

$$\text{Vulnerability} = (\text{Plinth} + \text{Proximity} + 0.8^{*}\ \text{Land Use} + 0.8^{*}\ \text{Structure Type})/4 \quad \text{Eq (3)}$$

The vulnerability has been assessed for three rainfall types; namely, low (around 15 mm/hr), average (25 mm/hr), and high (35 mm/hr) have been presented in Figure 41, 42, and 43. Low rainfall (around 15 mm/hr) generates a WL of 2.5 m, whereas average rainfall generates a WL of 3-3.2 m. Such WL results in the inundation of the Khatunganj main road. The level of the Khatunganj main road is about 2.9 to 3.1 m. An average rainfall creates water inundation about 6 inches to 1 foot over the main road. Heavy rainfall with climate change scenario gives around 4.1 m WL meaning around 1 m depth of water inundation on the road.

Using such an inundation pattern combining with three other factors, namely, proximity to the canal, structure type, and land use type of the area, the vulnerability of the area has been enumerated. The vulnerability has been classified into four classes – not vulnerable, low, medium, and very vulnerable. With three rainfall cases (low, average, and high), the risk profile for the structures has been estimated. Majority of the structure on both sides of Khatunganj main road fall in the medium vulnerable class for all three rainfall cases. In the case of high rainfall, all structures are, to some extent, vulnerable.

Figure 41: Vulnerability for low rainfall

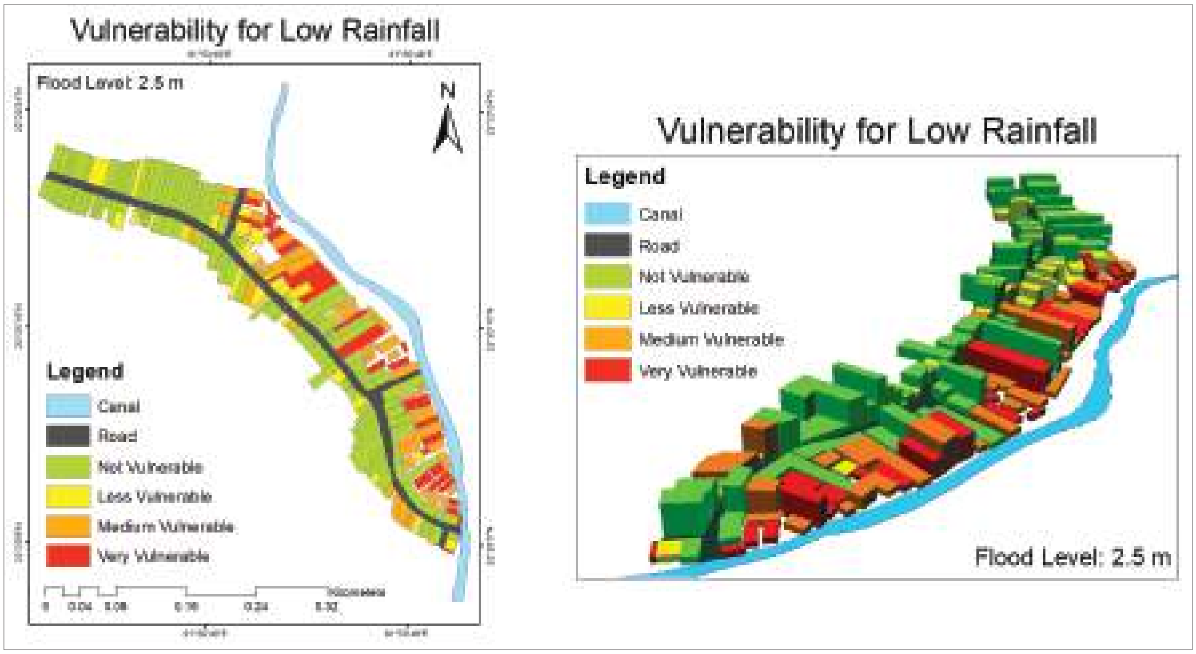


Figure 42: Vulnerability for average rainfall

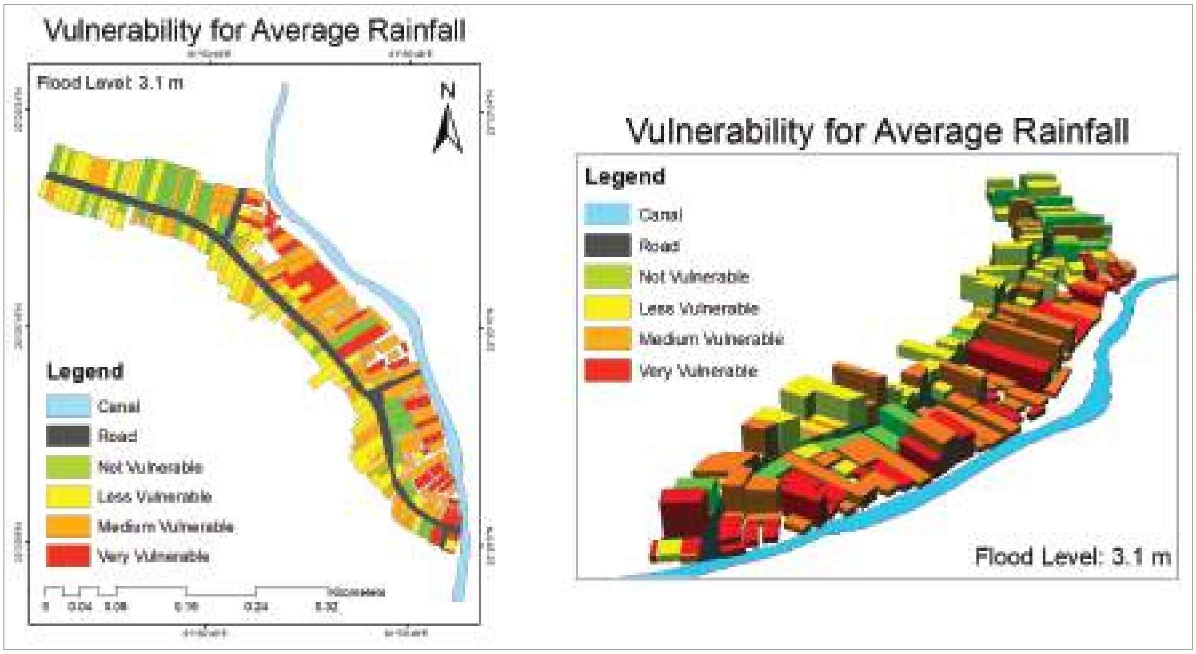
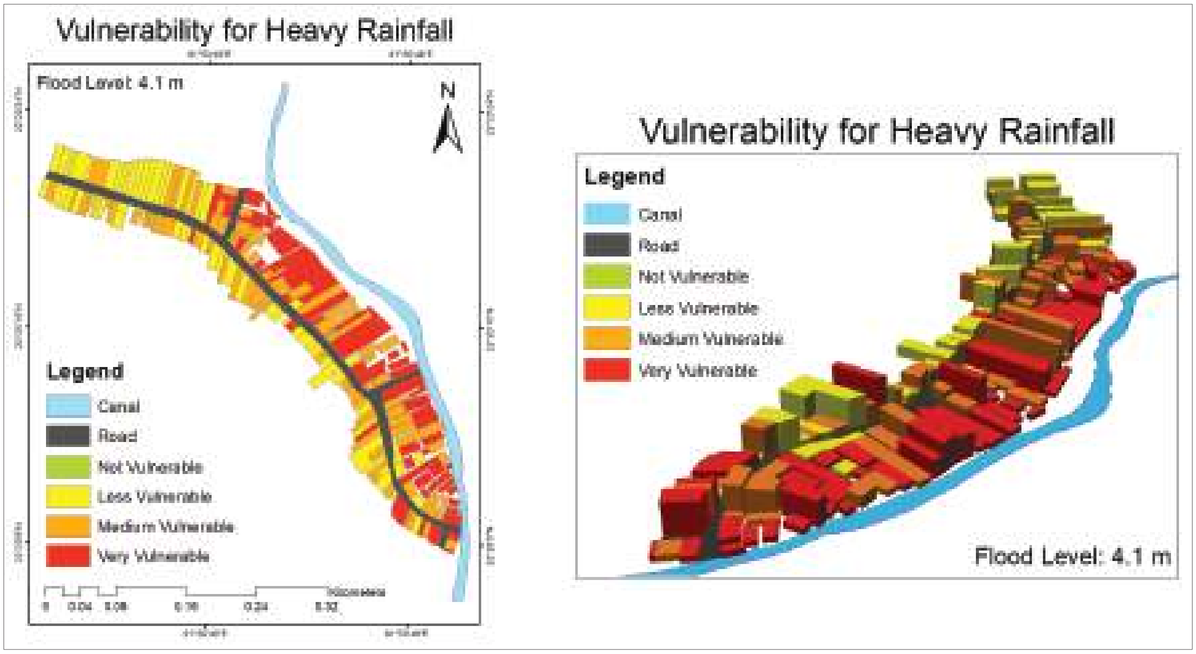


