Guidebook on

Towards Seismic Resilience in Dhaka City: An Urban Planning Perspective

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Prepared by

SATREPS-TSUIB Project

A Japan-Bangladesh Joint Research Project

The University of Tokyo
&
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Foreword

Natural hazards like earthquake focused in this guidebook are inevitable, and disaster mitigation is a global issue that we should tackle. These problems and proposed strategies to reach their solutions for making society more disaster-resilient are not local to one country and should, therefore, be shared among related countries and regions.

Bangladesh is located in an earthquake-prone region and has been under the rapid growth of economy and urbanization, causing densely constructed and populated cities. Although the Bangladesh National Building Code (BNBC) including seismic provisions was first published in 1993 and the revised code BNBC 2020 was enforced very recently, older buildings and even some newer buildings have not been constructed with proper seismic design concept and/or supervisions, leaving a huge number of existing vulnerable buildings in urban centers to future earthquake events. Seismic evaluation and retrofitting of such vulnerable buildings are therefore of great urgency for a safer and more resilient society to future damaging earthquakes, which is also a key for a continued and sustainable development of the society.

Motivated by the imminent threat exposed to the society of Bangladesh, a research project collaborating with the Government of Bangladesh was proposed and launched in 2015 entitled "The Project for Technical Development to Upgrade Structural Integrity of Buildings in Densely Populated Urban Areas and Its Strategic Implementation towards Resilient Cities in Bangladesh (TSUIB)" under JICA(Japan International Cooperation Agency) and JST(Japan Science and Technology Agency) joint program for "Science and Technology Research Partnership for Sustainable Development (SATREPS)". The major tasks and expected outputs from the SATREPS-TSUIB project include the development of strategic methodology under scientific evidence and data to effectively and efficiently identify vulnerable buildings in the huge number of building stock in Bangladesh as well as of seismic evaluation and retrofitting procedures, and this report offers evidence-based and practical guides and recommendations derived after the 6-year research project. Although Japan has repeatedly learned bitter lessons from damaging earthquakes and accordingly implemented seismic upgrading of existing vulnerable buildings, we do not have a cure-all medicine and the best solution in one area may not always be so in another area. It may often need to be customized to fit the needs and availability of each societal environment since the societal and design/construction practice background were different from those in Japan, and this is one of the most essential policies that we have emphasized and shared with research group members throughout the project. The implemented policy can be found in various parts of the guidebook.

Our road to the goal was not flat and smooth; we faced significantly restricted activities due to a safety reason after a terror attack in Dhaka that occurred just at the beginning of the project and COVID-19 that caused the pandemic in the final corner of the project. Also, during the project, we lost the most valuable person, Dr. Jamilur Reza Choudhury, the Vice Chancellor of University of Asia Pacific and the Chairperson of the Joint Coordination Committee of the project, who had always provided us with clear and brilliant directions with compassionate suggestions. Nevertheless, both Bangladeshi and Japanese colleagues have been collaborating to successfully achieve the goal through finding a way out of such difficulties and crises, and we would like to express our sincere gratitude for their greatest efforts and contributions to the project. Their efforts have been definitely the source of our success and we are very proud of them. We do hope and believe that all the achievements including knowledge, skills, experiences, and confidence obtained and developed during the project can serve as a basis for making a more earthquake-resilient society of Bangladesh.

This project has been long supported by the Government of Bangladesh, JICA Headquarter, JICA Bangladesh Office, and JST, which fully understand the impact of the research outputs on the society of Bangladesh. Dr. Kaoru Takara, Professor of Kyoto University and Research Supervisor of SATREPS-TSUIB project, visited Dhaka and encouraged us for a fruitful and best achievement to the goal. Mr. Koichiro Miyara and Ms. Atsuko Himeno, Project Coordinators, have spared no effort to accommodate local arrangements for smooth implementation of on-site research activities in Bangladesh. Finally, we would like to take this opportunity to thank all of them for their valuable supports.

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Preface

Natural calamities are a recurrent incidence in Bangladesh. Cyclone/tornado, tidal surge, flood/ inundation strike this country every year. It significantly influences local and national economies, resulting in major economic losses. People regularly facing such unavoidable situations have some preventive measures or basic plans to reduce the damage as much as possible. On the contrary, Government has some provisions to support the affected areas and their population.

There are many legal documents addressing natural hazards at national and local levels. Specific responsibilities are also mentioned, along with activities before and after the impact. Interestingly, a hazard like an earthquake has very little importance or has been overlooked in many cases due to its rare occurrence. However, due to its geographic location, Bangladesh is very prone to earthquakes, which, once they occur, are expected to cause significant damage. How should we cope with such low-frequency large-scale disasters?

