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Doctoral Dissertation

A Study on Physical Vulnerability to Flooding in Residential Areas and Coping Strategies of Local Community in Eastern Dhaka, Bangladesh

バングラデシュ東部ダッカの住宅地における洪水に対する物理的脆弱性と

コミュニティの対処戦略に関する研究

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Abstract

Dhaka, a mega-city at the forefront of rapid, unplanned urbanization, is considered to be one of the flood-prone cities in the world. The city's eastern fringe, though underdeveloped and low-lying, is experiencing rapid growth as a result of migration, which has compounded the nature and extent of flood vulnerabilities. This study analyzes the relationships between flood damage and the physical characteristics of residential buildings and residents' physical adjustments to buildings to understand flood vulnerability and interventions for building local resilience. The study employed different descriptive analyses, Phi and Cramer's V and Contingency coefficients analytical techniques and cluster analysis to examine the relationships between flood damage and physical characteristics of residential buildings and residents' physical adjustments to buildings in two neighborhoods of Eastern Dhaka.

Two study areas, one in the urban core (Sabujbagh) and the other in the peri-urban area (Khilgaon) of eastern Dhaka were chosen for this research; two mahallas (neighborhoods) in Sabujbagh area, each consisting of 250-500 households and three mahallas (neighborhoods) in Khilgaon area, each consisting of 75-125 households. Two mahallas, Uttor Basabo and Purbo Basabo in Sabujbagh area and Dhitpur, Tamburabad and Nalsata in Khilgaon area were selected for study based on their previous flood experience, settlement history, topography, and physical conditions. Therefore, two different community surveys were undertaken in these 5 neighborhoods (Uttor Basabo: 55 Purbo Basabo: 50 households, Dhitpur: 35 households, Tamburabad: 35 households and Nalsata: 30 households) based on flood damage, 5 major attributes of physical vulnerabilities and residents' physical adjustments to buildings along with demographic and socio-economic data. Descriptive statistical analysis showed that there were statistically significant relationships ($p \leq 0.05$) between flood damage to residential buildings and building typology, the age of the building, land cover conditions, plinth height and residents' physical adjustments to buildings. The relationships between the variables ranged from modest ($p < 0.5$) to moderate ($p < 0.8$). In addition, cluster analysis reveals that the damage extent to buildings is the most significant indicator of physical vulnerability to floods. Buildings older than 20 years and houses with natural materials are likely to suffer high flood damages relative to buildings built less than 10 years and built of durable materials. The study concludes with socioeconomic interventions regarding a targeted and people-centered flood management regime that focuses towards the age of the buildings, the composition of building materials, and the structural quality of houses to build the adaptive capacities of the residents and their long-term resilience to flooding.

This study provides a micro-level understanding of flood vulnerabilities in less consolidated communities of mega-cities. Its findings encourage interventions that respond to the neighborhood context, rather than only general city-level solutions. It suggests integrated community-based flood management that combines investments in drainage infrastructure and maintenance, green spaces and the involvement of residents, community leaders, and institutions to manage flood vulnerabilities. While an emerging body of work emphasizes flood vulnerabilities in cities of developing countries, few accounts for the intersections between physical vulnerability, flood damage, and residents building adjustments. This study provides insights for integrating residential building adjustments into strategies for local flood resilience in low-income peri-urban areas.

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LIST OF ACRONYMS AND ABBREVIATIONS

AAL	Average Annual Loss
ABCB	Australian Building Codes Board
ADB	Asian Development Bank
BBS	Bangladesh Bureau of Statistics
BCA	Building Code of Australia
BDT	Bangladeshi Taka
BNBC	Bangladesh National Building Code
BWDB	Bangladesh Water Development Board
CEGIS	Center for Environmental and Geographic Information Services
CIA	Central Intelligence Agency
CRED	Centre for Research on the Epidemiology of Disasters
DAP	Detailed Area Plan
DCC	Dhaka City Corporation
DFID	Department for International Development
DIT	Dacca Improvement Trust
DMAIUDP	Dhaka Metropolitan Area Integrated Urban Development Project
DMB	Disaster Management Bureau
DMDP	Dhaka Metropolitan Development Plan
DMP	Dacca Master Plan
DND	Dhaka-Narayanganj-Demra
DROP	Disaster Resilience of Place
DSP	Dhaka Structure Plan
EMA	Emergency Management Australia
EPWAPDA	East Pakistan Water and Power Development Authority
ESCAP	Economic and Social Commission for Asia and the Pacific
FAP	Flood Action Plan
FEMA	Federal Emergency Management Agency
FRMS	Flood Risk Management Strategies
GBM	Ganges-Brahmaputra-Meghna
GDP	Gross domestic product
GIS	Geographic Information System
GPCA	Green-area Protection and Coastal Afforestation
GWP	Global Water Partnership
HBRI	Housing and Building Research Institute
HDI	Human Development Index
IECO	International Engineering Company
IPCC	Intergovernmental Panel on Climate Change
ISSMGE	International Society for Soil Mechanics and Geotechnical Engineering
IWM	Institute of Water Modelling
JICA	Japan International Cooperation Agency
MEXT	Ministry of Education, Culture, Sports, Science and Technology
MFAN	Ministry of Foreign Affairs of the Netherlands

MOVE	Methods for the Improvement of Vulnerability Assessment in Europe
MoDMR	Ministry of Disaster Management and Relief
MPO	Master Plan Organization
MSL	Mean Sea Level
NGO	Non-Governmental Organization
NPDM	National Plan for Disaster Management
NWMP	National Water Management Plan
NWPo	National Water Policy
NYU	New York University
OCHA	Office for the Coordination of Humanitarian Affairs
OUA	Outer Urban Area
PWD	Public Works Department
RAJUK	Rajdhani Unnayan Kartripakkha
RDP	Regional Development Planning
SEPA	Scottish Environment Protection Agency
SPSS	Statistical Package for Social Sciences
TRADE	Training Resources and Data Exchange
TSD	Technical Suitability Determinants
UAP	Urban Area Plan
UNDP	United Nations Development Program
UNDRO	United Nations Disaster Relief Co-Ordinator
UNFCCC	United Nations Framework Convention on Climate Change
UNFPA	United Nations Population Fund
UNISDR	United Nations International Strategy for Disaster Reduction
USACE	United States Army Corps of Engineers
USD	United States Dollar
WMO	World Meteorological Organization
WRI	World Resources Institute

CHAPTER ONE

FLOOD IMPACT IN DENSELY POPULATED URBAN AREA

This chapter starts with the background of the research and follows by the research problem, research objective and process. It includes, in brief, the scope and significance of this research, the limitations and the outline of the thesis.

1. Background

Flooding constitutes a major disaster hazard across the world. In the past three decades, more than two billion people have experienced globally by floods, representing nearly 43% of all disasters recorded (Below and Wallemacq, 2018). According to Smith (2001), floods adversely affect around 75 million people globally, claiming over 20,000 lives per year. In 2018 also, floods affected the highest number of people, accounting for 50% of the total affected by 127 major cases and 2879 of death tolls (CRED, 2019). In recent years, the evolving trends of precipitation and higher peak discharges of rivers and canals due to climate change as well as rapid urbanization and continuous changes in land use at flood-prone areas has amplified flood vulnerabilities in many cities (Mitchell, 2003, Field et al., 2012). Due to the planar geomorphology and water availability, people have started to occupy and urbanize the floodplains (Miguez et al., 2015, Tingsanchali, 2012). Thus, the growth in the flood risk zone for several infrastructures as well as human settlements has been increased due to a larger number of inhabitants and facilities (Zevenbergen et al., 2008). Flood vulnerability in the developing countries is underpinned mainly by human development dynamics, less protection and inadequate infrastructure, while climate change impacts reinforce the vulnerability (Ahmed et al., 2018). For instance, in developing countries, settlements have been rapidly expanding in urban areas, and most often in an unplanned manner combined with rapid depletion of natural drainage channels and floodwater retention areas due to the encroachment in those drainage channels and low-lying lands (Khan et al., 2018). As a result, inundation has intensified and become a regular phenomenon in many towns and cities (Adikari et al., 2010).

Floods also increased cities' physical exposure to disaster risks, rendering it as one of the threatening developmental problems in recent days (Fatemi et al., 2020d). The 'Asia and Pacific' region is particularly vulnerable to natural disasters (UN-Habitat, 2015). Several of the large cities (e.g. Jakarta, Manilla, Dhaka, etc.) in the region are vulnerable to flooding as they lie in floodplains of major rivers where inundation is a known threat that occurs regularly (UN-Habitat, 2015). Even though flood disasters vary across the region, a significant and meaningful rise in flood patterns has been demonstrated over the past two decades (Below and Wallemacq, 2018, Dutta and Herath, 2004); worsened by urbanization and spatial patterns, levels of urban poverty, infrastructure, and local capacities. In cities such as Karachi and Yangon, settlements in hazard-prone areas near to centers of employment and services are preferred to safer but distant locations, leading to a continuous cycle of flood damage and repairs after seasonal rains (UN-Habitat, 2015). Therefore, urban flooding tends to become a huge threat to the city, especially the urban core and the peri-urban areas along the river floodplains (Bansal et al., 2015). Thus, this urban flood problem affects the city with a great amount of inconvenience for the people and destruction for the environment and society, resulted in heavy traffic due to waterlogging, often paralyzed daily activities and even, damaged the urban infrastructure causing physical and economic loss. Furthermore, it has been anticipated (Dinh et al., 2012) that with the growing impact of climate change globally, the frequency and magnitude of flooding events will intensify initiating extreme weather events such as extreme precipitation and high river discharge. The flooding events have been increasing worldwide with prolonged duration, high severity and more frequently. In the last two decades (from 2000 to 2019) more than 3199 events are registered (Ritchie and Roser, 2020). The cities with high population growth, rapid urbanization, and affected by climate change impact are experiencing this type of disaster risk (White, 2013, Ward et al., 2017).

Since the effect of climate change was nuanced and uncertain, countermeasures to perennial flooding have been considered as long-term initiatives (Kim et al., 2016). In respect of flood risk management strategies also the scenario should be similar due to increasing extreme precipitation events and high river discharges; and for this, cities should focus on developing resilience to flooding. In this regard, several studies focused on the awareness and response of various communities and groups to flood threats, especially in countries that are vulnerable to floods in Asia, including Bangladesh (Schmuck-Widmann, 1996, Rashid, 2000, Jabeen et al., 2010). In many countries, especially in tropical countries, the recent trend of rainfall events becomes unexpected with a short period of concentration and a substantial amount of damage. Besides, the traditional underground stormwater management systems also become inadequate and frequent to exceed their capacity. Therefore, cities and the city authorities have been experiencing difficulties to control and manage these unexpected complexities. For the state agencies, policy-makers and city planners, the issues regarding flood control, management and even distribution of risk information become very critical. Previously, the focus was on protection from the unavoidable circumstances of the disasters, whereas now the emphasis is on how to cope and prevent the impact of the disaster. This study suggests that the community level initiatives (i.e. community capacity building, community-level interventions along with individual response strategies) should be the key elements to cope, prevent and manage the flood risk.

Besides, community-level flood management plan may be important policy measures to achieve the goal of making a flood-resilient city. Therefore, the purpose of the study is to analyze the flood risk by concentrating response strategies of the individual as well as the community as a whole before, during and after the flooding events. The primary focus here is to study those initiatives, examine the influencing factors and suggest the necessary actions to strengthen their efforts to minimize the flood damage.

2. Problem Statement

Bangladesh is one of the most disaster-prone countries in the world. It is the 10th ranked country with highest disaster risk, according to the recent World Risk Index of 2019 (Mucke et al., 2019). This ranking is informed by its high risk (risk value 18.78) and high vulnerability (57.83) to climate change impacts and weak response capacities (86.13) of both its residents and institutions. Perennial floods are Bangladesh's major hazards and environmental threats -- aggravated by the regular flooding events through the overflow of the 700 rivers, tributaries and distributaries during the monsoon season (Fatemi et al., 2020d). Such water sources occupy nearly 5% of the land and the country are about 22155 km long (Ahmed and Roy, 2007). Bangladesh has the highest population densities with approximately 163 million people (UN, 2019). In turn, the experience of fluvial flooding along with riverbank erosion is common among residents, as a higher percentage of them lives in floodplains (Ferdous et al., 2019, Shajahan and Reja, 2011). Fifteen per cent of its land floods annually on average (Islam et al., 2016). A vast amount of the area of Bangladesh including the Capital City, Dhaka was flooded to an unprecedented degree by six large floods from 1987 to 2017.

Dhaka has become a megacity with 19.6 million people (UN, 2018a). It is surrounded by six peripheral rivers (Tongi Khal to the North, Dhaleshwari to the South, Balu and Sitalakhya on East, Turag and Buriganga on West) (WB, 2015b), which overflows occasionally during the monsoon, leading the area to be prone to seasonal floods. It causes significant damage to buildings and infrastructures both within and outside the cities, particularly the eastern periphery area which is rural and yet to urbanize and fully develop (Lamb, 2014). In Dhaka City, it is estimated that in those most devastating flooding years from 1987 to 2009, about 77% of the city's total area was inundated to depths ranging from 0.3 m to more than 4.5 m (JICA, 1992b, Sayed and Haruyama, 2016). The central part of the City has been developed on high ground with an elevation of 6-8 m above mean sea level (MSL)(Khan et al., 2018). However, the fringe areas, especially the eastern part, located on a slightly low land of 2 m to 6 m above mean sea level, are constantly flooded (Dasgupta et al., 2015). In fact, flash flooding in the streets after heavy rainfall have become regular occurrences in recent years, as the annual rainfall patterns are high in Dhaka, with an average of 1704.4 mm during the monsoon season of May to September (Yankson et al., 2017). The western Dhaka has been protected against the riverine floods by building an embankment since 1991(Bird et al., 2018), whereas the eastern part of Dhaka still suffers from riverine floods due to the absence of flood protection infrastructures. Dasgupta et al. (2015) reported that a proposal of building an embankment along the Balu rivers have been also developed with the western embankment according to the Flood Action Plan (JICA, 1992a) along with the eastern polder with several drainage pumps, but unfortunately it did not construct yet. This region around the capital in the last decade, however, is experiencing high population growth and rapid physical development which caused high concentrations and densities (Bird et al., 2018). The demand for affordable housing from population influx has contributed to the destruction of most of the river banks, diminishing the natural system 's productivity in flood control (Fatemi et al., 2020d).

In addition to valuable insights into various evidence of flood threats on the eastern fringes of Dhaka, these studies offer a wealth of knowledge regarding flood vulnerability. Despite this, existing studies emphasize flood risk assessment and management at the macro-level, although a growing body of theoretical and empirical work in disaster risk reduction reinforces the thinking that disaster risks such as floods are highly localized events that require nuanced understandings at the micro-level, not only to understand existing conditions but the multilayered and interconnected dimensions of physical vulnerability, damage and risk reduction complexity situated in the neighborhood context (Abunyewah et al., 2020, Abunyewah et al., 2019, Amoako, 2016, Amoako, 2018, Seddiky et al., 2020). There is also an overwhelming emphasis on the social and climatological aspects while the physical aspects are either weak or facile.

While an emerging body of work emphasizes flood vulnerabilities in rapidly urbanizing developing cities such as Dhaka, few accounts for the intersections between physical vulnerability, flood damage, and adjustments. Several studies have focused on flood impact in the city of Dhaka, although empirical consideration to eastern fringe is strangely thin (Haque et al., 2012, Barua and van Ast, 2011). Among the few, Haque et al. (2012) for example, show that local stakeholders are concerned with immediate solutions and effective implementation of the adaptation measures designed by the Government. Barua and van Ast (2011) recommended the implementation of previous flood control projects and initiatives for Dhaka through stakeholder engagement and local capacity building. Others, such as Kamal (2013) investigated flood hazard in the eastern fringe area between 1998 and 2004, evaluated the frequency and severity of potential hazards, including the overall damage and risk on a community-scale. Similarly, Gain et al. (2017) also focused on a detailed flood risk assessment incorporating vulnerability assessment, flood hazard maps, and damage estimations to identify priority measures in the flood hazard-prone areas.

Therefore, the central argument in this study is that to strengthen the overall flood risk management and to make a flood-resilient city, the multilayered and interconnected dimensions of physical vulnerability, damage and risk reduction complexity situated in the neighborhood context have to be studied, assessed and promoted to integrate with the macro-level risk management strategies. To this end, the following research questions directed the study:

- How do elements of the built environment, especially the residential buildings, damage by the impact of flood hazard?

- How do the individual and the community respond to cope, control and manage the flood damage of their houses?

3. Objectives of the Study

In this research, the physical attributes of residential buildings have been analyzed that impact flood damage, and physical adjustments (as coping strategies) to reduce flood risks and its effect of flood damage. Therefore, the primary focus was on physical vulnerability, without considering the social or cultural setting. Findings of this research will further advance existing knowledge and policy by providing a micro-level understanding of individual building's vulnerability to floods and physical responses to develop an integrated flood risk management strategy to reduce flood vulnerabilities in rapidly urbanizing cities. Specifically, the objectives of this research are the following:

- To determine the causative factors of flood hazard and the damage extent on the residential buildings of the particular flood-prone area.
- To examine the impact impounding factors influencing physical vulnerability and the correlation among those variables.
- To analyze the micro-level understanding of individual building's vulnerability to floods and physical responses to develop an integrated flood management strategy.

4. Scope

The case study areas, in the eastern fringe of Dhaka, are recorded as two very highly flood-affected zones that are exposed towards both riverine and local or overland flood (see section 3.2 for details). One of the areas has been selected near the city core of the capital and the other area has been chosen near the eastern boundary of the city, the neighborhood developed in the floodplains along the river. But both the area is in the administrative jurisdiction of the Dhaka City Corporation (DCC)—the metropolitan area. Both the areas have been developed for the residential purpose and the selection was based on the age of settlement, their previous experience with flooding and physical conditions (geo-morphological condition, drainage, road network).

5. Significance of the Study

The methods of vulnerability assessment for the buildings and infrastructure have been progressed recently for earthquake hazards (Lang and Bachmann, 2004, Mück et al., 2013), tsunami hazards (Sambah and Miura, 2013, Dall'Osso et al., 2009) and even, volcanic hazards (Jenkins et al., 2013, Zuccaro et al., 2008). Very few case studies (Sagala, 2006, Kelman, 2003) have described the physical vulnerability to flooding, whereas in most cases of vulnerability assessment, several researchers emphasized on social vulnerability (Vincent, 2004, King and MacGregor, 2000). In the context of Dhaka and even, Bangladesh, the number of studies in this regard tends to be very insignificant. Taking cognizance of this existing gap, this study investigates the flood damage and vulnerability of residential buildings, as well as physical responses at the neighborhoods in the eastern fringe of Dhaka.

While an emerging body of work emphasizes flood vulnerabilities in rapidly urbanizing developing cities, few accounts for the intersections between physical vulnerability, adjustments and flood damage. More so, the rural-urban interface zones, where populations are consolidating in flood-prone areas are rarely considered. In this study, the flood vulnerability context has been examined to identify the relationship between the physical attribute of residential buildings, adjustments and flood damage. The findings provide an important entry point for integrating physical elements into building coping capacities as well as the need to technically support local initiatives for flood resilience, management and control projects in the urban core and also peri-urban areas. Therefore, this study provides a micro-level understanding of flood vulnerabilities in less consolidated communities of mega-cities. Its findings encourage interventions that respond to the neighborhood context, rather than only general city-level solutions. It suggests integrated community-based flood management that combines investments in drainage infrastructure and maintenance, green spaces and the involvement of residents, community leaders, and institutions to manage flood vulnerabilities.

This study can be a model study as well as a blueprint of physical vulnerability assessment of flood-affected communities in Dhaka as well as Bangladesh. It investigated the flood damage to residential buildings at the community level and identified the response strategies embraced by the flood victims. A broad picture of active adaptation behavior directed towards specific types of disasters and severity can be projected from this study. This will even offer insight for policy-makers involved with disaster management and even, climate change adaptation. As Bangladesh is one of the countries most affected by natural disasters, especially hydro-meteorological hazards, this study can be beneficial to the growing body of theoretical and empirical work in disaster risk reduction worldwide. This study develops a simple method to analyze and examine the physical damage due to flooding in two contextually different highly flood-damaged neighborhood in response to perennial flooding events in Dhaka. Empirical methods have been applied to collect information related to flood damage of their houses and documented their real-life experience of before, during and after the flood. By understanding their individual and often collective actions, the local government organizations can engage appropriately and efficiently in the time of their need. Thus, this research-model will also support the state-agencies to develop a database to systematize their policies and actions to mitigate the vulnerability of the community—from the micro level to the macro level.

Lastly, this study concluded with some recommendations to strengthen the organizational capacity of the community. To enrich their community management skills, it introduced some community interventions, however, in the context of Dhaka, Bangladesh and to improve individual's technical knowledge to employ more flood-resilient strategies in their buildings, this study proposed a few building design-related interventions.

6. Previous Studies

Since the devastating flood of 1998, there have been several studies on flood damage in the city of Dhaka ((Mohit and Akhter, 2000, Gain et al., 2015, Khan et al., 2018), flood hazard assessment (Dewan et al., 2007, Masood and Takeuchi, 2012, Kamal, 2013, Thiele-Eich et al., 2015), flood management strategies (Faisal et al., 1999, Barua and van Ast, 2011, Haque et al., 2012) and coping strategies (Rashid, 2000, Jabeen et al., 2010, Braun and Aßheuer, 2011, Aßheuer et al., 2013) play a significant role to investigate different characteristics of flood in Dhaka context. However, very few have focused on the eastern fringe of the city core.

For example, Haque et al (2012) analyzed counter-measures and adaptive initiatives to mitigate flood risks at the eastern fringe of Dhaka and revealed that local actors are more concerned with an immediate solution and effective implementation of the adaptation initiatives designed by the Government, with less emphasis on micro-level approaches. Barua and Ast (2011) studied floodwater management strategies during the flooding of Dhaka in the rainy season. They recommended the implementation of previous flood control projects and initiatives for Dhaka, and to improve the governments' collaboration with the local people and all other related stakeholders and last of all, to strengthen local governance functions with a proper institutional framework. In another study, Kamal (2013) investigated the flood hazard which occurred in the eastern fringe area during 1998 and 2004 to clarify the systematic process, frequency and severity of potential hazards on a community level. An effective process has been followed for damage calculation using Geographic Information System (GIS) and risk assessment which can be applied in other parts of Dhaka city. In a similar type of research, Dewan et al. (2005) also developed a flood hazard map and assessed the flood risk using Geographic Information System (GIS). Moreover, Gain et al (2015) also have focused on a detailed assessment of flood risk which included vulnerability assessment, flood hazard maps along with tangible, intangible direct, and indirect, damage estimations. This study provides the estimation of total costs with their social and physical drivers, which should help identify priority measures in vulnerable areas. Learning from these previous research works provide important insights into different aspects of the eastern fringe area of Dhaka city. Braun and Aßheuer (2011), and Rashid (2000), though focused on the coping mechanisms of the low-income group in Dhaka, but those studies were based on socio-economic coping rather than physical coping strategies.

Overall, in these previous studies discuss, flood risk assessment, flood management strategies and coping strategies are discussed on the macro-level; whereas none of these studies explores and consider, at the micro-level, except Jabeen et al. (2010). Therefore, this study focused on the flood risk and damage assessment for physical structures, assessment on vulnerabilities and physical responses at the individual household or local level.

7. Limitations of the Study

Though several interesting results in terms of physical and behavioral aspects of flood victims have been analyzed, some difficulties have also been experienced to properly perform the fieldworks.

- The detailed data for the buildings of the peri-urban areas was not available due to the absence of detailed satellite imagery. Even the collected polyline shapefile was not updated, it was generated during the fieldwork.
- The questionnaire survey period was quite short, in practice 4 weeks per fieldwork. The research is on the physical and social aspects of the flood victims based on their response. The researcher felt that a certain period was needed for building a strong relationship to get better results. Moreover, the damage value of the buildings has not collected, as the respondents did not confirm the actual damage loss. It could not resolve within a short period of survey time.
- The study is designed based on the memory and experience of the flood victims, therefore hydrological and hydraulic sensitivity analyses are beyond the scope of this current study. The focus of the study was understanding flood vulnerability from a socio-ecological perspective by relying on residents' experiences and responses to flooding. This research analyzed the methodologies used by Amoako (2018) to document flood disasters responses using field observations, informal interactions, group discussions and mini-workshops. Jabeen et al. (2010) have used the similar combination of physical measurement of houses, sketches of house modifications, and livelihood assessments to expose the physical, social and economic implications of flood response strategies. Often integrated into the empirical flood study methods, these mechanisms offer insights into experiential components of flood disasters to explain the underpinnings behind quantitative results in the analytical method of flood vulnerability and damage assessment (Fatemi et al., 2020d).

8. Structure of the Dissertation

This dissertation comprises of seven chapters. Each chapter of this dissertation intertwines important aspects to organize the narrative of the research.

Chapter 1 provides a short background of the study depicting the global flood risk scenario, followed by the exposure, flood damage and vulnerability condition of Dhaka. It contains the research objectives and research questions to be addressed and lastly, the framework to conduct this research.

Chapter 2 provides a critical theoretical and conceptual review of determinants of disaster risk, flood as a disaster, exposure, vulnerability and coping strategies. The concepts, theories and models have been included here to support the study and understand the theoretical basis.

Chapter 3 provides a detailed narration of the methodological approach employed at the various stages, starting from pre-fieldwork to post-fieldwork. It also includes the methods adopted in data collection and analysis.

Chapter 4 presents the contextual evidence of the study area. The flood occurrences from the historical perspective of Bangladesh and also Dhaka, the vulnerability and the causes of flooding specifically in Dhaka has been reported. The national and city-level policies and plans regarding flood control and management have also been discussed to introduce the extent of integrated community-level initiatives in those policies.

Chapters 5 and 6 incorporates the analyses of empirical data obtained from the field works. Chapter 5 explores the physical vulnerability assessment, analysis of the factor influencing vulnerability and response strategies (building adjustments) at two neighborhoods of the urban core in eastern Dhaka. Chapter 6 examines the similar aspects at three neighborhoods of peri-urban areas of eastern Dhaka. In this chapter, the interconnection of the variables has also been established.

Chapter 7 is the final chapter that summarizes the findings obtained from the whole study and identifies the suggestions and interventions to make a flood-resilient community in Dhaka. The research process has been included in Figure 1.1.

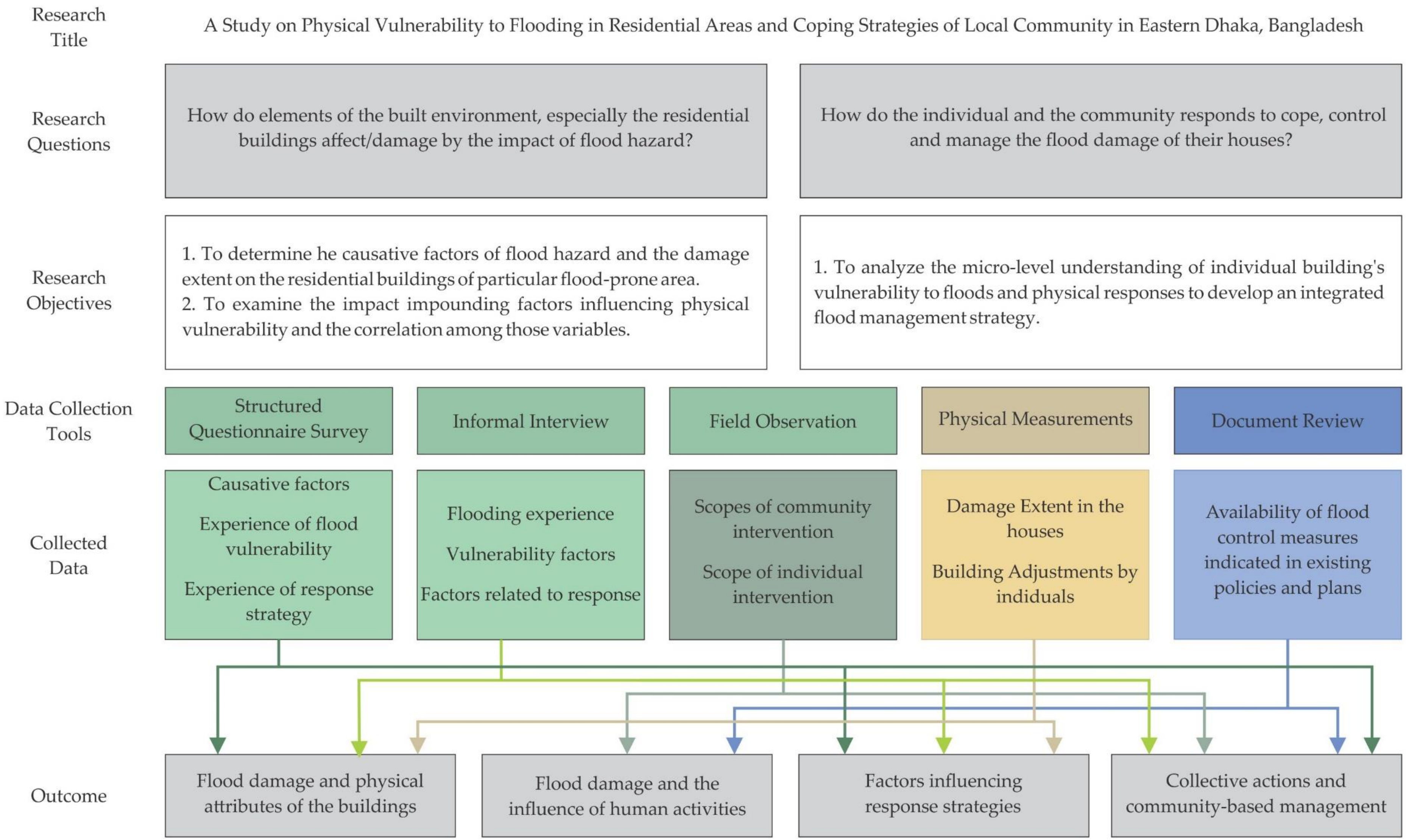


Figure 1. 1 Research Process

THEORETICAL FRAMEWORK: PHYSICAL VULNERABILITY TO FLOODING AND LOCAL COPING STRATEGIES

1. Introduction

Following the background to this study in the previous chapter, this chapter relates to a literature discussion of the main theories, concepts, and practices that underpin this research. This chapter will start with a discussion on the impacts of the flood on buildings and physical infrastructures. Then, to have a clear idea of physical vulnerability, the definitions and interactions of the key vulnerability terms are studied. Subsequently, analyzing several previous case studies, indicators of physical vulnerability to flooding, the assessment and methods for computation of the flood physical vulnerability are discussed. In addition, multiple hypotheses will be discussed on local coping mechanisms and the possible contributing factors in the type of coping mechanism in the community. It is also examined the integration of flood physical vulnerability with a local coping mechanism. Finally, it will discuss the factors, role and forms of community participation to control and manage flood risk. Therefore, the core idea of this section is to establish a framework in which these theories and literature review will ground the study and support the discussion of findings in later chapters.

2. Defining Determinants of Disaster Risk

2.1. Natural Hazard and Disaster Risk

Hazards can be described as the phenomena or physical events that cause potential damage, or human activities which cause an impact on human life, property damage, social and economic disruption, along with huge environmental degradation (Makoka and Kaplan, 2005). According to IPCC (2012)[p. 560], *"The potential occurrence of a natural or human-induced physical event that may cause loss of life, injury, or other health impacts, as well as damage and loss to property, infrastructure, livelihoods, service provision, and environmental resources."* Keller and DeVecchio (2015) used the terms such as, *'hazard, disaster and catastrophe'* through the interpretation of the interaction of humans with natural events like earthquakes, volcanoes, floods and wildfires. Similarly, UNISDR (2004) [p. 6], depicted that *''although we call droughts, floods, earthquakes and wildfires 'disasters' because of the devastating impact they have on communities, they are not in themselves disasters but are instead natural hazards – which have the potential to become disasters, especially when they strike unprepared communities or environmentally degraded area''*. A hazard is, therefore, a natural process which threatens human life and properties, whereas the impact of a hazard on society, is usually termed as a disaster through the property damage and injury or loss of life. When the human environment intersects with the natural phenomena like floods, earthquakes, wildfires and volcanoes by a hazard risk is created and thus, a natural disaster may result. For many years, physical damage, economic disruption, and other significant impacts to an entire community can be resulted due to a hazard, which is conceptually shown in Figure 2. 1 by FEMA (2013).

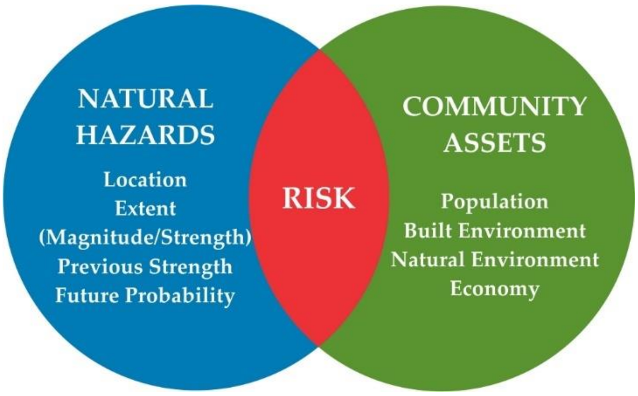


Figure 2. 1 The Concept of Risk as to the Relationship between Hazards and Community Assets
Source: FEMA (2013)

Burton and Kates (1964) presented one of the very first definitions regarding natural hazard as *"(t)hose elements in the physical environment (which are) harmful to man and caused by forces extraneous to him"*. Therefore, hazard involves the potentially harmful effect on the property, health, and even life of an individual; on the society as a whole or the environment (Nadim, 2013). Numerous disciplines and schools of thought have defined and applied the term hazard in different ways, e.g., EMA (1998); TRADE (1999); ISSMGE (2004); UNISDR (2009); IPCC (2012). However, general consensus depicted hazard as an important determinant of risk rather termed it as synonymous with risk (Nadim, 2013). United Kingdom's Royal Society (Warner, 1992) described the risk as 'the probability that a particular adverse event occurs during a stated period of time, or results from a particular challenge'. However, UNISDR (UN, 2016) defined disaster risk by *"the potential loss of life, injury, destroyed or damaged assets which could occur to a system, society or a community in a specific period of time, determined probabilistically as a function of hazard, exposure, vulnerability and capacity"*. Hazards thus affect communities or elements at risk as to the external factors, whereas vulnerabilities impact internal causes as to the turn of hazards into disasters (Figure 2. 2). In other words, vulnerabilities have been established by the impacts of a hazard on society or element at risk (Birkmann, 2006b).

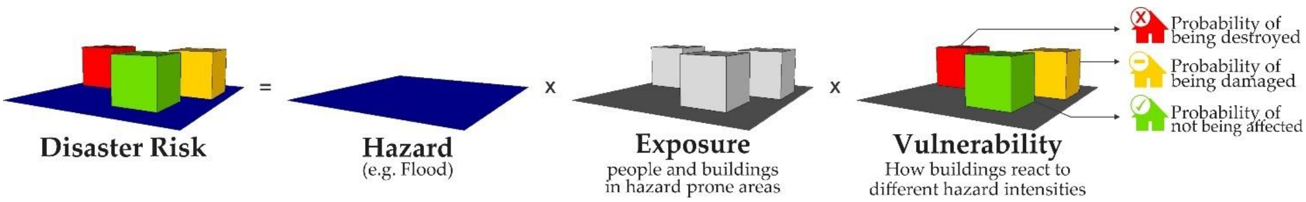


Figure 2. 2 The Concept of Risk as to the Relationship between Hazards, Exposure and Vulnerability (adopted from IDMC—Internal Displacement Monitoring Centre)

The seven distinctive characteristics of natural hazards have been defined by Albala-Bertrand (1993), irrespective of their origin: (a) magnitude, (b) frequency, (c) duration, (d) areal extent, (e) spatial dispersion pattern, (f) speed of onset and (g) regularity. Regarding direct damages and indirect losses, different hazards have different consequences. The effect of natural disasters is somewhat different from place to place. In densely populated regions, the effects can be more extreme than in less populated areas (Vilimek and Spilkova, 2009). Contrariwise, magnitude wise, large-scale events cause more damage, while small-scale events usually cause less damage. But fortunately, large-scale events typically coincide with low frequency and small-scale events are very frequent (Regmi et al., 2013). Alcántara-Ayala (2002) deals with natural hazards as these reflect events which cause harm not only to the physical and social spheres when they occur but also to the long-term effects due to their associated consequences. According to CRED (2015), as shown in Table 2. 1, natural hazards are categorized into subgroups as (1) Geophysical hazards; (2) Meteorological hazards; (3) Hydrological hazards; (4) Climatological hazards; (5) Biological hazards; and (6) Extraterrestrial hazards.

Table 2. 1 Definition and Classification of Natural Hazards (CRED, 2015, Shen and Hwang, 2019)

Classification	Definition	Disaster type
Geophysical	A hazard initiating from the earth. This hazard is synonymous with geology.	Earthquake, Volcanic activity
Meteorological	A hazard that lasts from minutes to days because of short-lived, micro-scalable, extreme environmental and atmospheric conditions.	Extreme Temperature, Fog, Storm
Hydrological	A hazard that occurs due to the occurrence, distribution and movement of surface and subsurface saltwater and freshwater.	Flood, Landslide, Wave action
Climatological	A hazard posed by long-term, mesoscale and macro-scale cycles from intra-seasonal to multi-decadal climate variability of the atmosphere.	Drought, Extreme Temperature, Wildfire
Biological	A hazard from the exposure to living organisms and their poisonous substances (e.g., venom, mold) or vector-borne diseases.	Epidemic, Insect infestation
Extraterrestrial	A hazard caused by asteroids, meteoroids, and that impact the Earth's surfaces, and affect the Earth's magnetosphere, ionosphere, and thermosphere	Impact, Space weather

Over the past decade, on average, approximately 60,000 people worldwide died per year from natural disasters (CRED, 2019). It accounted for 0.1% of global deaths, however, which ranges from 0.01% to 0.4% of total deaths and highly variable to large magnitude events (Ritchie and Roser, 2020). Over the 20th century, a significant decline has been observed in global deaths from natural disasters (Shen and Hwang, 2019). In detail, the estimated annual mortality rate was 400,000 to 500,000 in the early 1900s, along with a marked decline of noticed at least five times lower than these peaks with less than 100,000 from 1950 to early 2000s (CRED, 2019). Historically, a large number of deaths was detected due to floods, droughts, and earthquakes (Ritchie and

Roser, 2020). During the 1970s, about 69 natural disasters per year were recorded globally, and by the 2000s had increased to 350 per year (UN, 2011). In 2019, the worldwide recorded numbers of natural disasters were 361 (Ritchie and Roser, 2020). In the 21st century, including in 2019, Flooding events (170 events) have affected more individuals than any other type of disaster (CRED, 2019). It has corresponded with the projection of the World Economic and Social Survey 2008 (UN, 2008)[p. 81], in which the severity of hydro-meteorological disasters was stressed to *"pose a greater threat of becoming large-scale (catastrophic) disasters and also account for much of the rising trend of reported disasters in recent decades"*. In this research also, the main focus is on flood risk, physical damage and vulnerability.

As it has been mentioned above that a hazard turns into a disaster when an extreme event causes substantial damage and overwhelms peoples' capacity to cope and respond. As an unequivocal development issue, Dayton-Johnson (2006) highlighted natural hazards for the following five reasons:

- First, natural disasters have been disproportionately impacted the developing countries, with an even higher incidence of the death toll.
- Second, the poor are the primary victims of natural disasters, in which disadvantaged countries or households within a particular country are alluded to in the word 'Poor.' Hence, United Nations Development Program report (UNDP, 2004) stated that although just 11% people are vulnerable to natural hazards live in 'low-human development' countries, but constitute more than 53% of deaths from disasters. Similarly, the recent United Nations Development Program report (UNDP, 2019) stated that *"People in low human development countries are 10 times more likely than people in very high human development countries to die due to natural hazards leading to disasters. And the relative cost (as a percentage of GDP) of disasters is about four times lower in very high human development countries than in other countries"*.
- Third, the growth can be dampened by natural disasters, through the destruction of capital and diversion of resources towards relief and reconstruction.
- Fourth, human well-being can be severely damaged by natural disasters, more generally, with the weakening of households' savings and possessions.
- Fifth, and finally, development policy regarding natural disasters— both domestic as well as international— will credibly lead to reduce the impact on growth, poverty and welfare.

2.2. Exposure to Natural Hazards

While investigating the impacts of pre-disaster conditions in combination current circumstances on disasters, Lindell et al. (2006) stated that a disaster may be assessed by defining three pre-impact factors: hazard exposure, physical vulnerability, and social vulnerability. According to Kapucu and Özerdem (2011), *"A community's hazard exposure is determined by the geographical location of its people and the events that threaten their lives"*. UNISDR (2009) identified exposure as *"People, property, systems, or other elements present in hazard zones that are thereby* *subject to potential losses".* later, exposure has been defined as "the situation of people, infrastructure, housing, production capacities and other tangible human assets located in hazard-prone areas" (UN, 2016). Emphasis has been given to understand exposure to formulate the policies and actions to reduce disaster risk according to UN (2015), as also emphasized by the Sendai Framework for Disaster Risk Reduction (UNISDR, 2015b): *"Policies and practices for disaster risk management should be based on an understanding of disaster risk in all its dimensions of vulnerability, capacity, exposure of persons and assets, hazard characteristics and the environment".*

Generally, the term 'exposure' is used to describe the elements of community and the environment with the respective processes which are subjected to expose towards a particular danger or to a range of potentially hazardous phenomena (Birkmann, 2013). It implies the exposure can be determined by the spatial and temporal patterns (Birkmann et al., 2014). Temporal dimensions of exposure concern with the questions of when and how long an element at risk may be exposed to a particular hazard, whereas the spatial components of exposure concern with the question of how much area is exposed to a particular hazard relative to the overall area of the entity exposed such as a community, city, or even country (Birkmann, 2013). Therefore, exposure is seen as a component of vulnerability and respectively risk, due to its contribution to the degree of impacts caused by a hazard event (Birkmann, 2006b).

United Nations' Global Humanitarian Overview 2019 report (OCHA, 2019a) [p.15] state that, *"Between 2014 and 2017, disasters caused by natural hazards affected more than 870 million people per year in more than 160 countries and territories around the world, causing loss of life, devastating livelihoods, and forcing about 20 million people from their homes each year".* Contrariwise, UNFPA (2018) indicated 'Asia and the Pacific' region as the most disaster-prone region in the global context, with about 45 per cent of the world's natural disasters happening in these areas and more than 75 per cent of those impacted by natural disasters worldwide live in these areas. As stated in the Asia-Pacific Disaster Report 2019, this rise in disaster risks has culminated in the economic development of this area, combined with increasing urbanization and rapid population growth (ESCAP, 2019). For example, previous studies (Herold and Mouton, 2011, Shaw et al., 2013) revealed that between 1970 and 2010, the number of exposed population per year to flooding more than doubled from 29.5 million to 63.8 million.

In the case of climate-related hazards (ESCAP, 2019), people along the coastal region are vulnerable to cyclones and storm surges, especially in major cities in North-East Asia (i.e. the Republic of Korea, Japan, and the east coast of China), South Asia (Bangladesh, the Maldives and coastal areas of India) and also in South-East Asia (the Philippines, Indonesia, and Timor-Leste). Floods also influence people in the Ganges-Brahmaputra-Meghna Basin in South and South-West Asia, and in the Mekong River Basin in South-East Asia (ESCAP, 2019) (see Figure 2. 3).

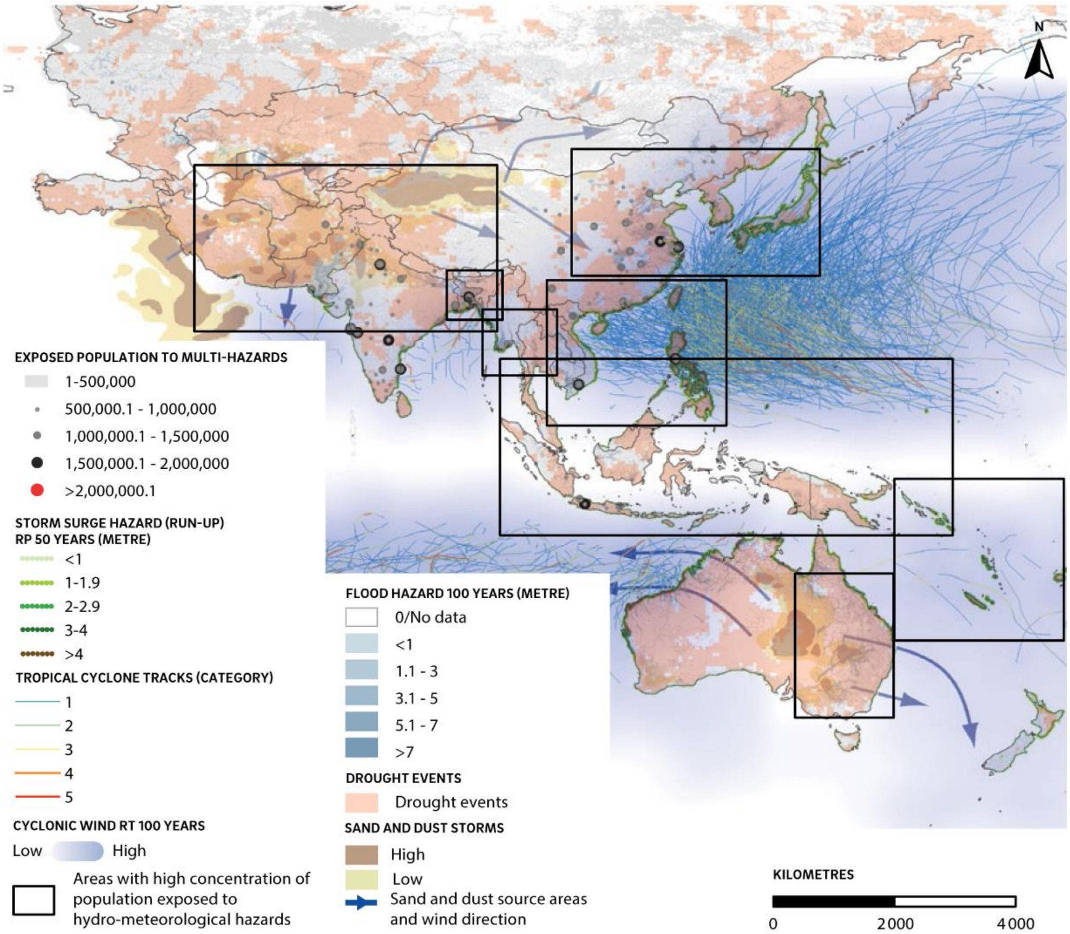


Figure 2. 3 Concentration of Exposed Population to Climate-Related Hazards
Source: (ESCAP, 2019)

The World Risk Index 2019 (Mucke et al., 2019) pointed out that exposure is determined by the number of citizens vulnerable to or affected by five forms of natural disasters: earthquakes, storms, floods, droughts and sea-level rise. Globally, four out of the 15 countries most exposed to natural disasters are from Asia and the Pacific, while Brunei Darussalam (Rank 4), the Philippines (Rank 7), Japan (Rank 8) and Bangladesh (Rank 15) are identified as highly exposed countries (Table 2. 2).