Figure 43: Vulnerability for heavy rainfall



4.2.7 Risk Profile

Based on the vulnerability analysis, the risk profiling of the structures on both sides of Khatunganj road and adjacent to Chaktai *khal* has been enumerated. Total 224 structures were identified at the study site, and for three flood scenarios of vulnerability analysis, these structures were classified into four vulnerable classes, namely, not vulnerable, less vulnerable, medium vulnerable, and very vulnerable. As analysed and based on obtained results, the water level in all scenarios remains more than 3.0 m, whereas the Khatunganj main road level is around 2.9 m to 3.05 m. Results indicate that in all scenarios, the road and subsequently adjacent structures are expected to be inundated. For risk profiling, three categories have been documented, namely (i) low rainfall, which is lower than normal (ii) 50 mm per day average rainfall that causes up to 3.5 m water level and (iii) heavy rainfall that generates more than 3.5 m rainfall. The number of structures in the classes for different rainfall and inundation scenarios are documented in table 4.4.

Table 4.4: Number of structures at risk due to different flood scenarios

	Low Rainfall	Average Rainfall	High Rainfall
Not Vulnerable	122	37	0
Less Vulnerable	33	83	68
Medium Vulnerable	42	74	85
Very Vulnerable	27	30	71
Total	**224**	**224**	**224**

4.3 Analysing Spatial Morphology

Spatial morphological analysis has been conducted to understand potential locations of development and challenges. This includes a space syntax analysis. Space syntax is built on quantitative analysis and geospatial computer technology and provides a set of theories and methods for the analysis of spatial configurations of various kinds and at all scales (Hillier, B. 2007). The global axial integration analysis with a radius of "N" expresses the vehicular movement or street connectivity in the context of the whole city, whereas a radius of 4 represents connectivity/integration at the local level. The base map for the space syntax analysis has been prepared from the existing GIS file of Chattogram city. The analysis is done on two-scale. The small scale only covers the surroundings road network and the larger scale covers the water transport network, including the surroundings road network, which has a significant effect on the connectivity of the site. Axial map analysis on 1.5 km surrounding road network and waterway network centering Khatunganj is used in this study.

From the analysis, integration values have been considered to understand the relation of existing land use with road and water networks. For referring to the water network, the terminology "blue network" has been used. UCL Depth Map 10 has been used to analyse the integration values of the road network and blue network. Integration values are presented in a chromatic scale ranging from blue to red. The blue color indicates the least integrated or least used ones, and the red color indicates the most integrated or the most used ones. From low to high, this chromatic scale follows dark blue, light blue, green, yellow, orange, and red color. Both global and local level integration analysis has been conducted for Khatunganj. Though a larger area has been analysed, this study will only focus on the area of the Khatunganj wholesale market. Figure 44 is showing the existing land use of the Khatunganj Wholesale market area, and Figure 45 is showing the global integration map of the road network. The base map for the space syntax analysis has been prepared from the existing GIS file of Chattogram city.

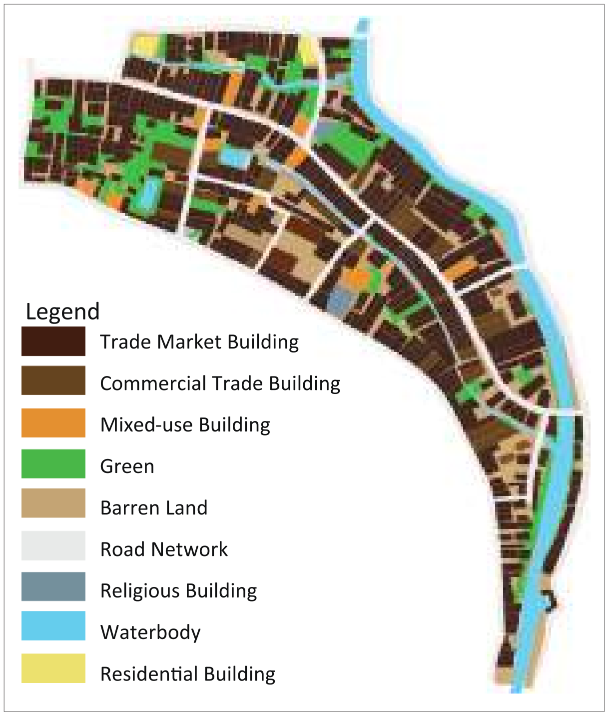
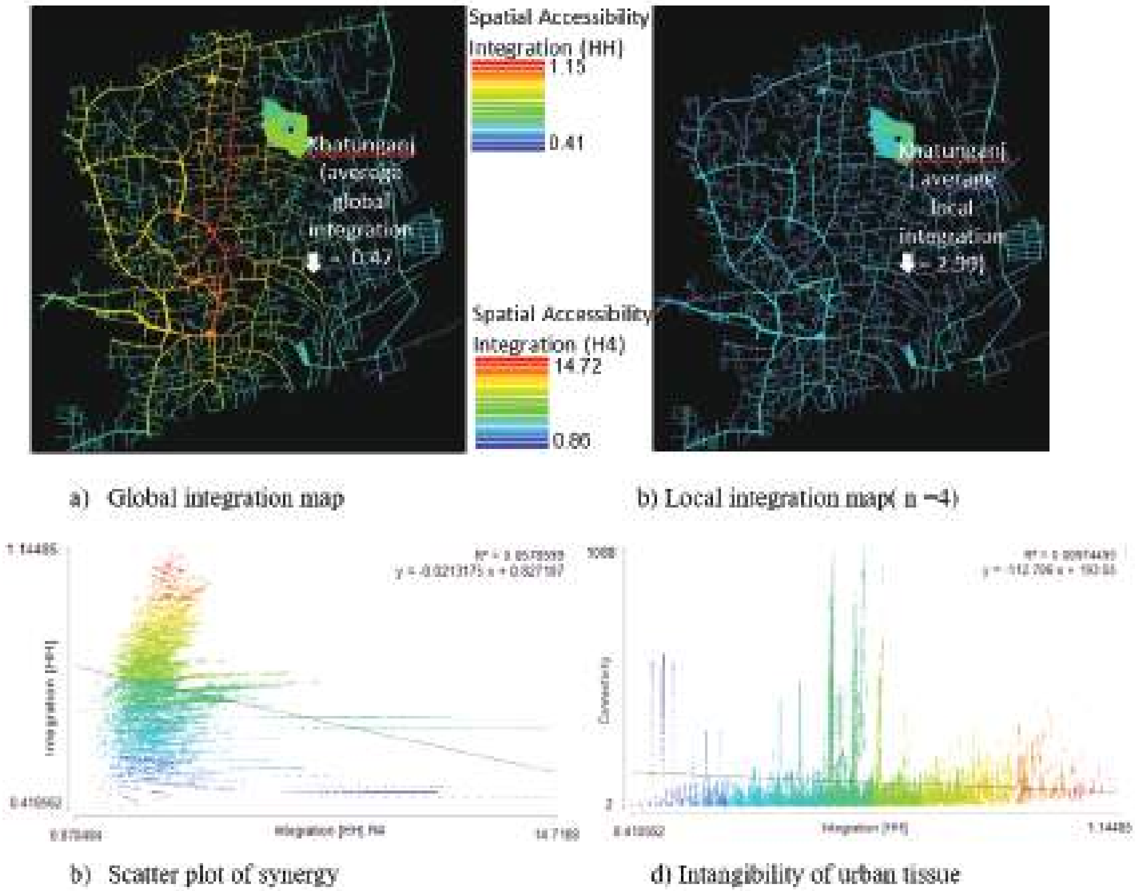


Figure 44: Existing land use of Khatunganj wholesale market area (Source: Analysis done at Design Studio VII, Spring 2019-20, Architecture Department, AIUB, Studio Guide: Research team

Figure 45: Global road network integration at Khatunganj wholesale market area

It is clearly observed from global integration analysis that the integration core lies linearly at J M Sen Avenue, centering the nodal point of Momin road, Nabab Siraj Ud Daula Road. The integration core moved linearly towards Nabab Siraj Ud Daula road from J M Sen Avenue. Integration parameter indicates the daily chosen path, natural movement and use of urban space (development, commercial use, isolation) depends on it (Hillier and Vaughan, 2007). Property value near integration area tend to be higher and therefore attracts commercial use for greater profit from investment (Desyllas, 1997). Growing commercial land use like the bank, commercial showroom along the global integration core area at J M Sen Avenue, and Nabab Siraj Ud Daula Road support these findings from the literature review. Also, from field surveys, it has been observed that there is a growing tendency of shifting the main trade office from Khatunganj to other commercial areas. Road network integration map (Figure 46) clearly shows that nowadays, with 0.47 average global integration and 2.99 average local integration value commercial importance of Khatunganj has dropped significantly.