After the Comprehensive Disaster Management Programme (CDMP, 2005-2010) Public Works Department (PWD) had undertaken some technical projects in association with JICA and JST like CNCRP, BSPP- where structural components were the main priority. In this SATREPS-TSUIB project, urban planning and social aspects are also considered to develop a methodology for making cities more resilient against seismic hazards. Under this urban planning group, it was tried to incorporate and integrate the engineering and technical aspects into the urban planning strategies to increase their feasibility.

This guidebook has eight (8) chapters, including the introduction. Chapter 2 is about Dhaka city's geomorphology, engineering geology, and soil amplification. In Chapters 3 and 4, two different methods were used to assess the seismic performance of structures. Chapter 5 discussed the emergency response and rescues like road network vulnerability assessment in ward levels and earthquake knowledge and emergency preparedness among the inhabitants. A retrofit prioritization method was described in this chapter. Chapter 7 and 8 contain the public awareness by using 'Town Watching Manual' and before and after scenario of 'Willingness to Pay' and policy review of existing legal documents in Bangladesh.

This guidebook is an output of several researches undertaken by graduate students from Jahangirnagar University and Tohoku University. Working group 4 team is highly appreciated their hard works and support. This is a joint collaboration between Tohoku University and Jahangirnagar University. Working group 4 is expecting more research collaboration in the future. Housing and Building Research Institute (HBRI) has played a vital role between the researchers and universities. Members from different working groups also took responsibility and provided beneficial suggestions. Working group 4 team also thankful to the Japan side Project Leader Yoshiaki Nakano and Project Director Md. Ashraful Alam for their continuous support during this period.

This is the beginning of a new journey towards risk-sensitive urban planning in Bangladesh. Many aspects are not addressed in this study that are equally important. Young researchers and professionals should come forward to take the challenge and responsibilities for making Bangladesh resilient against seismic hazards.

We hope that this publication will contribute to earthquake disaster preparedness in Bangladesh.

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List of Authors by each chapter

Chapter 1: Introduction (Rashied, Mahmud)

Chapter 2: Geology, Geomorphology, Engineering Geology and Geotechnical Aspects of Dhaka City (Rashied, Khan)

Chapter 3: Comprehensive Seismic Vulnerability Assessment (Afrose, Ubaura)

Chapter 4: Seismic Building Assessment (Nahar, Rahman)

Chapter 5: Emergency Response and Rescue (Chakrabarty, Islam, Hossain, Rahman)

Chapter 6: Development of Building Prioritization Method for Seismic Retrofitting (Afrose, Ubaura)

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Chapter 1 Introduction

1.1 Introduction

Dhaka, the capital city of Bangladesh, has a long historical background with many significant incidents before the partition of the Indian subcontinent in 1947. Dhaka was titled as the capital of Bengal twice during the Mughal period and the Pakistan period. After the great liberation war in 1971, it was indisputable that the former provincial capital of East Pakistan would be the next capital of Bangladesh. As the capital of Bangladesh, Dhaka has earned its significance and glory over time. It becomes the primary attraction centre for every aspect of life. However, Bangladesh is highly vulnerable to seismic hazards because of its location and Dhaka is also very much prone to earthquakes. This study aims to identify the seismic vulnerability of this city under three broader aspects - structural, social and emergency and responses. This guidebook is divided into several parts, including macro-level assessment and micro-level assessment. These are explained in the following chapters of this report.

It is essential to know the development characteristics and the growth pattern of the city before in-depth investigation for vulnerability assessment. In the following sections, the historical development of Dhaka, its development characteristics, populations, and growth pattern, are briefly discussed to have an inclusive idea of the city.

1.2 Historical Development of Dhaka

Historically, the origin of Dhaka city can be identified long before the Mughal period. Some literature showed that human settlement in Dhaka started in the 12th century [1][2]. Gradually, the importance of this area was acknowledged by The Mughal and established their capital in the 17th century. The historical development of Dhaka can be divided into five different periods such as i) Pre-Mughal Period, ii) The Mughal Period, iii) The British Colonial Period, iv) Pakistan Period, and v) Bangladesh Period.