Table 2. 2 Top 15 Most Exposed Countries to Natural Hazards Worldwide
Source: (Mucke et al., 2019)

Country	Exposure	Rank	Country	Exposure	Rank
Vanuatu	99.88	1	Guatemala	38.56	9
Antigua and Barbuda	69.95	2	Fiji	38.43	10
Tonga	61.41	3	Cape Verde	38.26	11
Brunei Darussalam	57.62	4	Uruguay	36.03	12
Solomon Islands	48.31	5	Chile	34.32	13
Guyana	44.98	6	Papua New Guinea	32.54	14
Philippines	41.93	7	**Bangladesh**	**32.48**	**15**
Japan	38.94	8			

2.3. Revealing the Vulnerability of People and Places

2.3.1. Vulnerability to Natural Hazards

Vulnerability is considered as 'the predisposition to incur losses and thus the component that has the potential to transform a natural hazard into a disaster' (Formetta and Feyen, 2019). Pelling (2012) (p.5) states that *"vulnerability denotes exposure to risk and an inability to avoid or absorb potential harm"*. The IPCC (2014)(p.5) defines *"vulnerability as the propensity or predisposition to be adversely affected which encompasses a variety of concepts and elements including sensitivity or susceptibility to harm and lack of capacity to cope and adapt"*. Previously, vulnerability characterized by physical susceptibility only; however, with a more detailed and clear understanding of this concept, now it includes susceptibility, adaptive capacity, coping capacity, exposure, social inequalities, and economic, physical, and institutional weaknesses (Bender, 2002, Birkmann, 2007). Despite the myriad of vulnerability definitions, most capture the notion of damage and impact, possible loss, threat, risk and stress (Harley et al., 2008). Vulnerability also comprises often requires a set of attributes where conditions transform into susceptibility to impacts (Lewis, 1999), which reflects on the characteristics of a group or an individual in terms of their capacity to anticipate, cope with, resist and recover from the shocks induced by natural hazards (Wisner et al., 2003). Vulnerability often has a link with a community or system 's features and circumstances; things that are susceptible to hazard and causing damage in a community or system.

Several common principles have emerged (Cutter, 2013), through the study of numerous meanings, structures, conceptual models, and evaluation techniques to understand vulnerability (Turner et al., 2003, Wisner et al., 2003, Adger, 2006, Eakin and Luers, 2006, Kasperson et al., 2014):

- First, in view of a social-ecological perspective, the vulnerability has been assessed. Therefore, it can be argued that hazards cannot be generated through the natural processes only by themselves, but the interaction with the human system is likely to trigger damage, and eventually, the vulnerability to the natural hazard has resulted.
- Second, place-based studies are clearly recognized and developing importance in examining vulnerability.
- Finally, through the lens of an equity concern, vulnerability is examined, in which what is vulnerable is as important as who is vulnerable.

Cutter (2013) has acknowledged a variety of discrepancies in research on the root factors of vulnerability. According to Alexander (2018), exposure to the hazard as the causal structure for some studies is often determined in terms of proximity. However, Wisner et al. (2003) proposed a new perspective, implying that vulnerability is induced by the underlying societal factors that give rise to unsafe conditions. Incorporating the elements from both, the third perspective has been developed which suggests that vulnerability requires both the exposure from the physical environment and the social response and how both are created locally to create hazardousness of places (Burton and Hewitt, 1971, Cutter et al., 2000, Turner et al., 2003). Conditions that engender vulnerability include improper design and construction of buildings, insufficient protection of properties, lack of public information and understanding, limited official recognition of risks and preparedness strategies, and disregard for sound environmental management (UNISDR, 2009, Mitchell and Garibay, 2011). Vulnerability is dynamic in time and space, is risk-specific and relies on a variety of variables such as economic institutional, social and environmental (Formetta and Feyen, 2019).

Global Humanitarian Overview 2019 Report (OCHA, 2019a) stated 'Asia and the Pacific' as the most disaster-prone areas of the world that remain vulnerable to both slow-onset and sudden disasters. The high interaction between risks induced by the disasters, inequalities in income opportunity, and deprivation renders this area more vulnerable than all other areas of the world (ESCAP, 2019). According to the Global Humanitarian Overview 2019 Report, this region experienced 236 cases of severe flooding, 217 storms and cyclones, and 55 earthquakes from 2014 to 2017, impacting 650 million inhabitants and causing about 33,000 deaths (OCHA, 2019a). The countries that are most likely to continue to be impacted with the combined vulnerabilities in this region include Bangladesh, Viet Nam, Philippines, Tajikistan, Armenia, Timur-Leste, Cambodia, Azerbaijan, Indonesia, Turkey, Myanmar, Afghanistan, Nepal and Pakistan (ESCAP, 2019). Figure 2. 4 shows the overall proportion of the vulnerable population at multi-hazard risk in these 14 Asia-Pacific countries.

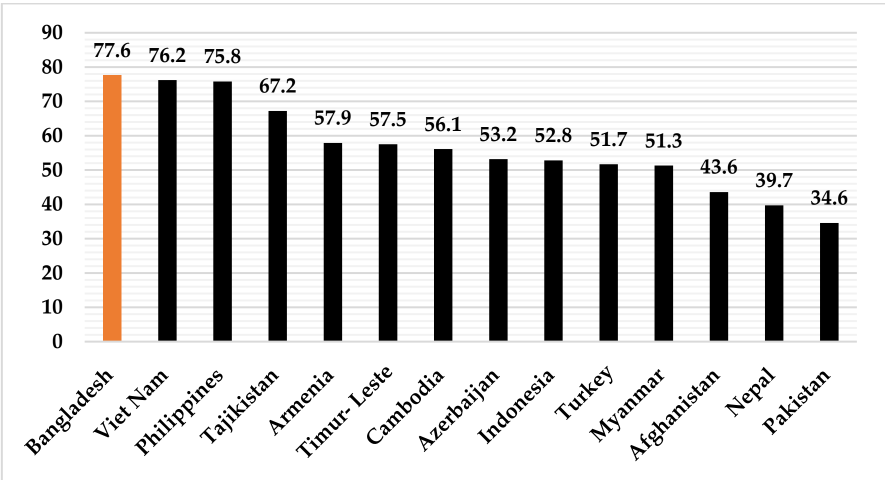


Figure 2. 4 Proportion of Population Living in High-Multi-Hazard-Risk Areas
Source: (ESCAP, 2019)

In the Asia-Pacific Disaster Report, 2019 (ESCAP, 2019) reveals that, for example, within South Asia, the most vulnerable communities live in the Ganges-Brahmaputra-Meghna (GBM) basin that is shared by Bangladesh, Nepal, India and Bhutan, and parts of Pakistan and Afghanistan. For this analysis, high population index, low human development index (HDI) and high land degradation or high-hazard risk were amalgamated to identify the socioeconomic-hazard risk areas among this subregion (Figure 2. 5).

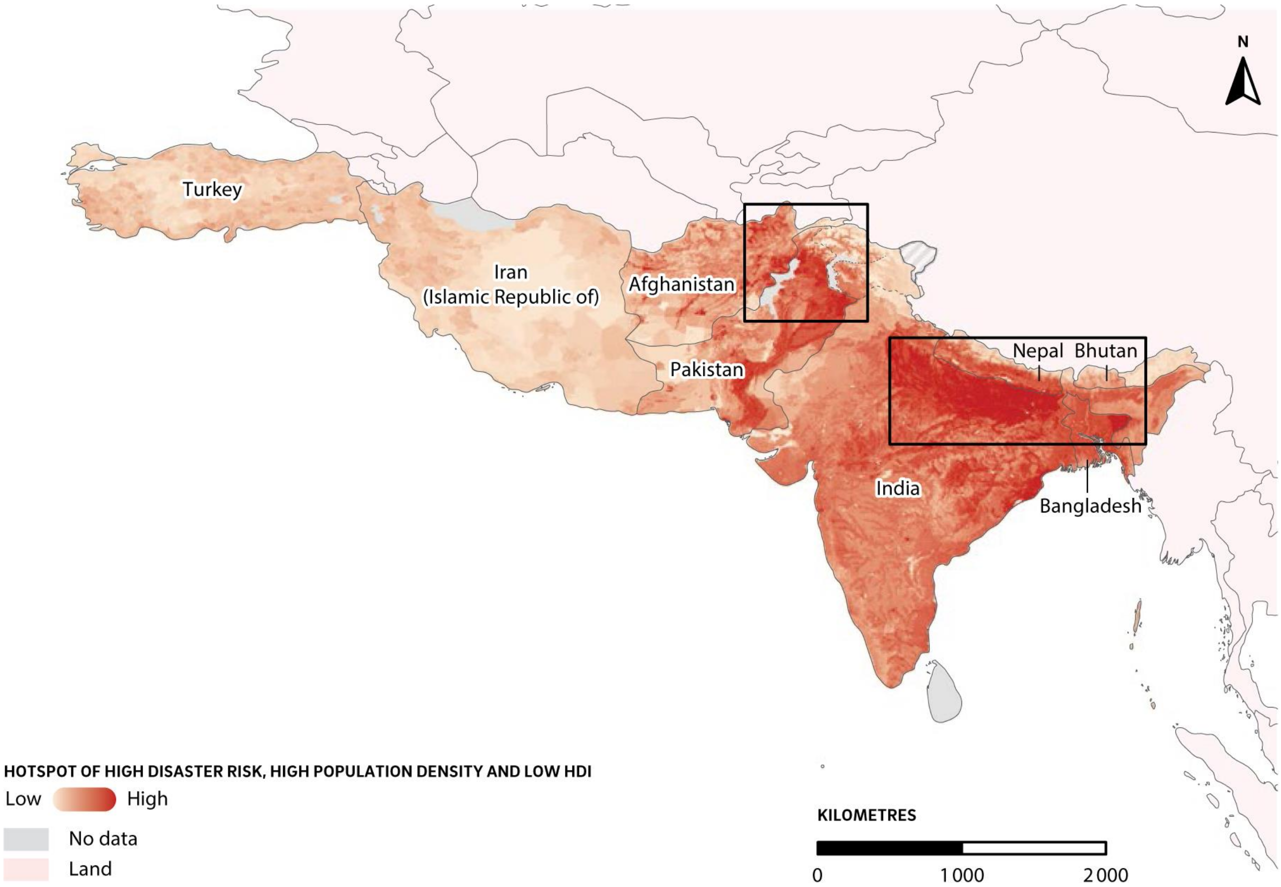


Figure 2. 5 Hotspots of Low HDI, High Population Density, and Hazard Risks
Source: (ESCAP, 2019)

2.3.2. *Types of Vulnerability*

Twigg (2004a) has defined vulnerability as the human aspect of disasters, which is the result of the range of social, economic, institutional, political, cultural and psychological factors that not only influence people's lives but also the environment that they live in. Similarly, according to Pelling (2012), vulnerability is the exposure to disaster and the failure to prevent or mitigate possible damage. In this context, Pelling (2012) differentiates the type of vulnerability such as:

(i) Physical vulnerability—experienced by the physical environment;
(ii) Social vulnerability — experienced by the community with their social, economic, and political systems; and
(iii) Human vulnerability — a combination of physical and social vulnerability.

However, Van Westen (2014) identified four different types of vulnerability such as Physical, Human-social, Environmental and Economic as well as their associated direct and indirect losses. Table 2. 3 shows the types of vulnerability and their associated losses.

Table 2. 3 Overview of Types of Vulnerability and Their Associated Losses
Source: Van Westen (2014)

Losses	Human - social	Physical	Economic	Environmental
Direct losses	- Fatalities - Injuries - Loss of income or employment - Homelessness	- Structural damage or collapse to buildings - Non-structural damage and damage to contents - Structural damage to infrastructure	- Interruption of business due to damage to buildings and infrastructure - Loss of productive workforce through injuries, fatalities and relief efforts - Capital costs of response and relief.	- Sedimentation - Pollution - Endangered species - Destruction of ecological zones - Destruction of cultural heritage
Indirect losses	- Diseases - Permanent disability - Psychological impact - Loss of social cohesion due to the disruption of community - Political unrest	- Progressive deterioration of damaged buildings and infrastructure which are not repaired	- Economic losses due to short term disruption of activities. - Long term economic losses - insurance losses weakening the insurance market - Fewer investments - Capital costs of repair - Reduction in tourism	- Loss of biodiversity - Loss of cultural diversity

In respect of the above-mentioned typology, Physical vulnerability, economic vulnerability, social vulnerability and environmental vulnerability can be defined by Van Westen (2014) as:

- The physical vulnerability can be expressed as 'Elements-at-Risk (EaR)' of the physical environment that experienced potential impact by the hazard.
- The economic vulnerability can be determined by the possible influences on economic properties and processes (i.e. job loss, business interruption, and secondary effects such as increased poverty).
- The social vulnerability can be determined by the possible influences of incidents on communities (i.e. disadvantaged, single-parent families, pregnant or lactating mothers, the disabled, children and the elderly), societal perception of risk, the capacity of communities to cope with disasters, and the state of social systems intended to support them cope.
- The environmental vulnerability can be determined by the possible influences of events on the environment (i.e. flora, fauna, ecosystems, biodiversity).

This particular research mainly focused on physical vulnerability. Papathoma-Köhle et al. (2011) stated that the vast majority of the researchers of natural sciences with technical background define physical vulnerability as *"[t]he degree of loss to a given element, or set of elements, within the area affected by a hazard"*. According to the World Bank (2014), physical vulnerability is determined as the structural and non-structural damage to buildings or building components or other infrastructures. The direct damages due to physical vulnerability included with structural damage or collapse to buildings and non-structural damage (Table 2. 3). Moreover, these damages could be indirect, in terms of the progressive deterioration of damaged buildings and other infrastructures (WB, 2014). With regards to urban flooding, damage to buildings, local infrastructures and the living environment are increasing due to both the intensification of extreme weather events and the development of settlements in areas at risk (White, 2013).

Physical damage on buildings are often extensive and can be described by the degree of deterioration of its materials and structures as well as its physical functions (Blanco and Schanze, 2012). For physical damage assessment, information on the elements at risk (e.g. persons, buildings, ecosystems), the exposure (e.g. proximity, topography, frequency, duration, depth) and area's susceptibility (e.g. socio-economic capacities, coping, recovery are important (Yankson et al., 2017). This information not only considers the state of existing infrastructure and buildings but also urban ecosystems and associated environmental services, existing urban green spaces and land use with its degree of degradation. The IPCC (2007) have also noted that physical vulnerability is a function of exposure, sensitivity and adaptive capacity. Adaptive capacity, in particular, is not only necessary to understand exposure but the adjustments and modifications that demonstrate the extent to which a system can withstand or recover from exposure to disasters such as urban floods.

2.3.3. Conceptual Framework of Vulnerability

Several analytic concepts and models were developed to systematize the different views on vulnerability. Downing (2004)[p. 19] emphasized that *"these conceptual models are an essential step towards the development of methods measuring vulnerability and the systematic identification of relevant indicators"*. In this section, an insight into various conceptual frameworks, such as the double structure of vulnerability as defined by Bohle (2001), the sustainable livelihood framework by DFID (1999), The Pressure and Release (PAR) Model by Wisner et al. (2003), MOVE framework developed by EU MOVE project and the disaster resilience of place (DROP) model by Cutter et al. (2008) has been established.

2.3.3.1. The Double Structure of Vulnerability

In 1989, Chambers (1989) introduced vulnerability as the *"exposure to contingencies and stresses and the difficulty which some communities experience while coping with such contingencies and stresses"*. Chambers (1989) proposed two sides to vulnerability:

- **The external side;** which is associated with the exposure to external stresses and shocks; and
- **The internal side;** which is related to defenselessness and incapacity to cope without damaging losses.

In 1993, Watts and Bohle (1993) and later in 2001, Bohle (2001) expanded the ideas of Chambers, developing 'double structure of vulnerability'. Based on this structure, the external side correlated with exposure to disaster risks. It is mainly constituted with 'Political Economic approaches' (e.g. socioeconomic inequality, upper-class wealth control), 'Human Ecology Perspectives' (population dynamics, and capabilities to control the environmental impact) and the 'Entitlement Theory' (related to the vulnerability to the inability of citizens to acquire or maintain assets through valid public means) (WB, 2014). However, the internal side is correlated to coping and capacity to cope with, anticipate, control and recover from the hazard impact. It is characterized by the 'Crisis and Conflict Theory' (management of resources and assets, crisis management capabilities and dispute resolution), 'Action Theory Approaches' (how individuals behave and respond freely or whether because of societal, financial or legislative restrictions) and 'Models of Access to Assets' (vulnerability mitigation via access to assets).

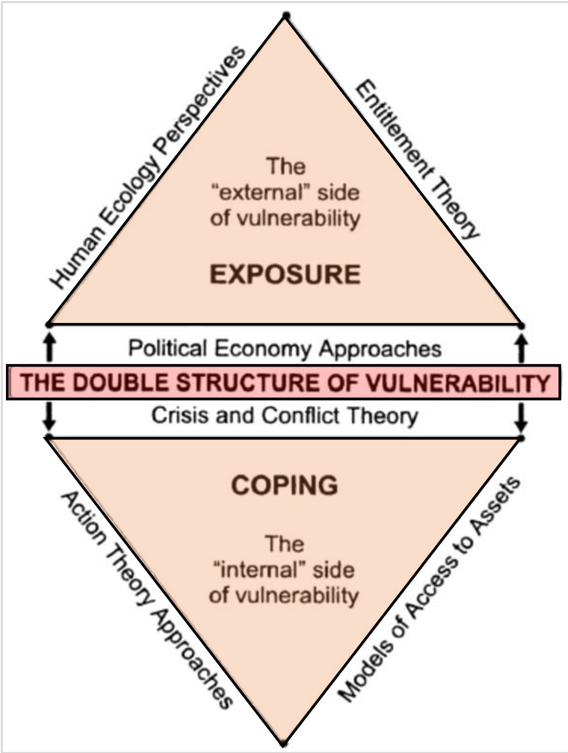


Figure 2. 6 Bohle's Conceptual Framework for Vulnerability Analysis
Source: (Bohle, 2001)

2.3.3.2. The Sustainable Livelihood Framework

Department for International Development (DFID) developed the 'sustainable livelihood framework' as a framework to assess vulnerability (DFID, 1999). The five livelihood assets or capitals (such as human, natural, financial, social and physical capital) act as key elements for this approach. The 'vulnerability context' which have been known as shocks, trends and seasonality, and the effects of shifting frameworks (i.e. Policies, institutions and processes) for the livelihood approaches and their outcomes (for further detail, see DFID (1999) and Figure 2. 7).

Chambers and Conway (1992) stated that "*A livelihood comprises the capabilities, assets and activities required for a means of living. A livelihood is sustainable when it can cope with and recover from stresses and shocks and maintain or enhance its capabilities and assets both now and in the future, while not undermining the natural resource base.*" DFID adapted this definition to conceptualize and develop the framework. Later, Kollmair and Gamper (2002) explained the framework briefly as "*…The framework depicts stakeholders as operating in a context of vulnerability, within which they have access to certain assets. Assets gain weight and value through the prevailing social, institutional* *and organizational environment (policies, institutions and processes). This context decisively shapes the livelihood strategies that are open to people in pursuit of their self-defined beneficial livelihood outcomes."*

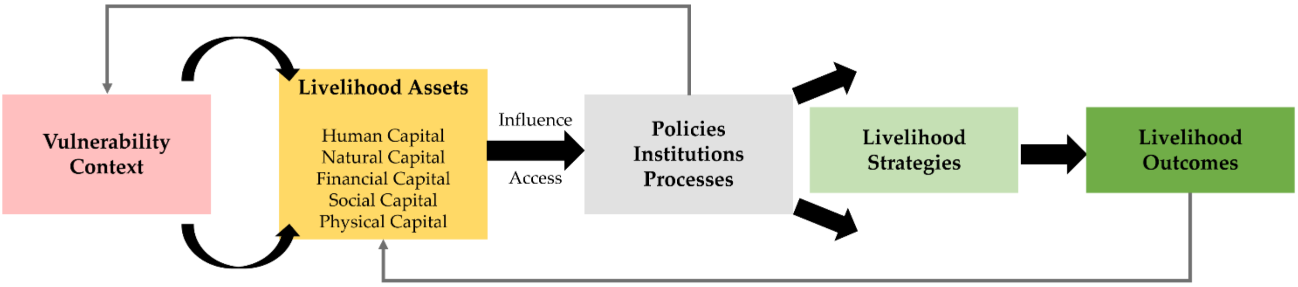


Figure 2. 7 The Sustainable Livelihood Framework

The system emphasizes the need to improve the communities especially, the existing disadvantaged populations to effectively reduce vulnerability (DFID, 1999, Schmidt, 2005). This framework suggested an approach that serves individuals and communities focused on their basic circumstances, rather burdened them with generic and ready-made approaches and remedies, without acknowledging the various capabilities these existing disadvantaged populations possess (De Haan and Zoomers, 2005).

2.3.3.3. The Pressure and Release (PAR) Model

The 'pressure and release (PAR) model' understands disaster as the intersection of two primary forces: socio-economic pressure (processes causing vulnerability) and physical exposure to the natural hazard. The *"PAR model is a tool that highlights how disasters occur when natural hazards affect vulnerable people"* (Wisner et al., 2003)[p. 49–86]. This framework indicates that vulnerability and the development of a potential disaster have been considered as a process which explains that increasing pressure can come from either side, but vulnerability has to be reduced through relieving the pressure. This model is focused on the commonly used equation defining risk as a function of the hazard and vulnerability:

$$\boldsymbol{Risk} = \boldsymbol{Hazard} \times \boldsymbol{Vulnerability}$$

In this context, the underlying driving forces of vulnerability have been illustrated along with the circumstances that occur in an environment that leads to disaster situations where there is a hazard. Such factors are known to be Vulnerability at three radical levels: root causes, dynamic pressures and unsafe conditions (Figure 2. 8).

(i) Root causes can be, for example, political ideologies or economic systems, which determine the access to and distribution of power, structures or resources (Birkmann, 2006b, Ciurean et al., 2013);

(ii) dynamic pressures represented, for example, all processes and activities that imply dynamic pressures lead to unsafe conditions through the social or demographic changes in time and space (e.g. rapid urbanization, rapid population decrease, etc.) (Birkmann, 2006a, Ciurean et al., 2013);

(iii) Unsafe conditions include different forms of human vulnerability, expressed by the temporal and spatial dimension (Birkmann, 2006b, Ciurean et al., 2013).

According to Birkmann (2006a), this framework is an important model due to its focus for identifying the root causes of vulnerability and addressing its motivating forces addressed in the human-environment system.

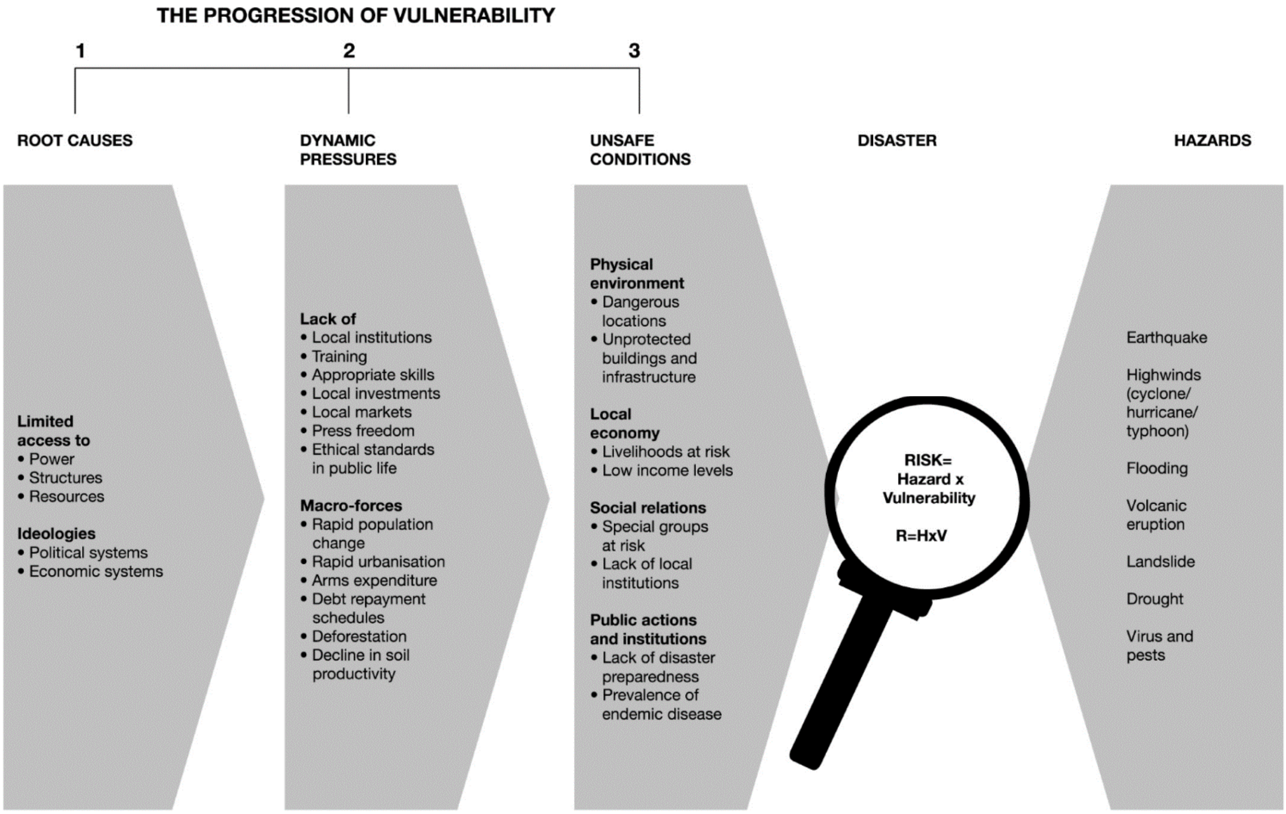


Figure 2. 8 The Pressure and Release (PAR) Model

Source: Wisner et al. (2003)

2.3.3.4. The MOVE Framework

The move framework was established under the EU MOVE project. The primary objective to formulate this framework to strengthen perceptions on the multifaceted existence of the vulnerability, taking account of main causal factors, such as exposure, susceptibility, lack of resilience (lack of capacities to react) as well as for the numerous thematic aspects of vulnerability: social, physical, economic, ecological, institutional and cultural (Birkmann et al., 2013). The framework illustrates two concepts (Van Westen, 2014):

(i) Risk has been determined as the function of the exposure of the community to hazards, in time and space, along with the vulnerability of the society.

(ii) Risk management and adaptation goals to adjust the initial vulnerability conditions during hazards.

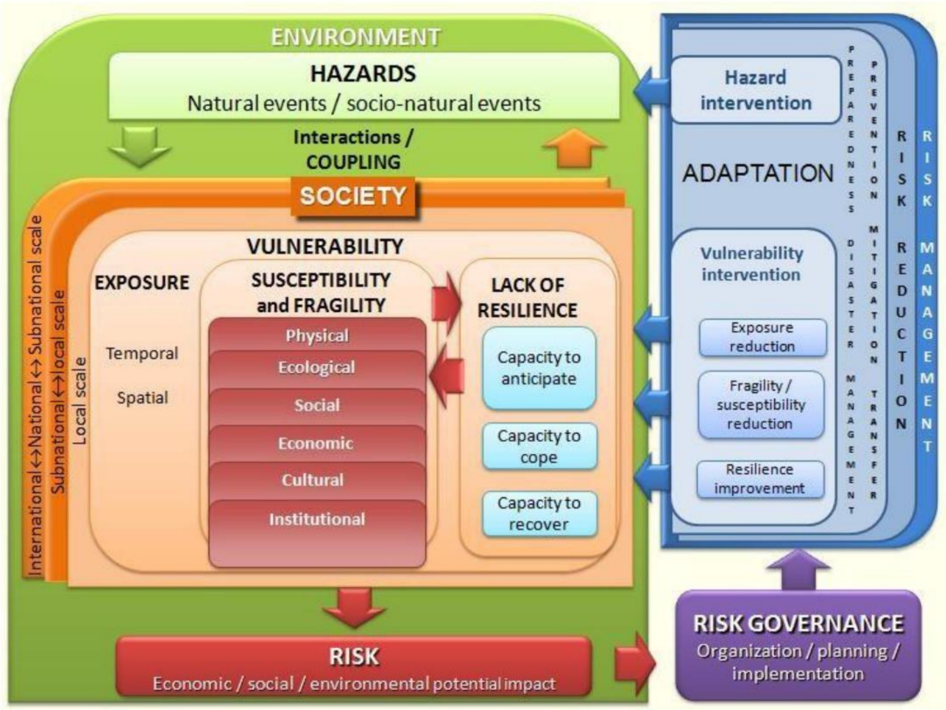


Figure 2. 9 the MOVE Framework

Source: Birkmann et al. (2013)

Generally, when hazard propagates, it exposes a particular area and its society. The vulnerability has been identified as a combined result of exposure (temporal and spatial), susceptibility (or fragility), and lack of resilience (capacity to anticipate, cope and recover). For effective management of risk, Identification and awareness of hazards, vulnerability and risk are necessary. Susceptibility and fragility describe the predisposition (weaknesses and lack of strength) of elements at risk that can be articulated in social, physical, economic or environmental conditions. Lack of resilience indicates limitations regarding access to and utilization of the resources of a community or a socio-ecological system to adapt to an identified hazard. The pre-event risk reduction, in-time coping and post-event response measures are included to manage, control and minimize the hazard impact (Birkmann et al., 2013).

2.3.3.5. The Disaster Resilience of Place (DROP) Model

Cutter et al. (2008) developed the disaster resilience of place (DROP). Burton (2012) [p. 22] declared this model as *"one of the advanced theoretical underpinnings of resilience concept"*. The starting point of this model initiated with the antecedent conditions, including both inherent vulnerability and inherent resilience. These antecedent conditions are considered as the product of context-specific, multi-scale processes within and between the components of socio-ecological systems (i.e. natural systems, the built environment, and social systems) (Cutter et al., 2010). These components of socio-ecological systems influence the degree of inherent vulnerability and inherent resilience of the certain community to disaster.

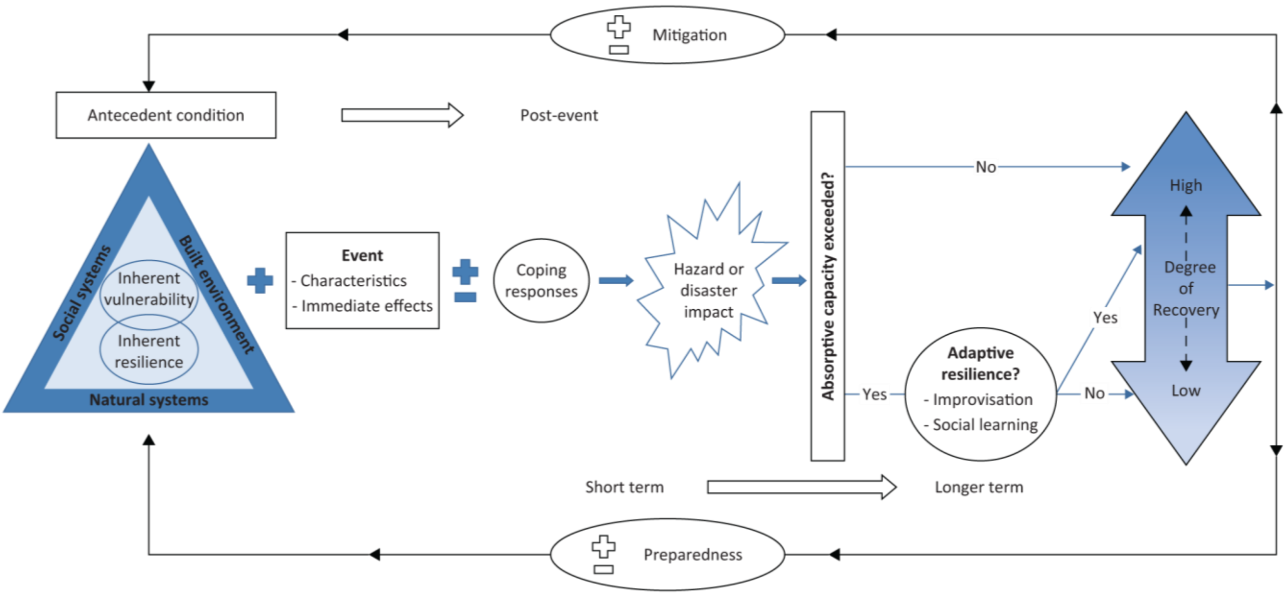


Figure 2. 10 The Disaster Resilience of Place (DROP) Model
Source: Cutter et al. (2008)

In the DROP model, those antecedent conditions merge with physical hazard characteristics (duration, frequency, magnitude, intensity, and rate of onset) to observe "the total hazard or disaster impact as a cumulative effect (or sum) of the antecedent conditions and event characteristics associated with the coping capacity of a community" (Cutter et al., 2008)[p. 602]. The overall disaster impact can be regulated by the absorptive capacity of the local communities. Absorptive capacity is defined by Jeans et al. (2017) as *"the capacity to take intentional protective action and to cope with known shocks and stress"*. The model demonstrates that the effect of the hazard event may be attenuated by adequate coping responses from the community and thus, the community's absorptive capacity will not be exceeded, that contributes to a high degree of recovery. Contrariwise, the absorptive capacity could be exceeded either with the lack of coping strategies to withstand the impacts of the disaster or with the severity of the disaster impacts which is beyond the coping capacities of the local communities. It is recommended (Cutter et al., 2008) that from this stage, the community could be able to demonstrate adaptive resilience through immediate interventions and social learning to initiate a rehabilitation phase. The potential knowledge gained from the adaptive resilience process along with the degree of recovery influence the condition of the social, natural, and built environment systems and also affect the resultant antecedent conditions for the next occurrence including preparedness and mitigation in their management process. In essence, the DROP model is devised to represent the correlation between vulnerability and resilience, in such way that is *"theoretically grounded, amenable to quantification and addressed real problems in real places"*(Cutter et al., 2008).

3. Flood Hazard and Disaster

The definition of flood is multifaceted, partly because it is a complex phenomenon and also different researchers have different perspective to define the flooding events. Chow (1956) presented one of the first definitions of a flood as *"a relatively high flow which overtakes the natural channel provided for the runoff'*. According to Rostvedt (1965), *"a flood is any high streamflow which overtops natural or artificial banks of a stream"*. The more general definition of the flood was introduced by Ward (1978) as *"a body of water which rises to overflow land which is not normally submerged"*. Yevjevich, (1992) introduced floods as "extremely high flows or levels of rivers, whereby water inundates flood plains or terrain outside the water-confined major river channels". Rayhan and Grote (2007) defined flood as "a natural calamity which occurs by huge rainfalls followed by the overflow of riverbanks and which usually occurs at the bottom of a valley and in coastal areas". UNDP (2019) indicated that flooding is one of the regular hazards causing loss of properties and life of the people and even severe economic downturns, particularly in developing countries. IPCC (2012) defined floods as: *"the overflowing of the normal confines of a stream or other body of water or the accumulation of water over areas that are not normally submerged. Floods include river (fluvial) floods, flash floods, urban floods, pluvial floods, sewer floods, coastal floods, and glacial lake outburst floods."*

3.1. Spatiotemporal Distribution and Socioeconomic Impact of Flood

Floods are perennial events in most parts of this populated planet, submerged landmass and killed thousands of people annually. Figure 2. 11 represents the distribution of annual floods for 1986–2015 according to the Global Flood Inventory (CRED, 2019). The new analysis from World Resources Institute's (WRI) through their global flood analyzer tool, 'Aqueduct Floods' revealed that the number of the affected population due to floods will double globally by 2030 (Kuzma and Luo, 2020). According to data from the tool (Kuzma and Luo, 2020), *"the number of people affected by riverine floods will rise from 65 million in 2010 to 132 million in 2030, and the number impacted by coastal flooding will increase from 7 million to 15 million"*. It also illustrated the threat to economies, and the risks for lives suggesting that the number of urban properties damaged due to flooding will be triple — from $157 billion to $535 billion annually (Kuzma and Luo, 2020). Global Assessment Report on Disaster Risk Reduction 2015 (UN, 2015)[p.72] confirmed that *"flood risk contributes US$104 billion to global Average Annual Loss (AAL). To put this figure into perspective, it is equivalent to twice the public health expenditure in the Middle East and North Africa or 30 per cent of annual public education expenditure in Latin America and the Caribbean"*. A recent risk analysis performed by SwissRe (2012) on 616 major metropolitan areas (covering 1.7 billion people, which is nearly 25% of the total population globally and comprising around half of global GDP) observed that more people has been threatened by flood risk than any other hazard. Similarly, Lewis and Purcell (2014) reported that around 379 million urban residents are at risk from riverine floods, while other natural disasters like earthquake and strong winds are expected to impact 283 million and 157 million respectively.

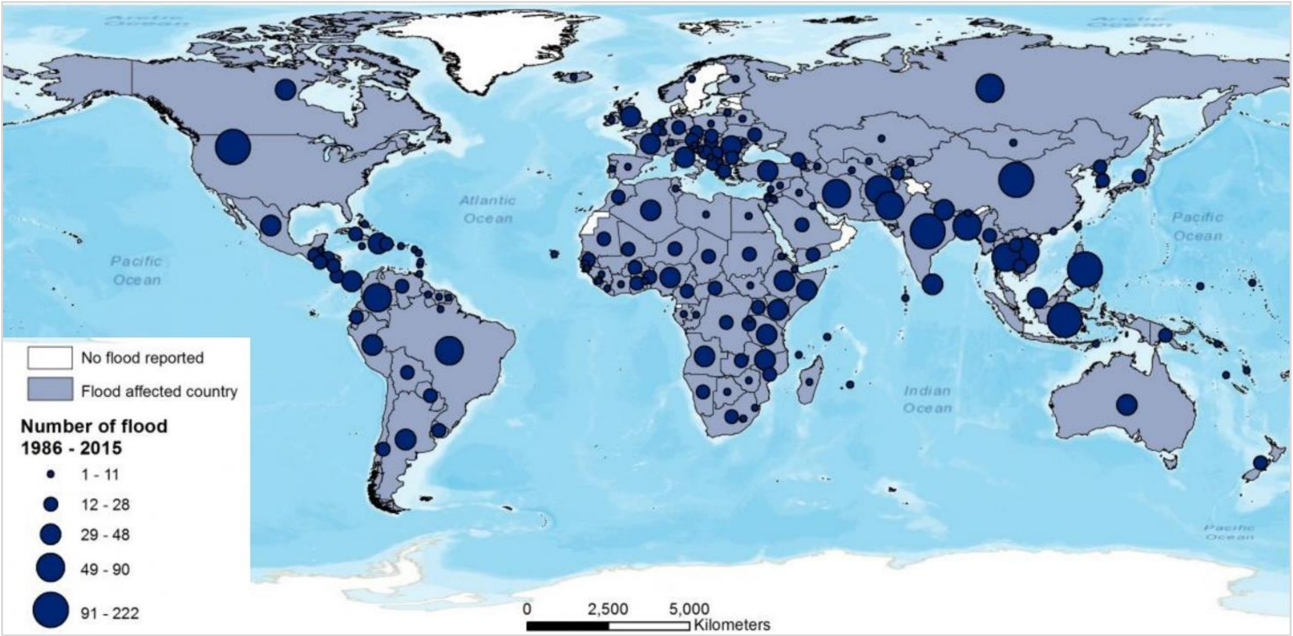


Figure 2. 11 Global Flooding Events 1986–2015
Source: (CRED, 2019)

Based on Asia-Pacific Disaster Report 2019 (ESCAP, 2019), *"of the total flood AAL, China represents 28 per cent and India 13 per cent, followed by the Russian Federation at 9 per cent and Australia at 7 per cent. Other countries with a significant proportion of the region's flood AAL include Japan, Bangladesh, Thailand, Viet Nam, Indonesia and the Republic of Korea. The countries with the highest flood risk are Myanmar, Lao People's Democratic Republic, Cambodia and Bangladesh"*. This report also claimed that at least ten countries of Asia-Pacific region among the top 15 countries in the world have the most people and economies exposed to river floods annually (see Figure 2. 12 to observe the hotspots of flood in Asia-Pacific Region). According to Kuzma and Luo (2020), *"India, Bangladesh and Indonesia, for example, have some of the largest populations affected by riverine and coastal floods each year. By 2030, these three countries will account for 44% of the world's population annually affected by riverine floods, and 58% of the population affected by coastal floods"*.

In the recent report of the South-Asia Floods 2019 (OCHA, 2019b), it has been narrated that over 25 million people were hit by floods in Bangladesh, India, Nepal and Myanmar because of torrential monsoon rain. It also reported that at least 600 people have died and more than half a million people have been displaced with their homes and other infrastructures destroyed or damaged. The situation has been projected to deteriorate further with the continuum of rains in those flood-affected areas (OCHA, 2019b). In this study, Bangladesh has been selected due to the climate change impact combined with its geography, population density and extreme poverty, which makes the country – one of the most vulnerable countries towards floods (Mirza, 2002, Kundzewicz et al., 2014).

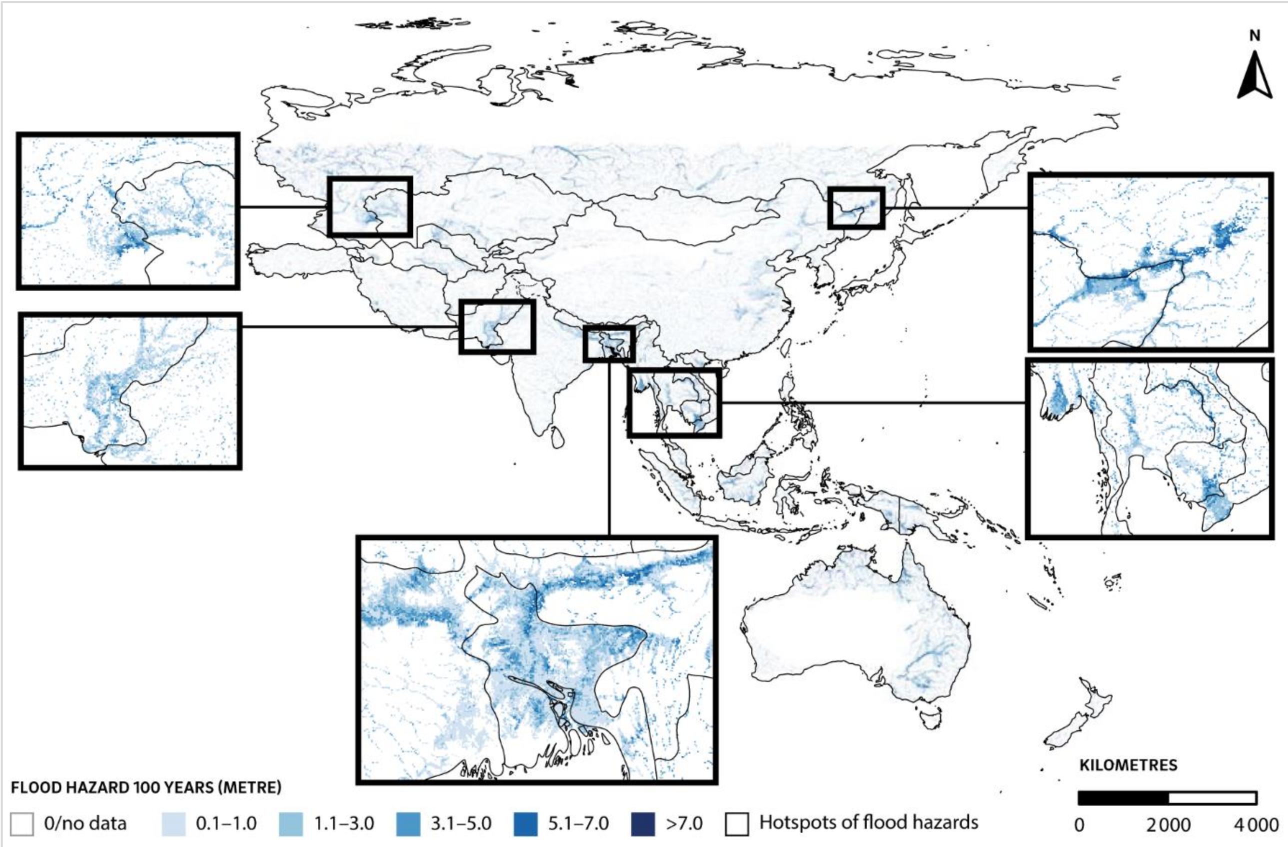


Figure 2. 12 Hotspots of flood hazard in the Asia-Pacific Region
Source: (ESCAP, 2019)

3.2. Types of Flooding

Generally, a flood occurs due to a combination of hydrological and meteorological extremes, for example, extreme precipitation and flows (Jha et al., 2012). Human activities, however, are also accelerated the flooding events through their rapid urbanization and unplanned growth in urban areas interfering with floodplains or the overtopping of an embankment which disregards the protection of planned developments (Balabanova and Vassilev, 2010). Keller and DeVecchio (2015) contextualized flood in the urban perspective, explaining it as the combination of rainfall and runoff, which is accelerated with rapid urbanization. Urban flooding related to the condition of the drainage system. Due to high precipitation, drains become blocked with sediment and debris, resulted in water flow and caused flooding in low areas (Keller and DeVecchio, 2015, Douglas et al., 2008). Kusi-Appiah (2017) mentioned that the categorizations of floods can be diverse. Floods can be categorized as riverine (or fluvial) floods, pluvial (or overland) floods, coastal floods and groundwater floods, depending on the combination of the sources, causes and socio-economic impacts on the environment and community as a whole (Kusi-Appiah, 2017). Moreover, according to Jha et al. (2012), the flood categories are flash floods, urban floods, semi-permanent floods, and slow rise floods based on the speed of onset and force of flooding. Similarly, Douglas et al. (2008) also identified four types of urban flooding: flooding from major rivers on whose banks the towns and cities are built; flooding from small streams whose catchment areas lie almost entirely within built-up areas; localized flooding due to inadequate drainage; and coastal flooding from the sea, or a combination of high tides and high river flows from inland. For this study, riverine (or fluvial) floods and pluvial (or overland) floods are considered only, however, riverine (or fluvial) floods, pluvial (or overland) floods, coastal floods and flash floods (as according to Parvin et al. (2018), Bangladesh generally experiences these four types of the flood) are explained.