Figure 46: Integration, synergy, and intangibility of Khatunganj wholesale market area
(Source: Model output as calculated by the authors)



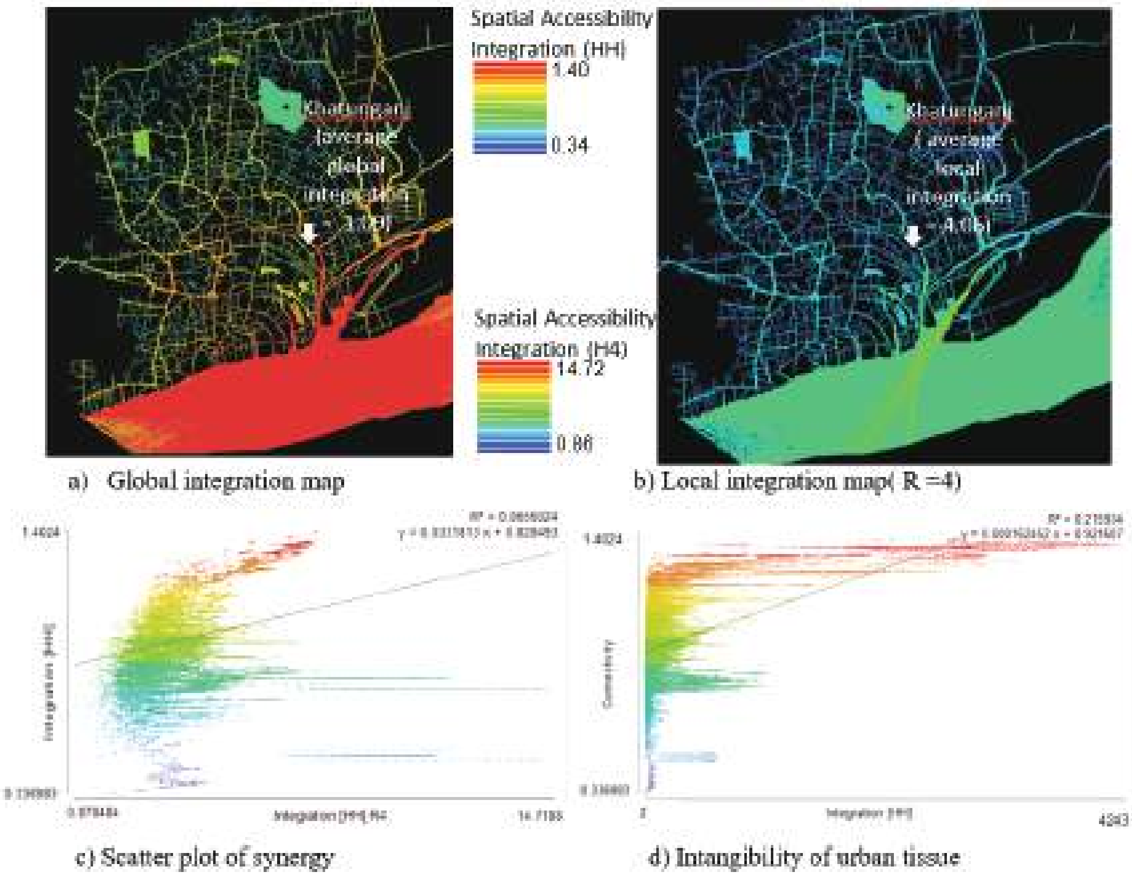
From synergy and intangibility analysis (Figure 46), it is obvious that further road connection towards the Khatunganj area will continue faster its decline as a commercial hub and isolate the area from the central integrated commercial core. Synergy and intangibility analysis shows that the global integration of Khatunganj is negatively correlated with local integration and connectivity. Also, both the system synergy (R^2 = 0.0579) and intangibility (R^2 = 0.0097) are very low. A lower intangible number indicates the way space is formed locally, does not coherent with the existing road network (Giannopoulou, Roukounis, Stefanis, 2012).

Existing land use relation with the road network and historical chronology of Khatunganj suggest that some other factors worked behind commercial development of the Khatunganj area, which might not be active now. For understanding the historical land use development of Khatunganj, a second integration analysis has been simulated considering an active blue network with the existing road network. For developing the blue network, all canals were considered actively connected both at a higher altitude of the city and with the Karnaphuli river. Figure 47 is showing the global integration analysis of the integrated road and blue network surrounding the Khatunganj area. An active Chaktai canal network has shifted the previously found (Figure 45) integration core to Khatunganj wholesale market area (Figure 47).

Figure 47: Global integration of integrated road and blue network at Khatunganj wholesale market area

This phenomenon clearly explains, without an active Chaktai canal network and its connection to the Karnaphuli river, the development of Khatunganj as a commercial hub was never possible. This phenomenon also indicates that if the water transport network is not activated again at Chaktai canal network, the Khatunganj Wholesale Market area will not survive as a commercial hub and will be converted as a local low-cost residential area in the future. But, an alternatively high integration value (Figure 48) of the Chaktai canal (integration value 1.32) supports the idea that an active water transport network from Karnaphuli via the Chaktai canal towards the city can revive the possibilities and glory of the Khatunganj wholesale market again.

Figure 48: Integration, synergy, and intangibility of Khatunganj wholesale market area



From synergy and intangibility analysis at Figure 48 shows a direct correlation for both local and global integration as well as between connectivity and global integration. A higher intangibly value of 0.2159 indicates the way space formed locally is coherent with an integrated road and blue network. This indication also states that for increasing commercial land value at Khatunganj wholesale market area, a water transport network from Karnaphuli towards the city through the Chaktai canal is a must needed intervention.

4.4 UMEP (Urban Multi-Scale Environmental Predictor) Modelling

This modeling work consists of three elements: i. pre-processing (for inputs of meteorological and surface information); ii. processing the data (modeling system, e.g., Urban Land Surface Models, ULSM); and iii. post-processing using tools to analyse the outputs (individual case and ensemble, indicators of uncertainty, user applications, etc.).

4.4.1 Pre-Processing

4.4.1.1 Meteorological File

The location and filename (.txt) of the meteorological file were specified here. The format used in most UMEP-related plugins where required meteorological data were generated using the Met data Processor in UMEP. Met Preprocessor can be used to transform required temporal meteorological data into the format used in UMEP. The following variables are usually required as a minimum: air temperature, relative humidity, barometric pressure, wind speed, incoming shortwave radiation, and rainfall; if available, other variables could be supplied as well (Lindberg F. et al. 2018). In the case of Khatunganj, air temperature, relative humidity, wind speed, wind direction, and rainfall data were collected from the Patenga weather station. Other data were taken from the Energy Plus weather data belonging to the U.S. Department of Energy's (DOE). In the case of the data from the Bangladesh Meteorological Department (BMD) station of Patenga, all the three-hourly data had been extrapolated to one hourly data to meet the requirement of the UMEP format. The variables included in the meteorological input file, along with their accepted range, could be found in table 4.5.