i) Pre-Mughal Period: Before the Mughal era, the history of Dhaka was not well documented by historians. It is assumed that Dravidians were the first people to arrive in Bangladesh [3]. However, the early settlements in Bengal before the Gupta Empire (4th Century A.D) are ambiguous. Historical evidence showed that the Bengal (including the West Bengal of India) was under the rule of the Mauryan Empire During 321-180 B.C; after the decline of the Mauryan dynasty, the Bengal became the state of Samatata that existed from A.D 319 to 540 [3][4]. The invasion of the Hephthalites, or White Huns, brought the Gupta Empire to an end and started to rule this region until the 7th century [5]. The Gupta Empire was divided into different small kingdoms with smaller areas and continued to rule Bengal. King Shashanka, the first independent king of Bengal, governed the region until the middle of the seventh century under the Gauda Kingdom [6]. In 750, Gopala became the king of Bengal and started the Pala Dynasty. Gopala was a Buddhist, and most of the kings under his influence were Hindus, a new religious faith known as Tantric cults emerged, combining beliefs from both religions [3]. Soon after, the Sena Dynasty took over the power under the leadership of Vijaysena (1097-1160), who was a strict Hindu believer and did not tolerate Buddhism or other religious faith except Hinduism. The Sena Dynasty ruled Bengal for more than 100 years. The last Sena king was Lashmansena, replaced by the Turks in 1204

[3][7]. From the early 13th Century, the Turks spread the Islamic faith under the patronization of the Delhi Sultanates [3][8]. They took full advantage of the inhabitants going under religious turmoil from the Pala dynasty to the Sena dynasty. The Turks continued their ruling until the Mughal took over power in 1576. During that time, Dhaka was considered a small trading centre with an expansion between Dholai Khal and Buriganga river [9]. The development of Dhaka city was primarily centered on these small commercial operations and Bazars along the Buriganaga river in a linear pattern, with Sadar Ghat serving as the focal point of all trades due to its water routes and accessibilities.

ii) The Mughal Period: Political unification of Bengal started with the rest of the subcontinent during the Mughal period; however, Bengal was never certainly subjected to the Mughal empire because of its distance from the central government in Delhi [10]. Nevertheless, to make the connections strong with the Bengal, the Mughal Empire sent Isha Khan the first viceroy of Bengal in 1608 [2][10]. Isha Khan established his capital in Dhaka in 1610, and the prosperity of Dhaka began. New roads, bridges, and buildings were built to make the administrative works more accessible with the central government. Bengal was known for its resources, primarily the agricultural sector of this province was so enriched that it was called the 'breadbasket' of India [3][9][10]. Besides, Dhaka grew as a manufacturing centre for various cottage products, including shell works, bamboo mats, fine cotton, refined butter, and cheese, along with various agricultural products shipped to various parts of the Indian subcontinent [3][9]. The economic potentiality, available resources, cheap workforce, and accessibility of this area attracted many traders like the Europeans, the Portugues, the Dutch, the English, the French, and the Armenians; they all came and established their trading posts in Dhaka in the 17th century [2][9][10]. In his study, Ahmed reported [11] that the most significant development of Dhaka took place under Shaista Khan (1662-1679). The city expanded 20 km in length and 12 km in width, with a population of near one million. Dhaka was developed during this period concentrating on the 'Bazars' or commercial areas, and it was so compact that walking was the primary mode of travel. The development of Dhaka was not organized. It grew organically, though the Mughals built forts and canals to deploy soldiers during an emergency; to some extent, the Mughal was not interested in building this city systemically. The provincial capital of Bengal shifted to Murshidabad from Dhaka in 1704, yet the commercial importance of Dhaka did not disappear. However, the glorious development of Dhaka had significantly disrupted due to losing its title as a 'capital'.

iii) The British Colonial Period: The British East India Company was formed in 1600 and established a factory beside the bank of the Hoogly river in 1650 during the Mughal era in West Bengal [10]. East India Company took the opportunity of the gradual fall of the Mughal empire and started their involvement in politics and took control over the Mughal. They established the capital of Bengal in Calcutta (present Kolkata) in 1757 [9]. Due to the change of administration, all focuses and concentration fell on Kolkata; as a result, the pace of development of Kolkata increased significantly. Dhaka started losing its importance as a commercial area and could not compete with Kolkata from the end of the 18th century to the middle of the 19th century. Islam [12] mentioned in his book that from 1800 to 1867, the population of Dhaka dropped from two hundred thousand to only sixty thousand [2]. However, the latter half of the 19th century can be considered the physical redevelopment of Dhaka. During this period, Dhaka had transformed into a modern city with metalled roads, open spaces, street lights, and piped water supply [2][8][11]. To revitalize the commercial activities in eastern