3.2.1. Riverine Floods

Urban areas settled on the low-lying areas in the middle or lower reaches of rivers have a huge exposure to experience extensive riverine floods. The chances of these floods mostly triggered by the excessive rainfall or tidal influence from the downstream or snowmelt in upstream areas. The amount of runoff depends on the ground conditions such as soil, vegetation cover, and existing land use condition. When the river run-off volume exceeds the local flow capacities, riverine floods occur (Gebremeskel, 2011). Roads and building construction on a floodplain may accelerate the occurrence of a riverine flood by introducing impervious surfaces on the flood plain, which ultimately stand a greater risk of flooding (Kusi-Appiah, 2017). Moreover, a fast-flowing watercourse, such as a river can gather speed or may overflow, if it is forced to squeeze through a tight gap creating a bottleneck effect (SEPA, 2016). In Bangladesh, riverine floods are very common and occur each year along the 'large, medium, and small rivers', by which more than 25% of the country is inundated in regular years (Parvin et al., 2018). However, during extreme flooding event (i.e. the flood years of 1988 and 1998), it can inundate up to 70% of the country (BWDB, 2019).

3.2.2. Overland or Local Floods

In urban areas, local floods are quite common due to heavy rains, a high proportion of impervious surfaces which block the runoff to absorb quickly, and inadequate drainage facilities (Sepalage, 2000). The drainage facilities tend to be blocked by rubbish and debris, resulted in low drainage capacity and thus, lead to increased surface runoff and back up effects, and ultimately, caused local floods (Gebremeskel, 2011). Local floods may not be as dangerous as flash floods, yet urban dwellers experience hassle and inconvenience by these floods because houses and roads go underwater even after a short period of intense rain (Sepalage, 2000).

3.2.3. Coastal Floods

Coastal flooding usually occurs due to extreme ocean-based storm systems such as cyclones and tropical storms. Flooding occurs due to higher storm tides compared to normal high tides. It also occurs accompanied by velocity wave action and relatively high-velocity water. The severity of the storm has a direct bearing on the velocity and range of coastal floods and damaging effects are caused by a combination of the higher water levels of the storm tide along with the rain, erosion, waves, winds and battering by debris. In Bangladesh, coastal floods or storm surges developed by cyclonic storms and the coastline of about 800 km along the Bay of Bengal in the southern part of Bangladesh become vulnerable to this type of floods. The maximum height of surges can exceed 10m to 15 m, during super-cyclones, contributing to floods in the entire coastal belt (Parvin et al., 2018).

3.2.4. Flash Floods

Flash floods are caused by a short drainage basin, steep slopes, and a high proportion of water-proof surfaces that are unable to absorb runoff. A quick and intense overflow with high water velocities following the rapid accumulation of runoff waters from intense rainfall in hilly areas resulted in the flash floods (Sepalage, 2000). They are more damaging in high-density urban areas than elsewhere due to their unpredictable nature with extraordinarily strong currents of debris and sediment, giving little or no time for communities on the trail to plan for them and to cause significant harm to infrastructure, human beings, or everything stands in their way (Gebremeskel, 2011). In the Northeast Haor Region of Bangladesh, flash floods devastated winter crops in almost every year, especially in the years 2002, 2004, 2007, 2009, and 2010 (MoDMR, 2014).

3.3. Causes of Flood in Urban Areas

It is anticipated (CRED and UNISDR, 2015) that the impacts of floods have been increasing in many parts of the world due to climate change (Hallegatte et al., 2013, Hinkel et al., 2014, Vitousek et al., 2017, Ward et al., 2017) socioeconomic development in flood-prone areas (Jongman et al., 2012), and land subsidence (Brown and Nicholls, 2015, Syvitski et al., 2009). As noted by Bates et al. (2008), floods can be determined by the climatic system, most notably precipitation, but also temperature patterns. Floods are often characterized by drainage basin conditions, such as pre-existing water levels in rivers, the soil quality and conddition, the pace of urbanization, and the presence of water management infrastructures (Kundzewicz et al., 2014). The causes of floods are varied, developing from several meteorological, hydrological and human factors aggravating these natural flood hazards.

3.3.1. Geomorphological Condition

For the formation and distribution of flooding, topography plays a significant role (Liu et al., 2017, Wang, 2015, Gao and Shi, 2016). The topographic variation depends on the elevation and slope of the landscape which are important factors in flooding after rainstorms (Lyu et al., 2016). As noted by Elshorbagy et al. (2017), a low-lying region along the river has a greater risk of the flood (impacted by more regular floods) than a higher elevation area or areas further away from the river. Correspondingly, Lyu et al. (2016) have found that the low-level land surface has a high potential for flooding, whereas surfaces with a steep slope have a low potential for flooding, as the floodwaters can quickly flow downward. However, the community keeps floodplains and low-lying areas more exposed and thus vulnerable by inhabiting them and developing valuable economic investments, with insufficient strategies to manage vulnerability in most cases which ultimately increasing flood risk (Balica et al., 2012, UNISDR, 2009).

3.3.2. Urbanization and Urban Expansion

The probability of flooding rises gradually with increasing urbanization and urban expansion, which intensified further by population growth, resources, and infrastructure in smaller areas (Ishigaki et al., 2009). The hydrological and hydro-climatological changes also increase the flood risk by the land-use changes and microclimatic changes driven by urbanization (WMO and GWP, 2008). Due to urbanization, the reduction of forest and wetland coverage is very common and thus, these are also reducing the role of the ecosystems in buffering flood events (Bradshaw et al., 2007). The increase in paved surfaces is another outcome of rapid urbanization increased in flooding frequency because of their reduction of flow resistance and poor infiltration (Huong and Pathirana, 2013).

3.3.3. Climate Variability and Climate Change

Milly et al. (2008) emphasized that climate variability and change have direct consequences on global flood hazard. According to IPCC (2007) and IPCC (2014), the growing occurrence of flood incidents globally was partially attributed to the rise in heavy precipitation related to climate change. Moreover, Huong and Pathirana (2013) indicated towards the global warming, which has been accelerated of the global water cycle and thus, the flood magnitude, as well as the flood frequency, has been increased in many regions. Additionally, due to climate change, the increases in sea level, tides and large-scale runoff (which result in water level change in the river) often impacts flooding in cities on coastal or river deltas (Huong and Pathirana, 2013). The sea-level changes are fairly well known by the IPCC (2007) report. In the next century, UNFCCC (2005) predicted a global average sea level rise of 9–88 cm. Climate change has made weather less predictable, temperatures more erratic, rainfalls more uncertain and excessive storm rainfalls more likely and ultimately, resulted in frequent flooding, especially in flood-prone areas (Huong and Pathirana, 2013).

3.3.4. Encroachments on River Beds and Natural Canals

Several unsustainable land-use practices are going on in the catchments and River Basin such as overexploitation of mountain ecosystem, illegal encroachments in river beds, artificial changes in natural river flows and unplanned infrastructural development in the river main and its tributaries (Hussain, 2010). The flood impact has been widened, while these unsustainable land-use practices are exacerbated. Moreover, due to these unsustainable practices, therefore, water-absorbing capacity has substantially decreased, surface runoff heightened, topsoil eroded and resulted in high sedimentation loads in rivers and dams (Hussain et al., 2003). Additionally, legal and illegal encroachments of existing natural canals connected to the rivers are blocking the natural flood control mechanisms and have become barriers for free passage of excessive flood water in the rivers.

3.3.5. Absence and Inadequate Capacity of Drainage Facilities

As noted by Veldhuis (2010), urban drainage systems are actively controlled by urban development and if unplanned, the efficiencies of urban drainage systems frequently degrade, with increased risk to flooding and waterlogging. The drainage networks in developing countries are typically limited, mismanaged and congested for several reasons, including the solid waste disposal in drains and canals, makes them vulnerable to flooding (Zurbrugg, 2003, Haque, 2013). Moreover, the carrying capacity of the drainage network is seriously interrupted by solid waste disposal in drainage routes, resulting in excessive waterlogging in the event of heavy rainfall (Pervin et al., 2020).

3.3.6. Absence of Embankments, Embankment Failure or Damage

Mukhopadhyay and Gupta (2015) stated that flood is caused due to inadequate capacity within the bank of rivers to contain the high flows brought down from the upper catchment due to concentrated heavy rainfall and to protect these flood-prone areas, provision of the marginal embankment along river banks and coastal areas was an age-old practice. Correspondingly, Rickard (2009) indicated about the conventional ways of protecting low-lying areas from floods through the construction of floodwalls and embankments. However, Roy and Dutta (2012) argued that embankments are often subject to failure and if they fail, the damage can be much greater than when there was no embankment.

4. Conceptualizing Flood Vulnerability

4.1. Flood Vulnerability and Flood Risk

Floods are among the most frequent and destructive environmental disasters that adversely affect human existence, creating significant economic pressures across the globe (Hallegatte et al., 2013, Jha et al., 2012, Ouma and Tateishi, 2014). Latest projections suggest that the flood risk will not decrease in future, but will affect several regions of the world and increase their vulnerability, due to climate change impact with high severity and more frequency (Jonkman and Dawson, 2012, Bates and De Roo, 2000, Birkmann, 2006b, Salami et al., 2017). The magnitude and scale of flood damage to a particular area can be determined by the vulnerability profile of that area and the flood characteristics including frequency, duration and depth (Birkmann, 2006b). In addition, Factors such as physical infrastructures, spatial positions, geomorphology and households' cultural, political and socio-economic circumstances affect how vulnerable they are to flood (Merz et al., 2007, Alcántara-Ayala, 2002, Few, 2003, Mutton and Haque, 2004, Paul and Routray, 2010). Thus, the intersections and interactions of social and environmental processes, are enabled flooding vulnerability and response strategies (Gallopín, 2006, Berkes et al., 2008).

To analyze flood vulnerability, it is essential to address the concept of 'vulnerability' first (Twum and Abubakari, 2019). It is difficult to provide a single or absolute explanation of vulnerability, as it is a multi-dimensional concept (Birkmann, 2006b, Vogel and O'Brien, 2004). Generally, it incorporates the *'ability to respond to hazardous conditions'* (Sayers et al., 2002)[p. xviii]. Vulnerability often represents the *"characteristics of a person or group in terms of their capacity to anticipate, cope with, resist and recover from the impact of the natural hazards"* (Wisner et al., 2003)[p.11]. The IPCC definition, highly popularized among the climate researchers, defines *"vulnerability as the degree to which a system is susceptible to, or unable to cope with, adverse effect of climate change"* (IPCC, 2001). From these definitions, the concept of vulnerability can be outlined in the perspective of either the variation in humans' capacity to cope with hazards or the variation in exposure to hazards (Few, 2003). Formetta and Feyen (2019) defined it as *"a spatiotemporal phenomenon— a dynamic event of space and time— hazard-specific, and with physical, environmental, social, economic and institutional dimensions"*.

This study focuses on vulnerability regarding physical structures and components of the built environment that expose individuals and elements to particular natural hazards such as floods (Fatemi et al., 2020d). Physical vulnerability, as it is called, results in physical loss and may influence the other dimensions of vulnerability such as social, economic and institutional (Fuchs, 2013, Papathoma-Köhle et al., 2011, Kappes et al., 2012). It is defined as *"the exposure to risk and inability to avoid or absorb potential harm in the built environment"*(Pelling, 2012)[p.5]. According to the World Bank (WB, 2014), *"physical vulnerability encompasses the structural and non-structural damage to buildings or building components or other infrastructures"*. These damages could be direct, in terms of gradual and consistent deterioration of buildings and other infrastructures (WB, 2014). Flood damage on buildings are often extensive and deteriorates their material compositions and structures as well as their function (Blanco and Schanze, 2012). The IPCC (Field, 2014) thus indicates that *"vulnerability encompasses a variety of concepts including sensitivity or susceptibility to harm and lack of capacity to cope and adapt"*. Therefore, information on the elements at risk (e.g. people; built environment; eco-systems), the exposure (e.g. proximity to the river; elevation of the area; frequency, duration and depth of floods) and areas' susceptibility (e.g. socio-economic capacities, coping and recovery) are essential for assessing physical damage due to flood (Yankson et al., 2017).

In the extant literature, flood risks and damage to buildings are typically assessed in two ways: empirical or analytical methods. Analytical methods use numerical models and computer simulation techniques to estimate the reliability of a structure and calculate its probability of failure as damage analysis, while empirical methods analyze damage data from the perspective of historical hazard events, or the opinion and previous experience of the flood victims (Van Westen, 2014). However, Van Westen (2013) emphasized an empirical method for its advantage of post-flood field survey. This method is particularly suited for flooding, which normally affects many buildings that are of the same type, and allows for correlating between the hazard intensity and the degree of damage (WB, 2014). Other studies view flood vulnerability as a socio-ecological phenomenon to integrate residents' experiences into unravelling flood damage and responses through interviews and surveys (Amoako, 2018, Renaud et al., 2010). Cognizant of this, the study adopts the empirical method as it is suited to the geographical scope of the study (peri-urban), where urban consolidation is still on-going and required data for analytical methods is either hard to access or practically non-existent (See methodology section).

4.2. Indicators of Physical Vulnerability

The role of hazards and their consequences as the damage has been highlighted in physical vulnerability assessment, while the human systems are reduced to mediate the outcomes (Ciurean et al., 2013). In the literature on natural hazards (UNDRO, 1979), physical vulnerability is generally characterized on a scale ranging from no damage (0) to total damage (1), reflecting the degree of the possible damage to the element at risk. In certain models, vulnerability is depended on both the acting agent (physical impact of a hazard event) and the exposed element (structural or physical characteristics of the vulnerable object) (Ciurean et al., 2013). For flood, the most common expressions of physical are vulnerability, damage matrices, fragility curves and vulnerability indicators (Kappes et al., 2012).

Pelling (2003) explained vulnerability as *"a concept, comprising exposure (location relative to hazard, environmental surrounding), resistance (livelihood, health), and resilience (adjustments, preparation)"*. Kappes et al. (2012) indicated that vulnerability indicators are one of the essential expressions to assess physical vulnerability. However, the variables causing this vulnerability cannot be simplified (Müller et al., 2011). Indicators for physical can be chosen through extensive literature review. A physical vulnerability analysis may identify multiple variables within a specific area:

(i) Main construction material for roof, walls and floor (building typology)(Papathoma-Köhle et al., 2011, Schneiderbauer, 2007, Taubenböck et al., 2011, Gain et al., 2015);

(ii) Position of buildings in relation to the street level (plinth height)(Schneiderbauer, 2007, Müller et al., 2011);

(iii) Building age of household Residence (Gain et al., 2015, Papathoma-Köhle et al., 2011);

(iv) Surrounding Land Cover Condition (Proportion of green spaces per building block) (Schneiderbauer, 2007, Niehoff et al., 2002);

(v) Availability of flood protection measures on building (building modifications) (Müller et al., 2011, Schneiderbauer, 2007).

In this study, damage due to flood has been selected as the primary variable to determine the physical vulnerability. The list of relevant indicators of physical vulnerability for this study are given below:

Table 2. 4 The Indicators of Physical Vulnerability

Variables	Relevance	Reference
Building Typology	Key building materials for roofs, walls and floors that decide the physical fragility towards flooding and specify the resistance to damage	Papathoma-Köhle et al., 2011; Schneiderbauer, 2007; Taubenböck et al., 2011; Gain et al., 2015
Plinth Height	Position of the houses defines the probability that the structures in comparison to the street level may experience damage in the case of a flood event.	Schneiderbauer, 2007, Müller et al., 2011
Building Age of Household Residence	Determine the building age, as old buildings are structurally weaker and keep the household more vulnerable	Gain et al., 2015, Papathoma-Köhle et al., 2011
Surrounding Land Cover Condition	Determine the proportion of green spaces per building block, because the higher the green area, the higher the retention capacity and the lower the flood risk	Schneiderbauer, 2007, Niehoff et al., 2002
Building Modifications	Determine the effectiveness of flood control measures in a particular building	Müller et al., 2011; Schneiderbauer, 2007

Additionally, to understand the demographic profile, several social vulnerability variables have also been studied such as the number of populations in the households, size of household, male-female ratio, their age, education level occupation, and monthly income level.

4.3. Flood Damage and Damage Reduction Measures

Urban flood damage on buildings are often extensive and can be described by the degree of deterioration of its materials and structures as well as its physical functions (Blanco and Schanze, 2012). For physical damage assessment due to urban flood, information on the elements at risk (e.g. persons, buildings, ecosystems), the exposure (e.g. proximity to river/coast, the elevation of the area, frequency of floods, duration, depth) and area's susceptibility (e.g. socio-economic capacities, coping, recovery (Yankson et al., 2017) are important. In particular, the present data takes into consideration the state and degree of deterioration of established dwellings, existing facilities and infrastructures, urban environments, and associated ecosystem services. The IPCC (2007) have also noted that physical vulnerability is a function of exposure, sensitivity and adaptive capacity. Adaptive capacity, in particular, is not only necessary to understand exposure but the adjustments and modifications that demonstrate the extent to which a system can withstand or recover from exposure to disasters such as urban floods.

Kreibich et al. (2015) have noted that flood damage reduction measures, including physical vulnerability responses, could be led by households, local, or state governments. Although there is significant variation among countries in flood responses and damage reduction measures, household's contribution to damage and thus risk reduction measures have become a relevant aspect of flood risk management portfolios in many countries (Bubeck et al., 2017). In several countries, those endangered by flooding are expected to undertake measures to reduce flood damage while the government often sets the overall goals and framework (Kreibich et al., 2015). In the developing world, where unplanned urbanization is common, studies show that formal flood response strategies adopted by authorities do not often reduce damage or risks for people in informal areas (Chatterjee, 2010). This has led to calls for urban planners and disaster management officials to analyze and understand flood damage reduction measures by households and integrate their potentials towards an integrated and hybridized form of flood management (Chatterjee, 2010). Such understanding can help people, communities and organizations use available skills and resources to tackle the adverse conditions, emergencies or disasters risks (UNISDR (2009).

Similarly, there is a need for the capacity of processes, organizations , individuals, and other organisms to adapt to potential damage, to take advantage of opportunities, or react to consequences (Field et al., 2012). In all cases, flood response measures depend on the choice of skills and resources, nature of the hazard threat, available capacities, and community and individual priorities. The capacity of individuals or community to adapt to floods requires the use of available expertise, resources and local knowledge in the face of hazards and other risks to minimize the likelihood of negative impacts (Twigg, 2004b, Wamsler and Brink, 2014). But it depends on the complexity of the challenge, the ability required to tackle it and a range of goals that shift based on the nature of the hazard for community and individuals. These capacities are increasingly seen as a key component of an individual level or community's level of vulnerability (Amoako, 2018, Amoako and Inkoom, 2018, Jabeen et al., 2010). Studies have stressed the need to identify capacities including physical capacities to the growing threat of urban flood risks and hazards (Owusu-Ansah et al., 2019). Indeed, people facing flood risk may take several actions: (a) to avoid floodwaters spreading and infiltration by physical means, and (b) to minimize negative impact due to flood through actions (Ligasan, 2010, Few, 2003). In this study, the focus was on the physical coping strategies to refer to physical measures taken by urban dwellers to reduce flood damage and adjust to urban flood risk. As Anderson and Woodrow (2019) have stressed about the need to identify the existing capacities of the community as well as individuals in designing disaster-related development interventions.

4.4. Flood Risk Management Strategies

During the past half-century, evolution has been observed in thinking of flood risk management strategies (FRMS), from flood control to flood risk mitigation, reflecting an increased understanding that building structures to control floods is only one of many possible approaches available to societies (Sayers et al., 2013). The integrated approach involves the structural measures, non-structural measures, development policies, spatial planning and others (Ishiwatari, 2010). Interpreting floods as process, and not as discrete occurrences in time and space, Serra-Llobet et al. (2016) distinguished four stages for flood risk management in the structure of the flood risk management cycle:

i) the characterization of hazard and risk (assessment and mapping);
ii) mitigation strategies, which include prevention measures (e.g., land-use management) and protection measures (e.g., levees and dams);
iii) emergency management (preparation and response); and
iv) recovery at short and long terms.

Correspondingly, Hegger et al., (2014) also distinguish between the five types of FRMSs. These FRMSs concentrates on the flood probability (Flood Defense or Protection); on the potential consequences of flooding (Flood Risk Prevention, Flood Risk Mitigation, Flood Preparation) and recovery after flood events (Flood Recovery) (Table 2. 5).

Table 2. 5 Types of Flood Risk Management Strategies (FRMS)
Adapted by the author from (Hegger et al., 2014)

Strategies	Characteristics	Measures	Main actors
Flood defense	Flooding can be prevented by infrastructural works, mostly referred to as 'flood defense' or 'structural measures'	Embankments, Storm-water Drainage	Water management actors at the national and regional level.
Flood risk prevention	Negative consequences of flooding can be avoided by proactive spatial planning or land-use policies.	Green-area Protection, Coastal Afforestation, Land Use Planning	Actors involved in planning processes.
Flood risk mitigation	Consequences of floods can be mitigated by smart design of the flood-prone area.	Urban Management, Building Regulations	Citizens, Developers, public and private actors.
Flood preparation	Consequences of floods can also be mitigated by preparing for a flood event.	Warning System, Disaster Management, Evacuation Plan	Meteorological office, flood forecasting centers, state agencies.
Flood recovery	facilitates a good and fast recovery after a flood event.	Rehabilitation Process, Relief & Insurance Support.	Disaster relief funds, insurance companies and the affected citizens.

The overall flood risk management strategies (FRMS) can be categorized into structural and nonstructural options (Hong et al., 2013). UN (2016) defined structural measures as *"any physical construction to reduce or avoid possible impacts of hazards, or the application of engineering techniques or technology to achieve hazard resistance and resilience in structures or systems"*. USACE (2006) indicated the function of structural measures which can alter the characteristics of the flood and reduce the probability of flooding in the location of interest. Some of the major structural measures include the flood defense strategies such as embankments, levees, storm-water drainage etc. On the other hand, according to UN (2016), *"non-structural measures are measures not involving physical construction which use knowledge, practice or agreement to reduce disaster risks and impacts, in particular through policies and laws, public awareness-raising, training and education"*. USACE (2006) specified non-structural measures which can alter the impact or consequences of flooding and have little to no impact on the characteristics of the flood. The major non-structural measures include flood risk prevention, flood risk mitigation, flood preparation and flood recovery strategies such as green-area protection, coastal afforestation, land use planning, urban management, building regulations, warning system, disaster management, evacuation plan, rehabilitation process, relief & insurance support etc.

Kobayashi and Porter (2012) categorized each of the three contributing conditions (hazard, exposure and vulnerability) for flood risk management using these structural and non-structural measures. Babić-Mladenović and Kolarov (2016) elaborated this concept to link them with the environment and society (see Figure 2. 13). According to Kobayashi and Porter (2012), structural measures are devised to modify flood hazard which includes flood frequency, depth of inundation, and flood extent, whereas non-structural measures are employed either to reduce exposure to flood hazard or to decrease vulnerability to exposure. Babić-Mladenović and Kolarov (2016) revealed that Structural measures creates an impact on the environment, while non-structural measures focus on people and society.

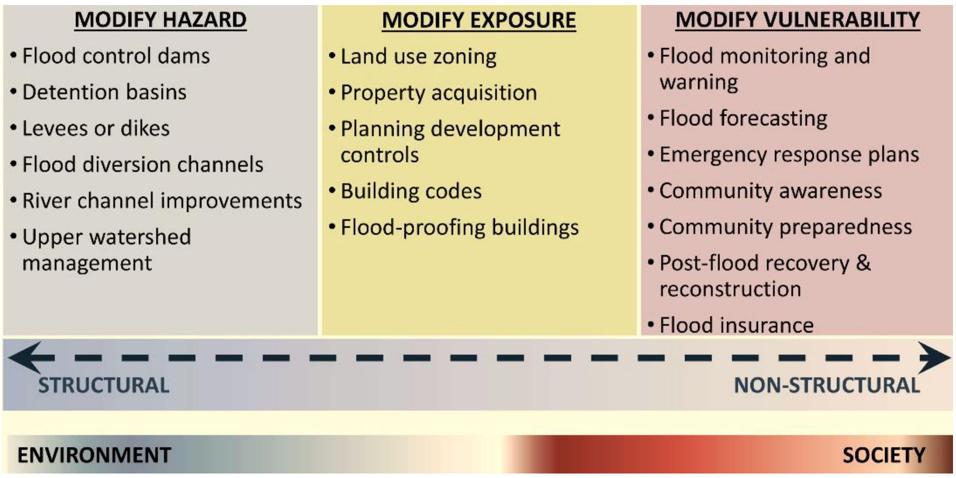


Figure 2. 13 Set of Flood Risk Management Measures
Source: (Babić-Mladenović and Kolarov, 2016)

4.5. Conceptual Framework of Flood Vulnerability and Adjustments

4.5.1. Modified MOVE Framework

In Figure 2. 14, the flood hazard environment encompasses residential buildings' exposure to flood in terms of physical elements at risk. Jabeen et al. (2010) have shown that this concerns the location of the houses and their specific design features, the surrounding land cover condition, elevation, and infrastructure (e.g.

drains). The condition of these physical elements and the frequency and level of damage to physical elements is indicative of the physical vulnerability level of the locality in context. Again, the condition and exposure of the physical elements is a representation of flood risk. However, several factors mediate the risk and vulnerability levels of various houses or other physical elements at risk (Amoako, 2018). These include local responses in terms of physical modifications and adjustments to elements at risk, preparations in anticipation of floods, and/or collective mobilizations to address neighborhood-level physical vulnerabilities (Amoako, 2016). Together, the extent to which such responses are initiated and the impact on flooding are indicative of coping or adaptive capacity at the local level. In many instances, capacity results from the interaction between exposure to flood and local responses. The complex assemblage of flood exposure and physical adjustments provides a conceptual lens to understand how local residents understand, survive, learn, evolve and manage the geophysical and social stresses of urban floods on their living environment. The MOVE framework (Van Westen, 2014) provides a framework to understand elements-at-risk to floods, flood damage, and micro-level physical adjustments but also what specific form of actions are relevant to addressing flood risks and vulnerabilities. This is essential for flood risk management and long-term relief these responses offer to areas susceptible to urban floods.

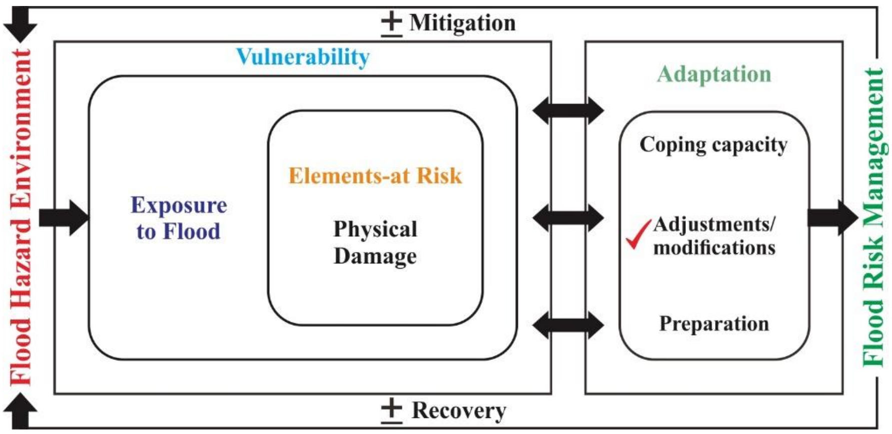


Figure 2. 14 Conceptual Framework of Physical Vulnerability and Adjustments

4.5.2. Modified DROP Model

The conceptual framework below frames the intersections and interconnectedness between the core elements of flood risks or occurrence, emergent coping mechanisms and their influence on flood impact (damage) and local adaptive capacity (Figure 2. 15). In Figure 2. 15, as a socio-ecological phenomenon, the flood hazard environment encompasses place-specific factors, such as the social system, natural system and the built environment. The degree of inherent vulnerability and resilience of any particular group or community at risk is highly influenced by these place-specific factors (Cutter et al., 2008). The built environment's exposure to flooding depends on factors such as building location and their specific design features, surrounding the land cover condition, plinth height and other infrastructure (drainage system) (Jabeen et al., 2010). During floods, the physical vulnerability of buildings also depends on proximity to rivers, elevation, along with the frequency, duration, and depth of floods (Ciurean et al., 2013). Hence, effective coping strategies reduce flood impact and absence of coping strategies intensify flood impact. Absorptive capacity is enhanced when local coping strategies withstand the flood impact (Twum and Abubakari, 2019). Nevertheless, if coping strategies are inadequate and flood impact is severe, then the physical damage will be beyond the absorptive capacity requiring the utilization of adaptive strategies developed through either improvisation or social learning to manage risk and recover from the flood events. Indeed, several studies (Danso and Addo, 2017, Jabeen et al., 2010, Davis, 2013, Moser and Satterthwaite, 2010) highlight the need to build a detailed understanding of the scale and nature of local coping strategies to ensure adaptive capacity at household and community levels and to integrate them into disaster management plans.

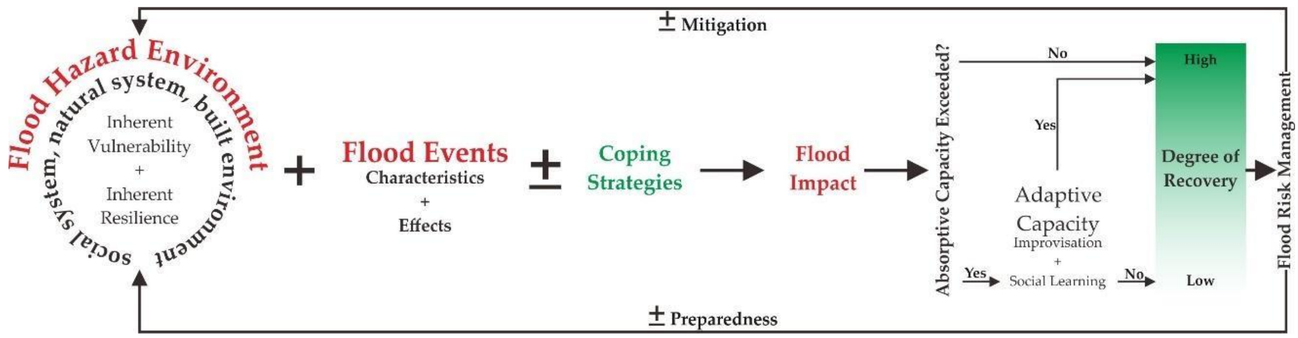


Figure 2. 15 Conceptual Framework Explaining the Relationship of Flood Vulnerability with Coping Strategies and Flood Risk Management
(modified from DROP model (Cutter et al., 2008))

5. Local Coping Strategies

5.1. Measures of Flood Coping Strategies

Few (2003) addressed that the coping capacity of individuals and communities is observed as a key component in recent times determining the vulnerability at household or community level. Few (2003) also claimed that people experiencing flood risk may act such as:

- to avoid floodwaters spreading and infiltration by physical means, and
- to minimize negative impact due to flood through actions.

Clarke Guarnizo and Munasinghe (1992) proposed a framework in which 'adjustment mechanisms' could be mapped based on categories of mechanisms (economic relationships, cultural arrangements, social organization and technology use) and on their relationship at different phases in the disaster lifecycle (before, during and after). Twigg (2004b) recommended that the flood response strategies mainly cover three phases: mitigation, preparedness and prevention. According to Twigg (2004b), mitigation can be defined as any action taken to minimize the extent of a disaster or potential disaster like flood, can take place before, during or after a flooding event. However, the term is used most frequently for disaster-related actions. Mitigation strategies can be categorized as structural (such as flood defense or building reinforcement) and non-structural (such as flood management training, land use regulation and public education). Moreover, preparedness can be defined as specific measures addressed before disasters (like floods) occur, ensure provisions when they threaten and organize the appropriate response. Prevention can be determined by the actions to minimize the adverse impact of hazards and related disasters. Drawing on the discussion above for coping mechanisms, several measures can be listed adopted from Batica (2015) (see Table 2. 6):

Table 2. 6 Measures of Flood Coping Strategies
Source: (Batica, 2015)

Measures	Instruments	Contribution Process
Capacity building of human resources	- Flood maps (Inundation and Risk) - Info material (brochures, public presentations, internet portals etc. - Education - Communication	- Face-to-face learning - Web-based learning - Training - Collaborative platforms
Land use control	- Spatial Planning - Flood risk-adapted land use - Building regulations	- Building codes - Zoning ordinances
Flood preparedness	- Flood Resistant buildings - Flood-Proofing through Wet-proofing and Dry-proofing	- Flood action plan (local scale) - Infrastructure adjustments and maintenance
Contingency measures	- Financial Preparedness - Insurance of residual risk - Reserve funds - Emergency Response through Evacuation and rescue plans - Forecasting and warning services - Control of Emergency Operations - Providence of emergency response staff	- Emergency infrastructure - Allocation of temporary containment structures - Telecommunications network - Transportation and evacuation facilities - Disaster recovery plans, pecuniary provisions of the government

Here, capacity building of human resources focused on increasing awareness of flood risk among key stakeholders in the urban system through presenting the brochures, short public presentations, creating internet portals with related useful information. The contribution can be also confirmed from face-to-face learning activities and training. Land use management focused on spatial planning and building regulations to control and manage flood risk. Modified building code and zoning can contribute to prevent a certain amount of inundation and minimize the flood damage. Floating or amphibious buildings and elevated buildings, dry and wet proofing of buildings can contribute to flood preparedness and thus, mitigate the flood damage (see section 5.2 for details). Lastly, contingency measures refer to financial preparedness, shelter management, improving flood insurance schemes, evacuation and rescue plans, etc. For this study, the primary focus was on Flood preparedness and some proposal was discussed on land use control.

5.2. Flood Coping Strategies in Urban Areas

According to Parker (2014), flood damages to all sectors including residential buildings can be categorized on two levels: (i) as tangible and intangible, and (ii) as direct and indirect. Direct, tangible damage to building, including physical damage to its structure, especially on walls and floors as well as to its building components such as installations, windows, doors, and other fixed utilities (Zevenbergen et al., 2007). On the other hand, rehousing and cleaning expenses are generally seen as indirect tangible damages (Zevenbergen et al., 2007). Loss of life, physical injury etc. are examples of intangible damage (Parker, 2014). For this study, the focus was on direct, tangible damage, that is most important for the assessment by the implementation of flood-resistant technologies of potential damage reduction. In this regard, Zevenbergen et al. (2007) proposed several important options to reduce the impact of flood actions on housing regarding flood-proofing technologies which consider within five categories: (i) Elevated configuration, e.g. building on columns or pilings, building with an elevated entrance; (ii) Dry flood-proofing, which are strategies to keep water out of the building; (iii) Wet flood-proofing, improving the ability of the property to withstand the effects of flooding the building is submerged; (iv) Construction of permanent or mobile flood walls and (v) Floating or amphibious homes

Similar to five categories of flood-proofing options proposed by Zevenbergen et al. (2007), Andjelkovic (2001) introduced five categories of flood-proofing by developing improvement actions with specific types of constructions to avoid the impacts of the flood (see Figure 2. 16).

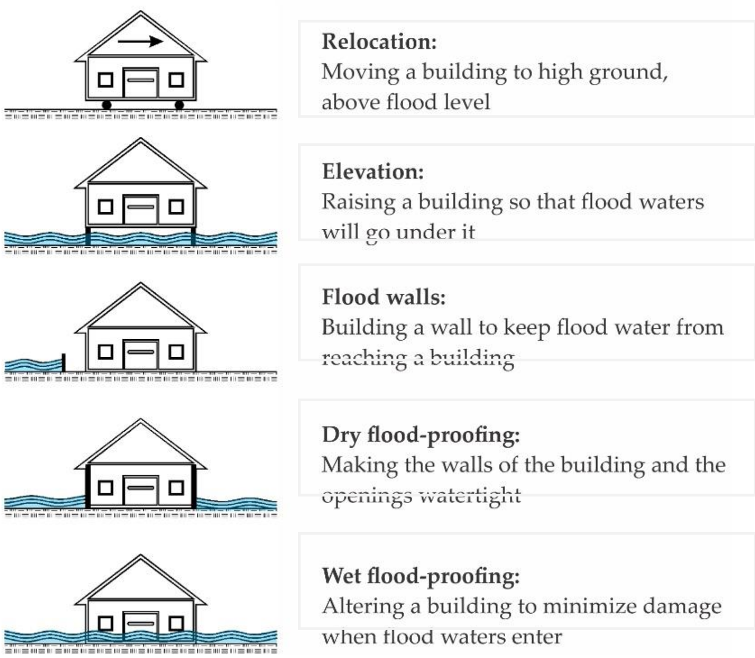


Figure 2. 16 Categories of flood-proofing
Source: (Andjelkovic, 2001)

Andjelkovic (2001) also proposed that construction of public buildings serving as flood shelters, either on natural or artificial high grounds or by positioning the structure on columns and stilts, enabling entry from exterior floors through a staircase to the top floors (see Figure 2. 16). Andjelkovic (2001) further mentioned that floodwalls or even, temporary blocks composed of sandbags can be used as barriers in places where floodwaters are shallow and slow-moving.

5.3. Flood Coping Strategies in Peri-Urban Areas

Peri-urban by definition is an *"area where urban and rural features and processes meet, intertwine and interact, usually located between city and countryside"* (Tacoli, 2003)[p.122 They are not simply the periphery of cities but areas where both rural and urban features reconcile (Ricci, 2012, Allen et al., 2006). In many countries of the globe, peri-urban areas are not necessarily formal and regulated by metropolitan urban authorities, as a result, their development is often uncertain (Eakin et al., 2010). Characteristically, peri-urban settlers occupy river floodplains and engage in agrarian activities (Douglas et al., 2008), as these areas are often unplanned. Their residents are also comparatively poor and disproportionately affected by flooding (Winsemius et al., 2018). Consequently, these communities actively develop their response strategies to their flood risk vulnerabilities (Grasham et al., 2019). Strategies to deal with vulnerabilities associated with physical and the built environment in peri-urban areas operate at different scales including (Jabeen et al., 2010, Wamsler, 2007, Douglas et al., 2008):

- Within the house: raising furniture or building high furniture where people can rest during flooding, blocking entryways to prevent floodwater from entering into houses, and creating paths to direct the flow of water easily.
- Modifications to house structures: installing rain-gutters, replacing walls or supporting structures with flood-resistant materials such as bricks or concrete.
- Modifications around the house: digging water channels, building dykes, laying sandbags.
- Improvements at the neighborhood level: cleaning drains and canals, building retaining walls, and putting plastic sheets on the slopes.

5.4. Roles of Community Participation in Flood Management

Hendra (2018) defined community participation as *"an effort to foster a sense of ownership and enthusiasm for various community development activities based on their involvement in planning, implementation and evaluation of development"*. Twigg (2004) conceptualized community participation as the "active involvement of people in making decisions about the implementation of process, programs and projects which affect them". In several areas of urban development, including disaster management, community participation has been encouraged to deal with those disaster events. Imelda and Zubair (2004) explained the scopes of the community participation in flood management through which they can contribute such as:

- coordinating and facilitating individual efforts;
- building synergy effects and reducing costs;
- strengthening solidarity and enhancing the effectiveness of cooperation within communities;
- providing platform for consensus-building and conflict avoidance;
- supplementing national and local government efforts; and
- harmonizing flood management efforts with other development activities.

Mikkelsen (2011) explained community participation as *"a form of community activities that arise as a logical consequence of the existence of awareness towards the responsibility that related to their self-interest"*. Mikkelsen (2011) also added that Community participation is a form of successful authorization of the public to implement a program or a specific action related to the public interest in the process of such implementation. WMO and GWP (2008) emphasized the essential role of community participation in every step, in flood risk management, that is preparedness for, response to and recovery from flood disasters. The community mobilization plays the key role to strengthen the organizational bases for local flood mitigation initiatives, which is started with the community actions. The individual efforts and activities are very common to mitigate the impacts of the flood. However, at the community level, if these activities can be developed in organized collectively, flood vulnerability can be significantly reduced.

5.4.1. Collective Action

Carbone and McMillin (2019) [p. 311] defined collective action *"as citizen-driven actions to facilitate community change"*. According to Ostrom (1998), collective action applies to circumstances where more people come together to accomplish a shared purpose, such as the restoration of flood levees by local community. It is claimed as an important aspect for empowering individuals for creating positive change in their communities (Drury et al., 2005). This may be turned into a way of mobilizing capital, co-ordinating events, exchanging knowledge or organization growth. (Poteete and Ostrom, 2004). Meinzen-Dick et al. (2004) identified four key elements of collective action:

- First, collective action must include a group of people.
- Second, members of the group must have a shared interest that they are willing to work to achieve.
- Third, the group must work together to advance the shared interest.
- Finally, participation by members must be voluntary, as opposed to paid, hired, or professional advocates.

Ireland and Thomalla (2011) emphasized the benefits of participating in organized communities are valuable for identifying and drawing on current dynamics of societies and collaborating with individuals who are already interested. According to Ireland and Thomalla (2011), collective actions can focus on— (i) increasing awareness of disasters and community members' preparedness; and (ii) building capacity for disaster risk reduction, early warning, and mobilizing local government resources.

Disaster preparedness activities includes the gathering and sharing of current information; hazard recognition, possible effects, high-risk areas, protected places, evacuation routes and those most vulnerable; public education campaigns; emergency plan preparation; early warning and evacuation exercises. Capacity-building activities include the recruitment and training of volunteers in emergency response activities such as the development of alternative warning dissemination infrastructure and procedures, engaged at the local level

Capacity-building activities involves the recruiting and training of volunteers for emergency response activities, such as establishing alternative warning dissemination procedures and infrastructure, employed at the local level (Ireland and Thomalla, 2011). In flood risk management, purposeful management of collective action can be highly effective for building resilience among flood-prone communities (Babcicky and Seebauer, 2017). In collaboration with public and private actors the integrated flood risk management approaches can be established to reduce flood risk by a collaborative initiative (Few, 2003, Bubeck et al., 2013).

5.4.2. Social capital

Ostrom (1998) defined social capital as "*the shared knowledge, understandings, norms, rules, and expectations about patterns of interactions that groups of individuals bring to a recurrent activity*". This has been incorporated both horizontal ties among a group (expressed to as "bonding social capital") as well as vertical ties between different groups (expressed to as "bridging social capital") (Coleman, 1988). Woolcock (2002) conceptualized social capital based on three categories: bonding, bridging and linking. Here, Adler and Kwon (2002) referred 'bonding' as the strong emotional connections among individuals, in the family or among close friends which could provide support and assistance in times of need. Granovetter (1983) described 'Bridging' as looser horizontal ties between individuals and groups in associations and joint activities, including political, civic and religious organizations. Szreter and Woolcock (2004) defined 'linking' as vertical ties between individuals and communities as well as formal institutions of government.

Several studies have verified the link between social capital and adaptation through the positive impact of social capital on community adaptation during and after natural disasters (Pelling, 1998, Cutter et al., 2003, Nakagawa and Shaw, 2004). Therefore, social capital can contribute considerably in all phases of the disaster risk management cycle (Kuhlicke et al., 2011, Aida et al., 2013). In the prevention phase, public information can complement and enhance competence, especially in circumstances of conflicting and uncertain situations when decision-making is made (Gamper and Turcanu, 2009). In the preparedness phase, strong social networks can contribute through facilitating formal and informal communication of risk and coping options, which can be acted as trusted sources to pass on the risk information by word of mouth and informal social ties and can make risk campaigns more effective (Norris et al., 2008). In the response phase, social networks can contribute to support flood victims by drawing upon neighbor help (Moore et al., 2004) or by providing temporary shelter after evacuation. In the recovery phase, private and public sector resources can be used efficiently with the support of social capital (Aldrich, 2011).

5.4.3. Social Learning

Bandura and Walters (1977) defined social learning as *"the learning processes in an individual through social interactions rather than direct experience such as observing and modelling the behaviors and attitudes of others"*. According to Van der Veen (2000), social learning is a communicative experience, in which an person develops intersubjective knowledge and creates a common understanding of reality. Webler et al. (1995) conceptualized social learning in a different way, as it is more than mere individual learning in a social situation, rather it indicates to *''the process by which changes in the social condition occurs. For instance, changes in popular awareness and changes in how individuals see their private interests are linked with the shared interests of their fellow citizens.''* Muro and Jeffrey (2008) stressed the importance of participatory strategies and approaches to promote social learning, concentrating on mutual-learning and inclusive decision-making mechanisms that, in effect, could change the social environment and open up new possibilities for collective action. Jensen and Ong (2020) explained that the ability of the group to handle differences of perspective, resolve conflicts between members, make and implement collective decisions as well as learn from experience depends on the capacity for social learning.