Table 4.5: Variables included in UMEP meteorological input file

No.	Header name	Description	Accepted range	Comments
1	iy	Year [YYYY]	Not applicable	
2	id	Day of year [DOY]	1 to 365 (366 if leap year)	
3	it	Hour [H]	0 to 23	
4	imin	Minute [M]	0 to 59	
5	qn	Net all-wave radiation [W m-2]	-200 to 800	
6	qh	Sensible heat flux [W m-2]	-200 to 750	
7	qe	Latent heat flux [W m-2]	-100 to 650	
8	qs	Storage heat flux [W m-2]	-200 to 650	
9	qf	Anthropogenic heat flux [W m-2]	0 to 1500	
10	U	Wind speed [m s-1]	0.001 to 60	
11	RH	Relative Humidity [%]	5 to 100	
12	Tair	Air temperature [°C]	-30 to 55	
13	pres	Surface barometric pressure [kPa]	90 to 107	
14	rain	Rainfall [mm]	0 to 30	(per 5 min) this should be scaled based on the time step used
15	kdown	Incoming shortwave radiation [W m-2]	0 to 1200	
16	snow	Snow [mm]	0 to 300	(per 5 min) this should be scaled based on the time step used

No.	Header name	Description	Accepted range	Comments
17	ldown	Incoming longwave radiation [W m-2]	100 to 600	
18	fcld	Cloud fraction [tenths]	0 to 1	
19	wuh	External water use [m3]	0 to 10	(per 5 min) scale based on time step being used
20	xsmd	(Observed) soil moisture	0.01 to 0.5	[m3 m-3 or kg kg-1]
21	lai	(Observed) leaf area index [m2 m-2]	0 to 15	
22	kdiff	Diffuse shortwave radiation [W m-2]	0 to 600	
23	kdir	Direct shortwave radiation [W m-2]	0 to 1200	Should be perpendicular to the Sunbeam. One way to check this is to compare direct and global radiation and see if kdir is higher than global radiation during clear weather. Then kdir is measured perpendicular to the solar beam.
24	wdir	Wind direction [°]	0 to 360	

For this simulation, meteorological data had been fixed to 2016.

4.4.1.2 Building Morphology

The three site-specific building morphology parameters needed were derived from the following Digital Surface Models (DSM) and other survey data (Table 4.6):

Table 4.6: GIS Data for building morphology calculator

Geodata	Name
Ground and building DSM	DSM _1m.tif (Resampled from UAV survey)
Vegetation DSM	CDSM _1m.tif (not available from UAV survey)
DEM (digital elevation model)	DEM_1m.tif (Resampled from UAV survey)
Land cover	From Existing GIS file and field survey data

DSM and DEM mentioned in the above data were processed through a Morphometric calculator to generate three site-specific building morphology parameters in the form of an isotropic file in text format. This data was then imported into SUEWS for modeling.

Existing Landcover Fractions

Landcover fractions had been derived from the existing GIS file and field survey data. They are as follows (Table 4.7):

Table 4.7: Existing land cover fraction

Sl no.	Land cover	fraction
1	Building	0.5590
2	Paved/Impervious	0.2021
3	Evergreen trees	0.0200
4	Grass	0.1405
5	Water	0.0784

Population Density

The population density in people/ha (hectare) around the interest area was considered 170 based on the survey and existing Bangladesh Bureau of Statistics data.

4.4.1.3 Landcover scenario

Besides the existing landcover scenario, three more landcover scenarios were considered in relation to the area's waterlogging problem. The primary purpose of the scenario run was to investigate the relation between the water storage and the surface water runoff of the site.

Scenario 1

Table 4.8: Land cover fraction for scenario 1

Sl no.	Land cover	fraction
1	Building	0.5590
2	Paved/Impervious	0.0000
3	Evergreen trees	0.0200
4	Grass	0.3426
5	Water	0.0784

Scenario 2

Table 4.9: Land cover fraction for scenario 2

Sl no.	Land cover	fraction
1	Building	0.5590
2	Paved/Impervious	0.0000
3	Evergreen trees	0.0200
4	Grass	0.0000
5	Water	0.4210

Scenario 3

Table 4.10: Land cover fraction for scenario 3

Sl no.	Land cover	fraction
1	Building	0.4600
2	Paved/Impervious	0.0000
3	Evergreen trees	0.0200
4	Grass	0.0000
5	Water	0.5200

4.5 Results of the UMEP Scenario Run

The results from the modeling of existing land cover fraction and the three hypothetical scenarios are given below:

4.5.1 Existing Land-Cover Scenario

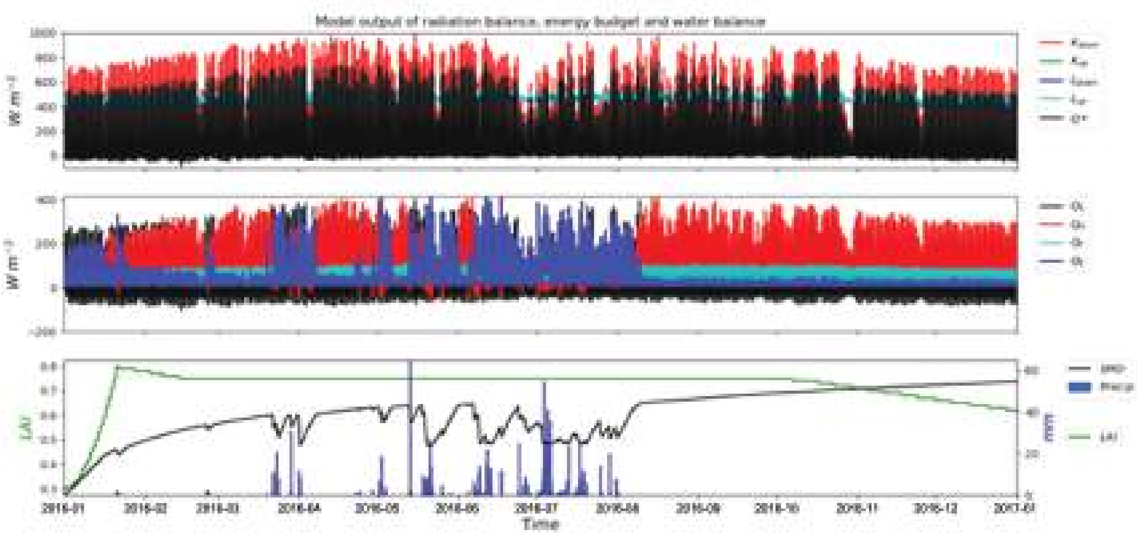


Figure 49: Existing condition: Radiation balance, energy budget, and water balance of the site

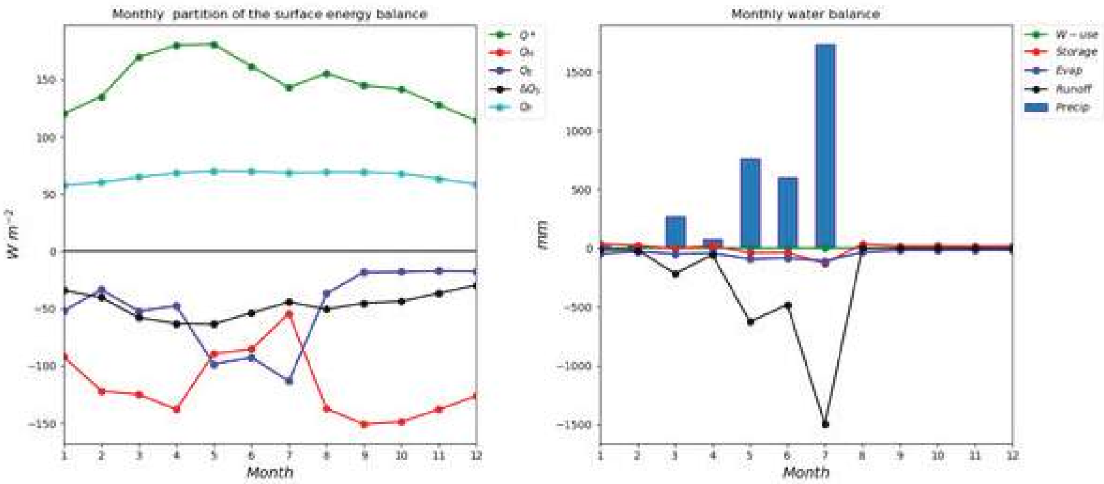


Figure 50: Existing condition: monthly partition of the surface energy balance and monthly water balance

It is clear from the existing situation (Figure 49 and 50) that the present water storage in terms of the water body is too low to manage the surface water runoff generated from the site. Hence it is clear that to increase the storage capacity of storm water of the site depends on how to manage it on site.

4.5.2 Scenario 1

In the hypothetical scenario (Figure 51 and 52), one paved area was reduced by increasing the grass area by the same amount. The results can be seen from the two figures below.