Bengal, a new railway line, 'Narayanganj-Dhaka-Mymenshing,' was constructed parallel to the Mughal roadways from Tongi through Tejgaon to Phulbari [2]. Although, the city was not developed in a planned manner. The development was encircled with the Mughal establishment; further expansion of the city happened organically until the beginning of the 20th century. In 1906 famous British Town Planner Sir Patrick Geddes was appointed to prepare a master plan for Dhaka [12]. During his week-long visit to Dhaka, he has roughly prescribed some guidelines for developing this area. In 1917 Geddes submitted the "Dacca Town Planning Report" based on his prior visit to this area. He suggested dividing Dhaka city into different zones, protecting the indigenous characteristics, and preserving the Ramna greenery [12]. In his report, he proposed some development outlines, residential houses, and colonial offices around the Ramna area. However, his plan was never formally implemented by the British empire.

iv) Pakistan Period: After the partition in 1947, the British empire divided the Indian subcontinent into India and Pakistan based on the two-nation theory given by Mohammad Ali Jinnah in 1934 based on the conflicting ideas and conceptions of Hinduism and Islam [10]. Pakistan formed with the Muslim majority in the northwest and northeast India. The administration of Pakistan formed in provincial state government, namely a) the West Pakistan (holds the central government in Lahore) and b) East Pakistan as a state government. Again Dhaka was entitled to the provincial capital of East Pakistan. During the Pakistan period, Dhaka experienced the first comprehensive master plan in 1959, the "Dacca Master Plan." Dhaka Improvement Trust (DIT), presently known as RAJUK (Rajdhani Unnayan Kartipakkha- the capital development authority), was established in 1956 to monitor and implement planning practices [2]. During the early '60s, major planning initiatives were undertaken to expand the city apart from the old town. The city expanded towards the north because of the high land. Dacca Master Plan, 1959 was prepared by a consortium of British firms Minoprio, Spensely & Macfarlane and identified two major problems for the development of the city. First, the shortage of land above flood level, and second the congestion in the old central area of Dhaka [13]. Consequently, the city expanded towards the north, where the land was high and suitable for development. The development process began with the development of the Dhanmondi area, which was originally used as a rice field for agricultural purposes and converted to a residential area to accommodate the growing population. The development of Mirpur Road made some unexpected growth on both sides of these high land areas up to Mohammadpur and Mirpur [2]. Later on, these areas were developed by the government for the migrated Muslim population. At that time, different parts of Dhaka was started developing near Dhanmondi, Mohammadpur and Mirpur, and the northern part of Dhaka. To control such rapid development, the government realized the importance of establishing DIT. In the following years, DIT had developed the Gulshan Model Town in 1961, Banani 1964 Uttara 1965, and Baridhara Town in 1972 [2].

v) Bangladesh Period: After the independence in 1971, Dhaka became the capital of Bangladesh once again. Since then, the city has ascended to prominence as the most vital and prominent hub for all national activities, including political, cultural trade, and business [9]. Dhaka has changed significantly, primarily of its rapid population growth. People migrated from different parts of Bangladesh for various reasons such as employment, education, or health [14]. Economic activities have widened since the independence of Bangladesh. The land use of this area has changed over time; according to the Dhaka Structure Plan 2015-2035, the non-agricultural sectors in Dhaka city increased 25% in 1972 to 50% in 2009. Agricultural land transformed into residential, commercial, and industrial areas. Such urbanization indirectly invited a large population group to migrate to Dhaka. To accommodate the enormous urban population, the city started developing in an unplanned way. The city has fully compacted in the old town and shifted towards the north. After the RMG industrial revolution in the early '80s facilitated the rural-urban migration single-handedly. Housing became one of the most crying needs for its inhabitants. The urban fringe areas started developing rapidly by encroaching agricultural land, water bodies, canals, and flood plain areas. The steady loss of the water bodies inside Dhaka city has created regular inundation and flooding. After the liberation, the first planning document, "The Dhaka Metropolitan Area Integrated Urban Development Project (DMAIUDP), directly related to the city's flood control. Planning Commission prepared it under the Ministry of Planning and funded by UNDP and ADB [13]. It was prepared between 1979-1981 to prepare long-term development strategies for future Dhaka, focusing on flood protection for the capital. During the last 50 years, many urban development plans have been undertaken by the government, like- Dhaka Metropolitan Development Plan (1995), Structure Plan (1995-2015), Urban Area Plan (1995-2015), Detail Area Plan (2010-2015), etc. Figure 1.1 depicts the gradual development of Dhaka city from the Pre-Mughal area to the Present-day; this map was reproduced based on Islam (2005) [16].