Social learning indicated as the key concept for integrated flood risk management along with adaptive co-management, multilevel governance, and (Van Herk et al., 2015, Rijke et al., 2012, Pahl-Wostl, 2009, Armitage et al., 2008). Social learning is theoretically important in several ways to generate adaptiveness (Lebel et al., 2010):

- Social learning can contribute to coping with informational uncertainty, that refers to deficits in knowledge about future developments (Lebel et al., 2010).
- **S**ocial learning can reduce normative uncertainty, that refers to uncertainty about goals and actions and also relates to perceptions of acceptable risk (Newig, 2007, Biermann, 2007).
- Social learning helps to build consensus on criteria for monitoring and evaluation (Lebel et al., 2010).
- Stakeholders can be empowered by social learning processes by which, they can influence adaptation and take appropriate actions through sharing knowledge and responsibility in participatory processes (Lebel et al., 2010).
- Conflicts can be reduced by social learning, whereas it can also identify synergies between adaptation activities of various stakeholders and thus, improving the overall chances of success (Armitage et al., 2009).
- Social learning improves the likely fairness of decisions and actions (Pahl-Wostl, 2009).

6. Conclusion

This chapter aimed at presenting a theoretical construction on the concepts of physical vulnerability, coping strategies, the indicators of physical vulnerability and conceptual framework explaining the relationship between physical vulnerability and coping strategies. This review indicated the different perspectives on physical vulnerability and coping strategies. It has been shown that the importance of community participation to enhance the adaptive capacity of the existing community before, during and after the disaster, for this study flood. In the study, different adjustments and modifications in two different areas have been captured to combat with these perennial destructive events in this chapter.

Figure 2. 17 is a representation of the conceptual framework for this study. This has been thematically categorized into three main levels. Level one as described before is concerned with physical vulnerability and coping strategies. Physical vulnerability is addressed with elements at risk, causative factor and impact impounding factors (indicators of physical vulnerabilities), whereas coping strategies have been addressed by local knowledge and physical adjustments. The second level presents the policy and or technical approaches formulated to deal with urban flooding. The national level and city level planning measures are analyzed and divergence and limitation have been identified. In the last level, the idea has been developed to strengthen the local community with organizational and technical support to manage and control the impacts of flood and thus, make them flood resilient community. This is basically, the ultimate aim for this study.

It the next chapter, the methodology for the study has been discussed to convey the steps and processes undertaken to collect, analyze and interpret the secondary and primary data.

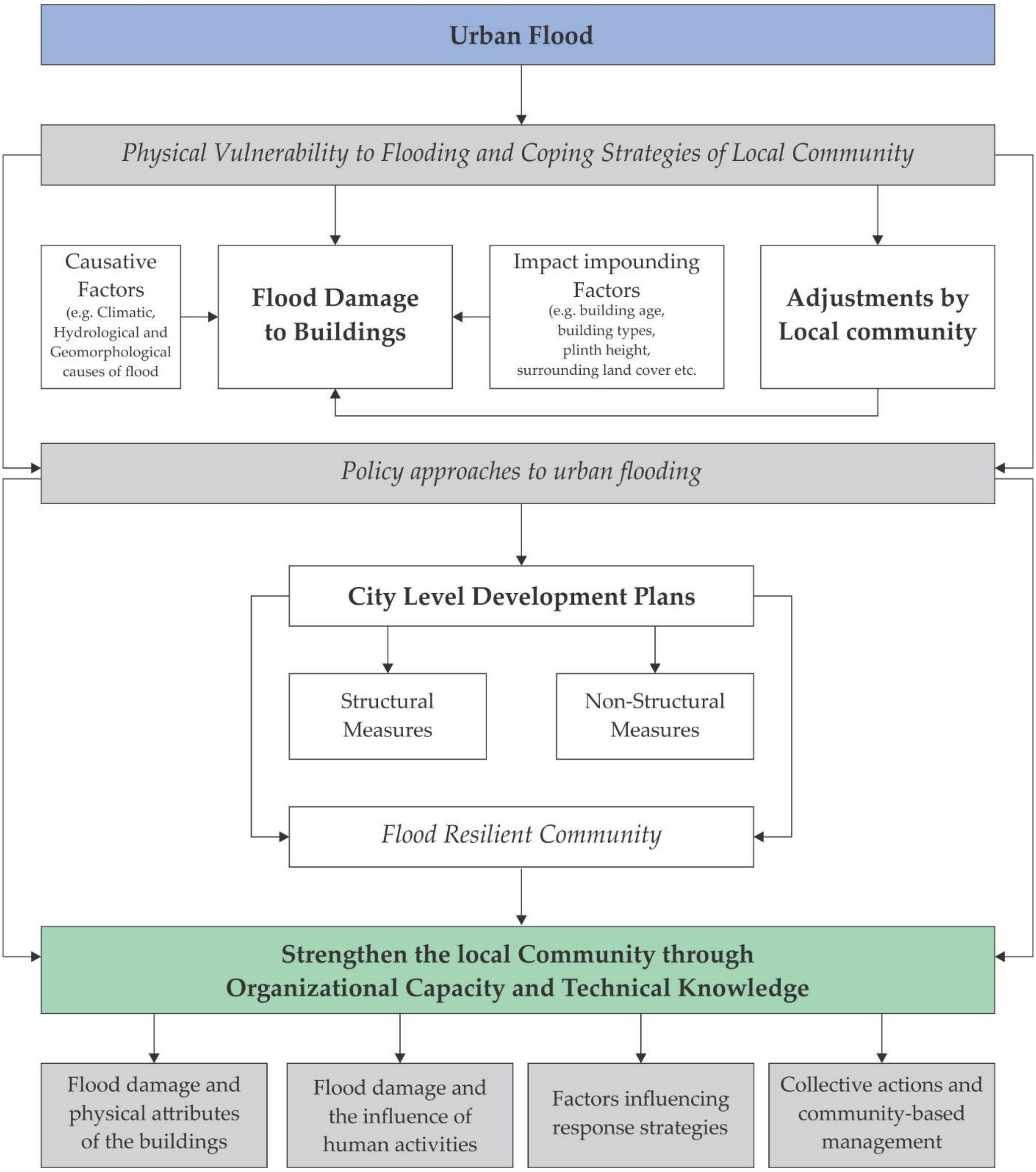


Figure 2. 17 Conceptual Framework of the Research

RESEARCH METHODOLOGY

1. Introduction

The case of this chapter is to explain the methodology (the procedures, methods, and instruments) used in this research. The research was conducted to assessing the physical vulnerability of elements at risk in flood-affected areas of Eastern Dhaka and their coping strategies. To achieve the objective of the study, participation and knowledge of the local people was considered. A three-stages (pre-fieldwork, fieldwork, and post-fieldwork) research methodology has been applied in which issues of research design, data collection, techniques for data collection and analysis as well as the rationale for the selection of the specific case study are considered.

2. Research Design

Analyzing flood damage to buildings as part of physical vulnerability is a complicated process, and can be done using either empirical or analytical research. Empirical research is either based on damage data from historical hazard events or affected peoples' opinion (Van Westen, 2013). For events that are relatively frequent and widespread, it is possible to collect information on the degree of physical damage to buildings or infrastructure after the event has occurred (Van Westen, 2014). This research design is particularly suited for flooding, which normally affects many buildings that are of the same type, and allows generating large enough samples to make a correlation between the hazard intensity and the degree of damage (WB, 2014).

Three main methods exist in this regard. The first method is done by experimenting to measure the flood damage when buildings and their contents are exposed to floodwater. Since experiments are not conducted in a real context, this method relies on a projected scenario to analyze the damage extent for construction and building materials (Smith and Ward, 1998). The second method is based on estimating the potential losses as the expected result from the flood events on a specific severity based on the generalized relationships between certain flood characteristics and physical damage. The weakness of this method lies in the fact that it produces synthetic, rather than actual direct loss values. Yet, it is regarded as more systematic than post-flood field surveys. The third method is based on the collection of actual flood damage information that is reported after the flood event. This method focuses on field interviews and questionnaires, it deals with real events which provide actual and contextual damage data (Smith and Ward, 1998). As the third method relies on time and the memory of flood victims, critiques argue that it may be useful immediately after flood events as there is a high possibility resident might forget undocumented details at a later time (Smith and Ward, 1998). However, recent studies have shown that combined in historical, geomorphological and meteorological and critical interviews, it is possible to generate reliable results from this method (Owusu-Ansah et al., 2019). The current study uses the third method, predicting the respondents have reported actual damages to the flood. To augment this, Penning-Rowsell and Wilson (2003) have suggested that at the time of data collection, the sub-category land use and depth-damage data should be considered. That is, identification of sub-groups of building types (one or two-storied, presence of a basement etc.), age of dwellings and the social class of the occupants are very essential for damage assessment.

2.1. Case Study as an Empirical Research

This study followed the above-mentioned case study research strategy. Yin (1984)[p. 23] defined the case study research strategy "as an empirical inquiry that investigates a contemporary phenomenon within its real-life context; when the boundaries between phenomenon and context are not evident; and in which multiple sources of evidence are used." This strategy, in its true essence, explores and investigates contemporary real-life phenomenon through detailed contextual analysis of a limited number of events or conditions, and their relationships (Zainal, 2007). This strategy was employed for this study as because the hydrological and geomorphological data are unavailable to employ engineering and analytical methods for both the urban core of eastern Dhaka and peri-urban areas of eastern Dhaka. This research strategy can be carried out as qualitative or quantitative, depending on the data sample, that is, quantifiable data or non-numerical data. When quantitative and qualitative data have been counted together to collect, analyze and interpret it becomes a convergent parallel mixed-methods study design. Therefore, for peri-urban areas of eastern Dhaka, a convergent parallel mixed method has been applied. The convergent parallel mixed methods research process facilitated a methodological triangulation of the qualitative and quantitative methods on flooding and local response strategies in eastern Dhaka (Morse, 1991). This method ensured the concurrent collection of qualitative and quantitative data during the research process, equal evaluation of the methods, and independent analysis and interpretation of the combined results (Creswell and Clark, 2018).

Nonetheless, coming from a socio-ecological systems perspective, employing the empirical method helps to integrate residents' experiences into understanding their flood vulnerability and response strategies (Paul and Routray, 2010, Amoako, 2018, Renaud et al., 2010). As this method is reliant on time and the memory of flood victims, critiques argue there is a high possibility resident may forget undocumented details at a later time (Van Westen, 2013). However, studies demonstrate that a combination of surveys with in-depth and critically triangulated interviews can generate reliable results (Satterthwaite, 2008, Yankson et al., 2017, Amoako, 2018, Owusu-Ansah et al., 2019). In following these studies and given the acute lack of official documentation and data (e.g. topographical maps, hydrological data etc.), time and resource constraints, this empirical method was the most suitable. Subsequently, the empirical method provides an exploratory analysis to understand experiences with flood risks and building damage embedded in the everyday life of those perennially confronted with flood disasters.

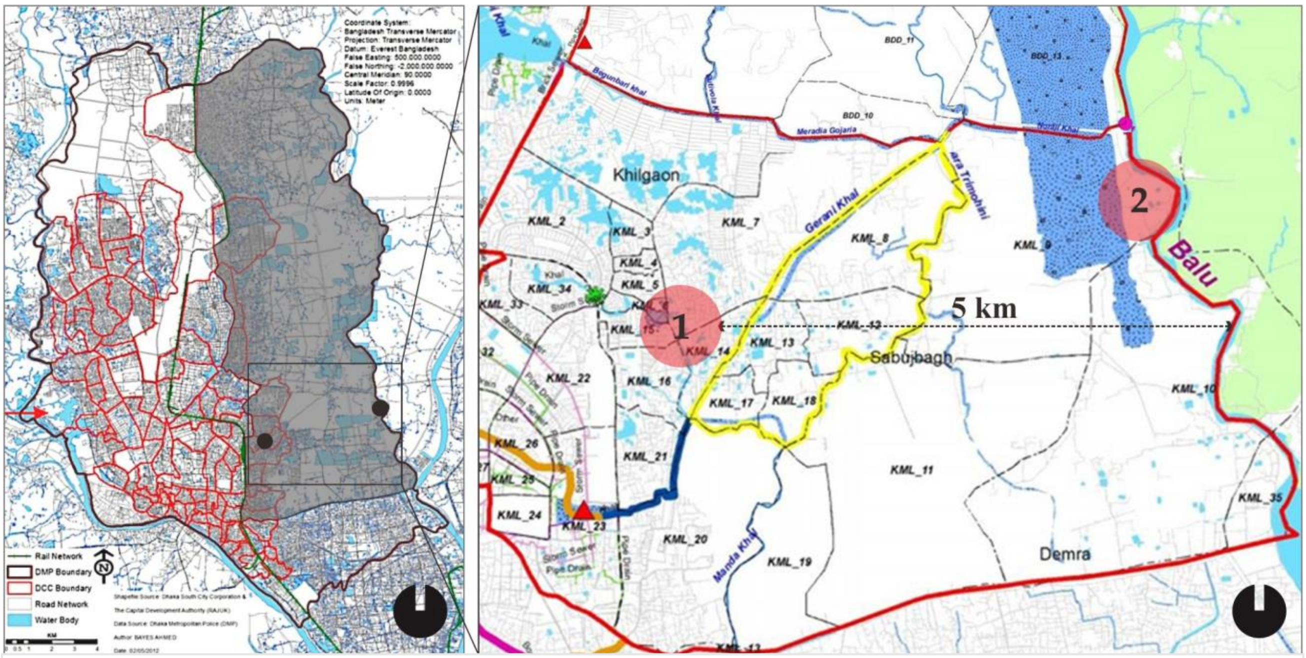
2.2. Study Settings and Justifications

This study was conducted in two different areas: (i) the urban core in eastern Dhaka and (ii) the peri-urban areas of eastern Dhaka in Bangladesh. This selection of study areas was informed by three justifications:

- First, studies predict the current and future impacts of flooding to be more harmful and hazardous in developing countries such as Bangladesh (Tanoue et al., 2016, IPCC, 2014).
- Secondly, from a list of top 15 countries with the greatest population exposed to riverine flood risk, Bangladesh ranks second (Luo et al., 2015, Yu et al., 2010). Bangladesh subsequently offers an avenue to explore flood response strategies that can be relevant to other developing countries.
- Third, although there is a vast body of scholarly work on flooding and coping strategies in Bangladesh (Jabeen et al., 2010, Paul and Routray, 2010, Rashid, 2000, Braun and Aßheuer, 2011), scholars have paid little to no attention to the critical issues of physical vulnerability and its associated local response strategies in either core in eastern Dhaka or the peri-urban areas of eastern Dhaka. More importantly, as urban growth and consolidation are occurring at these urban fringe areas where flood risks are pronounced, empirical engagement and a nuanced understanding of flood vulnerabilities and response strategies in such areas are critical to future sustainable urban development planning and management of Dhaka.

2.2.1. Urban Core in Eastern Dhaka

Under this category, the study area chosen for this research is situated in the southeastern part of Dhaka metropolitan area of Dhaka city (see Chapter 5 for Detail). Here, the study area Sabujbagh -Ward number 27 ('ward' is the smallest administrative division of the city in Bangladesh) in Dhaka East is around 5 kilometers away from the nearest river, Balu river. The reason for the selection of Sabujbagh (ward 27) was its location in a high flood-damaged zone. This ward is divided into 10 mahallas (or neighborhoods) with each consisting of about 250-500 households. For this study, two mahallas were selected namely Uttor Basabo and Purbo Basabo. The selection was based on the age of settlement, their previous experience with flooding and physical conditions (geo-morphological condition, drainage, road network). Uttor Basabo is selected because as the oldest neighborhood of Sabujbagh, it had very weak physical infrastructure (drainage and road network) which makes this neighborhood vulnerable. Along with that, it is in the low-lying zone from its surrounding area and experiences perennial flooding during every monsoon season. Purbo Basabo is selected mainly for its geo-morphological condition, as it is located between two natural canals connected to the Balu river. During monsoon, this neighborhood affected both by rain-induced flood and also by overflow from the canals. According to the records (Kamal, 2013), it had the highest flood damage in Sabujbagh.



Here, 1 = Urban Core in Eastern Dhaka; 2= Peri-Urban Areas of Eastern Dhaka

Figure 3. 1 Location of Study Areas in Eastern Dhaka

2.2.2. Peri-Urban Areas of Eastern Dhaka

Under this category, the study area chosen for this research is situated at the eastern boundary of the Dhaka metropolitan area of Dhaka city (see Chapter 6 for Detail). The study area chosen is about 7.5 km from the city core and under the jurisdiction of Khilgaon Thana (Thana meaning 'sub-districts' in Bengali). This whole area is situated along the Balu River, which is a high flood-damaged zone (Islam, 2009). Three mahallas (or neighborhoods), Dhitpur, Tamburabad and Nalsata were selected based on their previous experience with flooding, the age of settlements and proximity to the Balu river.

3. Methods of Data Collection

3.1. Study variables

A physical vulnerability study has to consider several variables within an area such as (i) Main construction material for roof, walls and floor (building typology)(Papathoma-Köhle et al., 2011, Schneiderbauer, 2007, Taubenböck et al., 2011, Gain et al., 2015); (ii) Position of buildings in relation to the street level (plinth height)(Schneiderbauer, 2007, Müller et al., 2011); (iii) Building age of household Residence (Gain et al., 2015, Papathoma-Köhle et al., 2011); (iv) Surrounding Land Cover Condition (Proportion of green spaces per building block) (Schneiderbauer, 2007, Niehoff et al., 2002); (v) Availability of flood protection measures on building (building modifications) (Müller et al., 2011, Schneiderbauer, 2007). In this study, the physical vulnerability was measured using flood damage as the variable. In addition to demographic variables, four other variables were used to measure the characteristics of buildings in the study areas.

The extent of flood damage was coded as 0 = no damage, 1 = low damage, 2 = medium and 3 = high damage. Building typology was grouped as 1 = buildings built with natural materials (mud, bamboo etc.), 2 = buildings built with temporary materials (corrugated metal sheet, wood etc.), and 3 = buildings built with durable materials (brick, concrete etc.). Age of the building was categorized as 1 = 0-5 years, 2 = 6-10 years, 3 = 11-15 years, 4 = 16-20 years and 5 = above 21 years. The surrounding land cover was coded as 0 = no setback area; 1 = setback with the impervious (paved) surface; 3 = surrounding with the impervious (paved) surface; 4 = setback with a permeable (green) surface, and 5 = surrounding with the permeable (green) surface. The plinth height of the building was defined as 1 = 0.1-0.25m, 2 = 0.26-0.5m 3 = 0.51-0.75m, 4 = 0.76-1m and 5 = Above 1m. Finally, in addressing the physical vulnerability to flooding, respondents modified their residential buildings in various ways, which were categorized as 1 = Raised homestead, 2 = Raised Plinth level, 3 = Strengthened Plinth, 4 = Strengthened walls and 5 = Strengthened whole house.

3.2. Data Collection

Data was collected through a structured questionnaire survey, semi-structured informal interviews, transect walks and field observations, photographic documentation, videos and sketches (Figure 3. 2). The fieldwork 1 was conducted during the monsoon season of May to September of 2018 and the fieldwork 2 was conducted during the monsoon season between August and September of 2019.

3.2.1. Questionnaire survey

3.2.1.2. Fieldwork 1

To collect relevant data on physical vulnerability, flood damage and coping strategies, the data collection process focused on residential buildings in the two selected neighborhoods. In both neighborhoods (M1 and M7), 4 different zones were defined according to the road network. From each zone, between 11 and 17 buildings were selected for the survey. For the selection of the houses, a simple random method was applied. A total of 105 buildings were surveyed— 55 houses (from a total of 459 houses in Uttor Basabo) and 50 houses (from a total of 381 households in Purbo Basabo). A questionnaire survey was conducted with household heads (for small houses), building managers or caretakers for apartment complexes. Building managers or caretakers were interviewed because in apartment complexes they are responsible for maintenance works and addressing disaster hazards such as flooding. In each *mahalla*, houses were selected based on the availability and willingness of the head or building manager or caretaker to be interviewed. A closed-ended questionnaire instrument was used for a one-on-one interview with the household head or building manager or caretaker in all the 105 houses from both neighborhoods. The questions were about their demographic characteristics, flood experience, flood damage on their physical properties, and physical modifications to address flood risk to their buildings.

3.2.1.2. Fieldwork 2

For the questionnaire survey, the sampling was done at the household level of flood-affected eastern peri-urban areas of Khilgaon Thana in Dhaka. Questionnaires were administered in three mahallas – Dhitpur (M1), Tamburabad (M2) and Nalsata (M3) – selected based on their previous experience with flooding, the age of settlements and proximity to the Balu river. The total number of houses in those three mahallas was 286 (in Dhitpur- 105 houses, in Tamburabad- 104 houses and in Nalsata- 77 houses). In each mahalla, between 30 and 35 houses were selected for the questionnaire survey. In total, 100 houses were surveyed (in Dhitpur, 35 houses out of 105; in Tamburabad, 35 houses out of 104 and in Nalsata, 30 houses out of 77). A questionnaire survey was conducted in the three mahallas with household heads or the oldest member of the household in each house. To administer the questionnaire, each mahalla was divided into three zones where houses were randomly selected based on the willingness and availability of the household head or oldest member to be interviewed.

3.2.2. *Informal Interview*

During Fieldwork 2, 30 semi-structured informal interviews were also conducted with household heads. These informal interviews were conducted to clarify the results from the questionnaire survey (e.g. flood return period, flood depth, flood damage to houses, adjustments to buildings after floods, and recovery). In each mahalla, nine informal interviews were conducted with residents and one discussion with the community leader. Data from community leaders provided avenues to compare earlier information and to seek clarification where necessary. The informal interviews were recorded in Bengali (local language) and lasted about 30 minutes. Photographs were taken to document evidence of physical damages and local response strategies.

3.2.3. *Field Observation*

During both the fieldwork (1 & 2), the flood damage to residential buildings and set back condition was observed and recorded on the maps. The surrounding land cover of the property was documented through the observation to triangulate the questionnaire survey data. Transect walks were also undertaken to understand the geomorphological conditions of the study area. The source of the flood (river or inland canals connecting the rivers) were also identified during the Transect walks.

3.2.4. *Physical Measurements*

During both the fieldwork (1 & 2), physical measurement of the building height, plinth height and ground level height from street level was also documented. High-water marks after the flood were also measured from surveyed buildings. These measurements helped to understand the physical flood damage and the adjustments done by the respondents.

3.2.5. Photographic documentation

Photographs were taken to document evidence of physical damages and local response strategies. Videos and sketches were also made to identify locations of the building during fieldwork. Photographs became a useful source of evidence for the fieldworks to interpret and report the field data. Images with high-watermarks helped to understand the extents of flood damages.

3.2.6. Climatic and Water level Data Collection

The annual precipitation data were collected from the Bangladesh Meteorological Department and water level data were collected from the Institute of Water Modelling.

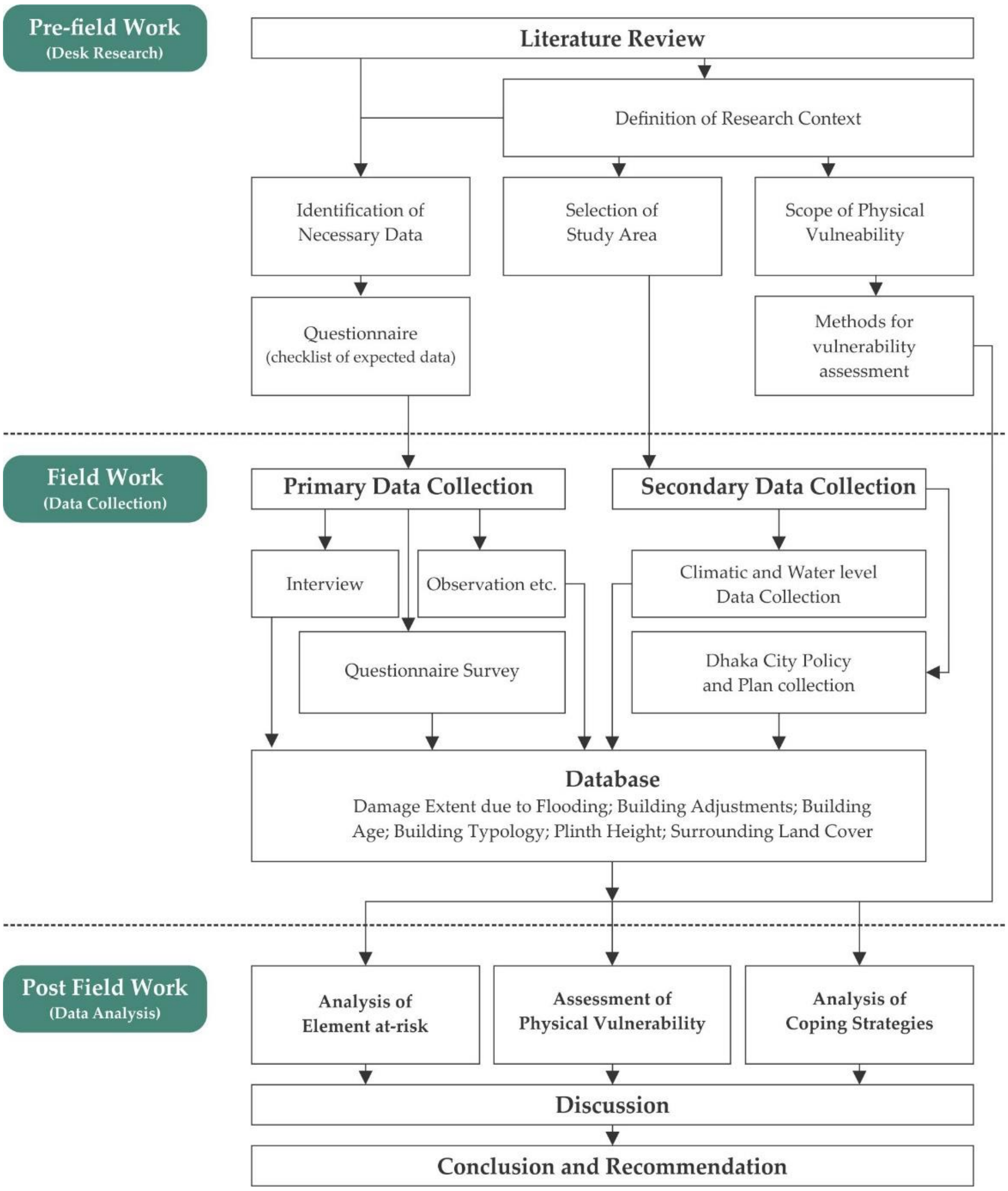


Figure 3. 2 Outline of Data Collection Process

4. Data Analysis

The questionnaire survey data was collated and analyzed using SPSS version 23 (Statistical Package for Social Sciences) and Microsoft Excel.

4.1. Descriptive Analysis with Bivariate Graphs

An objective of this research was to explore the relationships between the physical characteristics of buildings in the study area and the extent of flooding that these buildings experience. Taking cognizance of the fact that the nature of data determines the kind of analysis that can be performed, an appropriate data analytical technique was adopted for the data analysis. The data for this study is predominantly categorical. As a result, the analysis of frequencies and contingency tables (cross-tabulation) were used to present the data results. Such is the recommendation by Frey (2018). Among the bivariate (the relationship between two variables) graphs and tables, cross-tabulation is the most prominent. Cross-tabulation allows researchers to determine the relationships between categorical data. However, like frequency tables, they only show distributions or probabilities.

4.2. Descriptive Analysis with Bivariate Statistics

To measure correlation among two variables bivariate statistics are used. Phi and Cramer's V and Contingency coefficients are such types of statistics. In this study, to determine the relationships between the variables with categorical data, two main nominal measures of correlation namely the Phi and Cramer's V and Contingency coefficients were employed. According to Cramer and Howitt (2004), a cross-tabulation table enables researchers to measure the association between categorical data using the Phi and Cramer's V as a statistical measure. The measure allows researchers to determine a correlation coefficient between variables as well as how strong the association is. The closer the value to 1, the stronger association between variables (Muijsn, 2011). Generally, when Phi and Cramer's V < 0.1, there is weak correlation; < 0.3, there is modest correlation; < 0.5, there is moderate correlation; < 0.8, there is strong correlation; and < 1, there is a very strong correlation. The formula for this measure is:

$$\sqrt{\frac{x^2}{NX(S-1)}}$$

Where:	x^2	=	Chi-square value for the table,
	N	=	Total number of cases in the table
	S	=	Smaller of the number of columns or the number of rows.

The Contingency coefficients also measure the association between categorical data by converting a chi-square value into a correlation coefficient. According to Cramer and Howitt (2004), a Contingency coefficient measures the strength of the relationship between categorical variables and ranges from 0 to 1 like Phi and Cramer's V. The formula for this measure is:

$$\sqrt{\frac{x^2}{x^2 + N}}$$

Where:	N	=	Total number of frequencies in the contingency table
	x^2	=	Value of chi-square for the table

In this research, a p-value of < 0.05 has been used to determine the statistical significance of the relationships between the categorical variables. Cross-tabulation also allows us to determine the independence between variables (Cramer and Howitt, 2004). The study reports on one dependent variable, the 'type of damage in physical structure due to flooding'. The independent variables are (i) Age of the Building; (ii) Plinth Height of the Building; (iii) Land Cover of the Property; and (iv) Building Adjustments (v) Building Typology.

4.3. Cluster Analysis

A two-step cluster analysis was performed to examine the interconnections among individual variables. Cluster analysis is an exploratory analysis that tries to identify structures within the data. More specifically, it tries to identify homogenous groups of objects if the grouping is not previously known (Mooi and Sarstedt, 2011). Four variables provided the basis to identify building clustering in the study area. i) Type of Damage in physical structure due to flooding; (ii) Type of Transformed Parts of the House; (iii) Age of the Building; and (iv) Building Typology.

4.4. Thematic Content Analysis

The interview data were analyzed using thematic content analysis where responses were grouped according to themes and their relation to results from the quantitative data. Caulfield (2019) defined thematic analysis as a method of analyzing qualitative data in which a set of texts, such as interview transcripts are usually applied. In this analysis, the data has been closely examined to identify common themes – topics, ideas and patterns of meaning that come up repeatedly (Caulfield, 2019). In this study, a set of text from the respondents was used to elaborate on the quantitative data

5. Conclusion

The research design, the methods of data collection and the data analysis procedure have been elaborated in this chapter. The main methodology was based on a structured questionnaire survey, transect walks and field observations, photographic documentation, videos and sketches. In particular, this dedicated chapter on methodology has been developed to explain the procedures and tools used for this study to the readers of Bangladesh.

FLOOD IN THE CONTEXT OF DHAKA, BANGLADESH

1. Introduction

To be able to identify and assess the current flood vulnerability, damage and impact of the flood on physical infrastructure in the study area, an overview of urban flooding condition in Bangladesh is necessary. Specifically, a discussion on the frequency of the flood occurrence, the causative factors of flooding, government policy towards flooding for Dhaka city is necessary to understand the overall context of the study area. Confronting devastating flood regularly is a critical challenge for Bangladesh. Dhaka, the capital and a megacity at the forefront of rapid, unplanned urbanization; has been experiencing consistent challenge and threat of flood since 1954. Since then, to ensure flood protection and control, the City authorities adapted diverse Flood Risk Management Strategies (FRMS). Regardless of the overall progress in flood risk management policies in National Development Agenda, the inertness of their implementation keeps the City still vulnerable. This chapter will provide a contextual outline from the perspective of flood vulnerability and flood management effort of Dhaka city.

2. Floods in Bangladesh

2.1. Floods of Bangladesh in a Changing Climate

As a low-lying developing country, Bangladesh is always considered as one of the most vulnerable countries to climate change (Younus and Harvey, 2014). Bangladesh is one of the world's most disaster-prone countries; it is ranked the 9th highest disaster risk country, according to the 2018 World Risk Index (Mucke, 2018). This ranking is informed by its high risk and vulnerability to climate change impacts and weak response capacities of both its residents and institutions. Perennial floods are the main disasters and environmental risks in Bangladesh-- worsened by the frequent flooding of the 700 rivers, tributaries and distributaries during the monsoon season. Altogether, these water bodies cover about 5% of the land surface and are about 22155 km in length (Ahmed and Roy, 2007). Bangladesh has approximately 163 million people and high population densities (UN, 2019). Juxtaposing this with the fact that a greater proportion of the population lives in floodplains, experiences with fluvial flooding and riverbank erosion is common among residents (Ferdous et al., 2019, Shajahan and Reja, 2011). Cash et al. (2013) concerned that about 70% of Bangladeshi people are at risk of perennial flooding. In each year, the threat to be engulfed between 30% and 70% of the country by flooding is also the most common scenario (Agrawala et al., 2003).

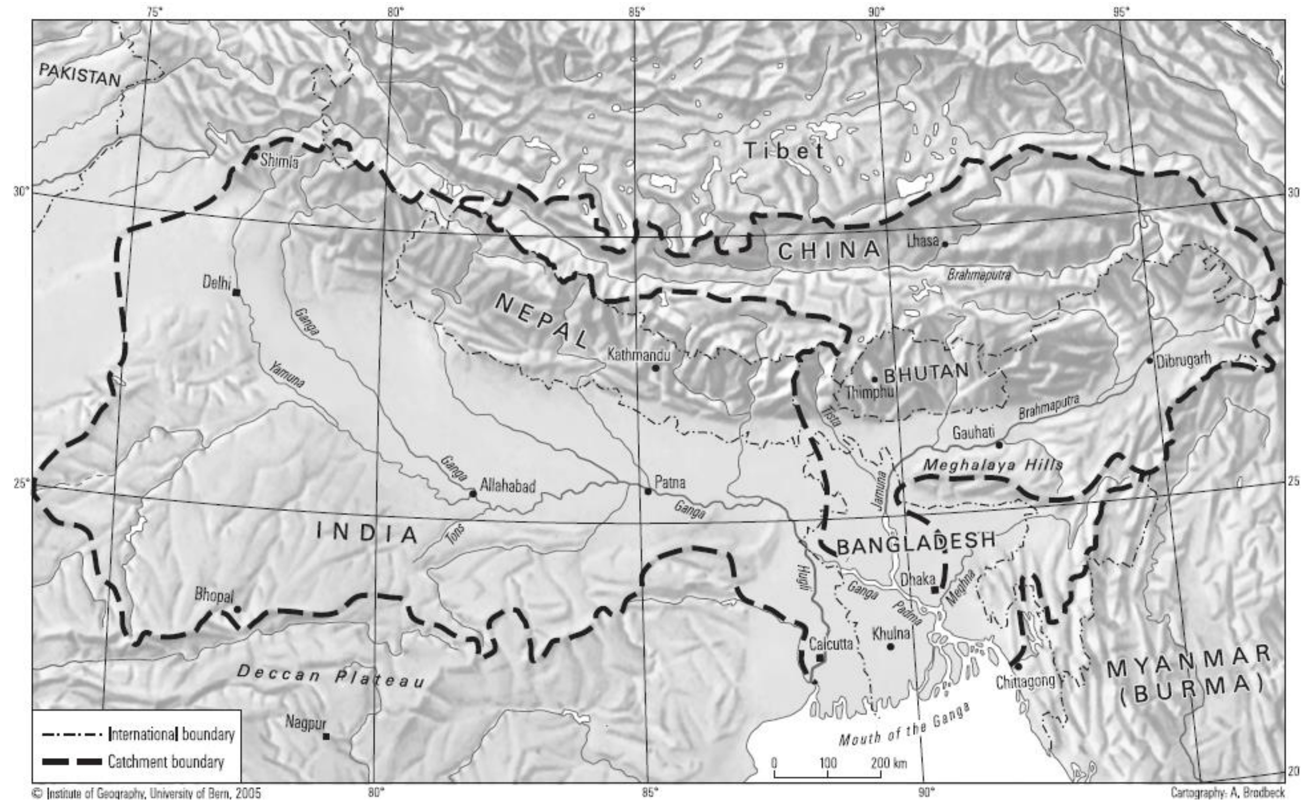


Table 4. 1 Location of Bangladesh and Catchment area of the Ganga, Brahmaputra and Meghna rivers.
Source: (Hofer and Messerli, 2006)

Bangladesh is one of deltaic country, starts from the foothills of Himalayas at north and stops at the Bay of Bengal on South (Table 4. 1). Rayhan (2010) claimed that more than half (60%) of the land area of Bangladesh is less than 6m above the mean sea level, which is one of the major reasons that make the country exposed to all kinds of hydro-meteorological disasters. Moreover, 80% of the country's landmass comprises of the floodplains of Ganges, Brahmaputra, Meghna (GBM) basins and several other minor rivers (Brouwer et al., 2007). Approximately 40% of the worlds poor live on or close to this major transboundary GBM river basin in South Asia and affected by floods, cyclones and storm surge regularly (ESCAP, 2019). Marín (2020) concerned about the rapidly rising sea level (1.5 times faster than the global average) and river erosion which has been submerged coastal villages and caused the forced displacement of millions of people. Marín (2020) added that almost 700,000 people lost their homes per year, over the last decade, and anticipated that more 10 to 13 million people will be forced to move before 2050. Thus, Bangladesh becomes one of the most vulnerable and worst impacted by climate change, even according to Global Climate Risk Index 2020, Bangladesh ranked as seventh in the list of "Countries most affected in the period 1999-2018" (Eckstein et al., 2019).

Brouwer et al. (2007) indicated another reason that intensified the flood problem is an increased volume of rainfall caused by climate change over the past decades. According to Dastagir (2015), vulnerability to severe floods during the monsoon season will increase with climate change in the flood-prone areas of Bangladesh.

Correspondingly, Alam et al. (2015) show that during the monsoon season, an increase in precipitation and annual flow is analyzed in different parts of Bangladesh. Consistent with this, Mohammed et al. (2017) observed that Bangladesh will experience more frequent floods with a greater magnitude in a 2.0 °C warmer world than a 1.5 °C warmer world. Mirza (2011) predicted about the future changes in precipitation which will frame four distinct implications regarding the environment and the flood extent in Bangladesh:

- Changes in the timing of the occurrence of floods, with a possible change of the hydrological cycle.
- An increase in monsoon precipitation which intensifies the magnitude, frequency, depth, extent, and duration of floods.
- Changes in the timing and the synchronization of the flood peaks of the major rivers.
- The abrupt change of land use pattern with the increased magnitude, depth, and duration of floods.

2.2. Flood Damage and Vulnerability in Bangladesh

Floods of different scales are perennial events in several locations in Bangladesh every year (see Figure 4. 1) which resulted in the loss of life, damage of crops and property and thus, lead to epidemics (UNDP, 2013). 20-25 per cent of the country is inundated in an average year (MFAN, 2018), whereas approximately 37 per cent, 43 per cent, 52 per cent and 60 per cent of the country is predicted to flooding of return periods of 10, 20, 50 and 100 years respectively (MPO, 1986). It is a part of the world's most dynamic hydrological and the biggest active delta system (BWDB, 2019). The interaction between the rapidly increasing population, the intensity of agricultural production, the extreme variability of precipitation in the monsoon circulation, and the scale and dynamics of the river systems makes floodplain management in this country a truly challenging task (Hofer and Messerli, 2006). This terrain experiences enormous damages to properties and considerable loss of life, especially in the year of 1954, 1955, 1974, 1987, 1988, 1998, 2004, 2007, 2015, 2016 and 2017 (see Table 4. 2).

During the 1974 flood, approximately 52,600 square kilometer area (around 36% of the total land area) was inundated, affecting almost 38 million people. A total of 57.9 million USD were lost. The death toll was over 28700. In 1987, the inundated area was over 57,000 square kilometer area (around 39% of the total land area), estimated over 1 billion USD, affecting 29.7 million people, followed by 2680 deaths. The flood occurred during 1988, inundated 89,970 square kilometer area nationwide (61%) and 2440 human deaths were recorded. Approximately, 73 million people were suffered and over 2 billion USD were lost. After a decade, during 1998, the most devastating flood hit Bangladesh and caused inundation on 1,00,250 square kilometers (68%). In that event around 1000 people were dead; 15 million were affected; 500,000 homes, 23,500 km roads and 4500 km embankment were damaged, crops of 500,000 ha of land were destroyed and the damage was worth about US$ 2.8 billion (Benson and Clay, 2002).

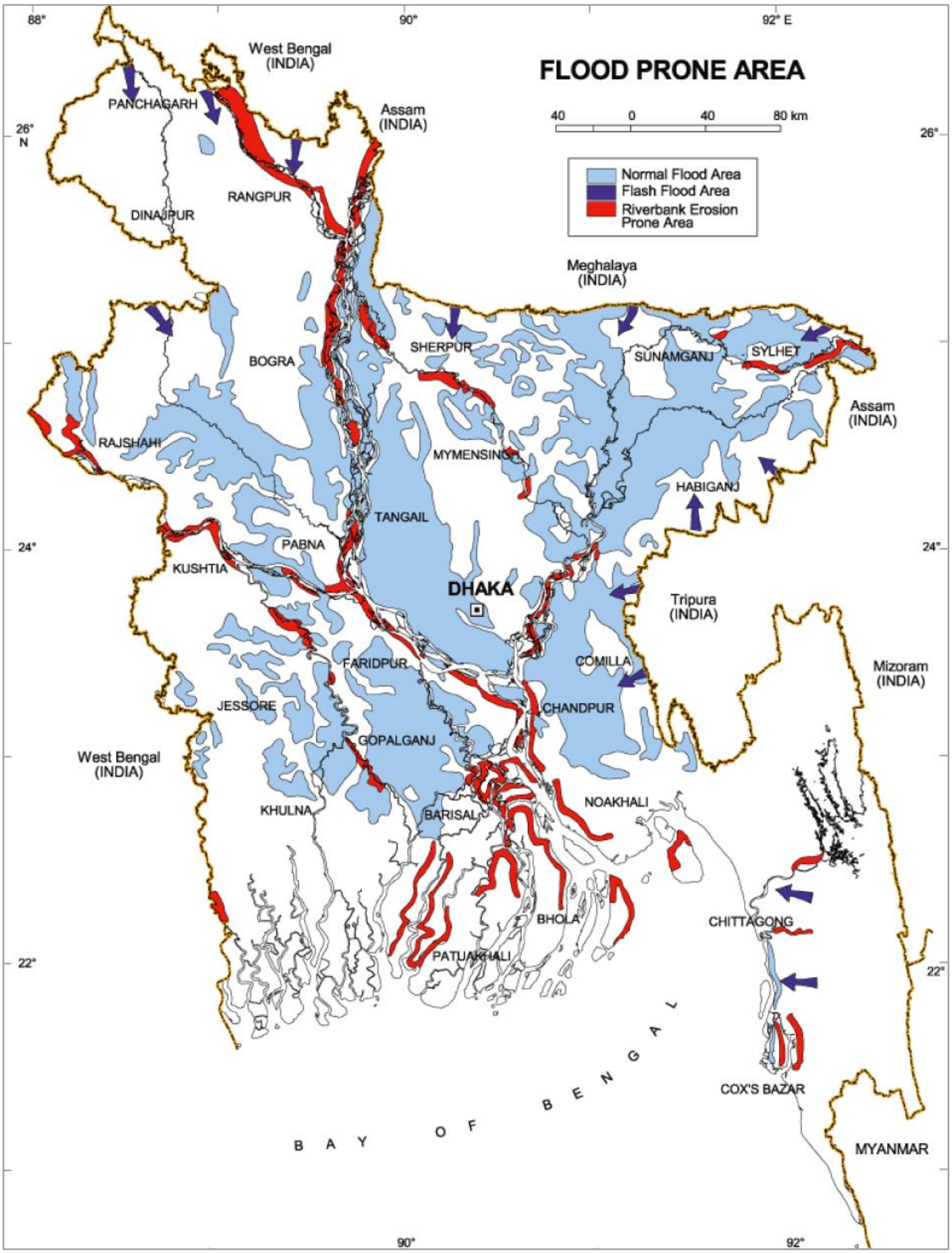


Figure 4. 1 Map of Flood Affected Area of Bangladesh
Source: (HBRI, 2018)

During the 2004 flood, 38% of the country inundated which was about 55000 square kilometer area. In that event, persons affected 6 million and died about 800, damaged 58,000 km roads and 3,100 km embankment, crop damage 1.3 million ha, damage worth about USD 2.2 billion (ADB, 2005). The flood occurred during 2007, inundated 62300 square kilometer area nationwide (42%) and 500 deaths were recorded. Approximately, 4.5 million people were suffered and over 114 million USD was lost. After 8 years, in three consecutive years 2015, 2016 and 2017, the country was flooded by 32%, 33% and 42% respectively. In the most recent flood during 2017, 6.7 million people are affected and 628 million USD were lost. The total flood affected area, the number of affected people and the total loss of the country in the most severe 13 flooding events presented in Table 4. 2 (BWDB, 2019).

Table 4. 2 Year-wise Flood Affected Area and people in Bangladesh

Year	Flood Affected Area		Affected People due to Flood		Total loss
	Sq. km	(%)	Sufferers	Death toll	($)
1954	36,800	25	Data not available	112	Data not available
1955	50,500	34	Data not available	129	Data not available
1969	41,400	28	Data not available	126	Data not available
1970	42,400	29	10,000,000	87	25,000,000
1974	52,600	36	38,000,000	28,700	57,920,000
1987	57,300	39	29,700,000	2,680	1,057,500,000
1988	89,970	61	73,000,000	2,440	2,137,000,000
1998	1,00,250	68	15,000,050	1,000	2,800,000,000
2004	55,000	38	6,300,000	800	2,200,000,000
2007	62,300	42	4,540,000	500	114,000,000
2015	47,200	32	200,000	19	40,000,000
2016	48,675	33	2,604,455	14	150,000,000
2017	61,979	42	6,775,352	121	628,000,000

3. Floods in Dhaka

3.1. Location and Contextual Settings

Dhaka is among the ten largest cities in the world with a population of more than 20 million residents (UN, 2018c). With a density of 47,400 people per square kilometer, Dhaka is the most densely populated city in the world (Ahmed, 2019). More recently growth rates have stabilized at a relatively high rate of 3.72% (Amin, 2018). The city is surrounded mainly by six peripheral rivers (Turag and Buriganga on West, Balu and Sitalakhya on East, Tongi Khal to the North, and Dhaleshwari to the South) (WB, 2015a), which overflows regularly during the monsoon season, making the city vulnerable to perennial fluvial flooding. The city is surrounded by tributaries and distributaries of the great rivers of the Bengal Delta. While these rivers are responsible for the strategic location and the fertile soils of the region, they also carry with them the threat of destructive flooding for the city (Hafiz, 2011). Dhaka metropolitan area is divided into four zones based on the existing setup of the flood management structures and administrative boundaries of Greater Dhaka: Dhaka East, Dhaka West, Dhaka-Narayanganj-Demra (DND) and the Outer Urban Area (OUA). The study area chosen for this research is situated at the eastern part of Dhaka metropolitan area of Dhaka city (Figure 4. 2). As per Regional Development Planning (RDP) of Rajdhani Unnayan Kartripakkha (RAJUK, Capital Development

Authority of the Government of Bangladesh), the eastern part of Dhaka will become predominantly urban residential and commercial in future.