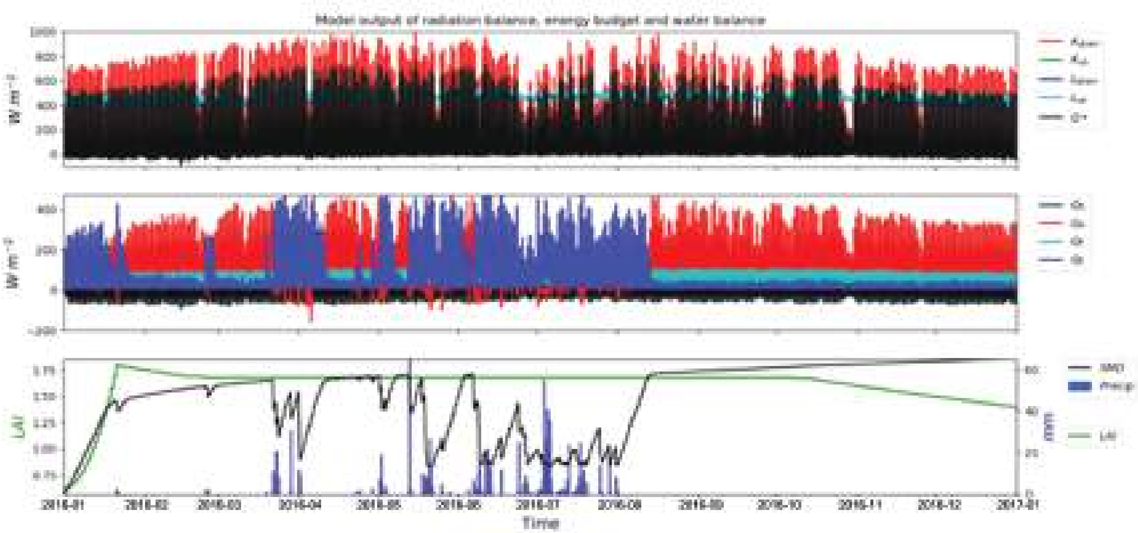


Figure 51: Radiation balance, energy budget, and water balance of the site

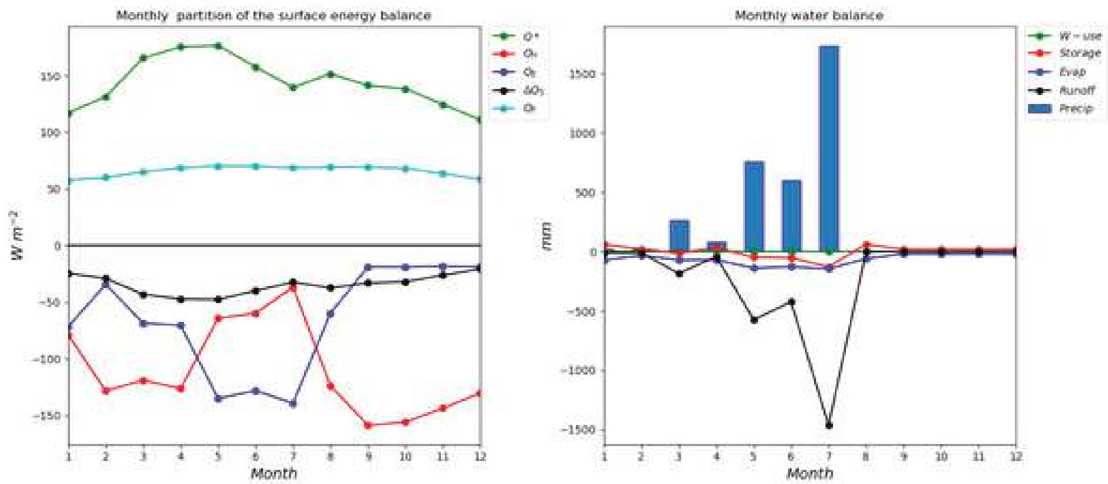


Figure 52: Monthly partition of the surface energy balance and monthly water balance.

From scenario 1, it is clear that increasing the grass area improves the water storage very little.

4.5.3 Scenario 2

In scenario 2 (Figure 53 and 54), all the grass surface area is converted to the water body, and the buildings remained unchanged to existing conditions. The results from this scenario are given in the figures below.

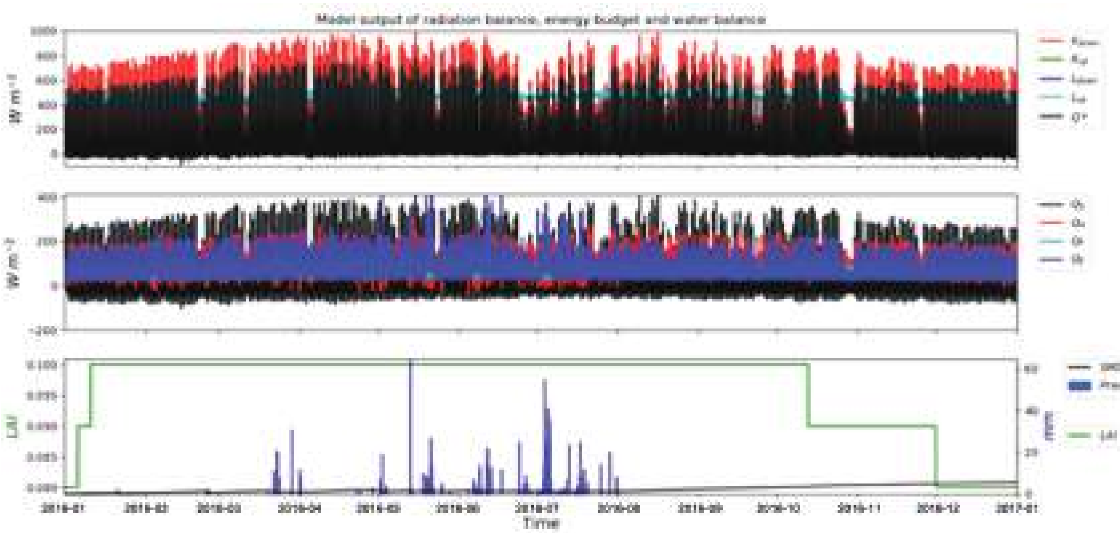


Figure 53: Radiation balance, energy budget, and water balance of the site

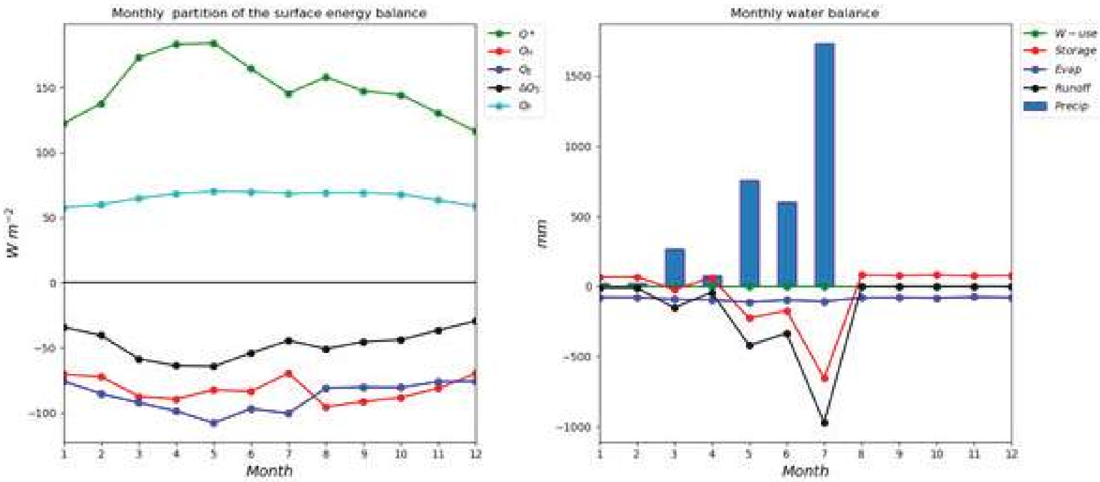


Figure 54: Monthly partition of the surface energy balance and monthly water balance

From scenario 2, it is evident that increasing the water body significantly increases the water storage and also reduces the storm water runoff.