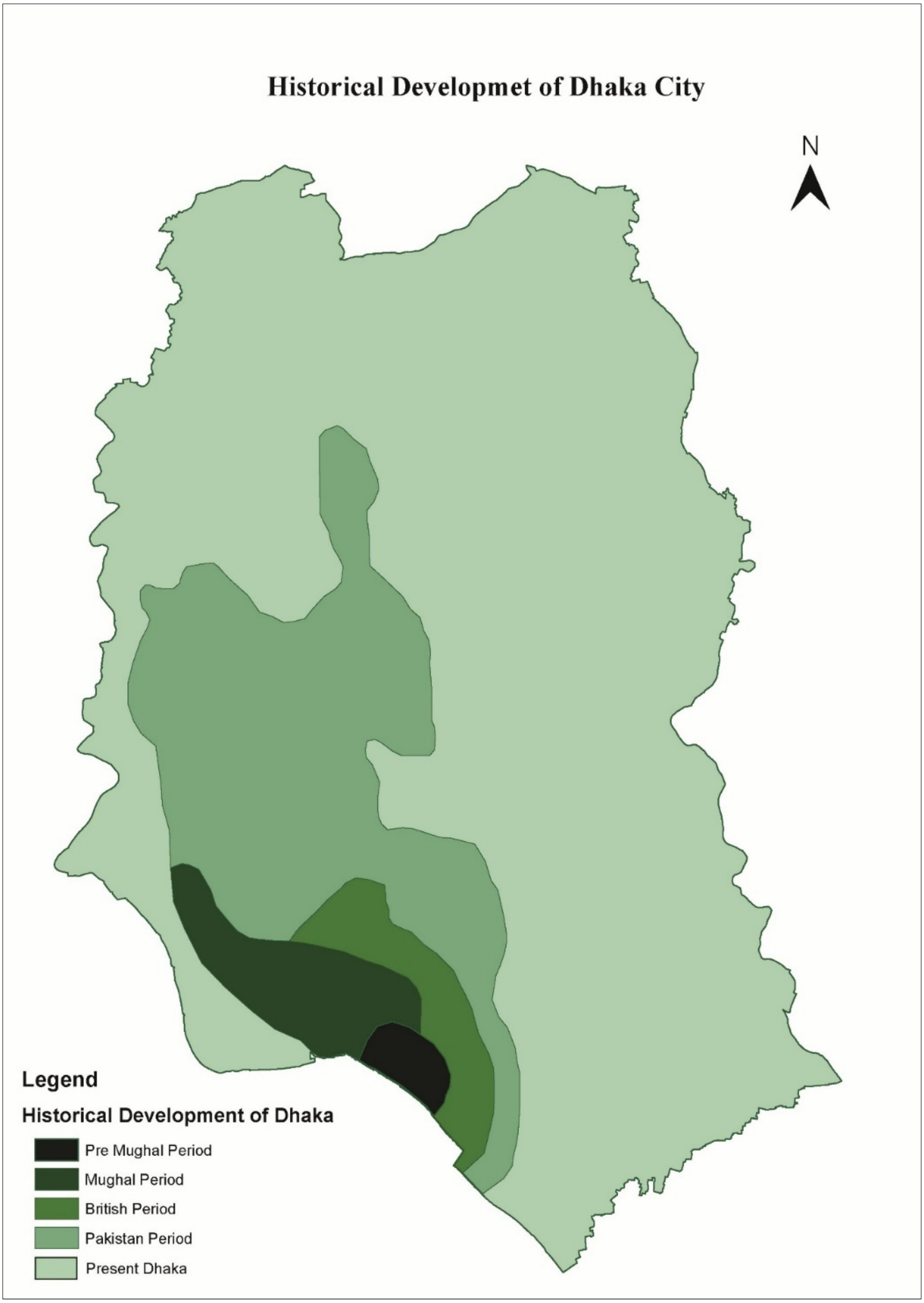

Figure 1.1: Historical Development of Dhaka City from Pre-Mughal Period to Present Day
[Source: After Islam 2005]

1.3 Development Characteristics and Growth Pattern of Dhaka

Throughout Dhaka's history, it has been apparent that the city was built for commercial purposes. The Mughals were the first who truly realized the importance and potentiality of the economic benefits of this area. As mentioned in the earlier section, one of the primary reasons was its accessibility, especially the water connectivity of Dhaka. Sadarghat was the focal point for business and other commercial activities. Since Dhaka was entitled to capital during the Mughal and Pakistan periods, administrative and political activities were also a driving force for its development.

People used to stay close to their workplace in general. As a consequence, human settlements started growing surrounding the main business areas in Dhaka. Gulisthan, Bakshi Bazar, Azimpur, Hazaribagh, Karwan Bazar, Tejgaon, Motijheel became the main attraction areas for investors. At the same time, human settlements started developing in those areas and became congested over time. The city expanded towards the north, and new business centres near the New Market area, Karwan Bazar, Mag Bazaar, Mouchak, Farmgate, Rampura, Gulshan, and Uttara started to develop.