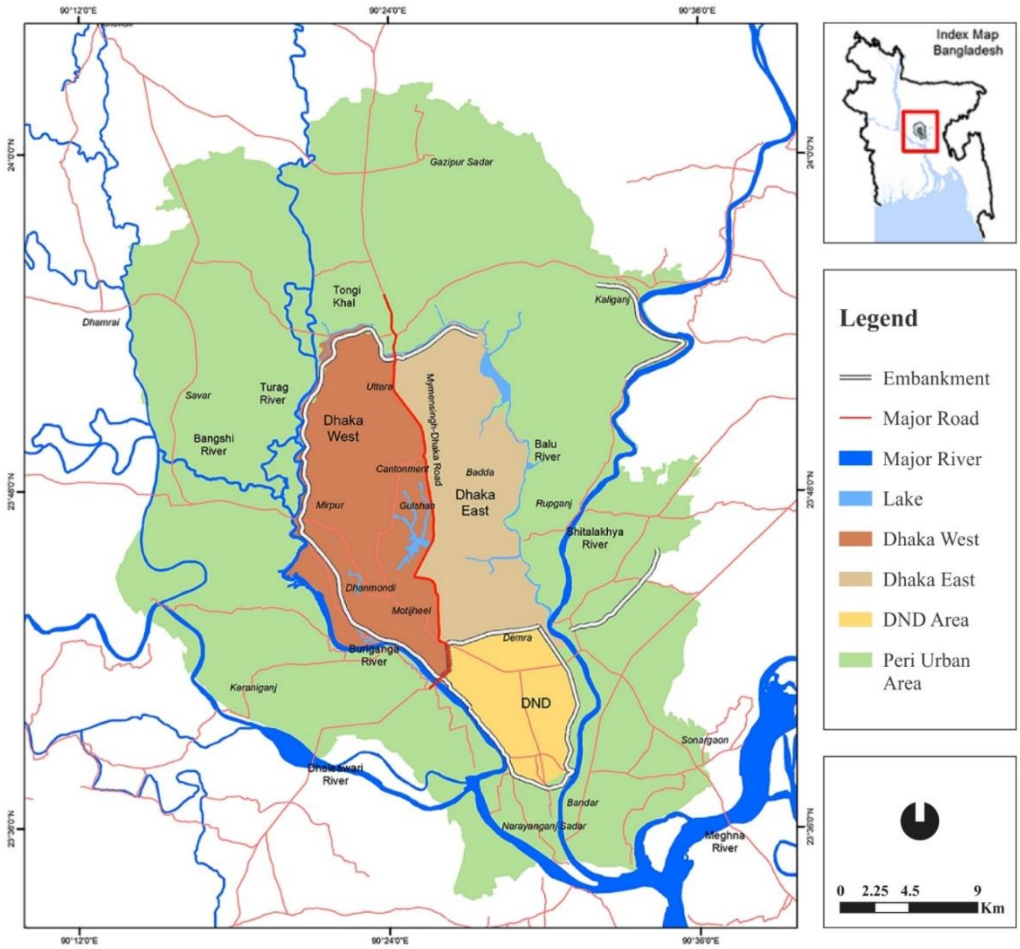
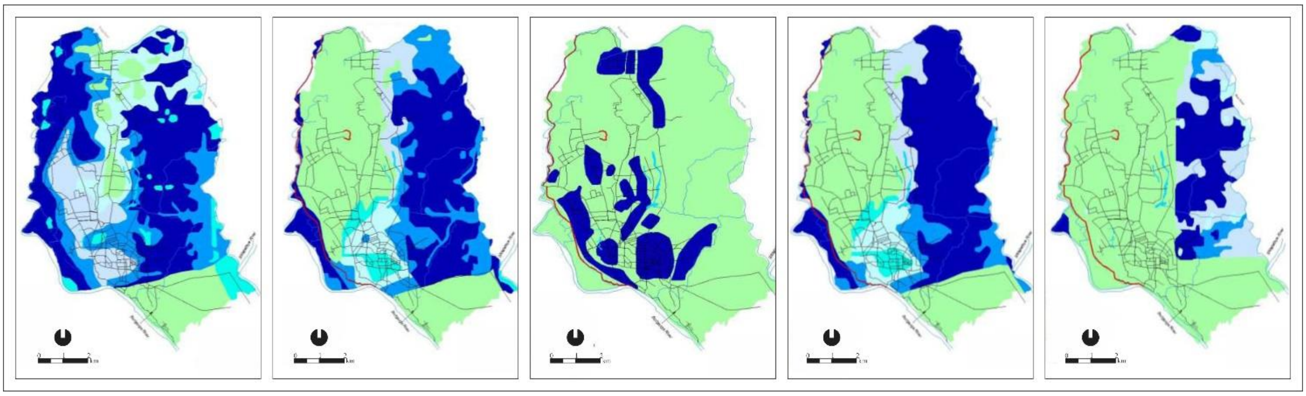


Figure 4. 2 Four Zones of Dhaka Metropolitan Areas
(Source: Center for Environmental and Geographic Information Services - CEGIS)

The eastern fringe of Dhaka city is mostly underdeveloped with some rural settlements along the bank of Balu River (Lamb, 2014). The region slopes roughly from north-west to the south-east. The altitude varies between 18 meters in the north to 4 meters in the south of the region. Land level topography illustrates that approximately 70% of the land is below 5m.PWD (IWM, 2015). The eastern part, a low-lying area of the City constituting nearly 124 square kilometers, is at the most severe risk of flooding. Though this area is not protected by embankments, it mainly consists of a few natural open channels (canals). However, the rapid urbanization and huge concentration of population towards the Capital has made the eastern fringe area highly dense in the last decades. The need for accommodation due to pressure from population influx has meant that a large portion of these low-lying areas has been encroached upon, reducing the efficiency of natural drainage tremendously. Consequently, flood risk has been a regular phenomenon here. Even though the Government has envisioned protecting the area from river and rain-induced flooding, no implementation works have been carried out yet.

3.2. Flood Occurrences in Dhaka City

By being located adjacent to the Buriganga, Turag and Balu rivers, Dhaka has been subject to periodic flooding since its early days (Khan et al., 2018). There have been incidents of urban floods in the past and they continue to exert disruptive effects on the spatial, socio-economic and environmental aspects of Dhaka's many communities. Major floods happened in 1954, 1955, 1970, 1974, 1980, 1987, 1988, 1998, 2004, 2007 and 2009 (Figure 3). The largest flood ever recorded occurred in 1988 with catastrophic effects— a death toll of 150 and 2.2 million affected people (Huq and Alam, 2003). During the 1988 flood, almost all of the eastern part and about 70% of the western part of the capital were inundated. About 30% of residential buildings were damaged as well as more than 384 km of paved roads (Alam and Rabbani, 2007). Another major flood occurred again in 1998. The 1998 flood was the most severe in terms of extent and duration. It was caused by a combination of both river and stormwater. The city was flooded for over two months (Huq and Alam, 2003). Around 56% of Dhaka West was inundated, while almost all of the eastern part was underwater. Dhaka East was again inundated by urban floods in July 2004, mainly due to overflow from the Balu River. This was followed by the second period of stormwater flooding because of intensive rainfall in mid-September— the highest recorded daily rainfall of 341 mm, compared to a mean monthly rainfall of 264 mm in September (Rahman et al., 2005). A relatively less damaging flood, in comparison with 1998 and 2004, occurred again in 2007 in which a huge part of Eastern Dhaka was cut off rendering several roads and highways inaccessible. Flooding persists as a major challenge in Dhaka, especially the eastern fringe where another major stormwater flooding occurred after a 24-hour intensive rainfall in July 2009, about 333 mm of rain and the highest in 53 years in July.



1988 **1998** **2004** **2007** **2009**

Figure 4. 3 Major Flood in Dhaka from 1988-2010
Source: Ahmed (2012)

Currently, about one-fifth of Dhaka is categorized as flood-free high ground. Approximately 38% is exposed to flooding once every 5 years. The other 42% is subject to flooding at intervals of between 5 and 100 years (Alam, 2004). During June to August, the months of heaviest rainfall, most of Dhaka becomes continuously inundated. Now, Dhaka gets inundated after only one hour of intense rainfall (Barua and van Ast, 2011). Urban flooding has, therefore, become a burden for the inhabitants, as it poses challenges to social functioning, the environment and economic activities (Alam and Rabbani, 2007).

3.3. Causes of Flooding in Dhaka City

An understanding of the causes of urban flooding, vulnerability and exposure is needed to assess the present and potential flood risk (Genovese, 2006). However, these causes may vary from place to place according to the flood characteristics, level of exposure and socio-economic structure of the people. According to Faisal et al. (1999), historically, the major reason for flooding in Dhaka is the rise of water level of the rivers surrounding the city combined with heavy rainfall during the monsoon period. In line with this, Islam (2009) emphasized that the level of the rivers is affected by both discharges from upstream rivers and by the backwater effect caused by the sea, from downstream rivers. Moreover, Barua and van Ast (2011) indicated that the annual stormwater flood caused by excessive rainfall during the monsoons, mostly combined with the high-water levels of the surrounding rivers obstructing gravity drainage. Along with these, the excessive transboundary inflow and lack of flood defense structure, especially at the eastern fringe of the city, intensify the flood situation. Faisal et al. (1999) added that low maintenance of the flood defense structures, inadequate capacity of pumping as well as lack of institutional coordination worsen the situation. Chowdhury et al. (1998) have identified four main causes of perennial flooding in Dhaka:

(i) Increased impervious areas reducing infiltration and increasing surface runoff;
(ii) changes in drainage flow patterns as a result of the construction of roads and other infrastructures;
(iii) filling up of low-lying areas, natural drainage and retention systems (canals, lakes); and
(iv) Inadequate drainage paths, improper operation and maintenance of the existing stormwater drainage system.

Furthermore, improper solid waste disposal in the drainage system led to the clogging of existing drainage pipes, thereby contributing to waterlogging in existing residential areas in Dhaka (Bird et al., 2018). In the absence of public infrastructure in the area, the lack of investment in basic flood protection, the lack of proper waste collection and disposal, and the unplanned and uncoordinated growth by the private sector will likely compound the impacts of flood disasters (Bird et al., 2018).

3.3.1. Unplanned Urbanization and Population Growth

Unplanned urbanization with haphazard development is one of the major reasons that intensifying the flood hazard of Dhaka city. Since the independence of Bangladesh in 1971, Dhaka as the capital has been expanding rapidly. Chowdhury and Faruqui (1991) explained that with slow growth in the 1950s, Dhaka city gradually picked up its pace in the 1960s and since 1971, the growth has been phenomenal. Previous studies (Dewan, 2013, Dewan et al., 2012, Griffiths et al., 2010) show that due to rapid urban growth, impervious surfaces have been increased by converting natural wetlands and productive agricultural land. For instance, the urban extent of Dhaka in 2014 was 36,541 ha, increasing at an average annual rate of 3.3% since 1999, whereas the urban extent in 1999 was 22,825 ha, increasing at an average annual rate of 5% since 1989 when its urban extent was 13,878 hectares (NYU, 2016).

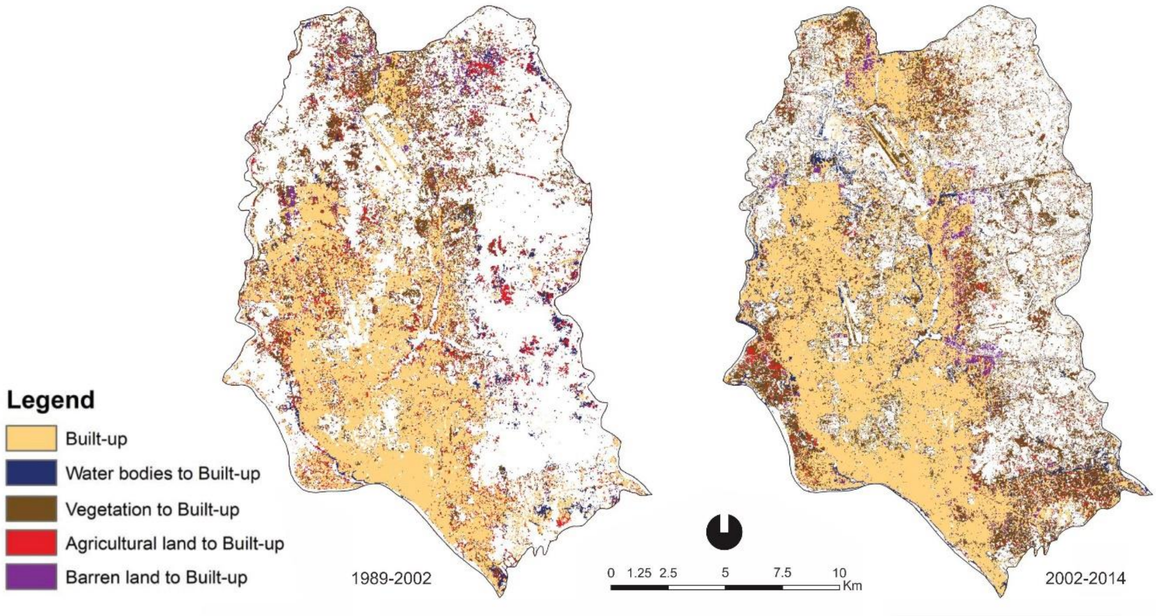


Figure 4. 4 Area of Significant Change in Built-Up Land in Dhaka City from 1989 to 2019
Source: (Morshed et al., 2017)

The current population of Dhaka in 2020 is estimated at 21,005,860. According to UN World Urbanization Prospects 2018 (UN, 2018b), in 1950, the population of Dhaka was 335,760 which has been grown by 3,408,683 since 2015, increasing at an average annual rate of 3.60%. Therefore, to focus to fulfill the increasing need of this rapidly growing population, the management of floods and floodplains becomes a neglected priority and thus, resulted in a considerable extent of flood damage (Mohit and Akhter, 2000). Dewan et al. (2012) blamed these rapid changes in land use and cover as the primary reason to prolong the flood duration.

3.3.2. Impact of Climate Change

Despite insignificant contribution on global greenhouse gas emissions, previous studies demonstrated that Bangladesh would be the worst victim of climate change (Yu et al., 2010, Winsemius et al., 2018, Marín, 2020, Fatemi et al., 2020c). Therefore, climate change impact and climate variability are projected to be the highest on hydro-meteorological disasters, particularly floods (Mirza, 2011), as the monsoonal rainfalls show an increasing tendency in Dhaka (Alam and Rabbani, 2007). Along with climate change, rapid urban growth also intensified flooding in the city (Roy, 2009). In support of this, an analysis of rainfall patterns in Dhaka from 1953 to 2017 (Figure 4. 5) confirms that a significant escalation of the annual precipitation over this period (1953 to 2017). Mean annual rainfall was 1704.4 mm (with a standard deviation of 324.8 mm).

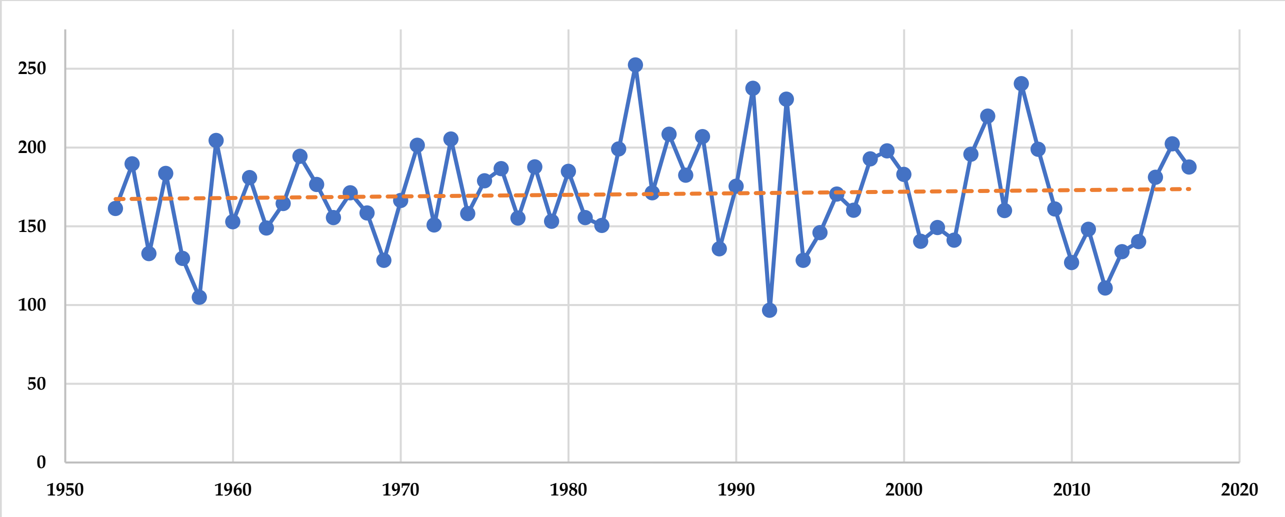


Figure 4. 5 Annual Average Rainfall for Dhaka from 1953-2017

3.3.3. Low Elevation

According to the topographical feature, Dhaka is a flat alluvial plain with irregular contour lines and intertwined with numerous canals (Dasgupta et al., 2015). Dhaka lies at a very low ground elevation with 71.5 per cent of land below 5 m in elevation. Around 26.7% of the land is 6–10 m and the rest of the land (only 1.4%) is in relatively higher ground, which is 11-16 m above the mean sea level (Dewan, 2013). However, Dasgupta et al. (2015) projected that the unpredictability of Dhaka's land-elevation pattern will remain intact in future which may cause the rainfall-generated surface flow to move in an unexpected direction, and submerge some areas that cannot be foreseen.

3.3.4. The rise in river water level

The Bangladesh Water Development Board (BWDB) who is responsible to obtain water level data on daily basis, defines the danger level for Dhaka when the water level is 6 m or higher (BWDB, 2019). Thiele-Eich et al. (2015) observed that since 1909 to 2009, the average number of days above danger level per year was 5, while in 2003–2007 the number of days above danger level was increased to 18. The identified reasons for these rivers to cross the danger level is the heavy surge from the upstream synchronized with heavy rainfall (Faisal et al., 1999).

3.3.5. Encroachment of Lowlands

Encroachment of low lands due to rapid urbanization has been shrunk the retention capacity of the whole city for during flooding season. Islam et al. (2010) observed that 32.57% of the water bodies and 52.58% of lowlands decreased from 1960 to 2008 in Dhaka city. Islam (2009) and Ishtiaque et al. (2014) confirmed the consequence of wetlands loss, resulted in intensifying the flood vulnerability and shrinking the natural drainage system of the city. Correspondingly, IWM (2006) stated that encroachment of low lands of such extent triggered the rise of water level of the river, which lead to drainage problem and also increased the flow velocity of the rivers.

3.3.6. Dilapidated Drainage Systems

Due to the rapid urbanization and continuous loss of wetlands, the capacity of the gravity drainage system of the city is below as per standard. Shams (1999) confirmed that the limited stormwater drainage is too inadequate for a city of 850 sq. km of Greater Dhaka. Moreover, the pumped drainage system also failed to serve due to electricity shortages and poor maintenance (Dewan, 2013). The dumping and littering of solid wastes into these decaying drainage infrastructures caused blockages in many occasions and further aggravated the situation (Hossain and Rahman, 2011).

3.3.7. Embankments, Embankment Failure or Damage

Nishat et al. (2000) observed that the construction of the flood protection embankment in western Dhaka allow submerging only 36km² (23%) during 1998, while 117km² (75%) were submerged in 1988 in absence of this embankment. Correspondingly, Alam and Rabbani (2007) mentioned that this embankment helped to protect more than 50% of the city from the floods in 1998 and 2004. Dasgupta et al. (2015) reported that the absence of a flood-protection embankment made the Eastern Dhaka exposed to flood risk during flooding events.

However, during the devastating flood of 1998, Faisal et al. (1999) identified several leakage points, which caused the partial flooding of the western Dhaka. Among the identified two types of leakage, the first one was attributed to the incomplete construction of the floodwall. Due to public pressure, it discontinued at the inland river port point and floodwater penetrated through this facility during the high flood. Another one is created by local people who removed parts of the floodwall for easy movement in some areas, even several buried sewerage pipes were demarcated that passed under the floodwall disposing domestic sewage directly into the river (Faisal et al., 1999). These types of damages allowed water breached back into the city during the flood.

4. Government Policy Towards Urban Flooding

4.1. National Flood Risk Management Policies

Efforts by the successive governments for prevention, controlling, and mitigation of floods in Bangladesh started after the devastating floods of the 1950s. Since then, an incremental change has been observed by the successive governments in which the focus of flood mitigation policies developed and implemented to 'control' and, more latterly, 'manage' the flood risk (Sultana et al., 2008). The overall trend of flood prevention and control approaches of Bangladesh can be viewed in terms of three distinct phases of its development (Table 4. 3).

Table 4. 3 Flood Risk Management Policies of Bangladesh in Different Phases (Adapted from Haque (1993); Cook (2010); and Parvin et al. (2018))

Policy Regimes	Flood Management Strategies	Plan/ Policy/ Acts
The first phase (1955-1986) Structural Period	This phase focused on **flood defense strategies**, is characterized by an increased willingness to implement technical adjustments. The approach was predicated on controlling hydrological resources using physical structures; initially with large-scale projects and later small-scale, low-cost, and quick-return projects.	Krug's Report 1957, Water Master Plan 1964, National Water Plan 1986
The second phase (1987-2000) Behavioral Period	This phase focused on **flood risk prevention and mitigation strategies**, is characterized by a paradigm shift from 'flood control' to 'flood risk prevention and mitigation' and combined with structural solutions, the combinations of structural and non-structural measures along with water-related social development began to dominate that had previously been limited to risk reduction.	Flood Action Plan 1990, National Water Plan 1991, Water and Flood Management Strategy 1995, National Water Policy 1999.
The third phase (2001-present) Development Period	This phase focused on **flood risk prevention and recovery strategies**, is realized the need to improve disaster response and preparedness at the local level, with the provision of immediate rescue resources, emergency funding mechanisms, and better information management and contingency planning.	National Water Management Plan 2001, National Plan for Disaster Management (2010-15, 2016-20)

After the consecutive floods of 1954 and 1955, the creation of the Krug mission was prompted in which the focus was in increasing agricultural production and large-scale projects for irrigation and flood control. The then East Pakistan Water and Power Development Authority (EPWAPDA) (presently Bangladesh Water Development Board -BWDB) prepared the first Master Plan of Water Resources in 1964 which was also focused on some large-scale public works involving embankments for flood control, gravity irrigation through canal system and pumping stations for drainage and irrigation (Haque, 1993, IECO, 1964). This master plan comprised of 91 massive projects, funded by donor agencies (Haque, 1993) and designed to spread over the 20 years of 1965 to 1985 with an estimated cost of US$ 2.1 billion at the 1964 price (Chowdhury et al., 1997). Correspondingly, it was evidenced that over 8,000 km of embankments and other structures were built between the 1960s and 1993 at a cost of over US$ 5 billion (Haggart, 1994). But, these large-scale structural management mechanisms were heavily questioned, especially regarding their costs and benefits by critics, during the whole period (Haque, 1993). For this, the World Bank recommended shifting from large-scale projects towards small-scale and low-cost projects for flood control and irrigation (Sultana et al., 2008, WB, 1972). Consequently, to harmonize different needs of water resources utilization and economic development and avoid costly conflicts among water users, the Government realized a critical need to strengthen planning and formulated National Water Plan 1986 with the assistance of United Nations Development Program (UNDP) and World Bank (Ahmed et al., 2015, Sultana et al., 2008, Hossain, 2003). It also ensured inter-ministerial coordination of water-related policies and to respond to regional challenges concerning water resources and flood management (Haque et al., 2019) (see table 5).

A significant transformation occurred in the late 80s in which flood prevention policies emerged as a common agenda in national and international dialogues (Haque et al., 2019). The severity of flood during 1987 and 1988 reinforced to establish a long-term strategic solution and the World Bank initiated the Flood Action Plan (FAP), 1989–1995 (Hussain et al., 2004). FAP comprised of 26 components which concentrated on river training and flood control, floodproofing, flood forecasting, and early warning (Chadwick and Datta, 1999). Later, National Water Plan 1991 and Bangladesh Water and Flood Management Strategy 1996 was introduced to coordinate, construct, and maintain the water-related projects (Haque et al., 2019). During this period, the donors and government considered for a participatory development approach based on increased roles for NGOs and devolving responsibilities to local people (Sultana et al., 2008). But, the absence of the public views in decision-making process became the primary pitfall to implement the processes mentioned in these policies, especially in the FAP. Therefore, a critical paradigm shift in the policy framework was observed in the formulation of National Water Policy (NWPo) 1999, integrating structural and nonstructural solutions to protect lives, property, and infrastructure from floods in an equitable way (MoWR, 1999).

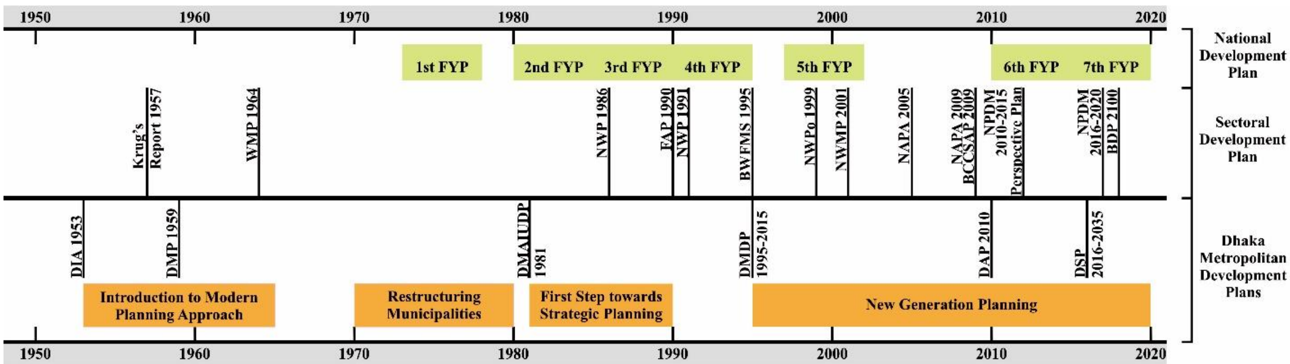
Further, the government approved a 25-year National Water Management Plan (NWMP) in 2004 to facilitate the implementation of the NWPo (Gain et al., 2017) providing the broader framework missing in earlier policies and plans under which line agencies can make regional or local water management plans and implement them in a coordinated manner (Ahmed et al., 2015). Water-associated disaster management initiatives further aided the foundation of formulating the National Plan for Disaster Management (NPDM 2010-2015) and later, NPDM 2016-2020 as a follow-up of the earlier plan where to update the flood hazard maps and an overall flood management plan was proposed (DMB, 2010, DMB, 2017) (see table 5). So, very recently, flood disaster preparedness and recovery strategies have been receiving wider policy attention, but the trend has not been linear, as different policy frameworks were initiated at different stages considering issues immediately at hand.

Table 4. 4 Incremental changes in the contents of FRM Policies in Bangladesh
(Adapted from Sultana et al. (2008) and Haque et al. (2019))

Plan/ Policy/ Acts	Key Policy intervention	Technical Context	Socio-political context
Structural Period (1955-1986)			
Krug's Report 1957	Protection of riverbank and flood through large scale constructions	Lack of knowledge of flood risks	Multilateral donors' interests in large projects
Water Master Plan 1964	Drafting a master plan focusing on flood control and drainage projects (both large and small)		
National Water Plan 1986	Drafting a National Water Plan	Complete ongoing projects, growing capacity for engineering	Inter-ministerial coordination for responding to the regional challenges
Behavioral Period (1987-2000)			
Flood Action Plan 1990	Permanent solutions to floods through structural mechanisms; Emphasis on river training, floodproofing, and warning	The debate over embankments covered technical feasibility, maintenance capacity, economic returns; Negative effects on the environment and livelihood of destitute populations, with uncertain agricultural benefits	Donor consortia, allied with the government, consultants and professionals failed to justify the implementation of major embankments and ultimately moved to the improvement of the existing schemes' performance, institutional efficiency and public participation
National Water Plan 1991			
Water and Flood Management Strategy 1995	The involvement of all stakeholders in the implementation phases of projects		
National Water Policy 1999	Integration of structural and nonstructural solutions for the protection of lives, properties, and infrastructure from floods	Participation of all stakeholders in decision making in all project cycle steps	Donors and government accepted the increased roles of NGOs and local people and include them in water management schemes
Development Period (2001-present)			
National Water Management Plan 2001	Providing guidelines to implement water and flood management functionalities at the regional and national level	Integration of environmental issues in the multilevel government policy	Local consultants' involvement to identify key environmental issues and probable solutions
National Plan for Disaster Management (2010-15, 2016-20)	Sustainable human development through enhancing resilience mechanisms	Introduction of a comprehensive disaster management process including flood risk management	Delineation and implementation of the responsibilities of all stakeholders associated with disaster management

4.2. Dhaka City Development Planning Directives

Dhaka is surrounded mainly by six peripheral rivers (Turag and Buriganga on West, Balu and Sitalakhya on East, Tongi Khal to the North, and Dhaleshwari to the South)(WB, 2015a), which overflows regularly during the monsoon season, making the city vulnerable to perennial fluvial flooding. According to Shaw (2013), during a flood events, different areas of the city become waterlogged for several days. Many roads become inaccessible for up to 8 hours during so-called normal floods, while in excessive rainfall this inundation could increase to a period of 12 hours or even more (Shaw, 2013). The illegal encroachment of low-lying flood plains, rivers, canals, and other water bodies traditionally used to drain or retain water during rainfall along with rapid and unplanned urbanization has intensified this issue (Dasgupta, et al., 2015). Since floods become the perennial events and thus, become part of life for the people here, to achieve physical resilience, flood management has been considered in different development plans of the city. A timeline of the policies, planning and development initiatives adopted by Dhaka and Bangladesh at different periods reveals gradual changes and paradigm shifts in flood control and management approaches are shown below in Figure 4. 6.



DIA= Dacca Improvement Act, DMP= Dacca Master Plan, DMAIUDP= Dhaka Metropolitan Area Integrated Urban Development Project, DMDP= Dhaka Metropolitan Development Plan, DAP= Detailed Area Plan, DSP= Dhaka Structure Plan, WMP= Water Master Plan, NWP= National Water Plan, FAP= Flood Action Plan, BWFMS= Bangladesh Water and Flood Management Strategy, NWPo= National Water Policy, NWMP= National Water Management Plan, NAPA= National Adaptation Program of Action, BCCSAP= Bangladesh Climate Change Strategy and Action Plan, NPDM= National Plan for Disaster Management 2010-2015, BDP= Bangladesh Delta Plan 2100, FYP= Five Year Plan

Figure 4. 6 National Policy, Strategy, Plans Related to Flood Risk Management with Dhaka City Development Plans

British Town Planner, Sir Patrick Geddes prepared the first planning document for Dhaka in 1917. But the then Government did not adopt the plan. Long after that, Dacca (former name for Dhaka) Improvement Trust was founded in 1956 under the Dacca Improvement Act, 1953, to manage the city planning and development. Dhaka's first comprehensive master plan, 'Dacca Master Plan 1959 (DMP)' was developed in 1959 by Dacca Improvement Trust as the first functional physical plan of the country. Later, other metropolitan development authorities came into place and formulated their physical plans such as DMAIUDP (1981), DMDP (1995-2015) and DSP (2016-2035) (Figure 4. 6). In Dacca Master Plan (1959), to ensure flood risk control and protection, only a few strategies were included, such as protection and improvement of the existing embankment at the Dhaka West, dredging the natural water channels and canals, and connection of the natural water bodies through the city. During this planning period, the first major flood control project in the Dhaka area was identified and started to construct in Dhaka-Narayanganj-Demra area from 1962. As one of the pioneer projects to manage flood in the greater Dhaka area, this project introduced the flood wall and embankment along the trunk road (WB, 2015a). Dhaka Metropolitan Area Integrated Urban Development Project (1981) was driven by stormwater drainage and flood problems in Dhaka metropolitan area and was designed to provide a long-term growth strategy for urban expansion (Kabir and Parolin, 2012). The proposal of the primary drainage network was provided for the first time. The focus was also on acquiring developed land and city expansion after realizing the difficulty to make low areas flood-free. Experiencing the destructive floods of 1988, the Government of Bangladesh formulated a Flood Action Plan (FAP) to minimize flood damage for the whole country. FAP-8, as a part of the Flood Action Plan, carried out a feasibility analysis for integrated flood management strategies to keep Dhaka flood-free (Das, 2010). This Plan is based on year-round water management integrating river management in water development projects with a high degree of protection for urban areas through a combination of structural and nonstructural interventions (JICA, 1992b). Among the 26 studies of this Plan, specifically two action plans (FAP 8A and 8B) emphasized on flood issues in Dhaka. FAP 8A covered plans for the broader area such as Dhaka-Narayanganj-Demra area and also Tongi, Savar, and Keraniganj included in the Detailed Area Plan (JICA, 1992b). This plan recommended structural measures to develop the drainage system through improving pumping capacity and dredging of khals along with nonstructural measures through flood forecasting and warning systems, land regulation, and zoning. The core city area was covered by FAP 8B with flood mitigation and stormwater drainage plans (WB, 2015a).

The Dhaka Metropolitan Development Plan (1995-2010) developed to identify the features of spatial development strategy through its three-tier—Structure Plan, Urban Area Plan and Detailed Area Plan which also formulated the utilization of city's existing urban resources through consolidation and accelerated development. The primary goal was to devise a hierarchical, multi-sectoral development plan to coordinate the flood and drainage management for the city (Barua et al., 2016). This plan introduced the first-ever policies on drainage and hydrology to ensure the protection of flood flow zones and retention ponds, and to develop the flood control and drainage through land-use planning (Rahaman, 2008). The Urban Area Plan acted as a midterm strategy for 1995 to 2005 to protect and preserve the retention ponds on the western embankment (RAJUK, 1997). Later, Detailed Area Plan 2010 addressed the safety and critical environmental issues including drainage, retention pond, flood flow zones through a land-use zoning plan along with an infrastructure development plan identifying areas of potential land use as a part of development control. Additionally, it was also prepared as a detailed implementation guide to integrating the development policies, guidelines and framework set by Dhaka Metropolitan Development Plan and a detailed development proposal, including three-dimensional proposals for each area; for example, for the provision or improvement of the road network, community facilities, utilities and services, outdoor spaces and squares, and overall, a detailed indication of urban design for the City.

The latest development plan, Dhaka Structure Plan (2016-2035) has considered maximum flood risk management strategies among the earlier planning directives having 55 objectives and 132 policies under 9 planning policy frameworks (RAJUK, 2015). Among those, 7 policies under 3 objectives are directly related to the reduction of flooding and the protection of communities, lives and properties from flooding. The policies include protection of flood flow zones, protection of canals and rivers, protection of floodwater retention areas, the building of new flood protection embankment, monitoring and evaluation of flood protection embankments around the city, improvement of capacity and institutional strength of the agencies responsible for flood control and drainage, and building urban resilience to floods (RAJUK, 2015). The plan mentioned about few strategies for the first time such as, the introduction of open spaces to convey and store floodwater during wet seasons; redesign of infrastructure into a collection of diverse functional elements that are flexible in operation and even, it recommended remodeling the future buildings to be elevated, floatable, or wet-proofed in delineating areas of flood plains and water retention areas. The Flood Risk Management Strategies included in the Dhaka city Development Plans are listed in Table 7.

Table 4. 5 Flood Risk Management Strategies Mentioned in Dhaka City Development Plans

FRMS		**DMP 1959**	**DMAIUDP 1981**	**FAP 8A &8B**	**DMDP 1995-2010**	**DSP 2016-2035**
Flood Defense	RCE					
	SD					
Flood Risk Prevention	GPCA					
	LUP					
Flood Risk Management	UM					
	BR					
Flood Preparation	WS					
	DM					
	EP					
Flood Recovery	RP					
	RIS					

'Box filled with color' means 'Mentioned in the Plan', while 'Box filled with no color' means 'Not Mentioned in the Plan'.
DMP= Dacca Master Plan, **DMAIUDP=** Dhaka Metropolitan Area Integrated Urban Development Project, **FAP=** Flood Action Plan, **DMDP=** Dhaka Metropolitan Development Plan, **DAP=** Detailed Area Plan, **DSP=** Dhaka Structure Plan
RCE= River and/or Coastal Embankments, **SD**= Storm-water Drainage, **GPCA**= Green-area Protection & Coastal Afforestation, **LUP**= Land Use Planning, **UM**= Urban Management, **BR**= Building Regulations, **WS**= Warning System, **DM**= Disaster Management, EP= Evacuation Plan, **RP**= Rehabilitation Process, **RIS**= Relief & Insurance Support.

Flood Defense   Flood Risk Prevention   Flood Risk Management   Flood Preparation   Flood Recovery

5. Conclusion

This chapter illustrates the contextual scenario of flooding vulnerability of Bangladesh and also urban flood condition in Dhaka. Recent flooding events and the causes of flood revels the weakness in the existing flood control and management strategies. The Dhaka city Development Plans confirmed that in Dhaka, mostly the flood defense strategies have been applied. However, in the plans, the lack of integrating flood preparation and recovery strategies (such as disaster management, evacuation plan, rehabilitation process, relief & insurance support etc.) have still not been existed and thus, these strategy areas need to be improved in future. The lack of involvement of the stakeholders (especially community people, flood victims etc.) weakens the overall planning decisions. It should be noted that there is a need for comprehensive and coordinated effort at all levels of planning and development to address the localized impacts of disasters such as floods. This calls for local-level capacity for disaster management to be built by technical preparation, professional development and logistical support for organizations in executing successful disaster management strategies.

FLOOD VULNERABILITY AND DAMAGE IN URBAN CORE OF EASTERN DHAKA

1. Introduction

Dhaka, a megacity at the forefront of rapid, unplanned urbanization, is considered to be one of the flood-prone cities in the world. The city's eastern fringe, though underdeveloped and low-lying, is experiencing rapid growth as a result of migration, which has compounded the nature and extent of flood vulnerabilities. Overflow of surrounding rivers during monsoon along with excessive rainfall have made urban floods a perennial problem for both residents in the city and peripherals. Flood vulnerabilities and damage are localized events and understanding them is critical for disaster risk reduction and flood management in Sabujbagh ward of eastern Dhaka. The study employed the Phi and Cramer's V and Contingency coefficients analytical techniques to comprehend the relationship between physical characteristics of residential buildings, building adjustments, and flood damage. Findings indicate that flood vulnerability in the area is due to deficits in drainage infrastructure and variable rainfall patterns. Flood damage to residential buildings was influenced by factors such as the age of the buildings, building materials, plinth level height, and land cover conditions. Interestingly, the study found that no individual factor was enough to eliminate flood damage. The study, therefore, suggests integrated community-based flood management that combines investment in drainage infrastructure and maintenance, targeted green space development and social organizing that involves all residents, community leaders, and institutions at the local level to manage flood risks. This chapter has been adapted from Fatemi et al. (2020a and 2020b).

2. Flood Extent in the Study Area

The study area chosen for this research is situated at the southeastern part of Dhaka metropolitan area of Dhaka city (Figure 5. 1a). The study was conducted in *Sabujbagh* (Ward number 27; one of the 92 wards in eastern Dhaka) which is about 5 kilometers from the *Balu* River (Figure 5. 1b). It is considered to be a high flood-damaged area (Kamal, 2013, Fatemi et al., 2020b, Fatemi et al., 2020a). This ward is divided into 10 *mahallas* (or neighborhoods) with each consisting of about 250-500 households. For this study, two *mahallas* (Figure 5. 1c), were selected namely *Uttor Basabo* (M1) and *Purbo Basabo* (M7). The rationale for selecting these two neighborhoods was based on their previous experience with flooding, the age of settlement, and physical conditions (geo-morphological condition, contour, drainage, road network) (Figure 5. 2).

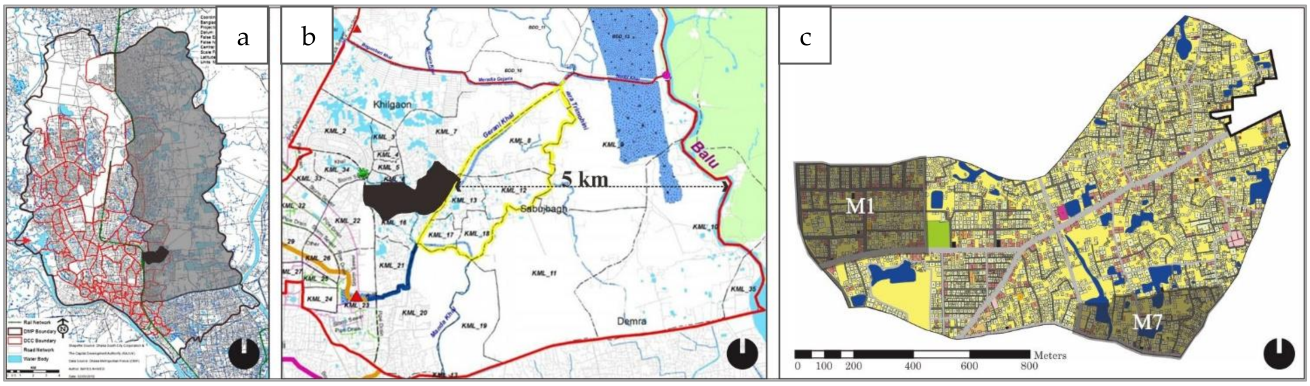


Figure 5. 1 a) East Dhaka b) Sabujbagh in Eastern Fringe c) Map of Studied Areas-M1 and M7

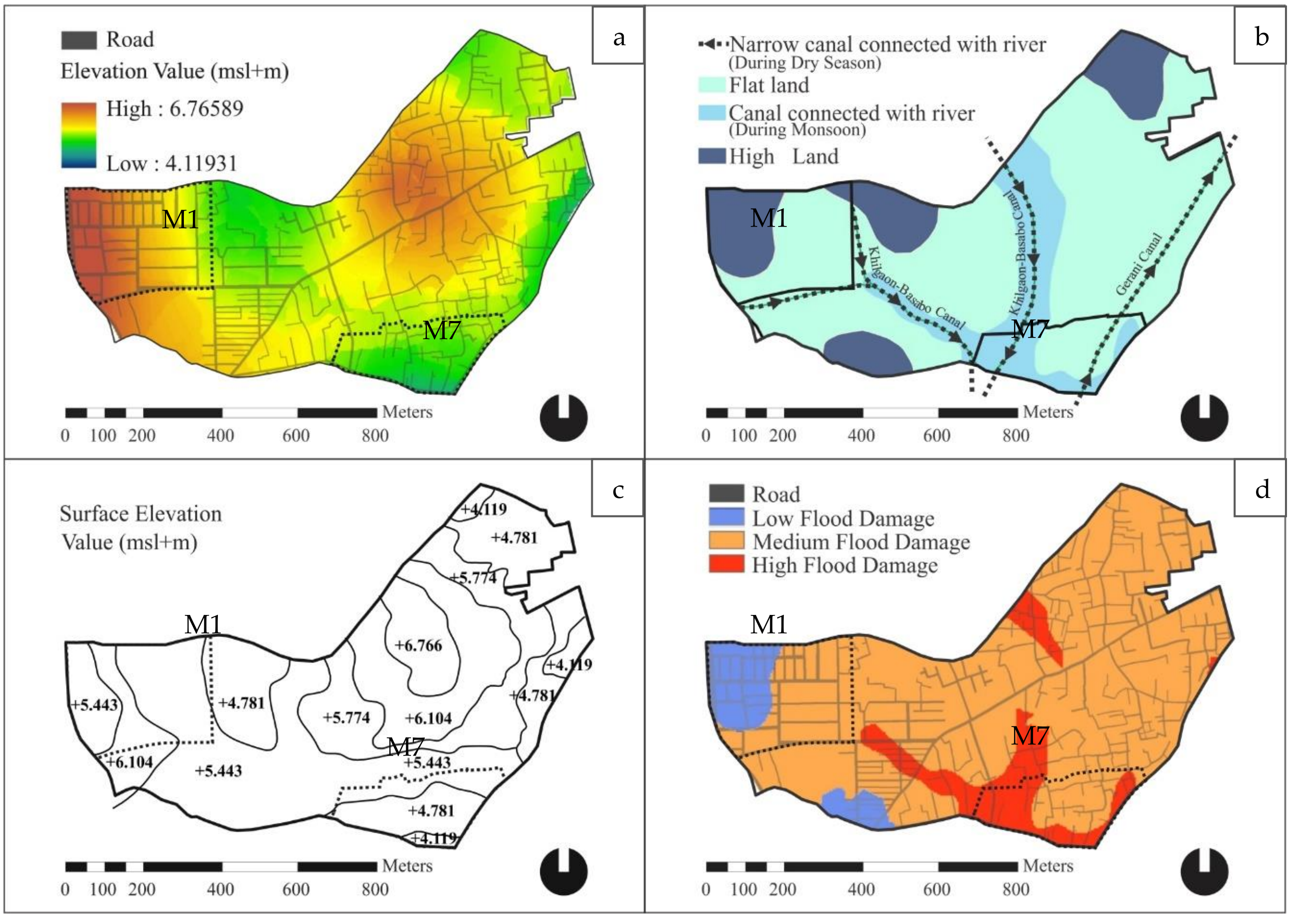


Figure 5. 2 a) Digital Elevation Model; b) Geomorphological Map; c) Contour Map; d) Flood Damage Map of Ward 27 (Modified from Kamal, 2013)

2.1. Uttor Basabo

This is the oldest neighborhood of *Sabujbagh* area. It is located near the northwestern end of ward 27 (Figure 5. 1c), which is nearest to the city core among the other *mahallas*. At both west and south side, it is connected with the city by two wide roads (sequentially 36m and 18m). It has a total land area of 33.77 hectares. The whole road network of this area is geometrically designed in the grid-iron pattern (Figure 5. 3). There are about 459 houses in the community. The buildings in this area are mainly for residential purposes with some commercial developments near the west and south peripheral roads. The prominent feature of this area is that most residential buildings are either single-storied detached houses or 6 storied apartment buildings. Apartment buildings were developed after 1995 when the real estate sector became very popular in Dhaka. According to the Building Construction Rule, 1992, the maximum floor height for apartment buildings should be 6 stories. For this reason, a significant number of single-storied detached houses and 6 storied apartment buildings are predominant in this area.