4.5.4 Scenario 3

In the scenario 3 (Figure 55 and 56), three fractions of the water body were further increased by reducing the existing building appropriately. The results can be seen in the figure below:

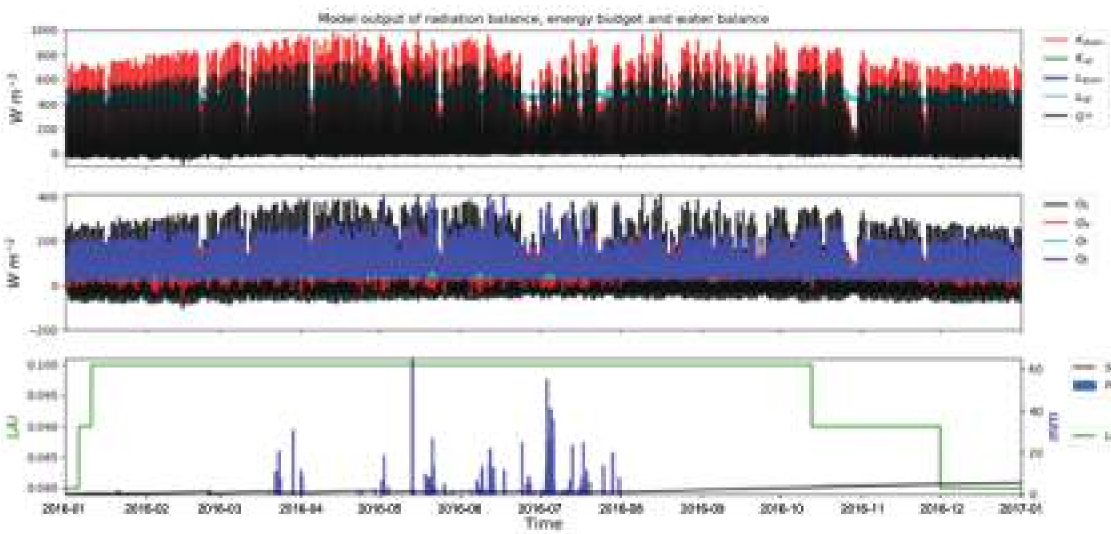


Figure 55: Radiation balance, energy budget, and water balance of the site

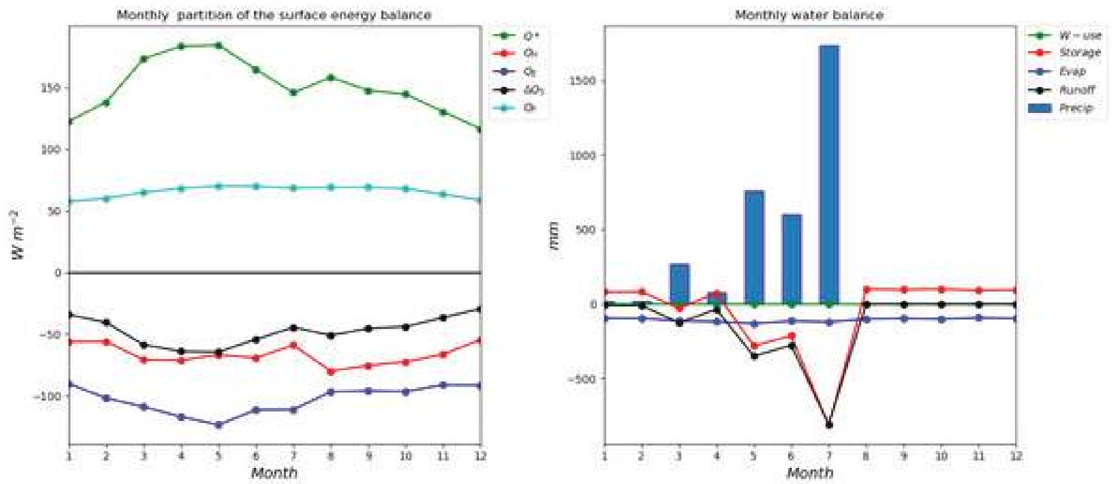


Figure 56: Monthly partition of the surface energy balance and monthly water balance

From scenario 3, the effect of the increase of water body and decreasing the fraction of building an appropriate amount from the existing conditions balance both water runoff and storage. Hence, these could be an ideal combination as a starting point for future urban planning and design intervention.

Chapter 5

Conclusion

5.1 Concluding Remarks

Khatunganj, with a heritage of thousands of years, is losing its former glory as a center of trade and commerce mainly due to urban drainage problems generated by anthropogenic activities. This study investigated the root causes of this problem of urban flooding, and showed that high direct costs and losses are involved related to waterlogging on the parts of the traders. If we consider Khatunganj and its neighboring areas as the extended Khatunganj market, the estimated figure turns out to be a whopping taka 500 crore plus only in the year 2020. The consequences for consumers and retailers should also not be overlooked. It is understood that the direct economic losses and costs due to waterlogging in the year 2020 only for Khatunganj wholesale market was not less than taka 100 crore upto September, 2020. The figures for the last ten years indicate a clear rising trend in losses and costs, which in the near future is expected to increase further mainly due to climate induced changes in rainfall patterns, changes in tidal flooding and the risk sensitivity in the nature of trading.

This study did an extensive analysis of the waterlogging problem in the Khatunganj commercial area. In fact, waterlogging at Khatunganj is a common and recurrent problem. A low rainfall results in inundation in the area and the consequences are huge economic losses in the commercial area. The study aimed to enumerate the vulnerability of the area due to waterlogging. To carry out such analysis, in addition to the economic analysis, a hydrologic-hydraulic model was also developed that gave an inundation scenario, and from the inundation scenario vulnerability of each structure was assessed.

It is evident from hydrologic-hydraulic model that low rainfall (around 15 mm/hr) generates a WL of 2.5 m, whereas average rainfall generates a WL of 3-3.2 m. Such a WL results in inundation of the Khatunganj main road with a water depth of 6 inches to 1 foot. The road level is about 2.9 to 3.1 m. Heavy rainfall with climate change scenario gives around 4.1 m WL, meaning around 1 m (3 ft) depth of water inundation on the road and its vicinity. All structures on both sides of the road go underwater in such a scenario.

Using such an inundation pattern combining with three other factors, namely- proximity to the canal, structure type, and land use type of the area, the vulnerability of the area was enumerated. The vulnerability was classified into four classes - not vulnerable, low, medium, and very vulnerable. With three rainfalls (low, average, and high), the risk profile for the structures was estimated. Most of the structures fall in the medium vulnerable class for all three rainfall cases. In the case of high rainfall, all structures were, to some extent, vulnerable. Water retention options increase in canal capacity, and regular maintenance of the canal is extremely important for managing such a crisis.

The study identifies the appropriate proportion of urban land cover for a given climatic scenario, which could be a guideline for all the relevant agencies for designing and implementing BGI to revitalize the area by addressing the problem of Urban Flooding as BGI network addresses the morphological characteristics and water dynamics of an urban area considering a range of micro and macro levels parameters such as population density, existing grey elements and natural elements like hidden and existing water elements, green corridors. Particularly the study emphasized the increase of 'Urban Blue' as a solution to the waterlogging of Khatunganj.

5.2 Knowledge Sharing

Two knowledge sharing workshops were held in November, 2020 and March 2021. Through these events, useful observations and suggestions were gathered from government officials, personnel of Khatunganj Trade and Industries Association, officials of UNDP, and other stakeholders. These observations and suggestions have been incorporated in the final report. The list of participants for these events are given in Annex 2 & 3

5.3 Action Matrix

Based on the above findings, the following actions, in particular, are suggested to be made by involving the relevant stakeholders in a time bound manner:

Table 5.1: Action Matrix

SL	Issue/ action/ Recommendation	Policy/ Plan/ Regulation	Relevant Agency/ Ministry	Time frame/ priority
1	Revitalizing Chaktai Canal by Demelishing all RCC work from the bottom of Chaktai canal. Widening the canal to allow adequate flow of water to revive bio-diversity.	Long term policy to protect water ecology.	CDA CCC	Immediate
2	Revitalization and reconnection of water-based transportation in the supply-chain by reactivating the chaktai canal as a water transport path by demolishing present bridges over the Chaktai canal and construct a new bridge suitable for navigation under the bridge.	Plan for integrating Chaktai canal with other modes of transport.	CDA CCC BIWTA	Medium-term
3	Vision planning of Khatunganj through Urban blue-green infrastructure (BGI). BGI for Khatunganj needs to include Green: Trees, Shrubs, grass, etc. Blue elements such as rainfall and flood, water-body Man-made interventions, such as permeable pavements, bioswales, retention basins, and constructed wetlands as an integrated whole.	Creating Separate Urban Design policy and act following the principle of "Smart resilient city" using "Big data/ Artificial Intelligence (AI)" to implement Urban blue-green infrastructure (BGI) at the different urban scale	CDA CCC Research Organization, ie. Universities/ Individual researcher on the field of Urban blue-green infrastructure (BGI)	Medium-term
4	Multimodal transport hubs (MTHs) at Khatunganj to integrate Road connection with the waterway	Plan for Multimodal transport hubs (MTHs).	CDA CCC BIWTA BRTA	Long-term