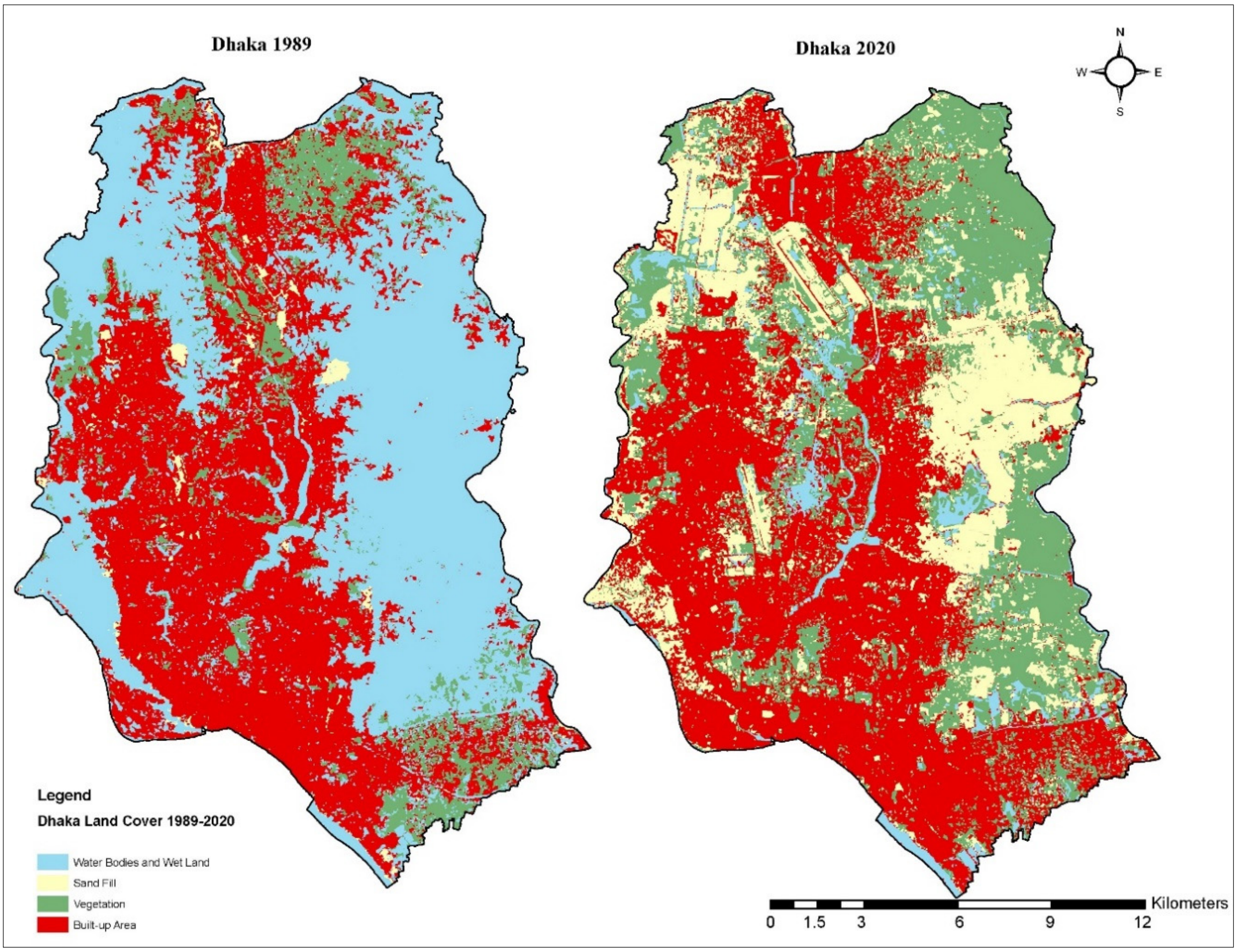

Figure 1.2: Land Cover Change of Dhaka from 1989 to 2020.
(Developed by Author)

Understanding the development pattern of Dhaka city NDBI (Normalized Difference Built-up Index) is applied on Landsat 7 imagery. Figure 1.2 shows the development of Dhaka during two different periods- 1989 and 2020. It shows that a significant area of water bodies and wetlands have transformed into built-up areas and vegetation. However, these green shaded areas in figure 1.2 are not vegetation. These are bare lands covered with grass. Waterbodies and wetlands are also turned into sand fill areas, especially in the north-western and eastern parts of Dhaka. Supervised classification was applied to the imagery, converted to polygon, and intersected the feature polygons to calculate the landuse change. Figure 1.3 shows the landuse changes over the past 30 years.