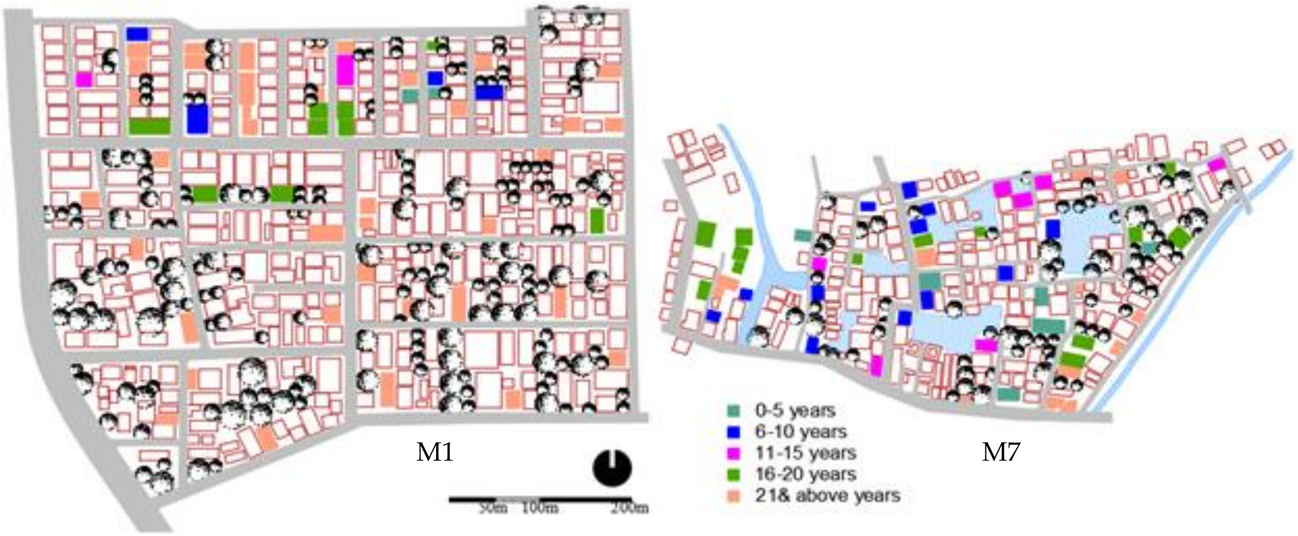


Figure 5. 3 Spatial distribution and the age of surveyed buildings in Uttor Basabo (M1) and Purbo Basabo (M7)

2.2. Purbo Basabo

This is a relatively new neighborhood of *Sabujbagh* area. It is located near the southeastern end of ward 27 (Figure 5. 1c), which is located between two natural canals. This area is enclosed by *Gerani Khal* (Canal) at the east (width-4.5m) and *Khilgaon-Basabo Khal* (Canal) at the west side (width-6m). It has a total land area of 15.67 hectares. The whole road network of this area is spontaneously developed (Figure 5. 3). There are about 381 houses in the community. Here too, the dominant type of buildings is mainly for residential purposes with some commercial developments at the south side, beside the 18m wide road. Though this neighborhood has similar types of buildings as Uttor Basabo such as single-storied detached houses and 6 storied apartment buildings, some high-rise buildings were going up to 8 or 9 floors. These buildings are those designed after the revision of the building construction rule in 2008. The new rule permitted a maximum height of 12 depending on the area and soil quality.

3. Causes of Flooding in the Study Area

Respondents from the study identified four main causes of flooding namely: excessive heavy rainfall, congested drainage paths, improper maintenance of the existing drainage during the monsoon season, and the overflows from rivers. The majority (50.5%) alluded to challenges with existing drainage as the cause. The responses from respondents are presented in Table 5. 1.

Between the two study areas, there exist differences in the proportion of respondents for the causes of flooding. While 67.3% of respondents in Uttor Basabo suggested that flooding in their neighborhood is caused by improper maintenance of existing drainage systems, 32.0% of respondents alluded to this factor in Purbo Basabo. Again, 12.0% of respondents in Purbo Basabo intimated that flooding in their neighborhood is due to the overflow of rivers. However, no respondent in Uttor Basabo referred to this. From the data, clear differences have been found in the responses across all four factors in the study areas.

Table 5. 1 Community perceptions on causes of the inundation in the studied area

Major Causes of Flooding	**M1: Uttor Basabo**		**M7: Purbo Basabo**		**Total (N=105)**	
	Number	%	Number	%	Number	%
Excessive Heavy Rainfall	17	30.9	22	44.0	39	37.1
Congested Drainage Paths or Inadequacy	1	1.8	6	12.0	7	6.7
Improper Maintenance of the Drainage	37	67.3	16	32.0	53	50.5
Overflow from River	0	0.0	6	12.0	6	5.7
Total	55	100.0	50	100.0	105	100.0

Figure 5. 4 a) Narrow drainage infrastructure and b) Inundation due to heavy rainfall and drainage congestion

At present, the entire ward (including Uttor Basabo and Purbo Basabo) does not have a dedicated stormwater drainage system. Instead, its drainage system remains, for the most part, natural, narrow, and open (Figure 5. 4a). Numerous natural depressions connect to main drainage channels, through which water is discharged into the Balu River. Unfortunately, natural channels that help with the flow of water have been converted to residential areas without proper planning as the neighborhood grew. It was observed that landowners have developed their lands using an unregulated and improper landfilling, causing obstructions to the original drainage system. As such, in both areas, the drainage system was significantly inadequate-- a confirmation of why 50.5% of respondents indicated this as the cause of flooding in the study areas. In some sections of the neighborhoods, existing drainage infrastructure was blocked by the solid waste and construction debris. All these have contributed to flooding during the monsoon months (Figure 5. 4b).

Residents also indicated excessive heavy rainfall as a cause of flooding in their neighborhood. An analysis of rainfall patterns in Dhaka from 1953 to 2017 confirms residents' observations (Figure 5. 5, Table 5. 2). Flood frequency analysis method and Weibull plotting position show a significant escalation of the annual precipitation over this period (1953 to 2017). Mean annual rainfall was 1704.4 mm (with a standard deviation of 324.8 mm). At least, for every 5-year period, the annual precipitation was similar to mean annual precipitation (Table 2), which was very high in the two study areas. Again, at least once in every 10-year period, there is a probability of the annual precipitation being 21% higher than the mean. These demonstrate the significant threat that heavy rainfall poses to residents in Uttor Basabo and Purbo Basabo and residents of Dhaka in general (Figure 5b).

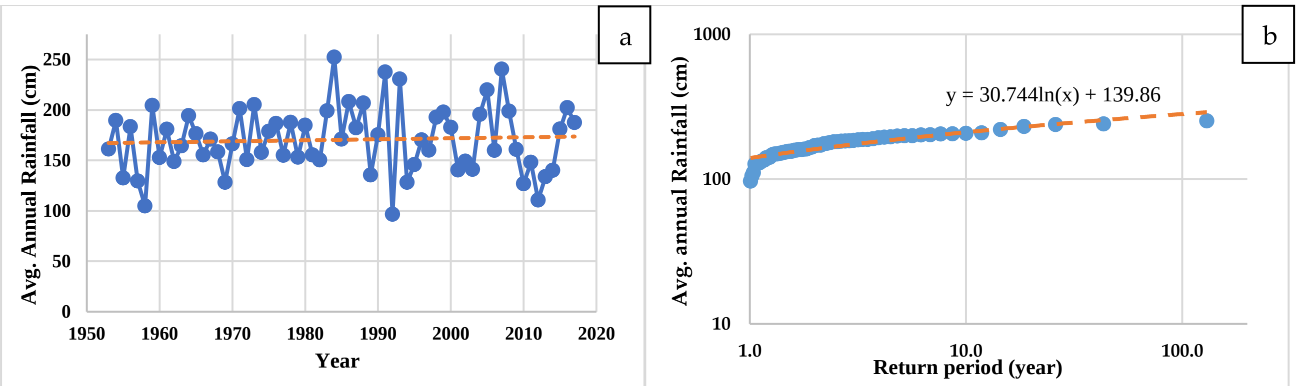


Figure 5. 5 a) Annual Average Rainfall and b) Frequency Analysis for Dhaka from 1953-2017

Table 5. 2 Estimated Progression of Annual Precipitation in Dhaka for a 100-year Period

No. of Years	**2**	**3**	**5**	**10**	**20**	**50**	**100**
Annual Precipitation (mm)	1611	1748	1920	2153	2387	2695	2929

4. Flood Damage and Physical Vulnerability

In terms of the physical vulnerability of residential buildings, data from the building inventory study included five attributes: building age, surrounding land cover condition, plinth height from the surface, damaged parts of the building due to inundation, and transformations in buildings to control the floodwater. The proceeding discussion, therefore, emphasizes the level of damage to individual buildings (dependent variables) due to flooding concerning each attribute (the independent variables). The level of damage to residential building property was based on four categories: no damage, low damage (plot, ground surface elements and boundary walls are affected), medium damage (plot, first-floor equipment, appliances, etc., and building exterior surfaces are affected) and high damage (plot, first-floor equipment, appliances, building furniture, fixtures, etc., and interior surfaces are affected) (Figure 5. 6).

No Damage Low Damage Medium Damage High Damage

Figure 5. 6 Categories of Inundation Condition and Damage due to Flood.

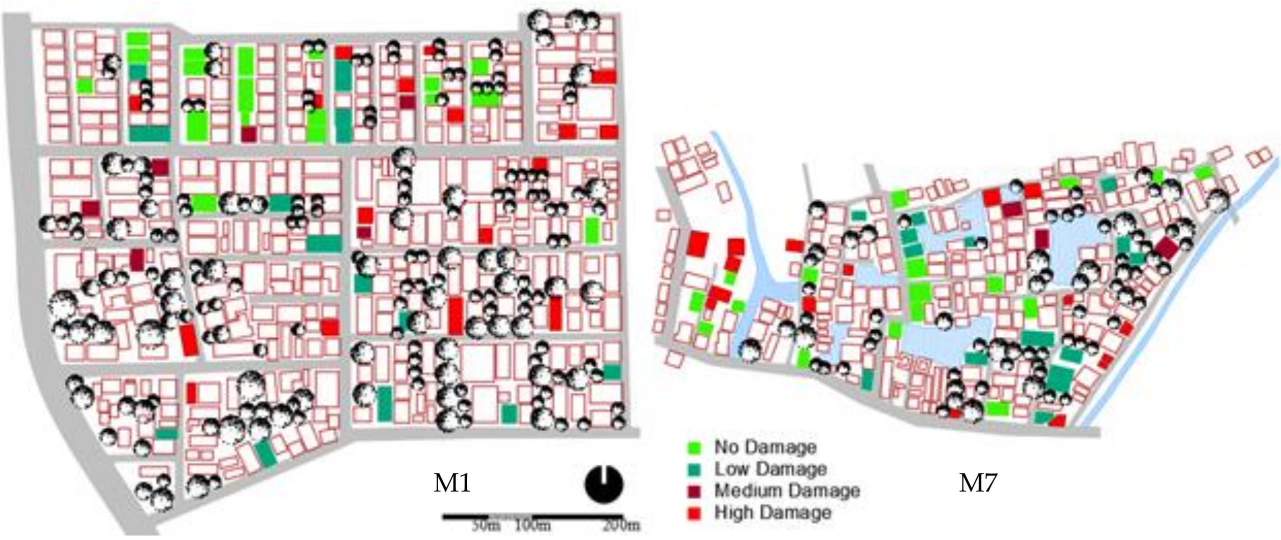


Figure 5. 7 Damage to Residential Buildings in Uttor Basabo (M1) and Purbo Basabo (M7)

About one-third of respondents (33.3%) reported no damage to their residential buildings, while the rest of the respondents (66.7%) indicated damage to their buildings. In Uttor Basabo, those who reported low damage, medium damage and high damage constituted 25.5%, 10.9% and 30.9% respectively. Similar responses were recorded for Purbo Basabo. About 34% reported no damage to their residential buildings. In Purbo Basabo, those who had their buildings damaged reported low damage (30%), medium damage (6%) and high damage (30%).

4.1. Physical Attributes and Flood Damage to Residential Buildings

The study also sought to understand the relationships between specific physical attributes of residential buildings of the two neighborhoods and the extent of damage they experienced. This is an important aspect of comprehending physical vulnerability to flood hazards and specific interventions required to improve physical resilience and disaster risk reduction. From the analysis of the data using cross-tabulations, the relationships between the variables ranged from modest to moderate, with a p-value of less than and equal to 0.05, except for Plinth height of buildings which was significant at 0.066 (Table 5. 3).

This result gives us the basis to reason that the age of buildings, plinth height of buildings, land cover of the properties, and the type of transformed parts of houses can influence the extent of inundation inside the property and type of damage in physical structure due to inundation in this study. These relationships are examined further in the subsequent sections and the appropriate conclusions drawn concerning these observations.

Table 5. 3 Results of the Relationships Between the Study Variables

Independent Variables	Phi		Cramer's V		Contingency Coefficient		No. of Valid Cases
	Value	Approx. Sig.	Value	Approx. Sig.	Value	Approx. Sig.	
Age of The Building	.544	.028	.314	.028	.478	.028	105
Land Cover of the Property	.496	.011	.287	.011	.445	.011	105
Plinth Height	.477	.066	.276	.066	.431	.066	105
Building Typology	.445	.001	.445	.001	.407	.001	105
Building Adjustments	.612	.001	.353	.001	.522	.001	105

4.2. Flood Damage and Age of the Buildings

The age of buildings is necessary to analyze the vulnerability of these buildings based on their strength of the structures and also to evaluate their management process during the flooding. In this case, the age of the residential buildings was considered in 5 categories of 5-year intervals where the newest was 0-5 years and above 21 years was the oldest (Table 5. 4).

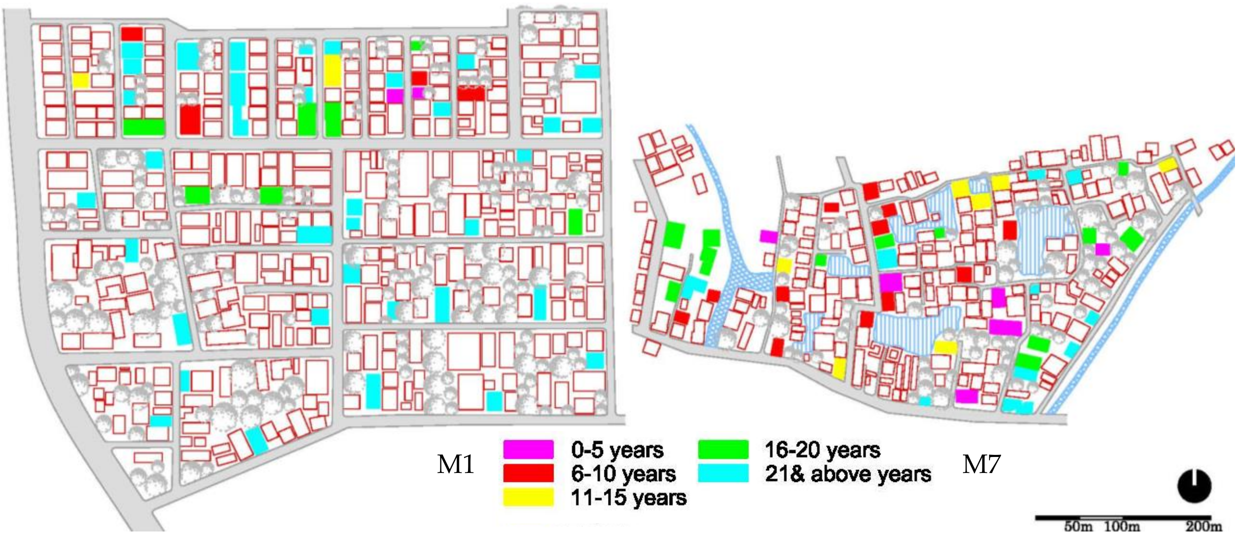


Figure 5. 8 Age of the Buildings in Uttor Basabo (M1) and Purbo Basabo (M7)

The results demonstrate that the age of buildings is a major factor in the level of damage residential buildings experience in Uttor Basabo and Purbo Basabo. There is a greater risk of damage to older residential buildings compared to relatively newer buildings.

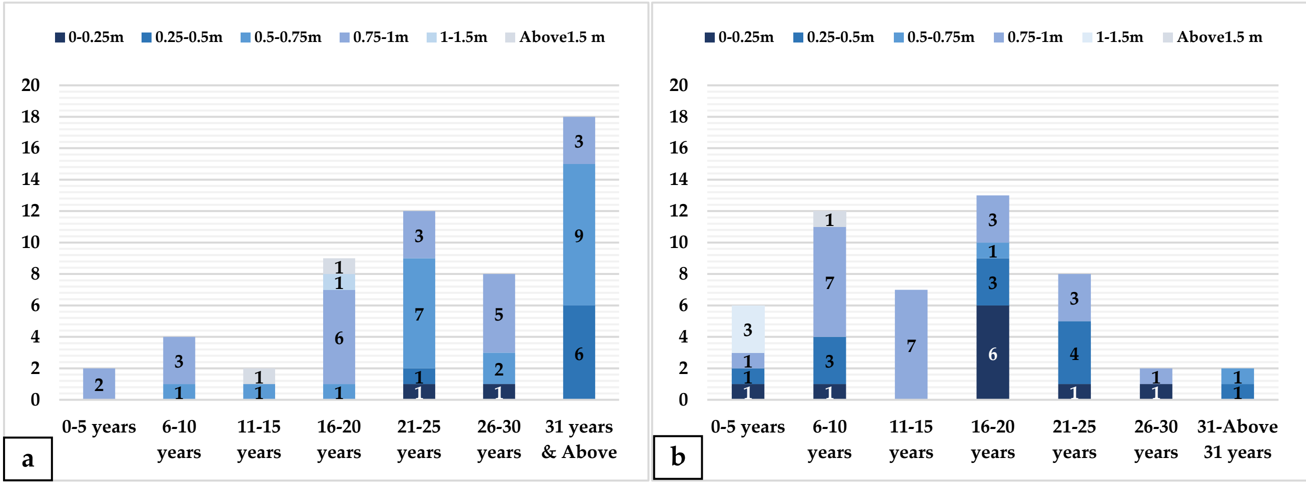


Figure 5. 9 Age and Plinth Height of the Building for a) Neighborhood M1 and for b) Neighborhood M7

In M1, survey results indicate that houses that were built more than 20 years ago (69%, 38 out of 50) experienced inundation levels above 1m (Figure 5. 9a). Those less than 20 years still experienced flood inundation levels of up to 0.75m. Comparatively, in neighborhood M7, 76% of buildings were built within recent years to 20 years range and the remaining 24% of buildings were built more than 20 years ago. Though the buildings were relatively new here, more than half of them (58%) regularly experience the impact of flooding. Here, residential buildings built more than 20 years ago (12 out 50; 24%) had flood inundation levels of less than 1m (Figure 5. 9b). However, those built less than 20 years ago (38 out 50; 76%) also had flood inundation level of above 0.75m. The reason for this unique result is due to site selection for house construction. Further interviews during the survey clarified that historically, residents chose to build houses on high elevation sites which adequate green cover around houses. Still, recent house constructions are done in low elevation sites with little consideration of surrounding land covers. In this particular case, one can infer that the age of the buildings alone cannot determine the vulnerability or exposure to floods.

Moreover, from the results, the proportion of buildings that experienced some form of damage due to flooding increased from 50% for buildings that are 0-5 years to 80% for those 21 years and old. Again while 50% of buildings 0-5 years had no damage due to flooding, only 20% were observed for buildings 21 years and old-- with 68.8% for 6-10 years, 33.3% for 11-15 years, and 31.8% for 16-20 years. Similarly, buildings with the highest proportions of report damage to flooding were those that were old, increasing from 12.5% to 46.0% for buildings 0-5 years old and 21 years and above respectively. The decline in the proportion of reported building damage as the age of building increases shows that older buildings are at higher risk of flooding than newer buildings.

The Phi and Cramer V's, as well as Contingency coefficients for these observations, were statistically significant (p-values = 0.028) with values of 0.544, 0.314 and 0.478 respectively (Table 5. 3).

Table 5. 4 Age of Residential Buildings and Damage due to Flooding

Damage due to Flooding	Age of the Building											
	0-5 years		6-10 years		11-15 years		16-20 years		21+ years		Total	
	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
No Damage	4	50.0	11	68.8	3	33.3	7	31.8	10	20.0	35	33.3
Low Damage	2	25.0	3	18.8	3	33.3	9	40.9	12	24.0	29	27.6
Medium Damage	1	12.5	1	6.3	1	11.1	1	4.5	5	10.0	9	8.6
High Damage	1	12.5	1	6.3	2	22.2	5	22.7	23	46.0	32	30.5
Total	8	100	16	100	9	100	22	100	50	100	105	100

4.3. Flood Damage and Surrounding Land Cover Condition

The surrounding land cover condition of the buildings of these neighborhoods is also a significant attribute in comprehending the physical vulnerability to floods in the study areas. Surrounding landcover conditions is necessary to manage surface water channelized towards the underground. In this case, surrounding land cover conditions of the buildings are considered in 5 categories; no setback area; setback with the impervious (paved) surface; surrounding with the impervious (paved) surface; setback with a permeable (green) surface, and surrounding with the permeable (green) surface (Figure 5. 10).

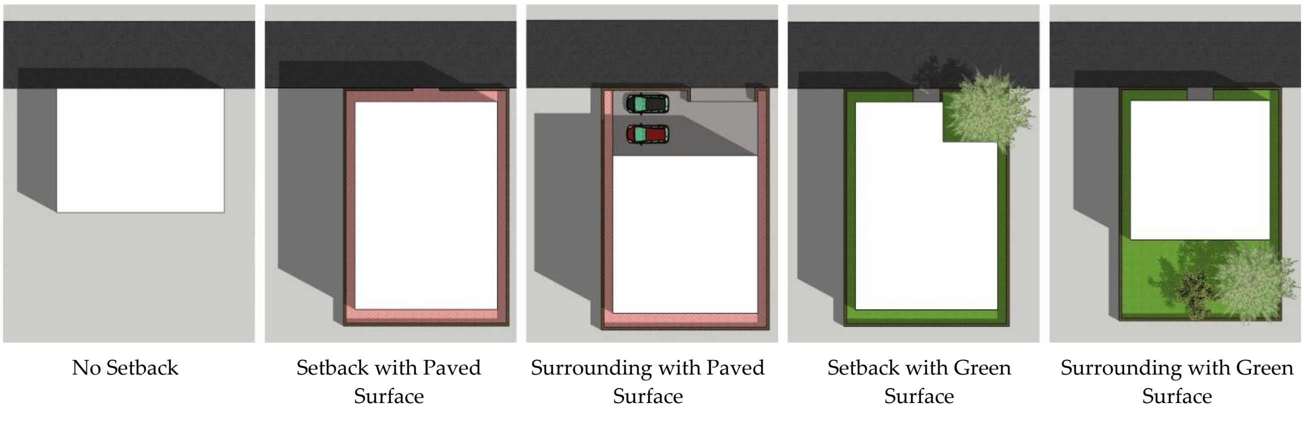


Figure 5. 10 Surrounding Land Cover Conditions Categories

In M1 Neighborhood, the percentage of different land cover conditions of the buildings were: no setback area (7%), a setback with impervious surface (15%), surrounding with impervious surface (58%), a setback with permeable surface (13%), and surrounding with permeable surface (7%) (Figure 5. 12a). Among buildings surrounded with a paved surface and thus impervious, the study showed that 12 houses (among 32) have no damage during the flood. Again, buildings having a setback with the impervious surface also had 3 houses (among 8) with no flood damage.

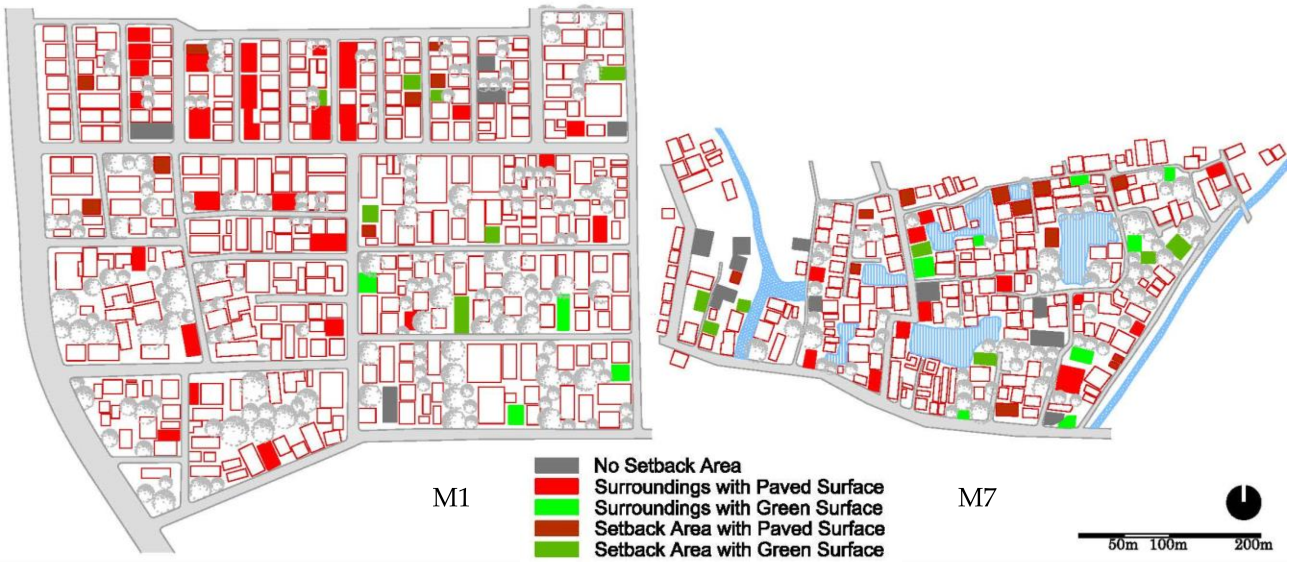


Figure 5. 11 Surrounding Land Cover Condition in Uttor Basabo (M1) and Purbo Basabo (M7)

Further field investigation revealed that the reason for this was either the relatively high plinth level height (from 0.75m-1m or above) from the surrounding areas or their high topographical location. Moreover, among buildings surrounded by green surface and thus permeable, the study showed that 4 buildings (among 4) had flood damage (1 house of high damage and 3 houses of low damage). Again, buildings having a setback with permeable surface also had 6 buildings (among 7) with high flood damage (Figure 5. 13a). This study result contrasts previous studies which have shown that houses with limited open space and distance between neighboring houses increase vulnerability to floods (Birkmann, et al., 2013; Gain, et al., 2015). Observations during the field showed that this exceptional case was apparently due to either the relatively low plinth level height (from 0m-0.5m) from the surrounding areas (Figure 5. 14) or the regular drainage congestion at their surroundings that prevent the flow of surface water.

In M7 Neighborhood, survey results showed that No setback area (22%); Setback with impervious surface (22%), Surrounding with impervious surface (26%), Setback with permeable surface (14%), and Surrounding with permeable surface (16%) (Figure 5. 12b). Among buildings surrounded with a paved surface and thus impervious, the study showed that 6 houses (among 13) have no damage during the flood. Again, buildings having a setback with impervious surfaces also had 3 houses (among 7) with no flood damage (Figure 5. 13b). Field observations showed that high plinth level height (from 0.75m-1.5m or above) from the surrounding areas reduced flood damage even when residential buildings had impervious land covers. Among buildings with the surrounding green surface, the study showed that 5 houses had flood damage (2 houses of high damage and 3 houses of low damage).

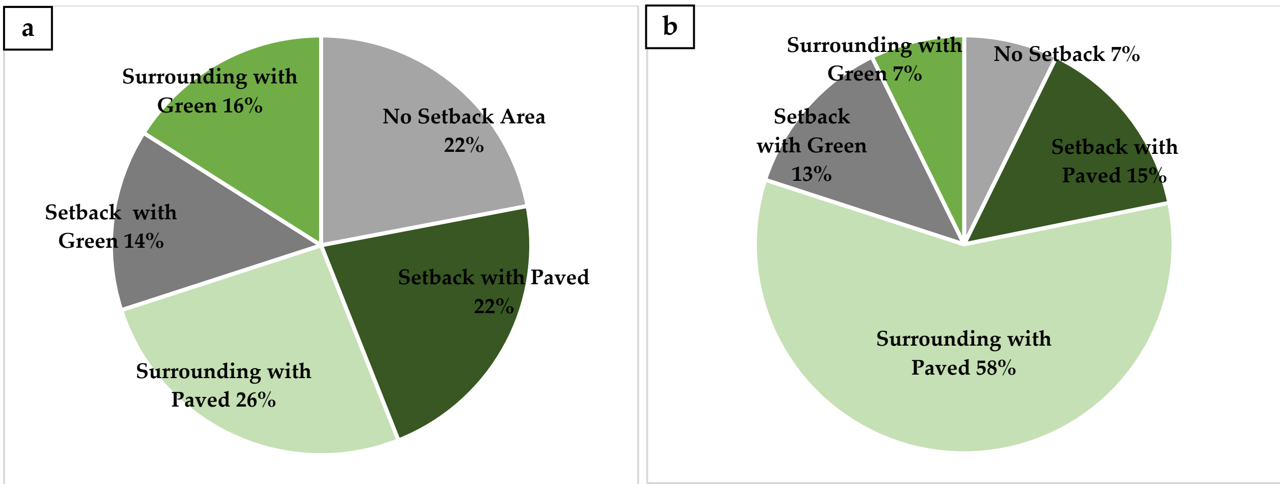


Figure 5. 12 Surrounding land cover conditions in Percentage for Neighborhood - a) M1 & b) M7

Again, houses having a setback with the green surface also had 4 houses with flood damage (1 house of medium damage and 3 houses of low damage). Here too, plinth height accounted for the differences in flood damage between residential buildings with either green and impervious surfaces (Figure 5. 14). On the other hand, houses with surrounding green areas but low plinth levels were not safe from flood damages, an indication that physical vulnerability in the study areas cannot rely on single initiatives but rather composite and integrated strategies that address the multiple sources of vulnerability.

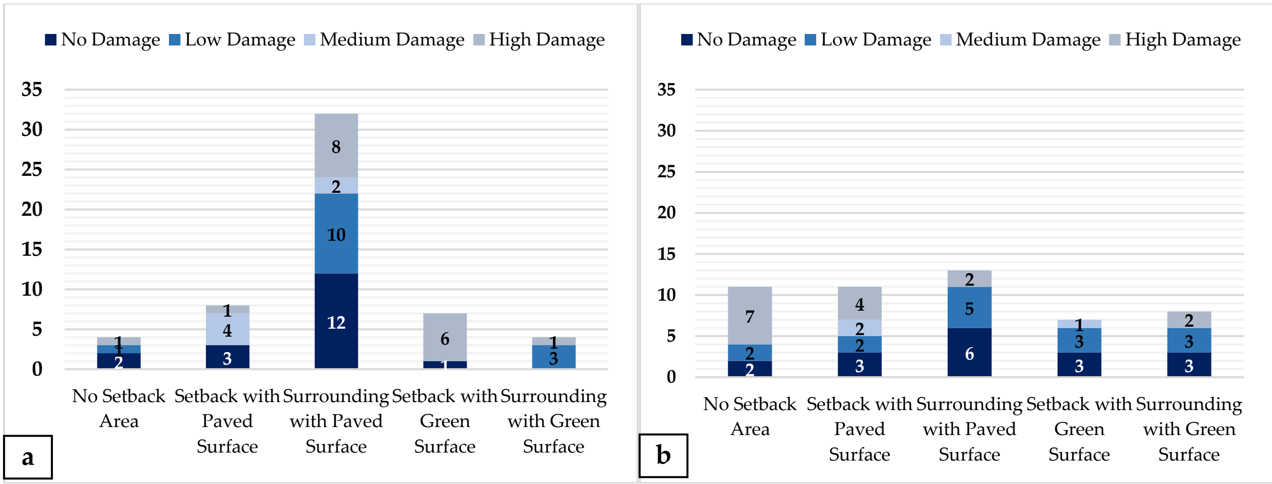


Figure 5. 13 Land cover and damage of the Building a) for Neighborhood M1 and b) for Neighborhood M7

Moreover, the Phi value (0.496), Cramer's V value (0.287) and Contingency coefficient (0.445) were all statistically significant (p-values = 0.001) (Table 5. 3). Thus, the results show that damages to buildings are less likely for buildings with paved surfaces and surroundings, while buildings with no setbacks are at higher risk of damages to the building and inside properties. More than half (53.3%) of residential buildings with no setbacks had high damage from flooding compared to those with surroundings with paved surfaces (22.2%) and green surfaces (25.0%).

Table 5. 5 Landcover of the Property and Damage due to Flooding

Damage due to Flooding	Land Cover of the Property											
	No Setback Area		Surrounding with Paved Surface		Surrounding with Green Surface		Setback Area with Paved Surface		Setback Area with Green Surface		Total	
	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
No Damage	4	26.7	18	40.0	3	25.0	6	31.6	4	28.6	35	33.3
Low Damage	3	20.0	15	33.3	6	50.0	2	10.5	3	21.4	29	27.6
Medium Damage	0	0.0	2	4.4	0	0.0	6	31.6	1	7.1	9	8.6
High Damage	8	53.3	10	22.2	3	25.0	5	26.3	6	42.9	32	30.5
Total	15	100	45	100	12	100	19	100	14	100	105	100

Green surfaces here include grass and trees (both spontaneous and planted growth) in the setback area or surroundings of residential buildings. Even for those with setbacks, those that had green surfaces experienced high damages (42.9%) compared to those with paved surfaces (26.3%). Comparing setbacks with paved and green surfaces, the percentage of damage reported is greater for those with green surfaces. Specifically, the results show that 73.3% of buildings with no set back experienced some form of damaged compared with 59.9% of buildings that have surrounding with paved surface, 75.0% for buildings that have surrounding with green surface, 68.4% for building with paved surface setbacks and 71.4% for buildings with green surface setbacks (Table 5. 5). Damage to residential buildings with the green surface was attributed to the poor drainage condition; mostly blocked drains of solid waste and construction debris.

4.4. Flood Damage and The Height of the Plinth Level

The height of the plinth level seems to be another important aspect for these neighborhoods in terms of flood management to control the surface water inflowing towards the buildings. The plinth height of buildings was in five categories: the categories were in intervals of 0.25m starting from 0.1m and the last limit was 'above 1m' (Figure 5. 14).

In the M1 neighborhood, the survey result showed that 18 buildings (5 buildings with 0.5-0.75m and 13 buildings with 0.75-1m plinth) had no damage. Among the other buildings, the buildings with low plinth height (0-0.25m and 0.25-0.5m) had mainly high damage (only 1 had medium damage). High buildings with high plinth height (1.1.5m and above 1.5m) had low damage. But buildings with medium plinth height (0.5-0.75 and

0.75-1m) had a various extent of damage; here buildings (17 buildings, 31%) with lower-medium plinth height (0.5-0.75) had more damage, than the buildings (9 buildings, 16%) with upper-medium plinth height (0.75-1m).

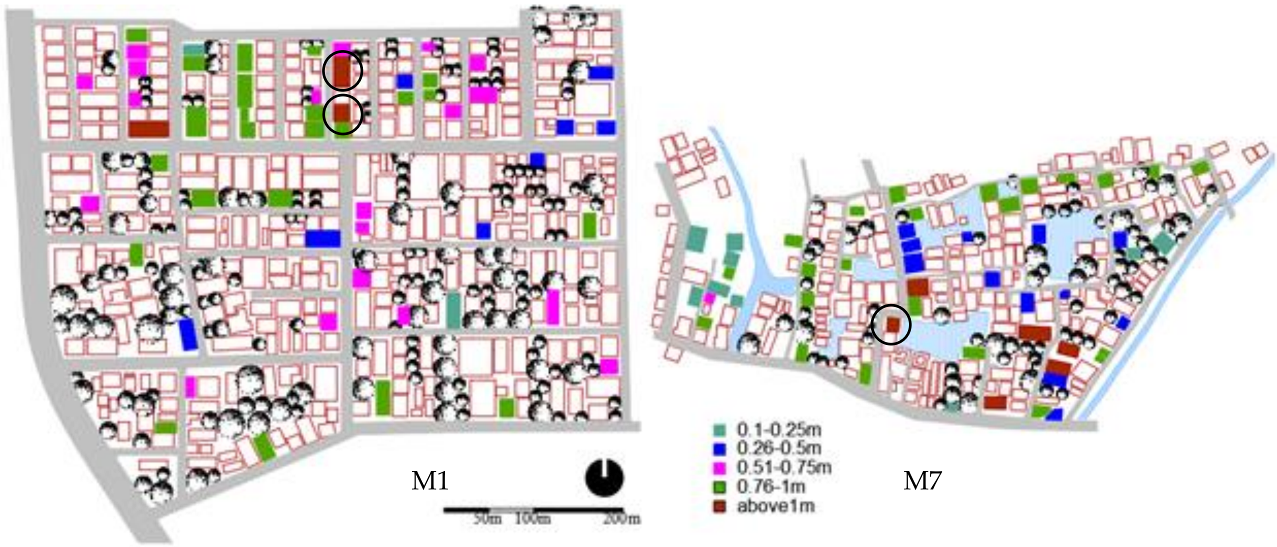


Figure 5. 14 Plinth Height of the Building for A) Neighborhood M1 and B) Neighborhood M7

On the other hand, according to the survey, in the M7 neighborhood, 16 buildings (2 buildings with 0-0.25m, 3 buildings with 0.25-0.5m, 9 buildings with 0.75-1m and 2 buildings with 1-1.5m plinth) had no damage. Here, the buildings with low height plinth (0-0.25m and 0.25-0.5m) and medium plinth height (0.5-0.75 and 0.75-1m) had a various extent of the damage. Among the buildings with low height plinth, 8 buildings (16%) had high damage, 2 buildings (4%) had medium damage and 7 buildings (14%) had low damage. Again, among the buildings with medium plinth height (0.5-0.75 and 0.75-1m), 7 buildings (14%) had high damage, 1 building (2%) had medium damage and 7 buildings (14%) had low damage.

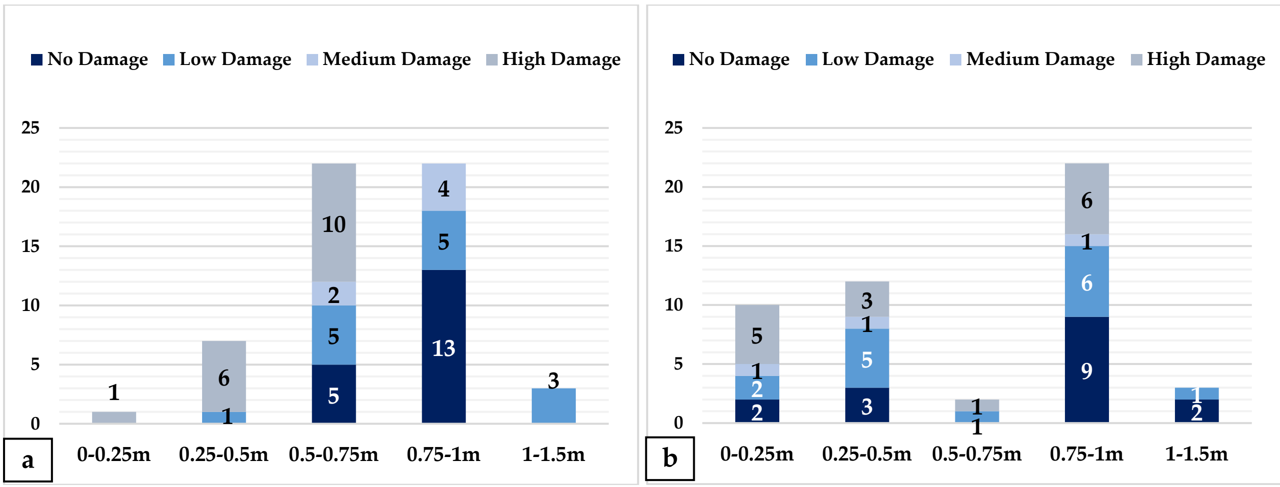


Figure 5. 15 Plinth Height and Damage of the Building for a) Neighborhood M1 & b) Neighborhood M7

Therefore, in both M1 and M7 neighborhoods, the study found that old buildings (20 years or more) had lower plinth height (M1: 84% with 0-0.75mm; M7: 67% with 0-0.75m) as compared to relatively newer buildings (M1: 82% with 0.75-1.5m; M7:58% with 0.75-1.5m). The reason for newer houses with higher plinth height is due to residents' experience of flood in the past and also a mitigation measure to reduce flooding impact due to the low elevation of the site. It another unique finding, the surveyed observed that some houses with higher plinth level experienced floods (2 houses in M1 and 1 house in M7; circled in Figure 5. 14). Further observations and interviews during the survey revealed that this situation was due to drainage congestion and blocked sewer lines. In both areas, it was common to see poor sanitation practices which led to indiscriminate garbage disposal into drains and sewers.

Table 5. 6 Plinth Height of the Building and Damage due to Flooding

Damage due to Flooding	Plinth Height of the Building											
	0.1-0.25m		0.26-0.5m		0.51-0.75m		0.76-1m		Above 1m		Total	
	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
No Damage	3	25.0	3	15.8	4	17.4	22	50.0	3	42.9	35	33%
Low Damage	2	16.7	6	31.6	6	26.1	11	25.0	4	57.1	29	27.6
Medium Damage	1	8.3	1	5.3	2	8.7	5	11.4	0	0.0	9	8.6
High Damage	6	50.0	9	47.4	11	47.8	6	13.6	0	0.0	32	30.5
Total	12	100	19	100	23	100	44	100	7	100	105	100

From Table 5. 6, 50% of buildings with plinth height between 0.1-0.25m experienced high damages to residential buildings. This declines as the plinth height increased with no record of high damage for residential buildings with plinth height of 1 m and above. At the same time, when plinth height is between 0.1-0.25m, 25.0% of respondents report low damage on residential buildings. The proportion of low damage to buildings declines as the plinth height rises: with 15.8% for 0.26-0.5m, 17.4% for 0.51-0.75m, 50.0% for 0.76-1m, and 42.9% for plinth height of residential buildings of 1m and above. Additionally, 57.1% of all those with plinth height of above 1m experience low damage compared to those with residential building plinth heights of 0.1-0.25m (Table 5. 6).

4.5. Flood Damage and Building Typology

In this study, the building typology was classified in terms of their construction materials. The first category consists of buildings built with temporary materials (mud, steel sheet, wood, etc.) and the second category comprises buildings built with durable materials (brick, cement, concrete, etc.) (Figure 5. 16).

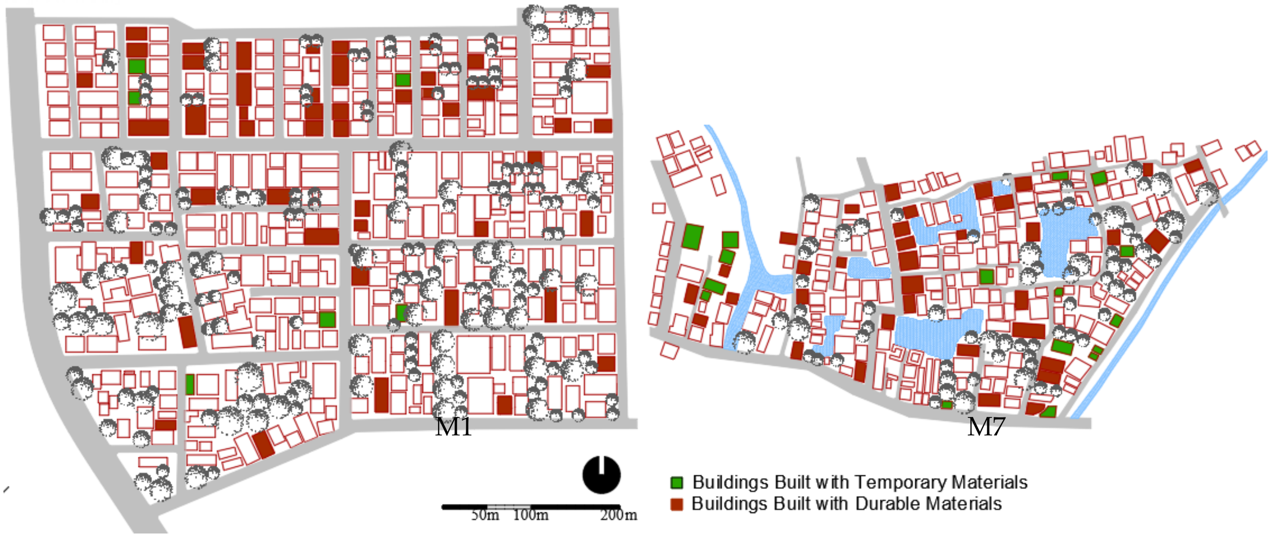


Figure 5. 16 Building Typology For A) Neighborhood M1 and B) Neighborhood M7

From the analysis, it can be observed that all the buildings built with temporary materials (mud, steel sheet, wood, etc.) (11%, 4+2=6 in number) in neighborhood M1 had flood damage (2 houses of low damage and 4 houses of high damage) (Figure 5. 17). But surprisingly, 13 buildings built with durable materials (brick, cement, concrete, etc.) were highly damaged (Figure 5. 17). From the survey, this was due to the plinth height (0m-0.75m) from the surrounding areas (Figure 5. 14).