SL	Issue/ action/ Recommendation	Policy/ Plan/ Regulation	Relevant Agency/ Ministry	Time frame/ priority
5	Integrating and generating urban tourism economy by Introducing water-based “Heritage Tourism” at Khatunganj	National Heritage Tourism Planning policy	Bangladesh Parjatan Corporation CDA CCCI	Long-term
6	‘Uploading’ the trade and the inventory on to the eCommerce network at Khatunganj	-	Ministry of Commerce CCCI	Medium-term
7	Responsible waste management practices in terms of source separation, onsite treatment of waste, and recycling center.	A local waste management plan	Traders and sellers of Khatunganj wholesale market	Immediate
8	“Waste to Energy” plant to manage solid waste at City/Local scale.	Long term waste management plan	CDA CCC	Medium-term
9	Proper planning on land use to maintain water retention area in the Chaktai *Khal* Catchment	জলধারা সংরক্ষণ আইন	CDA	Medium-term
10	To increase the water retention capacity of the *Khal* by Dredging of the canal. By widening/ deepening the roadside drain	Plan for lowering water inundation at Khatunganj	CCC	Short-term
11	Maintaining the linkage of drainage network for proper disposal of domestic wastewater and storm water	Drainage regulation of city corporation	CCC	Short-term
12	Regular Maintenance of the canal and drains to keep the canal free from blockage	Drainage regulation of city corporation	CCC	Immediate
13	Dredging of Karnaphuli to reduce the effect of Sea Level Rise due to climate change	Navigation policy of Government	BIWTA/CPA	Short-term
14	Construction of tidal gate at the confluence of Chaktai *khal* and Karnaphuli river	Plan for lowering water inundation problem at Khatunganj	CCC/CDA	Short-term
15	Countrywide LIDAR based land cover data for disaster management and climate change adaption.	National Data collection policy	Bangladesh Space Research and Remote Sensing Organization (SPARRSO)	Long-term

SL	Issue/ action/ Recommendation	Policy/ Plan/ Regulation	Relevant Agency/ Ministry	Time frame/ priority
16	Time-series data on loss of life and wealth related to Hydro-meteorological disaster like Flood, storm surge, etc. should be collected by all government, semi-government, private authorities to project future scenario of the urban area due to disaster. This will help all types of businesses to make an informed decision.	National/Local Data collection policy	All the relevant government authorities, i.e., LGED, Department of Disaster Management (DDM), semi-government and private agencies (NGOs)	
17	Digitize all collected data on the disaster, Displacement, transport, etc., and submit to Central Database, which should be readily available for all the researcher and relevant person/organization.	National Data collection, storage, and distribution policy	Planning Commission Ministry of Planning	Medium-term

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Annex

Annex-1

Survey Questionnaire

Confidential (for research use only)

Study on Economic Impacts of Waterlogging on Local Trade: The Case of Khatunganj Wholesale Commodity Market, Chattogram

1. Enterprise Characteristics

1.1 Name of the enterprise : ....

1.2 Address of the enterprise : ....

1.3 Type of business : .... 1.4 Years of operation : ....Yrs

1.5 Annual turnover (in BDT) : .... 1.6 Investment amount: ....taka

1.7 Name of the respondent : .... 1.8 Designation: ....

1.9 Contact number (optional): ....

2. Genesis, Nature and Extent of the Waterlogging Problem

2.1 Since how long you are facing the problem : ....Yrs

2.2 What is the primary reason for waterlogging in the area? : ....

2.3 What is the secondary reason for waterlogging, if any? : ....

2.4 Is your enterprise affected from waterlogging? : (a) Yes (b) No

2.5 Extent of impact on your enterprise : (a) Severely (b) Moderately

2.6 Nature of impact on your enterprise : (a) Financial (b) Non-financial

2.7 If the answer for Q 2.6 is (a), then answer the following questions [for the last year 2020 only]:

SL	Type of Financial Loss/Impacts	Amount of Loss (Tk.)
1	Loss of capital assets	
2	Damages to stocks	
3	Damages to business properties rather than capital assets	
4	Loss from reduction in sales	
5	Cost on additional investment made to present waterlogging related damages (e.g. raising floor height)	
6	Cost of repairment and renovation	
7	Additional transportation cost	
8	Relocation of business cost, if any	
9	Any other extra cost incurred, ...	

2.8 If the answer for Q 2.6 is (b), then please answer the following questions (for last one year only):

SL	Type of Non-financial Impacts	Type of Answer (Please Tick)	
1	Mental trauma	(a) Yes	(b) No
2	Anxiety/psychological pressure	(a) Yes	(b) No
3	Demotivation of doing business	(a) Yes	(b) No
4	Reputational damage to buyers/consumers	(a) Yes	(b) No
5	Any other, ...	(a) Yes	(b) No

2.9 Can you please give us some idea about the extent of losses that your business had to bear in the last few years?

SL	Type of Financial Loss/Impacts	Amount of Losses (Tk.)								
		2019	2018	2017	2016	2015	2014	2013	2012	2011
1	Loss of capital assets									
2	Damages to stocks									
3	Damages to business properties rather than capital assets									
4	Loss from reduction in sales									
5	Cost on additional investment made to present waterlogging related damages									
6	Cost of repairment and renovation									
7	Additional transportation cost									
8	Relocation of business cost, if any									
9	Any other extra cost incurred									

3. Institutional Issues and Action Plans

3.1 Who, according to you are mainly responsible for the management of ongoing waterlogging problem in city's Khatunganj wholesale market? ....

3.2 Are you happy with the type of intervention made to solve the problem of waterlogging in the Khatunganj wholesale market?

SL	Authority	Type of Answer (Please Tick)	
1	Chattogram Municipal Corporation (CCC)	(a) Yes	(b) No
2	Chattogram Development Authority (CDA)	(a) Yes	(b) No
3	The Chittagong Chamber of Commerce & Industry (CCCI)	(a) Yes	(b) No
4	Khatunganj Trade & Industries Association	(a) Yes	(b) No
5	Individual business enterprises	(a) Yes	(b) No

3.3 What are the main obstacle for a better solution for the ongoing waterlogging problem in the Khatunganj wholesale market of Chattogram? [multiple answer is acceptable here]

SL	Type of Obstacle	Type of Answer (Please Tick)	
1	Lack of interest by the civic authorities for its solution	(a) Yes	(b) No
2	Lack proper planning	(a) Yes	(b) No
3	Lack of availability of the required resources	(a) Yes	(b) No
4	Lack of proper coordination	(a) Yes	(b) No
5	Lack of understanding on the gravity of the problem and its economic consequences	(a) Yes	(b) No
6	Any other, ...	(a) Yes	(b) No

3.4 What, according to you, should be the desired actions by the following authorities in solving the ongoing waterlogging problem in the Khatunganj wholesale market of Chattogram?

SL	Authority	Desired Action
1	Chattogram Municipal Corporation (CCC)	....
2	Chattogram Development Authority (CDA)	....
3	The Chittagong Chamber of Commerce & Industry (CCCI)	....
4	Khatunganj Trade & Industries Association	....
5	Individual business enterprises	....