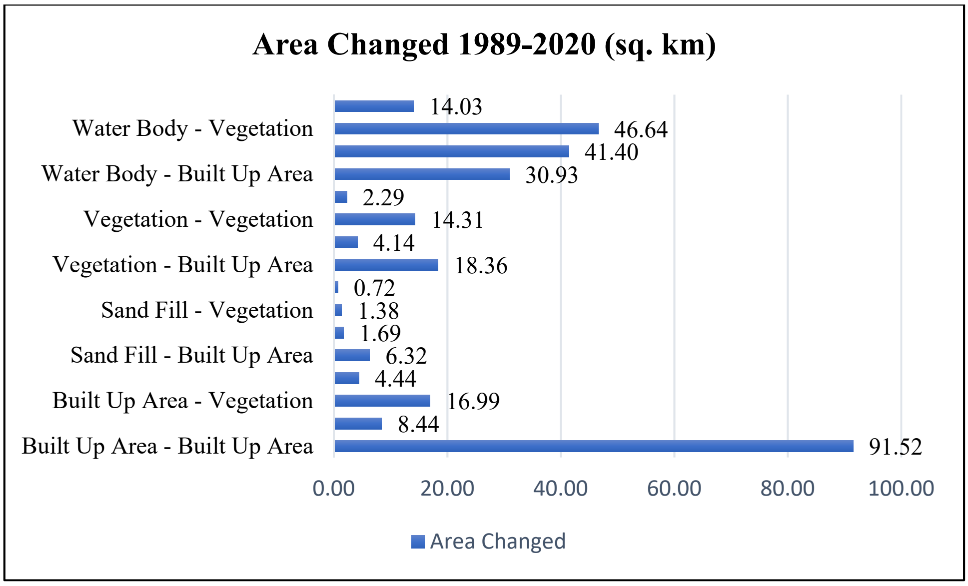

Figure 1.3: Landuse change of Dhaka from 1989-2020.

This chart shows that almost 31 sq. km of waterbody changed into built-up areas, 41 sq. km area has been sand-filled, and 46 sq. km of land changed into developable land over the last 30 years. Moreover, other land cover classes are also changed, like 18.35 sq. km of vegetation turned into built-up areas up to 2020.

The raster analysis and the detailed area plan of RAJUK indicate that such rapid development occurred around the central business district (CBD) areas. This study looks at some old and newly developed commercially significant regions to evaluate Dhaka's growth trend. Figure 1.4 shows that settlements were established around the CBD areas. Fifteen CBD areas are located on the map and created 2500 m buffer from the centre, and it clearly shows that most of the development happened within the 2500 m buffer. Sadarghat, Motijheel, New Market, Dhanmondi, Mohammadpur, Karwanbazar, Tejgaon were developed during the Pakistan period, where Dhanmondi and Mohammadpur were developed only for residential use.

Banani, Gulshan, Baridhara, and Uttara were developed as model residential towns during the Bangladesh period. Over time residential areas turned into a commercial hub and created other commercial regions like Bashundhara, Rampura, Mohakhali, etc.