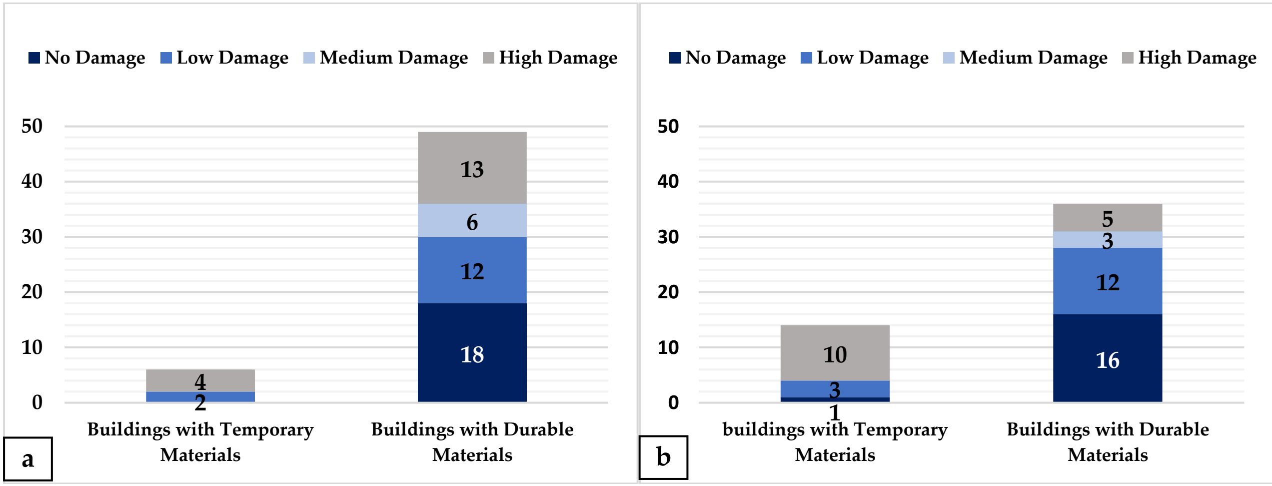


Figure 5. 17 Building Typology and Vulnerability in Neighborhood a) M1 and b) M7

From the results, it can be seen that all the buildings built with temporary materials (mud, steel sheet, wood, etc.) (26%, 3+10=13 houses) in neighborhood M7 had flood damage (3 houses of low damage and 10 houses of high damage). Here again, 5 houses built with durable materials (brick, cement, concrete, etc.) also experienced high damage (Figure 5. 17). However, further field investigations showed that this was not due to the building material per se. Rather, it appeared to be a result of either the building located near stagnant ponds that overflowed during the season of heavy rainfall or the congested drains or sewerage (due to indiscriminate solid or construction waste disposal).

Moreover, the results indicate that buildings with durable materials experience low damage compared with those constructed with temporary materials. Specifically, 70% and 5% of buildings with temporary materials reported high damage and no damage respectively compared to 21.2% and 40.0% of buildings with durable materials (Table 5. 7). The result was highly statistically significant ($p = 0.001$), with modest correlations of Phi (0.445) and Cramer's V (0.445) and Contingency coefficient (0.407) values.

Table 5. 7 Building Typology and Damage due to Flooding

Damage due to Flooding	Building Typology					
	Buildings built with temporary materials		Buildings built with durable materials		Total	
	No.	%	No.	%	No.	%
No Damage	1	5.0	34	40.0	35	33.3
Low Damage	5	25.0	24	28.2	29	27.6
Medium Damage	0	0.0	9	10.6	9	8.6
High Damage	14	70.0	18	21.2	32	30.5
Total	20	100.0	85	100.0	105	100.0

5. Physical Response to Flooding

Modifications or adjustments of residential buildings represent a common physical response by respondents to address their physical vulnerability to perennial flooding. These modifications are predominantly at the building level and are grouped into 4 categories: No Change; Change in between plot and road level (Figure 5. 18, a. Raising the Sill Level between road and property line), Change at plinth level (Figure 5. 18, b. Raising the Sill Level between Lobby outside and Foyer of the House) and Change in-wall and upper level (Figure 5. 18, c. adds or replace with new material at the lower level of the wall). The primary goal of these modifications at the building level is to address the physical vulnerability of residential buildings to flooding. Specific modifications included raising the sill-level between road and property line, raising the sill-level between lobby outside and foyer of the house, and plastering or adding water repellent color etc. at the lower level of the building wall.

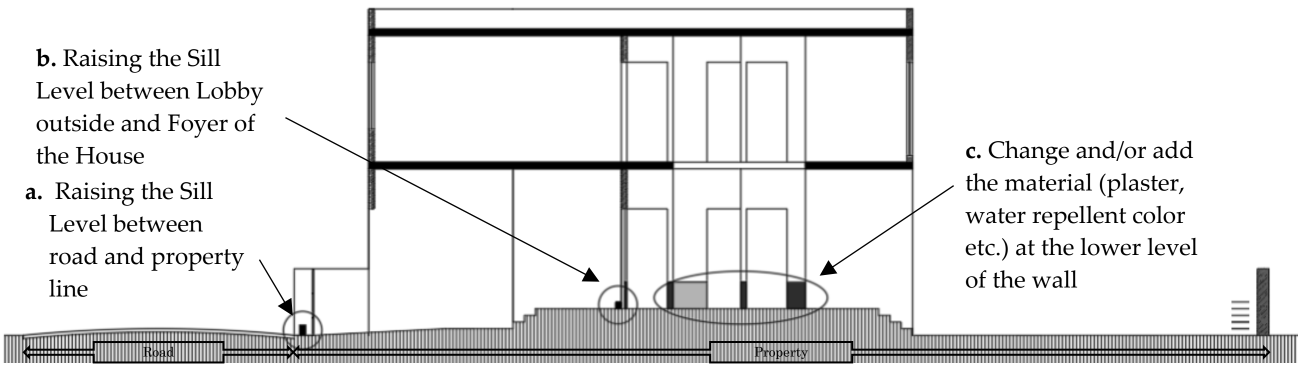


Figure 5. 18 Building's Adjustments due to Inundation or to Control Overflow inside the Plot

The data analysis reveals that there is a moderate association (Phi value = 0.612, Cramer's V = 0.353, and Contingency coefficient = 0.522) between physical modifications to residential buildings and damage to flooding. These were statistically significant (p = 0.001). In effect, residents are likely to modify their residential buildings as a result of their experiences with building damage due to flooding. From Table 5. 8, 59.5% of those who did not adjust their buildings had no experience with damage from flooding. However, more than 50% made changes to their houses due to damage from flooding across about the different categories of changes observed; whether changes to the ground level, to the plinth level or both. This was especially strong if the damage was on the building or inside the property (High Damage). For instance, 55% made changes to the plinth level due to damage to their buildings and 80% changed both the ground and plinth level due to high damage to their residential buildings.

Table 5. 8 Modified Parts of the Building and Damage due to Flooding

Damage due to Flooding	Type of Transformed Parts of the House											
	No Change		Change in Ground Level		Change in Plinth Level		Change in both Ground & Plinth Level		Don't Know about the Change		Total	
	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
No Damage	22	59.5	9	23.7	2	10.0	1	20.0	1	20.0	35	33.3
Low Damage	8	21.6	13	34.2	6	30.0	0	0.0	2	40.0	29	27.6
Medium Damage	6	16.2	1	2.6	1	5.0	0	0.0	1	20.0	9	8.6
High Damage	1	2.7	15	39.5	11	55.0	4	80.0	1	20.0	32	30.5
Total	37	100	38	100	20	100	5	100	5	100	105	100

6. Collective Action and Social Networks

In these neighborhoods, the lack of collective action and the absence of social networks are found during the fieldwork. Most of the buildings' modifications were based on individual initiative and extremely context-specific. Even during the survey, no community-based flood management platform or activities has been found for sharing experience and knowledge regarding flooding events.

89% of the respondents in the M7 area and 96% of the respondents in the M7 area responded negatively when they are asked about community steps to reduce flooding occurrences. But, 55% of the respondents in the

M1 area and 64% of the respondents in the M7 area thought their community people as a support network for help during the inundation period.

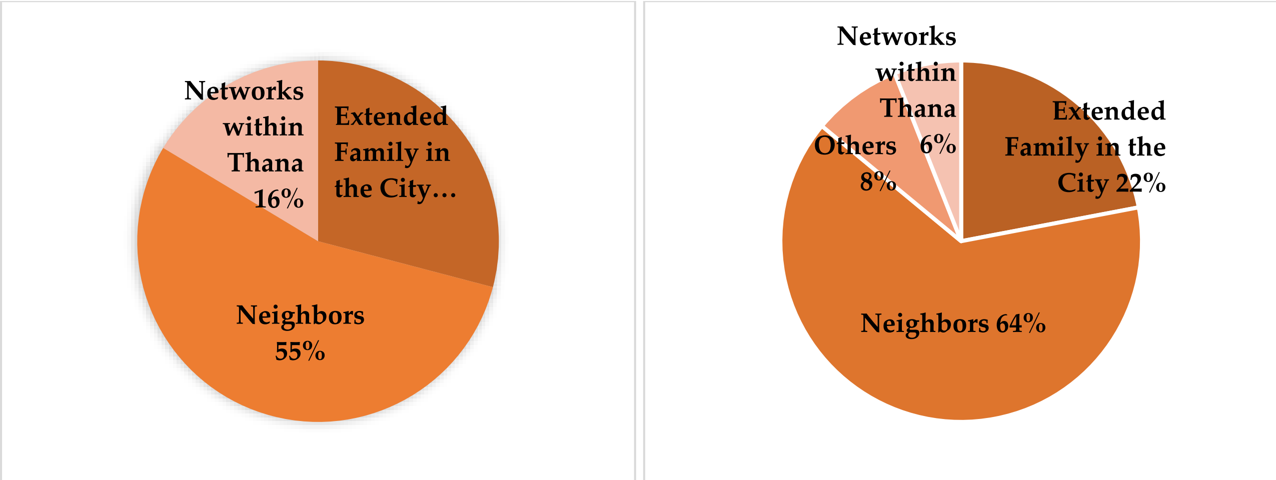


Figure 5. 19 Percentage of Support at the Neighborhood a) Neighborhood M1 b) Neighborhood M7

Again, 62% of them in the M1 area and 30% of them in the M7 area believe that community-level initiatives are highly needed to organize a forum to discuss the overall disaster management of this neighborhood. So, the respondents resided in these neighborhoods stayed here, had no common characteristics to act collectively for a cause to improve their neighborhoods, but they felt that community steps are more effective rather an individual effort to mitigate the flood vulnerability.

7. Conclusion

This study set out to explore flood vulnerabilities of residential buildings at the eastern fringe of Dhaka. Specifically, the study analyzed the factors that influenced flood damage to residential buildings and physical adjustments to reduce damage. Although several studies exist on analyses of flood damage to properties, most of these are in the developed world context (Chow et al., 2016, Few, 2003). In Bangladesh, there is a growing field of flood vulnerability studies, but few micro levels of the neighborhood context, exceptions include (Jabeen, 2010). In this study, it has been complimented but also moved beyond existing studies to emphasize physical vulnerability and flood damage to individual residential buildings at the basic level of the urban neighborhood in Dhaka. This study posits that neighborhood-level understanding of physical vulnerabilities to floods is critical to initiate flood management strategies and actions that are tailored to contextual conditions while avoiding the limitations of blanket city-level solutions that ignore differences at the neighborhood level.

This study submits that excessive rainfall patterns and deficits in infrastructure drive physical vulnerability of residential buildings to flood damage. Fundamentally, the physical vulnerability of residential buildings to flood damage are both embedded and embodied in rainfall patterns and drainage infrastructure challenges. In this context, the damage to residential buildings in eastern Dhaka result from the age of the building, whether the building material is temporary or permanent, land cover conditions around the building unit, and building adjustments based on knowledge of the source of flood vulnerabilities. House modifications reduce the extent of reported damage to residential buildings; although there was no example of community-based collective responses to manage flood risks at the neighborhood level. In the end, building flood resilience at the neighborhood level will go away in fostering adaptive capacity and mitigating disaster risks in urban neighborhoods of Dhaka.

FLOOD VULNERABILITY, DAMAGE AND LOCAL RESPONSES IN PERI-URBAN AREAS OF EASTERN DHAKA

1. Introduction

In Eastern Dhaka, perennial flood remains a constant threat to people and livelihoods. Learning from the micro-level experiences of the poor in the peri-urban areas of Dhaka provides insights on the intersections between physical vulnerability, flood response strategies and adaptive capacity. Through a convergent mixed method, this study examines the physical vulnerability of residential buildings, flood damages and local physical responses in three neighborhoods of Eastern Dhaka. Results show that the level of damage to buildings is the most important predictor of physical vulnerability to floods. Buildings that are older than 20 years old and built with natural materials are likely to experience high flood damages compared to buildings that are less than 10 years and constructed with durable materials. The study concludes that in addition to socio-economic interventions, a targeted and people-centered flood management regime that pays attention to age, material composition and structural quality of houses is necessary to build the residents' adaptive capacities and long-term resilience to flooding. This study contributes to the emerging work on grassroots responses to flooding vulnerabilities with practical insights for urban planners and disaster management professionals on particular interventions needed to improve the performance of local responses to flooding risks and vulnerabilities. This chapter has been adapted from Fatemi et al. (2020d).

2. Flood Extent of Study Area

Eastern Dhaka is bounded by Dhaka Purbachal Road in the north, Pragati Sharani in the west, River Balu in the east and DND (Dhaka-Narayanganj-Demra) project area in the south. While Dhaka has a surface elevation ranging from 1 to 14m (JICA, 1992b), land elevation ranges from 2 to 5 m in eastern Dhaka—becoming close to zero near the River Balu (Dasgupta et al., 2015). It also experiences similar rainfall patterns as Dhaka city which has an annual rainfall of about 2000 mm, with 80% occurring during the monsoon season from June to October (Dewan et al., 2007). Eastern Dhaka is mainly rural with the vast expanse of agricultural lands along the floodplain of River Balu (Lamb, 2014, Nilufar, 2010). It is nearly 119 square kilometers and lies in the low-lying area of the city. Due to this, it floods frequently and continues to be at severe risk of flooding. Eastern Dhaka also has a network of natural canals that helps to drain and discharge stormwater run-off accumulation from the main city as well as within the area into River Balu (Islam, 2009). Despite this natural system, flooding remains a challenge. This informs the Dhaka Flood Control and Storm Water Drainage Master Plan, which aims to prevent and protect this peri-urban area against fluvial flood by building compartments (D1, D2 and D3), pumped drainage facilities and retention pond areas (JICA, 1992b, Dasgupta et al., 2015). The study focuses on the lower compartment of D3 (Figure 6. 1).

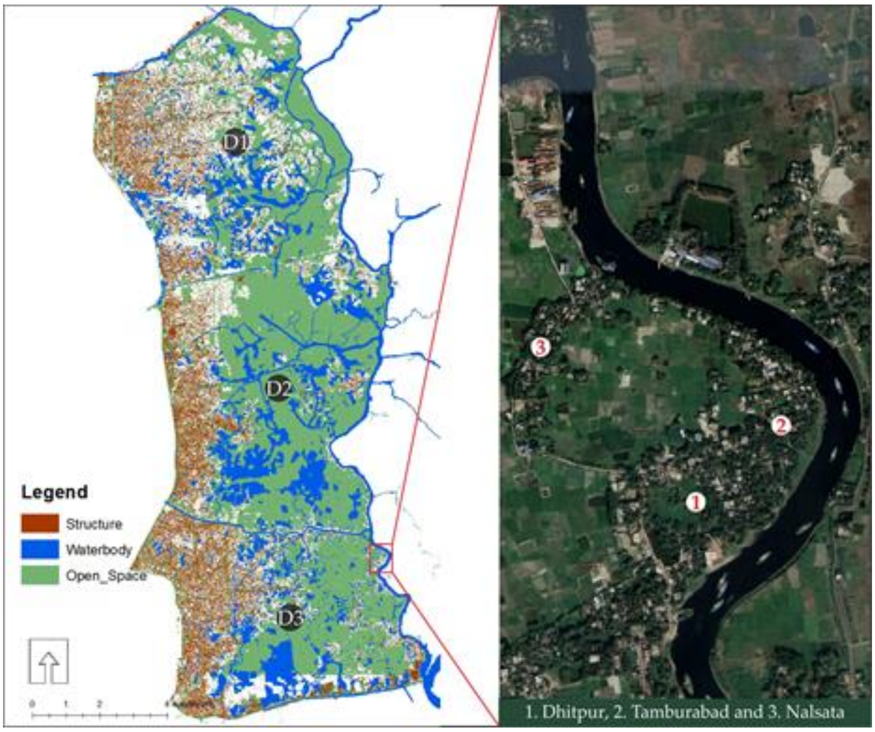


Figure 6. 1 Location map of The Study Area in Eastern Fringe (D3) and Study Area in Google Map.

The study area chosen for this research is about 7.5 km from the city core and under the jurisdiction of Khilgaon Thana (Thana meaning 'sub-districts' in Bengali). The major land use categories are agricultural (42.65%), residential (26.65%), other facilities (5.53%), vacant land (7.52%), and water bodies (17.49%). The area has three different mahallas (meaning 'neighborhoods' in Bengali) with each consisting of 180-220 households. This study uses surveyed data from these three mahallas (Figure 2) namely, Dhitpur (M1), Tamburabad (M2) and Nalsata (M3). These study areas are appropriate due to the high vulnerability to flooding (Dewan et al., 2007, Dasgupta et al., 2015, Kamal, 2013, Fatemi et al., 2020d).

3. Demographic and Socio-Economic Profile of the Households

The results of the study reveal that among the total 575 household members in the 100 surveyed households, 52% were male and 48% were female (

Table 6. 1). This is consistent with the national male-female ratio (1: 0.94) according to the Bangladesh Bureau of Statistics (BBS, 2017). Approximately, 42% household members in the surveyed households were between 25 and 54 years, suggesting that a large portion of the flood victims are within the economically active age cohort.

Table 6. 1. Demographic Profile and Composition of Households' in Three Neighborhoods.

Parameters	number	%
Number of households	100	-
Number of total populations	575	-
Gender		
Male	300	52%
Female	275	48%
Age		
Children (0-14 years)	165	29%
Early Working Group (15-24 years)	73	13%
Prime Working Group (25-54 years)	242	42%
Mature Working Group (54-65 years)	58	10%
Elderly (>65 years)	37	6%

However, the elderly (above 65 years) accounts for 6%, while 29% are children (between 0 and 14 years). These are also quite consistent with the national age structure (children 26.5%, early working group 18.5%, prime working group 41%, mature working group 7.5% and elderly 6.5%) (CIA, 2018). Generally, about one-third of the members within the surveyed households were children (29%) and the elderly (6%) -- usually considered as the cohort highly vulnerable to floods (Lee et al., 2015). Also, the mean household size was 5.75 members, while the majority of the sampled population (61%) live in households with between 4 and 6 members. About 21% had large family sizes; households with 7-9 persons constituted 11% and households with above 10 persons were 10%. Such large household sizes, with a high number of dependents, often have high consumption expenditures and lower savings (Shah et al., 2017).

The highest level of education for most household heads was primary education (43%) and 18% have no formal education (Table 6. 2). The predominant economic activity is farming and artisanship respectively 28% and 30%. Only 3% of the respondents were in civil service, while 3% of respondents were unemployed. Only 3% of the respondents were in civil service, while 3% of respondents were unemployed. Nonetheless, all those interviewed reported some income that is either connected to their occupation or non-occupation sources such as selling milk from cattle owned by the household in the case of housewives and unemployed. From those interviewed, 67% of them earn a monthly income of 5000-13200 BDT and 24% earn 13201-25000 BDT. The lower-income status of respondents is worrying as low-income people suffer the most from natural hazards (Dasgupta, 2007, Dewan, 2013) and have the least capacities to respond to short to long term flood risks and vulnerabilities compared to those in the higher income bracket (Green et al., 1994).

Table 6. 2 Socio-Economic Characteristics of Household Heads' in 3 Neighborhoods (N=100)

Parameters	number	%	Parameters	number	%
Household Size			**Education Level**		
1-3 members	18	18	No formal Education	18	18
4-6 members	61	61	Primary Education	43	43
7-9 members	11	11	Secondary Education	29	29
10+ members	10	10	Tertiary Education	10	10
Monthly Income (BDT)			**Occupation**		
Marginal (<5000)	0	0	Farmer	28	28
Low (5000-13200)	67	67	Housewife	31	31
Lower-middle (13201-25000)	24	24	Artisan	30	30
Middle (25001-50000)	6	6	Civil service	3	3
Upper-middle (50001-100000)	3	3	Unemployed	3	3
High (>100000)	0	0	Other	5	5

* 1 USD = 85 BDT (7 February, 2020)

4. Causes of Flood in the Study Area

In total, 48% of the respondents indicated overflow from River Balu as the cause of flooding, 29% indicated close proximity to River Balu, 13% reported heavy rainfall and 10% emphasized the inadequacy of the drainage or blockage in canals as the reason for inundation. However, there exist differences in respondents' understanding of the causes of flooding across the study area. In Dhitpur and Nalsata for instance, 40% and 87% of respondents respectively indicated the overflow of River Balu as the prime cause of flooding, while 71% in Tamburabad emphasized close proximity of their houses along 'River Balu' as the main cause (Table 6. 3). A community leader summarizes the causes of flooding as follows:

> *'During monsoon, heavy rainfall is an obvious event. As in the whole area, we do not have proper drainage systems, all the low-lying farmlands start to submerge with water. Moreover, stormwater from the city comes through the canals, but due to the waste dumping and landfilling in those canals, they become stagnant. Therefore, stormwater also started to overflow in our farmlands. And the worst happens when the river water exceeds the danger level and enhances the impact.' (Community Leader A, Dhitpur, Age 48)*

Table 6. 3 **Community Perceptions on Causes of the Inundation in Studied Areas.**

Major Causes of Flooding	M1: Dhitpur		M2: Tamburabad		M3: Nalsata		Total (N=100)	
	no.	%	no.	%	no.	%	no.	%
Heavy Rainfall	11	31	2	6	0	0	13	13
Overflow from River	14	40	8	23	26	87	48	48
Building on Flood Plains	0	0	25	71	4	13	29	29
Inadequacy of Drainage or Blockage in Canals	10	29	0	0	0	0	10	10
Total	35	100	35	100	30	100	100	100

5. Flood Damage and Physical Vulnerability

5.1. Physical Attributes and Flood Damage to Residential Buildings

The physical vulnerability, measured as the extent of flood damage to residential buildings was compared to five building attributes namely: building age, building typology, plinth height, building modifications to control the floodwater. This provided insight into the variations in physical vulnerability based on these different building attributes. The results from Cramer's V analysis revealed a modest to statistically significant (P-value < 0.05) relationship between the variables (Table 6. 4). Hence, these attributes influence as to the degree to which buildings are damaged by flooding in each Mahalla.

Table 6. 4 The Relationships between Building Attributes and Flood Damage.

Variables	Cramer's V		N of Valid Cases
	Value	Approx. Sig.	
Building Typology	0.329	0.000	100
Age of the Buildings	0.399	0.000	100
Height of Plinth Level	0.341	0.003	100
Building Modifications	0.425	0.000	100

The level of damage was measured using a Likert Scale: no damage, low damage (plot, ground surface elements, boundary walls are affected), medium damage (plinth level and first floor walls along with low damage elements are affected) and high damage (Building interior, furniture along with medium and low damage components are affected). All respondents reported some form of damage albeit at different extents (Figure 6. 2). In Dhitpur, 46% reported low damage, 28% of medium damage and 26% of high damage buildings in their neighborhood. In Tamburabad, 54% reported high damage, while medium damage was 40% and low damage was only 6%. In Nalsata, those who reported low damage, medium damage and high damage constituted 43%, 27% and 30% respectively.

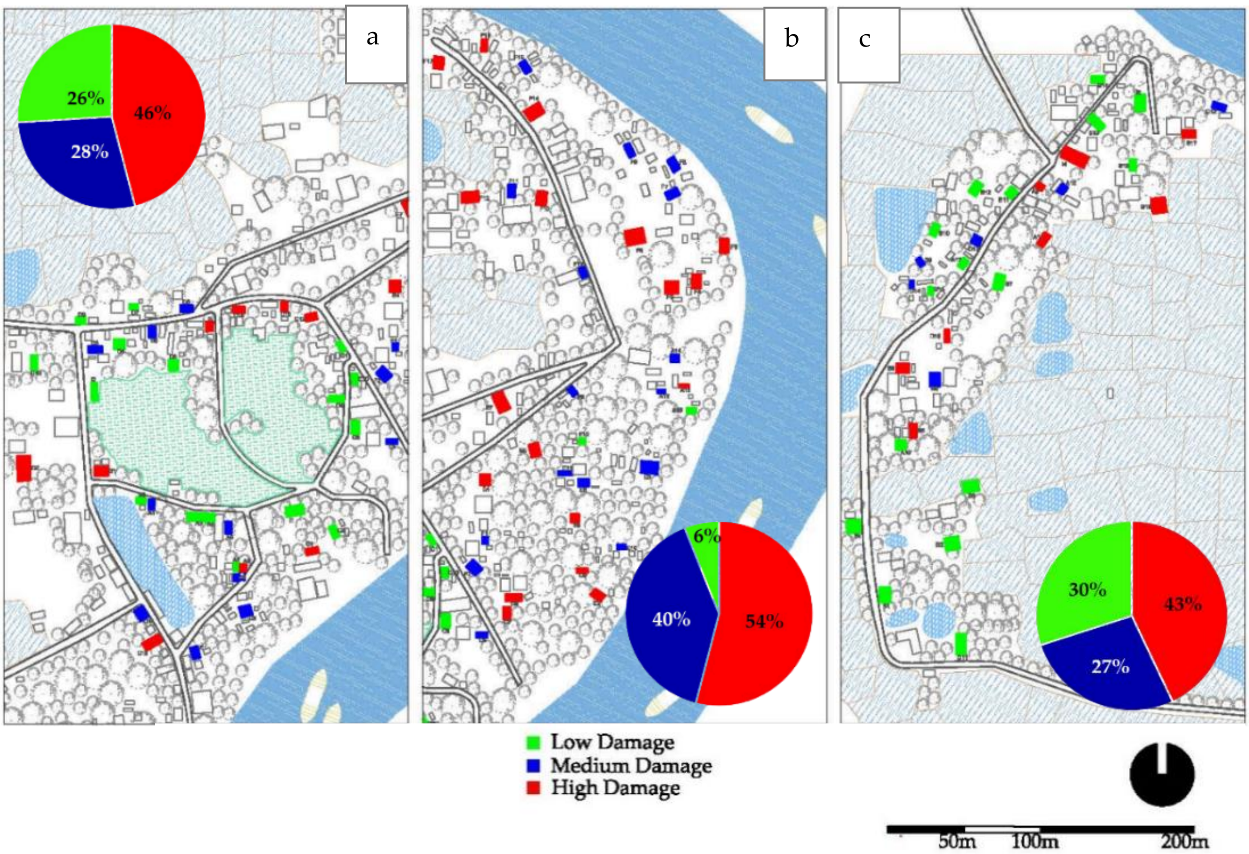


Figure 6. 2 Various Extents of Damage to the Buildings in Three Neighborhoods
a) Dhitpur, b) Tamburabad c) Nalsata.

5.2. Flood Damage and Building Typology

Three types of buildings were identified based on their construction materials. They are buildings built with (i) natural materials (mud, bamboo etc.), (ii) temporary materials (corrugated metal sheet, wood etc.), and (iii) durable materials (brick, concrete etc.) (Figure 6. 3). The extent of physical vulnerability to flooding was dependent on the type of building materials (Table 6. 4) and as one interviewee observes:

> *'Those houses built of mud and bamboo easily damaged or even washed away during the flood. In most of our houses, building materials are also not resistant to floodwater. Therefore, prolonged flood events caused irreparable damage to them. The houses along the river are in a more hazardous condition. When river water rises suddenly within a night, living in those houses becomes unsafe. The river erosion during the monsoon season also makes our lives challenging. Many people lost a portion of their land properties due to erosion.'* (Old resident, Tamburabad, Age 67)

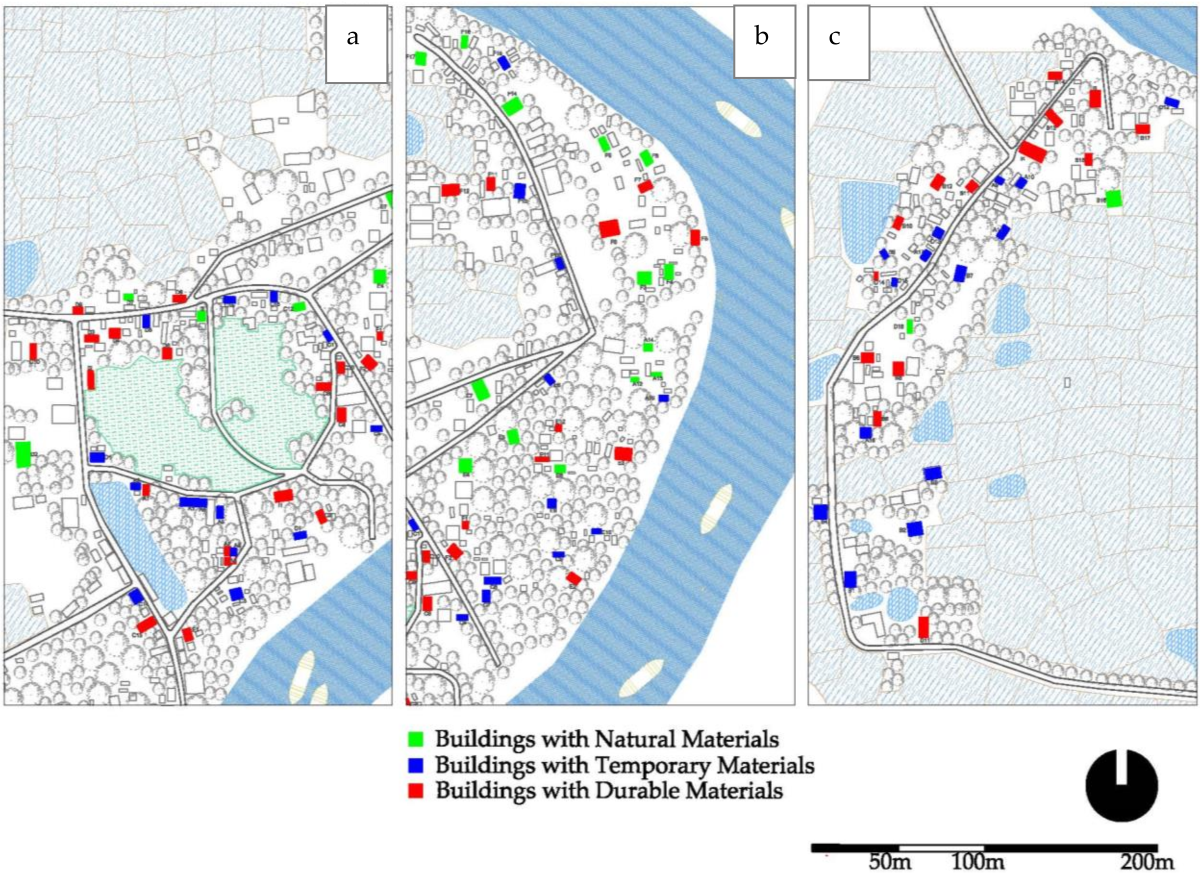


Figure 6. 3 Building Typology in Three Neighborhoods

a) Dhitpur, b) Tamburabad c) Nalsata.

Buildings with durable materials experience low damage compared with those constructed with temporary and natural materials. This result was statistically significant (p = 0.000), with modest correlations (Cramer's V=0.329) (Table 5). Specifically, 80% of buildings with natural materials reported high damage compared to 31.6% of buildings with temporary materials and 21.4% of buildings with durable materials (Table 6. 5).

Table 6. 5 Building Typology and Damage due to Flooding.

b)

Damage due to Flooding	**Building Typology**							
	Buildings with Natural Materials		Buildings with Temporary Materials		Buildings with Durable Material		Total	
	No.	%	No.	%	No.	%	No.	%
Low Damage	1	5.0	12	31.6	18	42.9	31	31
Medium Damage	3	15.0	14	36.8	15	35.7	32	32
High Damage	16	80.0	12	31.6	9	21.4	37	37
Total	20	100	38	100	42	100	100	100

5.3. Flood Damage and Age of the Buildings

The age of the buildings was considered in 5-year intervals where the newest was 0-5 years and above 21 years was the oldest (Figure 6. 4). The relationship between flood damage and the age of the building was statistically significant with modest Cramer V's of 0.399 (Table 6. 4).

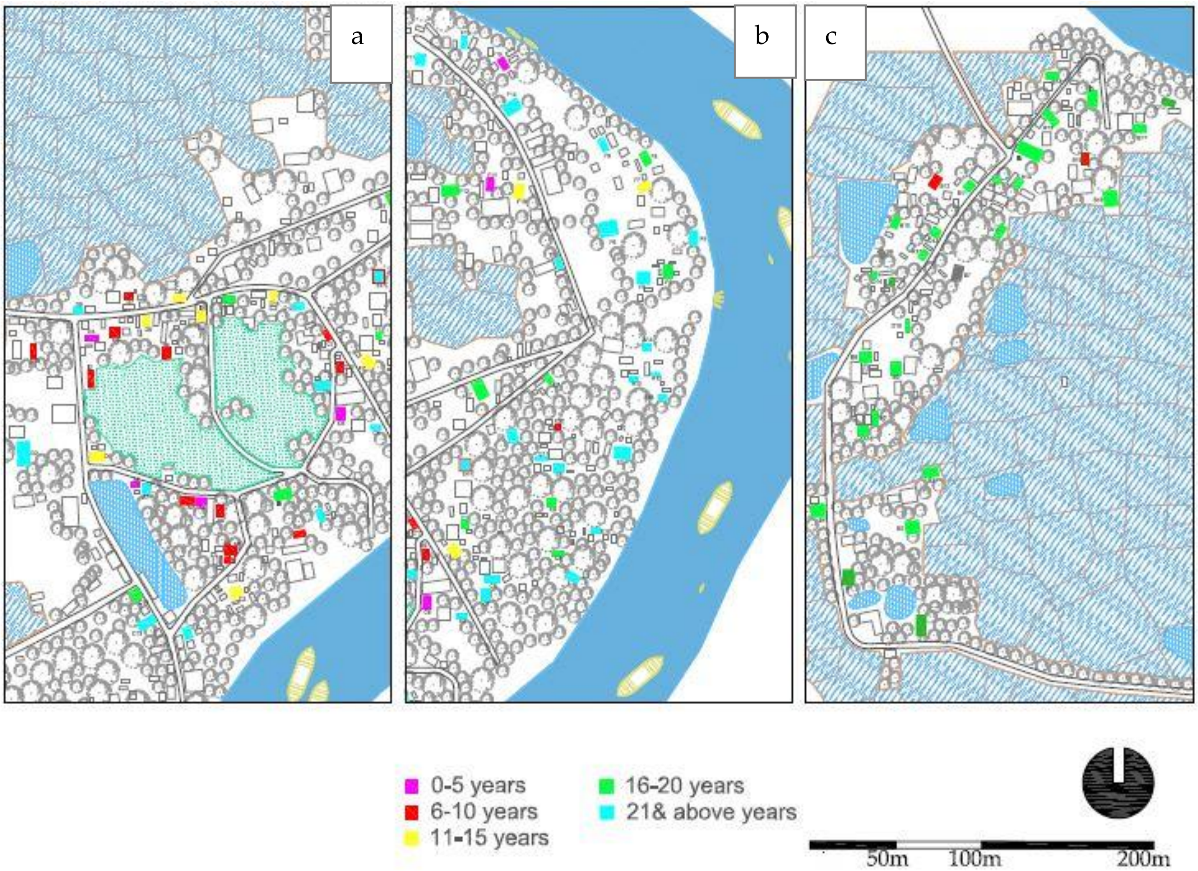


Figure 6. 4 Age of the Buildings in Three Neighborhoods
a) Dhitpur, b) Tamburabad c) Nalsata.

Table 6. 6 Age of Residential Buildings and Damage due to Flooding.

Damage due to Flooding	Age of The Building											
	0-5 years		6-10 years		11-15 years		16-20 years		21+ years		Total	
	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
Low Damage	9	64.3	14	58.3	1	8.3	1	7.7	6	16.2	31	31
Medium Damage	3	21.4	5	20.8	8	66.7	6	46.2	10	27.0	32	32
High Damage	2	14.3	5	20.8	3	25.0	6	46.2	21	56.8	37	37
Total	14	100	24	100	12	100	13	100	37	100	100	100

From the analysis, 64.3% of buildings 0-5 years had low damage, 58.3% for 6-10 years, 8.3% for 11-15 years, and 7.7% for 16-20 years, and 16.2% for buildings 21 years and old. Similarly, buildings with the highest proportions of damage were those that were old, increasing from 14.3% to 56.8% for buildings 0-5 years old and

21 years and above respectively. Again, the proportion of buildings experiencing high damage from flooding increased as the age of buildings increased from 14.3% for buildings 0-5 years to 56.8%, for buildings 21 years and above (Table 6. 6).

5.4. Flood Damage and the Height of Plinth Level

The plinth height of buildings was measured in five categories using intervals of 0.25m starting from 0.1m and ending with 'above 1m' (Figure 6. 5). The analysis confirmed that there is a statistically significant modest relationship (Cramer's V = 0.341) between the Plinth Level height and the damage extent from flooding (Table 6. 4).

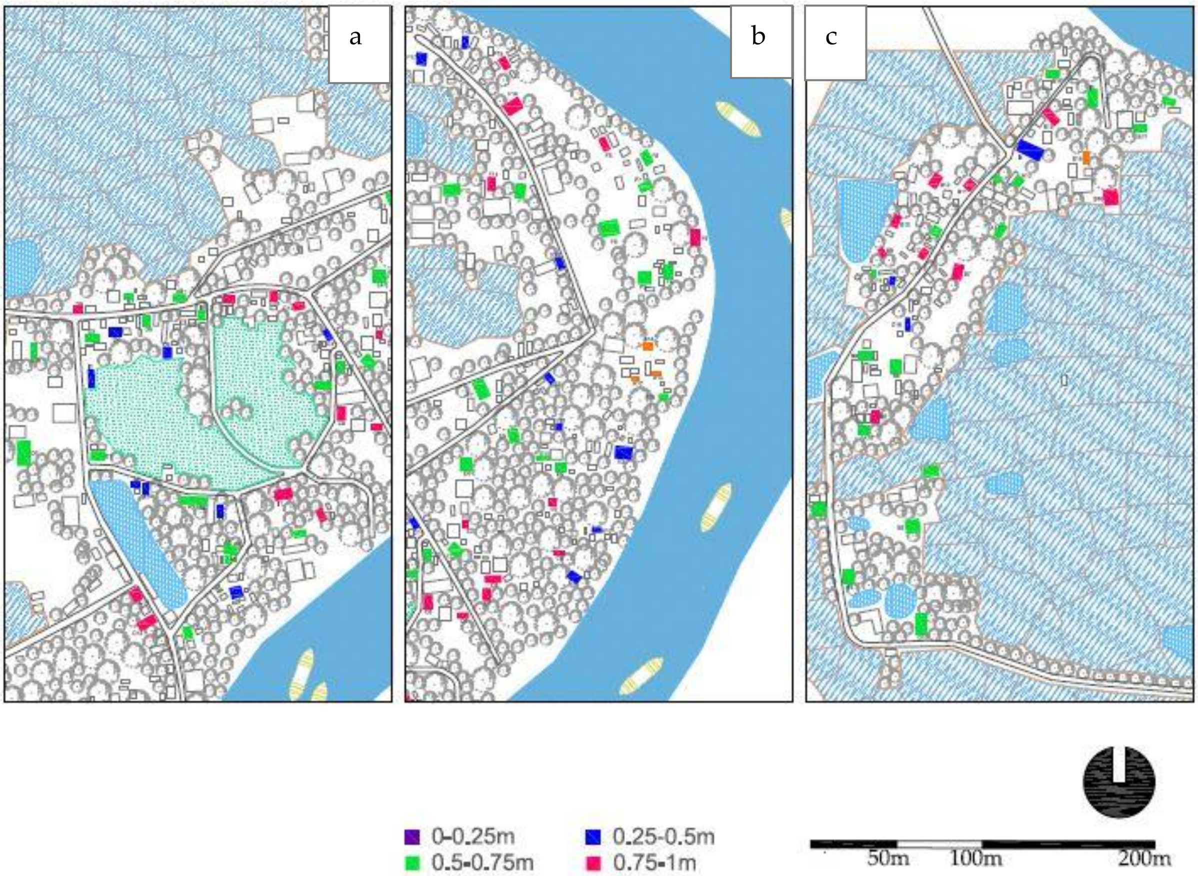


Figure 6. 5 The Height of Plinth Level in Three Neighborhoods
a) Dhitpur, b) Tamburabad c) Nalsata.

From Table 7, 70% of buildings with plinth height between 0.1-0.25m experienced high damages. This declines as the plinth height increased with no record of high damage with plinth height of 1 m and above. At the same time, when plinth height is between 0.1-0.25m, 10.0% of respondents report low damage. The proportion of low damage to buildings increased as the plinth height rises: with 26.5% for 0.26-0.5m, 22.6% for 0.51-0.75m, 38.9% for 0.76-1m, and 100% for plinth height of 1m and above (Table 6. 7). Akin with other building attributes such as building materials and age of building, this study reveals that the extent of damage from flooding is dependent on plinth height, which provides some insight into the subsequent discussions on flood response strategies by respondents.

Table 6. 7 Plinth Height of the Building and Damage due to Flooding.

Damage due to Flooding	Plinth Height of the Building											
	0.1-0.25m		0.26-0.5m		0.51-0.75m		0.76-1m		Above 1m		Total	
	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
Low Damage	1	10.0	9	26.5	7	22.6	7	38.9	7	100	31	31
Medium Damage	2	20.0	11	32.4	13	41.9	6	33.3	0	0.0	32	32
High Damage	7	70.0	14	41.2	11	35.5	5	27.8	0	0.0	37	37
Total	10	100	34	100	31	100	18	100	7	100	100	100

6. Physical Response to Flooding

6.1. Building Modifications

The most common action by respondents to address the physical vulnerability to perennial flooding was through modifications of residential buildings. By raising homestead and plinth level, strengthening the plinth and building walls as well as strengthening the whole building. Here, 'strengthen' means residents changing the existing non-resistant material with a flood-resistant and durable material. A respondent from Dhitpur narrated that:

> *'To protect our houses from regular flooding, we try to strengthen our houses, when we can manage. Raising the plinth height or Strengthen the foundation become very common modifications for us to protect our houses from the penetration of floodwater. Even a few of us renovate their whole structure with durable material. But all (of us) are not financially affluent enough and cannot save a lot to have a strong house within a short period.'* (Farmer, Dhitpur, Age 42).

The data analysis reveals that there is a statistically significant modest association (Cramer's V = 0.425, p = 0.000) between physical modifications and damage to flooding (Table 6. 4). While the primary goal of these modifications at the building level was to address the physical vulnerability of residential buildings to flooding, the nature of these modifications is dependent on the extent of flood damage. For instance, all respondents who raised their homestead by erecting and constructing barriers with mud/brick in their surroundings above the road level only experience low damage during floods compared to 66.7% of respondents who modified their entire building because they experienced high damages to their buildings from flooding (Table 6. 8). Respondents' actions through building modification demonstrate residents' awareness of their physical vulnerability to flood and agency to prevent flood disaster.

Table 6. 8 Modified Parts of the Buildings and Damage due to Flooding.

Damage due to flooding	Type of modifications of the houses											
	Raised homestead		Raised Plinth level		Strengthened Plinth		Strengthened walls		Strengthened whole house		total	
	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
Low Damage	8	100	9	40.9	7	41.2	6	23.1	1	3.7	31	31
Medium Damage	0	0	8	36.4	4	23.5	12	46.2	8	29.6	32	32
High Damage	0	0	5	22.7	6	35.3	8	30.8	18	66.7	37	37
Total	8	100	22	100	17	100	26	100	27	100	100	100

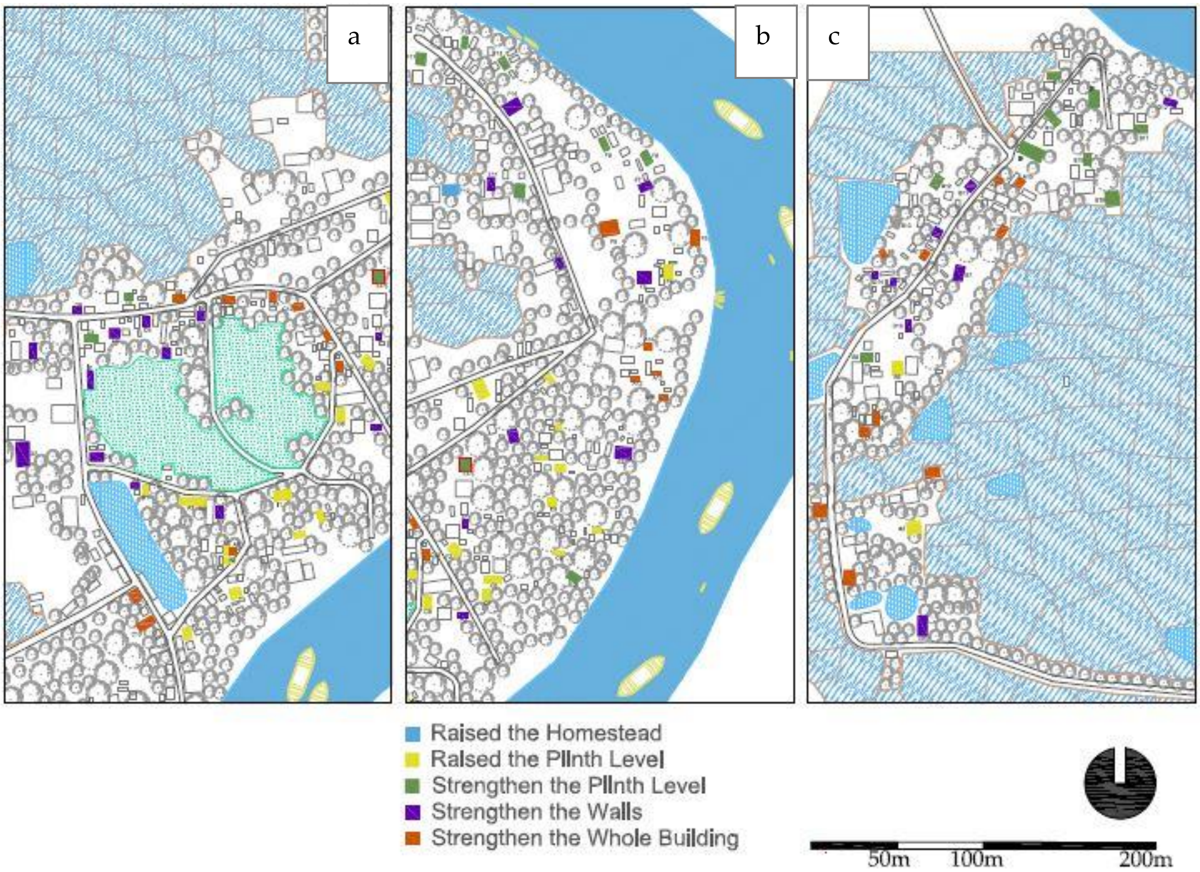


Figure 6. 6 Building Modifications in Three Neighborhoods
a) Dhitpur, b) Tamburabad c) Nalsata.