End of the Survey

Annex-2

Government of the People's Republic of Bangladesh
Bangladesh Planning Commission
Programming Division
National Resilience Programme (Programming Division Part)
Sher-e-Bangla Nagar, Dhaka-1207

Draft final report Sharing Workshop on Economic Impact of Waterlogging on Local Trade
Date: 15 November 2020, Venue: World Trade Center, Agrabad, Chattogram

Participant list

Name	Designation	Organization
Dr. Nurun Nahar	Project Director	NRP PD
Ms. Fatema	Sr. Assistant Chief	Prog. Div.
Arch. Rezaul Karim	Chief City Planner	CCC
Najmul Latif	President	IAB Ctg Chapter
Anjan Shekhar Das	Director	CCCI
Syed M. Tanvir	Director	CCCI
Ahid Siraj Chowdhury	Director	CCCI
Engr. Mohd Farque	Secretary In charge	CCCI
Wasfi Tamim	CEO	BCE
Md. Nurul Anwar	DS	CCCI
Uttam K Das	Asst. Sec.	CCCI
Tariqul Islam	ARO	CCCI
Shibam Baidya	Member	CCCI
Babar Raihan	Member	CCCI
Ahsanullah	CEO	Ktg. Trade Association
Dr. Reaz Mullick	Professor	CUET
Dr. Abu Taib Md. Shahjahan	NRP Consultant	AIUB
Sumaiyah Binte Mamun	Coordination & RA	LGED
Mohammad Jahedul Huq	Planning Specialist, NRP	UNDP
Md. Mokammel Hoque	Chairperson	Hosne Ara Foundation
Md. Hanif	Administrative Assistant	KTSI, Khatunganj

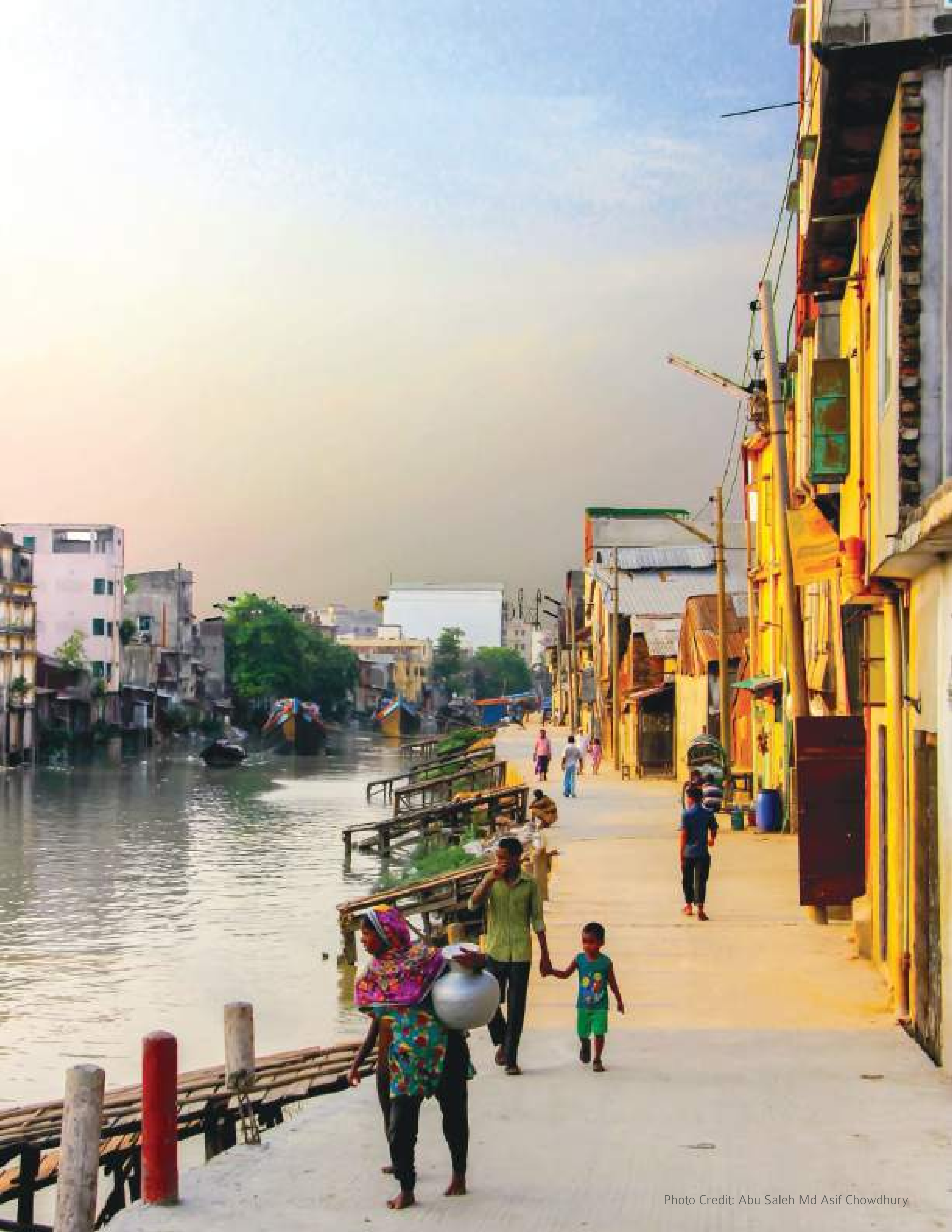
Government of the People's Republic of Bangladesh
Bangladesh Planning Commission
Programming Division
National Resilience Programme (Programming Division Part)
Sher-e-Bangla Nagar, Dhaka-1207

Dissemination Workshop on Study on Economic Impact of Waterlogging on Local Trade:
The Case of Khatunganj Chattogram
Date: 15 March, 2021, Venue: World Trade Center (WTC),
The Chittagong Chamber of Commerce & Industry, Chattogram.

Participant list

Name	Designation	Organization
Mr. Md. Rezaul Karim Chowdhury	Mayor (Chief Guest)	Chattogram City Corporation
Mr. Khandokar Ahsan Hossain	Chief, (Additional Secretary)	Programming Division, Planning Commission
Dr. Nurun Nahar	Join Chief & Project Director	NRP-PD, Planning Commission
Mr. Ahmed Mainuddin	Executive Engineer	LGED, Chattogram
Mr. Md. Shahidul Islam Mridha	Superintendent Engineer	BPDB, Chattogram
Mr. Raiyhan Ferdous Ratan	Assistant Engineer	LGED
Mr. Rajib Das	Executive Engineer	CDA
Eng. Rafiqul Islam	Additional Chief Engineer	Chattogram City Corporation
Mr. Pintu Chakma	Executive Engineer	RHD, Ctg
Mr. Kalam Chowdhury	Public Relation Officer	CCC
Mr. Mostafa Kamal Chowdhury	APS to Mayor	CCC
Mr. Arif Abdullha Khan	Programme Specialist	UNDP
Prof. Dr. Reaz A Mallik	Consultant	NRP/CUET
Dr. AKM Nazrul Islam	Consultant	NRP/DBCE
Mr. Syed M. Tanvir	Vice-President	CCCI
Mr. Mohammad Jahurul Alam	Director	CCCI
Mr. Syed Sagir Ahamed	Director	CCCI
Ms. Sumaiyah Mamun	Consultant (R/A) & Architect	LGED
Mr. Mahfuzul Hoque Shah	Executive Director	CCCI
Eng. S.M. Shahidul Alam	Secretary	IEB
Mr. Farid Uddin Ahmed	President	Chittagong Rice Mills Owners Association

Name	Designation	Organization
Mr. Shawpon Shaha	Vice-President	Chattogram Rice Traders Association
Mr. Mohammad Eddris Mia	President	Amir Market Business Association
Mr. Jahir Uddin Mohammad Babar	Assistant General Secretary	Pulses Mills Business Association
Mr. S.M. Salim	Acting President	Pulses Mills Business Association
Mr. Kamal Mostafa Chowdhury	Raja Corporation	Khatunganj, Chattogram
Mr. Alimul Mostafa Chowdhury	AMC International Company	Asadganj
Alhaz Md. Mohiuddin	General Secretary	Chaktai Khatunganj Arhatdar General Businessmen Welfare Association
Mr. Obaidul Kader Chowdhury	CEO	Mostafa Group
Mr. Gias Uddin	CEO	NETEX Group
Mr. Badrul Hayder Chowdhury	Regional Director	Bangladesh Open University
Mr. Amit Das	Reporter	SA TV
Mr. Shafiq Ahmed Sajjad	Reporter	Channel 24
Mr. Al-Amin Sikder	Reporter	Jamuna TV
Mr. Ali Akbar	Reporter	Bangla Vision
Mr. Masud Milad	Reporter	Prothom Alo
Mr. Dwripayan saha	Bureau Chief	The Daily Star
Mr. Sarowar Ahmed	Reporter	Daily Purberkon
Mr. Mohammad Omar Faruque	Reporter	The Business Standard
Mr. Ali Akbar	C.S	C.C.C
Mr. Stalin Day	Reporter	Bijoy TV
Mr. Sumon Goshamee	Reporter	NTV



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