6.2. Use of Flood-Resistant Building Materials

Respondents also changed building materials for building floors, walls, and roofs in response to their physical vulnerability to flooding. Although some forms of modifications are being undertaken to buildings to address flood damage, the materials used for the construction of plinths, floors, wall and roofs by some respondents cannot withstand a prolonged flood event. The study finds that 20% of interviewees reported using mud to construct their foundations, whereas 15% used untreated bamboo for their walls (Figure 6. 7).

Assessments using the Technical Suitability Determinants (TSD) of buildings materials to flooding by the Federal Emergency Management Agency (Table 6. 9) shows materials used for construction cannot withstand a prolonged flood event, thus increasing the physical vulnerability of those who use these materials to flooding. However, it needs mentioning that the low resistance of existing building materials to flood damage does not necessarily translate into a lack of awareness about high resistant materials among respondents. Contrariwise, respondents were knowledgeable as to which materials afforded better resistance to flood damage. As one respondent noted vividly:

> *'We experienced that brick or masonry houses are stronger than mud houses. But at first, people try to change their plinth material, and then the wall of the house. For roofs, the popular choice is corrugated steel, as it is cheaper (than RCC roof), easy to install and any panel can be changed, if it damages.'* (Craftsman, Tamburabad, Age 50).

Table 6. 9 Assessment of Building Materials Concerning Flood Resistance.

Building material categories	**Building material type**	**Technical suitability**[1]			**Percentage of the respondents**
		Resistant	Resistant to some extent	Non-resistant	
Foundation and plinth	Mud	-	-	•	20%
	Sand-cement	-	•	-	65%
	Concrete	•	--		15%
Wall	Bamboo	-	-	•	15%
	Wood	-	-	•	4%
	Corrugated Steel	-	•	-	39%
	Brick	-	•	-	42%
Roof	Clay tile	•			22%
	Reinforce concrete	•			28%
	Corrugated Steel		•		48%
	Others (thatch)			•	2%

[1] Technical suitability determinants adapted from Federal Emergency Management Agency (FEMA) (FEMA, 2008, Sakijege et al., 2014).

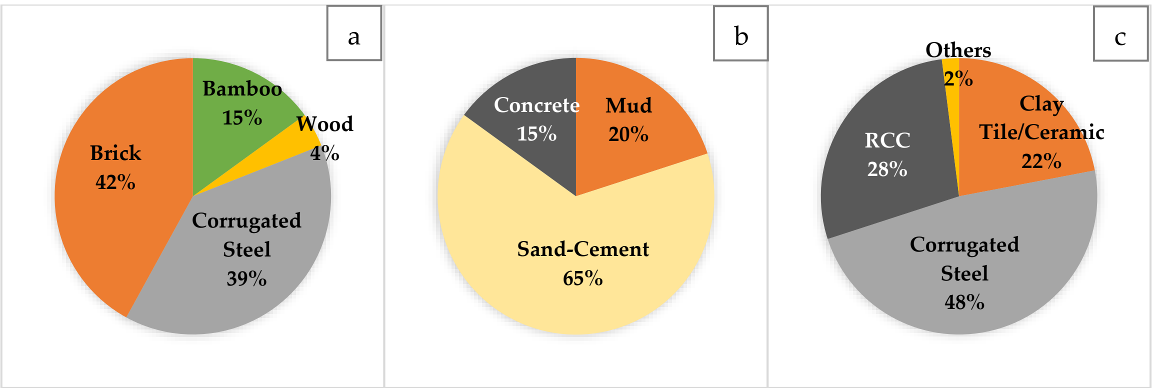


Figure 6. 7 a) Percentage of material used in foundation and plinth, b) Percentage of wall material, c) Percentage of roof material.

7. Building Clusters in the Study Area

The previous sections have shown that there is a relationship between flood damage and the individual variables of building typology, age of the building, plinth height of the building, and type of building modifications. Four variables provided the basis to identify building clustering in the study area. Three clusters emerged in the analysis with the ratio of the largest cluster to the smallest cluster being 1.32. The predictor importance of the variables for the clusters is (i) Type of Damage due to flooding = 1, (ii) Type of Transformed Parts of the House = 0.65, (iii) Building Typology = 0.34, and (iv) Age of The Building = 0.3 (Figure 6. 8).

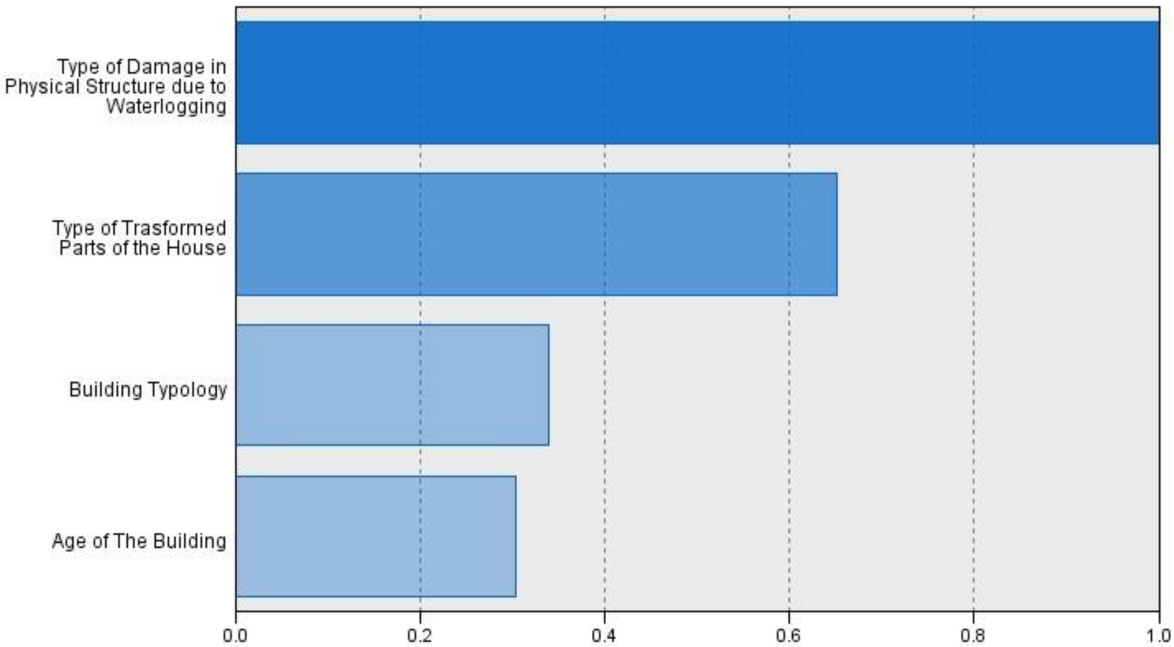


Figure 6. 8 Predictor Importance

Figure 6. 9 Silhouette Measure of Cohesion and Separation

The Silhouette measure of cohesion and separation was fair (0.2) (Figure 6. 9). The first cluster is composed of 89% of buildings with low damage from flooding; 75% of buildings that are less than 10 years old; 50% of building constructed with durable materials, and the predominant physical response to flood damage being raised homestead (29%) or plinth modifications such as strengthened (36%) or raised plinth height (32%). The second cluster is characterized by a majority of buildings with medium flood damage (68%) and constructed with durable materials (51%). Most of the buildings in this cluster are between 10 and 20 years old (67%), and the physical response strategy to flooding is predominantly strengthened walls (54%). The third cluster comprises buildings that have high damage from flooding (89%), constructed with natural materials (54%), more than 20 years old (63%) and the main physical flood response strategy being strengthened the whole building (60%). Table 6. 10 summarizes the components of the cluster. The clusters (Figure 6. 10) show that these variables interact to reflect the physical vulnerability of residents as measured by the extent of flood damage.

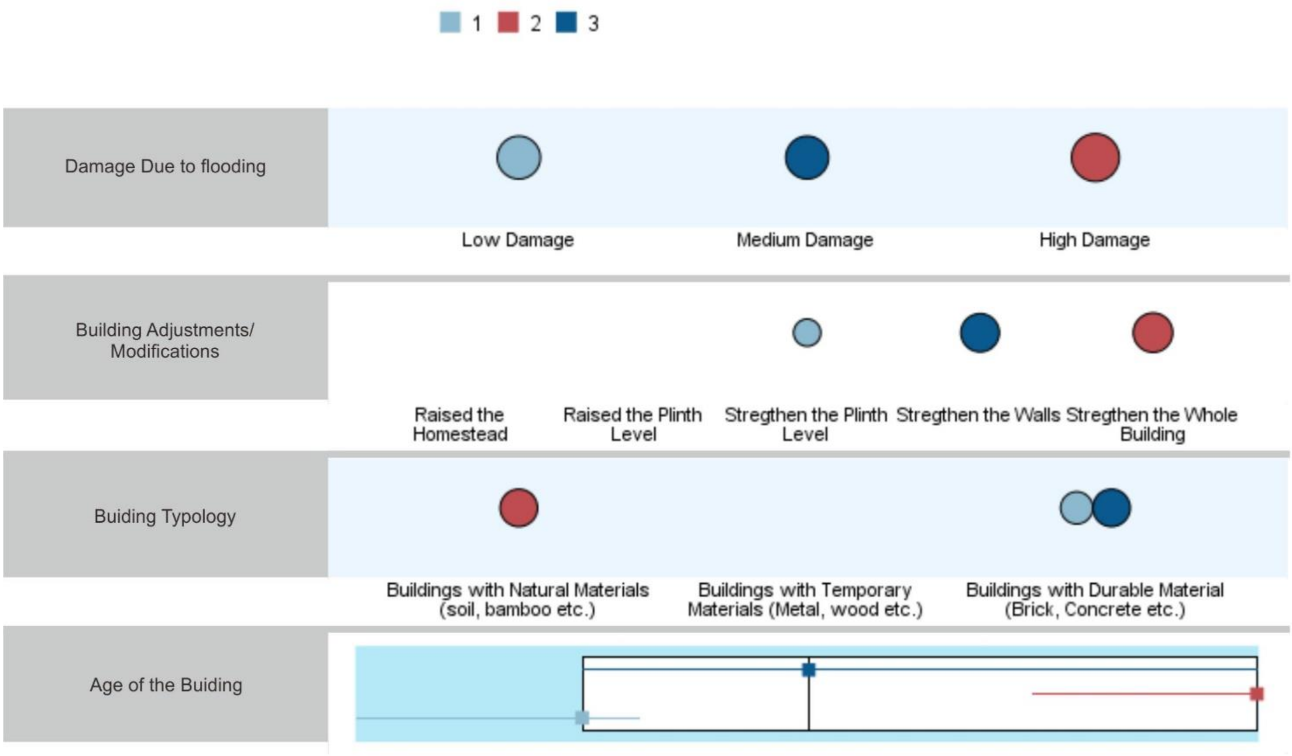


Figure 6. 10 Cluster Comparison

Table 6. 10 Components of the Cluster Analysis

Variables		Cluster 1		Cluster 2		Cluster 3	
		Count	%	Count	%	Count	%
Damage due to Flooding	Low Damage	25	89	6	16	0	0
	Medium Damage	3	11	25	68	4	11
	High Damage	0	0	6	16	31	89
	Total	28	100	37	100	35	100
Type of modifications of the houses	Raised Homestead	8	29	0	0	0	0
	Raised Plinth Level	9	32	12	32	1	3
	Strengthened Plinth	10	36	0	0	7	20
	Strengthened Walls	0	0	20	54	6	17
	Strengthened Whole Building	1	4	5	14	21	60
	Total	28	100	37	100	35	100
Building Typology	Buildings with Natural Materials (soil, bamboo, etc.)	1	4	0	0	19	54
	Buildings with Temporary Materials (Metal, wood, etc.)	13	46	18	49	7	20
	Buildings with Durable Material (Brick, Concrete, etc.)	14	50	19	51	9	26
	Total	28	100	37	100	35	100
Age of The Building	0-5 years	10	36	2	5	2	6
	6-10 years	11	39	10	27	3	9
	11-15 years	2	7	9	24	2	6
	16-20 years	0	0	6	16	6	17
	21+ years	5	18	10	27	22	63
	Total	28	100	37	100	35	100

8. Collective Action and Social Networks

In Eastern Dhaka, respondents collectively organized community-level actions to control inundation and also erosion during the monsoon season. Some of these collective responses involved the use of sandbags to block the water flow and stop erosion, cleaning the canals and make temporal drainage, making bamboo bridges between houses, and building rafts and boats. In all, about 89% reported that they participated in such collective activities to support flood response and damage reduction to buildings in the neighborhood. (Figure 8a).

A respondent remarked sharply:

'Our community is not very organized, rather they start to be active when difficulties arise'. (Housewife, Dhitpur, Age 38).

These collective activities thrive based on strong social networks for flood responses in these areas (Figure 6. 11a). Interviewees rely on family, relatives, and friends as their first point of call in case of flood occurrences or severe damage to buildings. The majority (72%) identified their neighbors as their main source of support during flooding. Only 10% of the households had relied on networks within the Khilgaon Thana and 15% on relatives and extended family living in the city (Figure 6. 11b). As noted by one respondent:

> *'We lived here for a long period of time. My grandfather settled here first. Majority of the people who lived here had ancestral properties. We have known each other for a long time and we have strong bonding. In times of difficulties, we help each other. For disasters like floods, we try, whatever we can, to support each other.' (Craftsman, Nalsata, Age 35).*

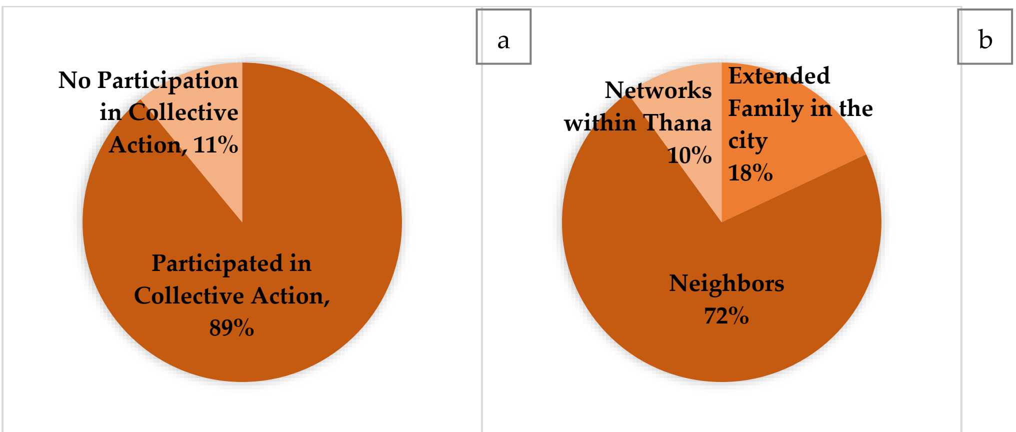


Figure 6. 11 a) Participation in collective activities, b) The forms of social networks.

9. Conclusion

Floods have increased the physical vulnerabilities of cities to disaster risks and have, therefore, become one of the threatening developmental problems of this era (Pelling, 2012). For those in Eastern Dhaka, flood remains a constant threat to livelihood and property in view of locational factors such as low surface elevation surrounded by the peripheral rivers. Infrastructure deficits further compound disaster risks in this urbanizing part of metropolitan Dhaka. This study analyzed three mahallas: Dhitpur, Tamburabad and Nalsata, which are highly vulnerable to flooding. The study reveals that the extent of damage depended on the physical attributes such as building typology, age of the buildings and height of the plinths. Buildings with durable materials, relatively newer buildings and buildings with higher plinth level experienced low damage from floods. On the other hand, buildings with natural materials, older buildings and buildings with lower plinth level had to face high damage during floods. Households have responded to their physical vulnerabilities by raising the homestead, raising and strengthening plinths, improving the condition of walls and strengthening the whole building. Flood response strategies are primarily household-based, with very little initiatives at the community level. Community collective actions should be strengthened to enhance the capacity of local people in organizing themselves before, during and after the disaster, especially during floods. There will also be a need to enhance household level flood strategies before, during and after flooding events to improve local capacity to deal with physical flood vulnerabilities.

CONCLUSION: SUMMARY OF KEY FINDINGS, PLANNING AND POLICY RECOMMENDATIONS

1. Introduction

This chapter concludes the research study. it summarizes the major findings, introduces policy implications, and identifies future research direction. It also presents the key contributions of this research concerning the findings and the objectives of this research for flood control and mitigation of Eastern Dhaka.

2. Summary of Findings

Based on the analyses of previous sections, the major findings have been organized along with four main themes: (i) Flood damage and physical attributes of the buildings; (ii) Flood damage and the influence of human activities; (iii) Factors influencing response strategies; and (iv) Collective actions and community-based management

Flood Damage and Physical Attributes of the Buildings

The Findings supported by the statistical analyses established that the type of building materials, age of buildings, the height of plinths and surrounding land cover affect the physical vulnerabilities of buildings in terms of the extent of damage from flooding.

- Houses made of natural and temporary materials such as mud, steel sheets and wood suffered higher damages as compared to those made of durable material such as brick and concrete which experienced little to no damage in the context of eastern Dhaka. This is because buildings with temporary materials become wet and collapse during floods, requiring regular replacement after every flood event. From the analyses, it is apparent that during intense flood events with high volumes of water, the likelihood of flood damage would be greater among buildings constructed with natural and temporary materials compared to durable materials.
- In Eastern Dhaka, houses built over 21 years are more susceptible to flood damage due to the increased depreciation of their conditions and strengths. Besides, it also revealed that in both areas, most of the old buildings are physically weak due to their poor maintenance arising from high cost and the perennial issue of gradual flood damages over time.

- In this study, buildings that have the surrounding with green surface and green surface setbacks experienced low damages compared to those with no setback areas during flooding.
- The residents of eastern Dhaka, especially of the peri-urban areas made physical adjustments to avoid floodwater inside their houses and damage due to inundation by constructing the plinth level higher to match the level of flood risk or strengthening the plinth with durable materials.

The mere presence of these attributes applications individually may not be enough if not combined with other flood management strategies.

Flood Damage and the Influence of Human Activities

Finding from this study shows that though flooding is caused by excessive rainfall and overflow of the rivers, human-induced factors such as improper maintenance of drainage system, waste dumping in the stormwater drainage system, the encroachment of the wetlands and natural retention areas, deforestation along the river banks accelerate flooding damages in rapidly urbanizing cities such as Dhaka.

- In the city and its peripheral areas, the deficit of a dedicated stormwater drainage system has been keenly observed. Moreover, the existing drainage infrastructure was also blocked by solid waste and construction debris. Residents attitudes toward waste management (especially disposal and collection) were highly questionable. During the fieldwork, residents were observed dumping solid waste and littering in the open canals connecting the river, and thus blocking the natural flow of these canals.
- From the study, it was found that the encroachment on the wetlands and natural retention areas, and the deforestation along the river bank affect the peri-urban areas overall flood damage situation. This exacerbates flood risk and exposure in the peri-urban areas, which are becoming highly vulnerable to riverine floods.
- The lack of community-based interventions, absence of leadership and members’ reluctance to participate in community improvement actions causing delays to perform community-level flood management activities.

Factors Influencing Response Strategies

Construction knowledge and skills, Favorable location, Experience and awareness, Vegetation and green landcover and Individual’s financial capacity were identified as the main factors that response strategies into flooding in Eastern Dhaka.

- This study confirmed that the respondents of eastern Dhaka were knowledgeable as to which materials afforded better resistance to flood damage. Residents begin from relatively weak materials (e.g. mud), and gradually and progressively install or modify their buildings with stronger flood resistance durable materials (e.g. steel or concrete) as social and economic circumstances allow. Their agency in dealing with their flood vulnerabilities corresponds to what some researchers have termed 'incremental improvisations' or 'adjustments' (e.g. Okyere and Kita, 2016).
- Flood prone peri-urban areas are mostly reliant on subsistence farming or fragile economic livelihoods, hence even though they continually modify their houses, they still rely on natural building materials due to poor low-income situation. Thus, in these areas, residents may reside for many years and learn to respond to flooding, have experience and awareness to cope and even manage the flood damage. However, their lack of economic progress limits their responses in terms of using structurally durable materials.
- In both areas, the respondents were aware of the necessity of vegetation and green surfaces to reduce the extent of flood inundation. The land cover condition especially, surrounding with the green surface has been found as a key indicator that influencing physical vulnerability.

Collective Actions and Community-Based Management

The study showed that physical adjustments to reduce flood damage are done at the individual level (house or apartment block), but they appear to depart from the previous studies on the role of social capital and social learning and community-based collective responses to flooding hazards.

The study revealed that the social structure of eastern Dhaka is not well organized, especially in the urban core as compared to the peri-urban areas. Most of the household in the urban core of eastern Dhaka were found to be individualistic and reluctant to participate in community improvement actions. Therefore, collective action and social learning process were found to be absent in those neighborhoods.

3. Planning and Policy Recommendation

Flood has been a constant threat in eastern Dhaka. Similar to other natural disasters, it cannot be possible to mitigate and prevent the occurrence of floods entirely. But the physical vulnerability analysis, identifying the causes and effects of floods, factors of response strategies of local peoples can provide some guidelines in form of capacity building, community interventions and also, individual interventions to reduce the impact of floods. In this regard, the local government authorities, stakeholders and Residents of the neighborhoods all have to play a role collectively to control and manage the impact of floods.

3.1. Capacity Building

Community Engagement in Flood Management Plans

In the response of an adage, "all disasters are local", it can be emphasized that all responses to disasters should start by engaging the local stakeholders, especially the local residents, community leaders, community associations and affiliated institutions. The engagement in the planning process will make the people learn about the preparation to face the disasters skillfully and carefully. For instance, in Thailand and Lao People's Democratic Republic, the local community engaged in participatory risk assessments and preparedness measures for flooding which ultimately improved their awareness and capacities for better response in emergencies.

Moreover, to sustain sound governance for disaster risk reduction, multi-stakeholder participation and norms of social reciprocity have to be allowed and encouraged. In this regard, community engagement can play a key role in flood risk management through exchanging information, coordinating with the state agencies and cooperating them in decision-making and even, in implementation processes.

Integrating Flood Management in City-level Development Plan

City-level Development Plan, especially spatial planning can influence in flood mitigation to a large extent. The inclusion of flood management issues in the city-development plan is crucial due to its focus on flood occurrences and damages due to flood by monitoring and control the overall land-use. However, the main flaw here in the recent Dhaka City Development Plan is the absence of some flood preparation and flood recovery strategies. Additionally, tardiness of the implementation of the planning, the settlement in the flood-prone area took place and being exposed to flood risk.

Moreover, a clear identification of zoning in the flood-prone areas along the river should be included in the City Development Plan. Separated zones such as prohibited zone, restricted zone and warning zone have to declare with a clear demarcation in support with the prevailing data. It should be declared that no development work can be performed in the prohibited zone, whereas people can be allowed to construct houses under certain conditions in the restricted zone. In the warning zone, people can be allowed to construct houses with little or no resistance, but they should be advised and warned about the disaster.

In Dhaka, one of the identified reasons for flood is the encroachment of wetlands and haphazardly land grabbing by property developers resulted in blocking the natural water retention areas and thus, waterlogging initiates. In flood-prone areas, disturbing the natural flow can be potentially hazardous towards floods. A set of regulations should be formulated to such development by landfilling; a new updated land use can be prepared in this regard especially for peri-urban Dhaka.

Integration of Building Code for Flood Prone Area

In the Bangladesh National Building Code (BNBC), the requirements to design and construct flood-resistant buildings are limited to ensuring the building, building elements or structure does not collapse due to flood actions. The Building Construction Rules for Dhaka (Imarat Nirman Bidhimala 2008) also limits its scope by mentioning that only buildings constructed within the 50m range of the rivers need special permission. Therefore, the study recommends the integration of specific guidelines as design requirements regarding construction of buildings in flood hazard areas, which can be an essential tool in respect to flood control in Dhaka. The physical vulnerability of the houses and their damage assessment and physical adjustments done by the local people can be sourced as the root study to prepare these guidelines. For instance, in Australia, Australian Building Codes Board (ABCB) developed such guidelines to provide additional requirements for buildings in flood hazard areas consistent with the objectives of the existing Building Code of Australia (BCA) which primarily aim to protect the lives of occupants of those buildings in events up to and including the defined flood event.

Effective Flood Risk Communication

With the progression of flood management, the emphasis has been given on the at-risk communities to understand their risk and prepare themselves to manage the risk. Therefore, communicating flood risk is now becoming an increasingly essential tool to develop flood resilience. These include: Flood hazard and risk maps, Real-time water level information, Flood warnings etc. In Switzerland, city authorities use hazards maps for city planning and inform the citizens about the risks and other compulsory or voluntary protective measures. In Ghana context, the communicating flood risk through pictorial graphics and local languages found to be effective at neighborhood level for the disaster preparedness from the previous studies of Abunyewah et al. (2020, 2019).

However, the key issue here is to tailor the flood risks and disaster management plans according to the contextual realities of flood victims, with due cognizance to literacy levels, socio-economic profiles and other cultural idiosyncrasies. Because effective communication of flood risk management strategies and plans can ensure disaster preparedness in flood-prone communities and neighborhoods.

3.2. Community Interventions

Erosion Control of River Bank

Peri-urban areas in eastern Dhaka along Balu river usually remain highly exposed to erosion along with perennial flood, especially during monsoon season. It can be managed and protected collectively through the community-based management system supported by the local authorities using low-cost or biological embankment. The similar measures have been introduced by the communities of Cai Son, Vietnam along the Can Tho River who were motivated by the message, "my riverbank, my responsibility".

Moreover, reconstruction of the waterfronts by raising the level of the riverbanks should be a good community-level intervention to protect the flood-prone area. Riverside plantation of steady trees should also be encouraged to grow due to their capacity in reducing the velocity of floodwater.

Canal and Drainage Infrastructure Maintenance

For the studied area, canals are acted as a natural drainage system and drainage infrastructures are acted as stormwater channels. But due to the residents' waste disposal behavior and absence of proper waste management system developed of local authorities, the canals and the drainage infrastructures have been obstructed, clogged and even, stagnant by losing their natural flow by waste dumping and continuous littering. These can be maintained and managed through community management by monthly cleaning and protecting them. For example, in Japan, through movement, such kind of activities has been performed. 'Machizukuri' was emerged from the citizens' environmental movements to perform different activities to maintain and improve the physical and/or non-physical aspects of their community.

Training on Post-Flood and Recovery Activities

Dissemination of information on the flood is very important to raise public awareness about the potential danger form the disaster. Training to combat future flood hazards makes the community prepared to cope. For instance, in the Netherlands, institutional capacity has been confirmed at all levels through stakeholder engagement, adequate information on flood risks, risk mapping and effective mitigation measures at the local level. Several initiatives can be organized by the community such as community-based public dialogues, regular experience sharing program, participatory flood risk mapping and assessment, workshops and distribution of risk communication and warnings documents in local language and with illustrations and sketches. In Vietnam, Malaysia and Ghana, collective action and social learning become effective tools in building resilience to floods.

3.3. Individual Interventions

The macro-level planning and policy implications devised and potentially implemented by the city authorities or local community whereas, the micro-level interventions should be initiated and implemented by individual owners. As the study identified that in surveyed buildings, adjustments of the houses are context-specific (natural, social and economic) and most of them are reactive measures.

However, for existing buildings, dry floodproofing can be applied which includes continuous impermeable walls, flood resistance in interior core areas, sealants and flood shields for openings in exterior walls, backflow valves in internal drainage systems. But, for the new buildings, the owners can apply the shared knowledge and experience derived adjustments studied in this research in their houses.

- The plinth level height of habitable rooms should be above the flood hazard level (regulatory flood datum).

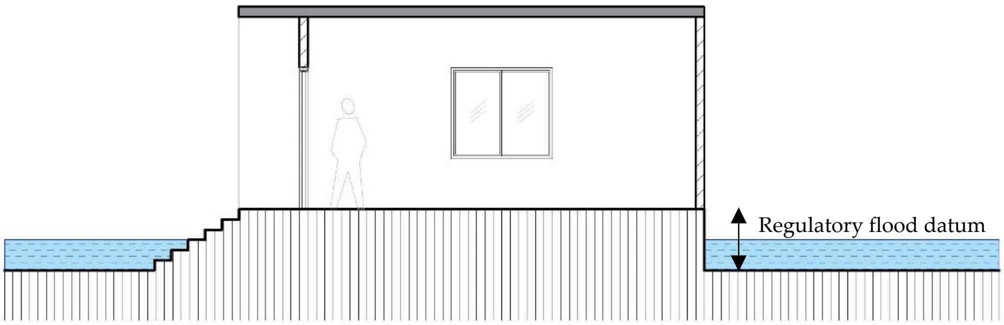


Figure 7. 1 Construction of Plinth above the Flood Hazard Level

- The building materials should be capable to withstand flooding conditions, for instance, resisting damage, deterioration, corrosion or decay due to floods and prolonged inundation.

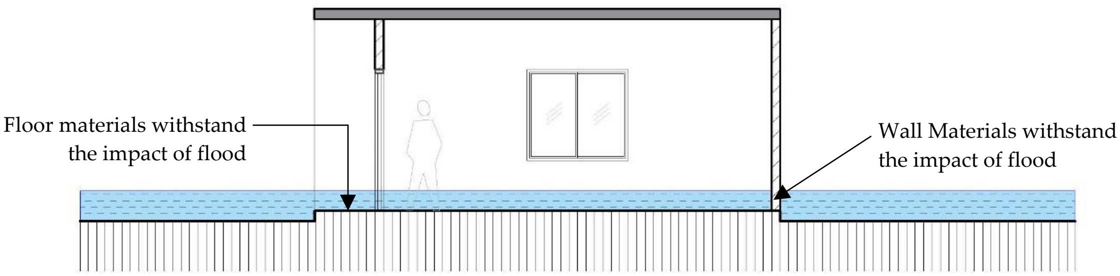


Figure 7. 2 Use of Building Materials Capable to Withstand Flooding Conditions

- In an individual plot, green surfaces as landcover should be provided to ensure the absorbing capacity of excessive rainfall, even dense plantation can be useful to reduce the flow of water during the flood.

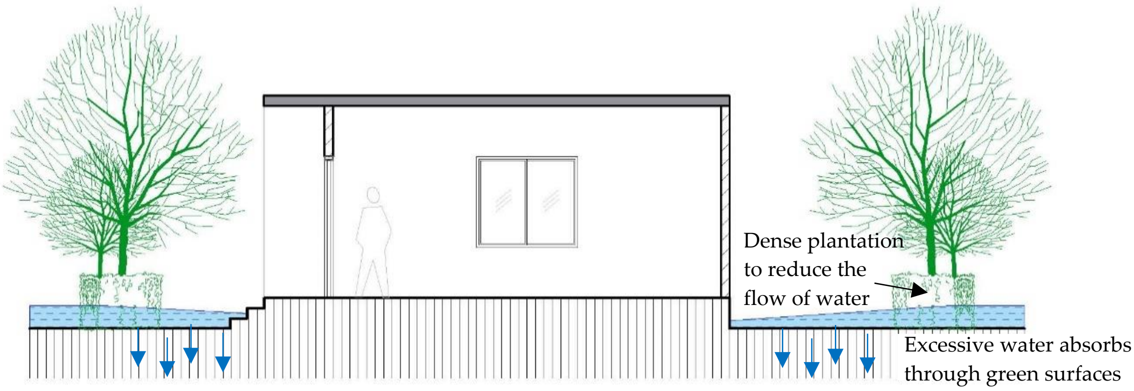


Figure 7. 3 Use of Green Surfaces as Landcover and Dense Plantation as Flood Barrier

- Stormwater disposal should be incorporated in the plot by introducing deep trenches in the surrounding ground and making level changes with a slope to connect to trenches.

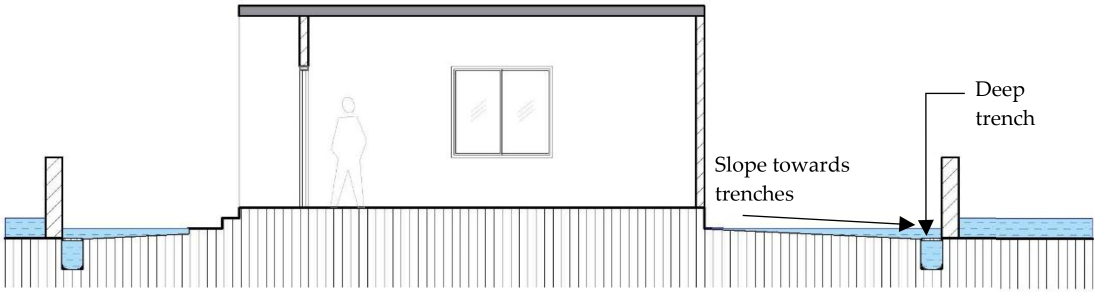


Figure 7. 4 Construction of Deep Trenches and Slope Connecting the Trenches

- Flood walls should be constructed surrounding the structure, determining the height based on flood depths, site topography, and design preferences to isolate the habitable areas for a certain time.

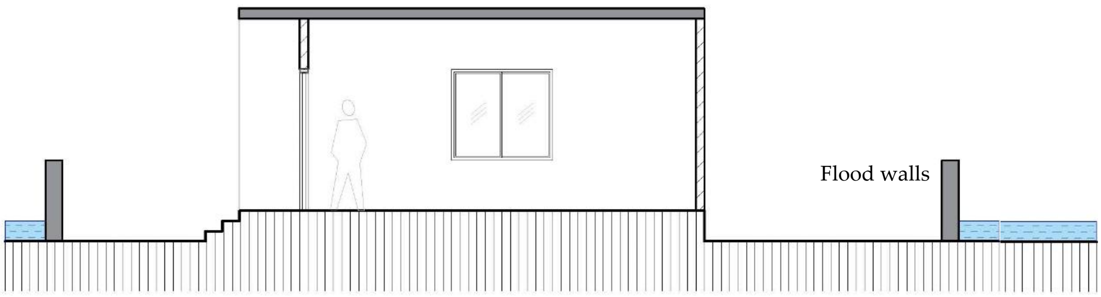


Figure 7. 5 Construction of Flood Walls to Keep Away Floodwater Reaching the Buildings

4. Contribution of the Research

This study contributes to the current literature in two ways.

Firstly, most of the previous studies on the flood vulnerability and damage assessment in the context of Bangladesh focused on macro-level (national level or city level). Micro-level approaches (community-specific) have received little attention, barring few exceptions (Jabeen et al., 2010, Paul and

Routray, 2010), more so in peri-urban eastern Dhaka where there is both scant data and limited state planning and management (Abunyewah et al., 2020). In this vein, this study provides avenues for co-production and co-learning opportunities between local citizens and institutions towards flood management planning and policies by unearthing local competencies and experiences from the aspect of residential buildings.

Secondly, apart from using traditional socio-economic indicators, this study considered physical vulnerability indicators to verify their relationships with the damage extent due to flooding in the context of peri-urban areas in the eastern fringe of Dhaka. However, it needs mentioning that given the small geographical setting and the sample size, the findings of this study are not meant to be definitive or generalized, rather provide exploratory insights into the interconnections between flood vulnerability, building damage and local adjustments in low-income settings as entry points for identifying key areas for building local resilience and adaptive capacity.

5. Future Research

This study has analyzed the exposure of the existing houses to flood-related vulnerability in two different contexts, 2 neighborhoods in urban core areas and 3 neighborhoods in peri-urban areas at the eastern Dhaka. The study showed that physical vulnerability to flood risks was not based on a single factor but a combination of factors (age of buildings, building materials, surrounding land coverages, and plinth height) and hence the frequency of flooding results from the multiplication of physical factors at the neighborhood level. Also, individual actions to reduce flooding (house modification) are primarily common and rely on flood experience. However, there is no community-level activities or residents' collective actions to reduce physical vulnerability to floods in their neighborhoods. These findings also initiate future research directions.

- Future research may need to consider expanding sample sizes in a relatively large geographical scale, in addition to in-depth hydrological and hydraulic sensitivity analyses for a comprehensive understanding of flood exposure and vulnerabilities.
- In this study, flood damage values were not explored determining the damage extent. Information on the cost, life cycle and water-endurance of properties related to buildings and flood damage, such as the age, type, and materials may be collected in detail for future research.
- In future, the other research should be done in the context of eastern Dhaka on
    - the impact of flooding on the value of the residential property, especially at the peri-urban areas;

- the use of Geographical Information System (GIS) to assess the flood impacts for emergency response;
- the use of human behavior research tools to correlate the factors influencing coping strategies of the community;
- the use of cluster analysis and bivariate correlation methods to develop the typology of community coping strategies.

Therefore, the future research will capture the flood damage, vulnerability and coping strategies of eastern Dhaka from different perspectives to develop an integrated flood control and management plan.

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Appendix 1

Household Questionnaire

The purpose of this research is to collect field data and generate information on the topic 'Climate Change and Densely Populated Urban Areas: Evaluating Urban Characteristics and Building Capacity for Urban Adaptation in Dhaka, Bangladesh', toward the fulfillment of the requirements for PhD (Urban Planning). Please, be assured of the confidentiality of your response and all information provided are for **academic purposes only.**

Name of interviewer:
Date of Interview:
Time of Interview:
Place of interview:

1. General Respondent Information

Q-1.01: Name of Household Head /HMC Head……………………………………………………………………………….
Q-1.02: Age of Household Head//HMC Head………………………………………………………………………………
Q-1.03: How many people live in your household? ……………………………………………………………………….

Male		Female	

Q-1.04: What is the level of education of those currently living in the household?

Level	Male	Female	Level	Male	Female
No Formal Education			Secondary/ SHS/ Vocational		
Primary/JHS			Tertiary (University, College etc.)		

Q-1.05: What is the marital status of those currently living in the household?

Single	Married (couple)	Married with 1 child	Married with 2 children	Married with 3 or more children	Divorced

Q-1.06: What is the age of those currently living in the household?

Age	Male	Female	Age	Male	Female
<1 year			19- 39years		
1-5 years			40-60 years		
6-12 years			>60 years		
13-18 years					

Q-1.07: How many people are there who are with special need (physically or mentally disabled)?

Male		Female	

Q-1.08: How long have you lived in this community?

1-5 years	6-10 years	11-15 years	above 15 years

Q-1.08.01: Please specify, from which year ……………………………..…………………………………………………..

Q-1.09: Which is your occupational status?

Employment	Male	Female	Employment	Male	Female
Self-employed			Service		
housewife			Student		
Retired			Others		
unemployed					

Q-1.10: Please identify the income range of your household.

Low (5K-10K)	Lower Middle (10K-25K)	Upper Middle (25K-50K)	Lower Upper (50K-100K)	Upper Upper (above 100K)

Q-1.10: Why did you decide to live in this settlement?
……
……
…………………………………………………………………………………………

2. Flood Experience

Q-2.01: How frequently does flooding occur on the property where your home is?

Every year	Every 2-5 years	Every 5-10 years	More than 10 years	no experience of flooding

Q-2.02: When was the last flood experience? ………………………………………………………………………………
Q-2.02.01: What was the duration of flooding? ……………………..………………………......................................

Q-2.03: Did you have flooding inside your property?

Yes	No	Don't know	Refused

Q-2.03.01: If yes, please indicate the extent of flooding:……………………………………………………………………

Q-2.04: If you were flooded internally, did you receive a warning before water entering your house?

Yes	No	Don't know	Refused

Q-2.04.01: What time did water enter your property? ……………………………………………………………………….
Q-2.04.02: What is your best estimate of the depth of flooding inside the property? ………………………………….

Q-2.05: Did the flooding affect outside areas of your property? E.g. gardens, driveway etc.

Yes	No	Don't know	Refused

Q-2.05.01: What is your best estimate of the depth of flooding outside the property? …………………………………

Q-2.06: To your knowledge, what was the cause of the flood?

Drain blockage or inadequacy	Overtopping of a river, watercourse or reservoir	Heavy rainfall	Urban run-off	Field run-off	Other

Q-2.08: Did you contact the administrative authorities during or after the flood event?

Yes	No	Don't know	Refused

Q-2.08.01: if yes, what was their response?
……..……
…….

Q-2.09: How and which weather forecast information do you access?

Information sources	Frequency	Relevance	Information sources	Frequency	Relevance
Television			Internet		
Radio			Local authorities		
Broadcasting systems			Neighbors		
Newspaper			Others		

Frequency	1 = every day	2 = every week	3 = 1/ 2 month/s	4 = events only	
Relevance	1 = most relevant	2 = very relevant	3 = relevant	4 = little relevance	5 = not relevance

Q-2.10: Do you have children in school?

Yes	No	Don't know	Refused

Q-2.10.01: If yes, how many? Their ages? ....

Number	1	2	3	4	5
Age					

Q-2.10.02: How much school time did they miss while evacuated?

none	1 day	7 Days	8-14 Days	15-30 Days	Over 30 Days

Q-2.10.03: What arrangements, if any, were made to have them attend school while you were evacuated?
....
....

Q-2.11: Can you tell me who you usually turn to for support and help in your community i.e. your support network? (Check as many as apply)

Friends	Extended family in the city	Neighbors	Network within the community	Other

Q-2.12: As a community have you taken any steps to reduce flood occurrence?

Yes	No	Don't know	Refused

Q-2.12.01: How/ why not?
....
....

Q-2.13: Has there been any forum to discuss disaster management in the community?

Yes	No	Don't know	Refused

2.13.01: If yes who led the process?
....
....

Q-2.14: How do you think the problem of flooding can be addressed in the community at the following levels?
Community/Household..
Ward..
Regional / Central Government...

3. House Form, Characteristics and Land Properties

Ownership

Q-3.01: What is your occupancy status?

Private ownership	Co-ownership	Renting	Caretaker	Other

Q-3.02: When was this house built? ……………………………………………………………………………………..

Housing Transformations

Q-3.03: How long have you lived in this House?

0-4 years	5-9 years	above 10 years

Q-3.04: Have you made changes to any part of the house for flood protection? (e.g. walls, windows, doors, ceilings, roofing or number of rooms)

Yes	No	Don't know	Refused

Q-3.04.01: If yes, which parts of the housing did you change?

Raised homestead	Strengthened Plinth	Strengthened whole house
Raised Plinth level	Strengthened walls	others

Q-3.04.02: How was the transformation done?

Local artisans	self	Professional (architects, engineers)

Building Profile (Observation by the interviewer)

Q-3.05: Please indicate the number of floor/s of your building. ……………………………………………………………
Q-3.05.01: Height of 1st floor……………………………………………………………………………………………………
Q-3.05.02: Plinth height from the ground surface………………………………………………………………………….
Q-3.05.03: Height from the street………………………………………………………………………………………….

Q-3.06: Describe the land cover of the property.

Surroundings with completely paved surface	Setback area with completely paved surface	Surroundings with green surface (plants, grass etc.)	Setback area with green surface (plants, grass etc.)	No set back area

Q-3.07: Describe some aspects of the building in which you are residing now. For scoring please follow the scoring system below:

1	2	3			4	5	6
Building Typology	Designed By	Building material			Structure Type	Damage/ Affected by Floods	Adjustments of the house after/during flood
		Roof	Floor	Wall			

1.	**Building Typology**	1 = individual house made from natural materials (timber, wood mud etc.) 2 = individual house made from natural and other materials (timber with concrete foundation)	3 = individual house made from concrete
2.	**Designed by**	1 = Local artisans 2 = Self	3 = Professionals
3.	**Material**		
	Floor Material	1 = Soil 2 = Wood 3 = Concrete	4 = Tile/ Ceramic 5 = Others 4 = Brick
	Wall Material	1 = Ply wood 2 = Bamboo 3 = RCC	5 = Others
	Roof Material	1 = RCC 2 = Metal	3 = Tile/ Ceramic 4 = Others
4.	**Structure Typology**	1=Post-Lintel 2=Post-Slab	3=Load-Bearing
5.	**Damage/ Affected by Floods**	1= no damage 3= medium damage (plinth level and first floor walls along with low damage elements are affected)	2= low damage (plot, ground surface elements, boundary walls are affected) 4= high damage (Building interior, furniture along with medium and low damage components are affected)
6.	**Recovery Mechanism/s**	1 = by Government/ state agencies 2 = by Private Company/NGO 3 = by Community	4 = by Building Owner/ Association 5 = by None

Comments:
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Appendix -2

INFORMAL INTERVIEW

(The interview was in local language-Bengali, the questionnaire presented here, is the translation of the original one)

1. Name of the Interviewee……………………………………………………………………………………
2. Age of the Interviewee ……………………………………………………………………………………..
3. Occupation………………………………………………………………………………………………………
4. How long did have you live in this community? Please describe the reason to live in this area.

………
………

5. How frequently does flooding occur in this area? Please share your experience during the most recent flood events.

………
………

6. What is the cause/s of the flood, according to you?

………
………

7. What was the duration of flooding? Describe the damage condition of your property and house during the flooding events.

………
………

8. Which areas were more affected by the flood, according to you? Please describe the damage extent of that area.

………
………

9. What are the techniques/measures you applied to protect your house during and after the flood? and Why?

………
………

10. What are the problems you experienced to make your house protected from flood damage?

………
………

Comments:
………
………
………
………
………