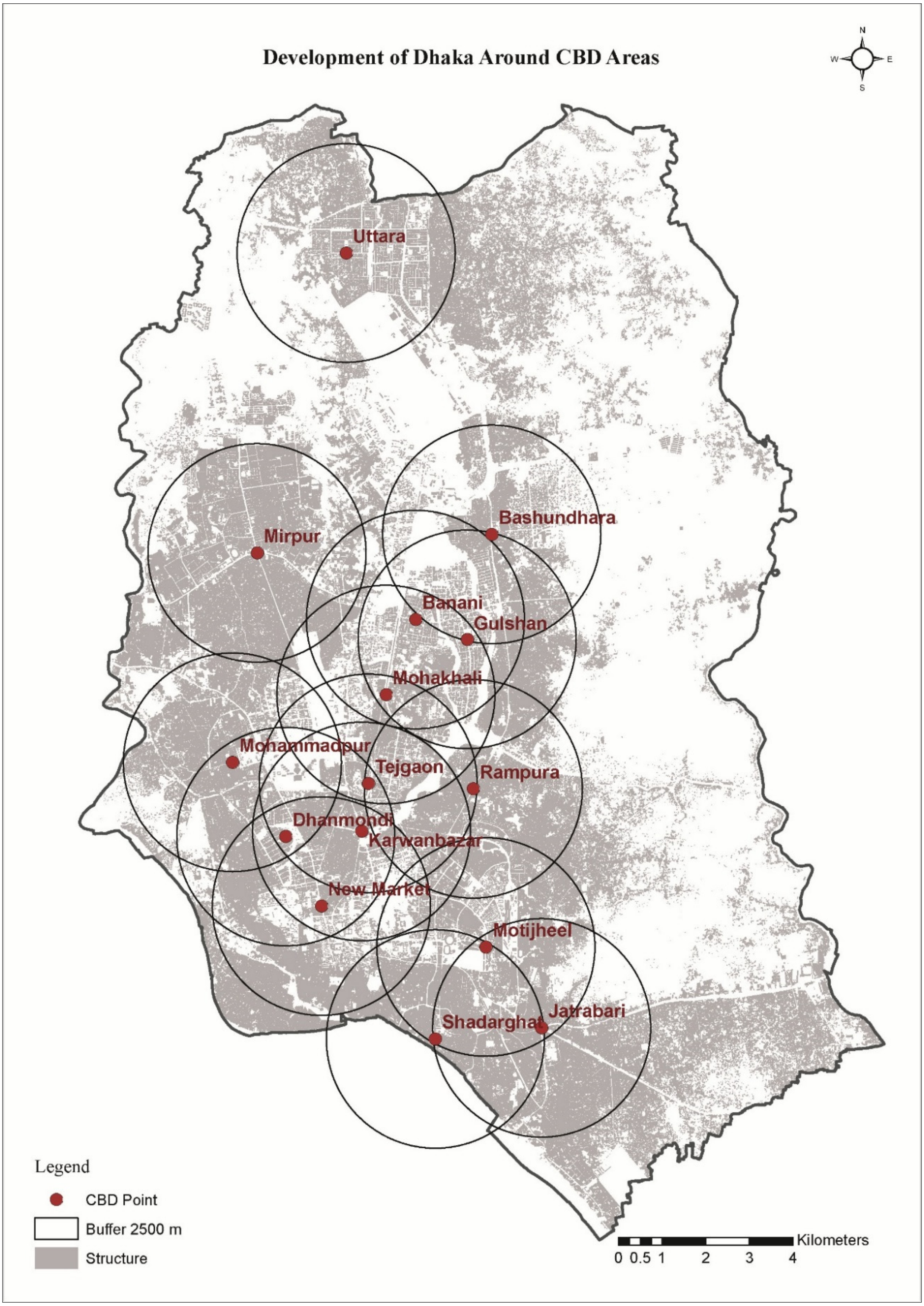

Figure 1.4: Development of Dhaka around CBD Areas

(Source: Developed by Author)

Figure 1.5: Trends of Future Development of Dhaka

(Source: Developed by Author)

However, the growth pattern of Dhaka city is pushing the development towards the eastern part of Dhaka. The road network pattern of DAP shows that (Figure 1.5), the development is approaching to the eastern horizon. On the other hand, RAJUK is also developing the 3rd phase of Uttara Model Town in the north-western part. Bashundhara, Aftabnagar, and United City are private residential areas. They are playing a significant role in land development. Other private land development companies are also participating on a small scale compared to Bashundhara Ltd. and Eastern Housing Ltd. The Green Model Town and Amulia Model Town are also developing simultaneously in Demra by different land development companies under Dhaka South City Corporation (DSCC). Apart from the planned model town, Uttar Khan and Dakkhin Khan in Dhaka North City Corporation (DNCC) are spontaneously developing without proper planning initiatives.

The future development of Dhaka is expected to follow in the eastern part. Purbachal Residential Project and Jhilmil Project (RAJUK) could be act as a development catalyst in the future to promote housing in that direction. Proper guidance and planning regulation must be enforced to control the development. However, water bodies, wetlands, and floodplain land are transforming into built-up areas. Such a transformation of land could lead to inundation problems during the monsoon. On the other hand, these areas are likely to be amplified during earthquakes, and construction costs might be higher than expected to withstand the seismic hazard. A detailed study of soil amplification is described in Chapter 2.

1.4 Population and Density of Dhaka

According to the World urbanization prospects, Dhaka is ranked as the 9th most populous city in the world in 2021. [17]. The national population census 2011 showed that the metropolitan area has over 8.9 million people within 396.64 sq. km [18]. However, the old city corporation area had a population near 1.6 million within 197.05 sq. km. in 2011.

The old city corporation was divided into two different entities- Dhaka North and Dhaka South City corporation under the Local Government (City Corporation) Amendment Bill 2011 [19]. Both the city corporation expanded their jurisdiction, and the city expanded from 197.05 sq. km to 303 sq. km according to the DAP. Figure 1.6 represents the area of Dhaka North and South city corporation with the extended unions. However, newly added unions are further divided into wards under both the city corporation. DNCC and DSCC both have 10 zones each and 54 and 75 wards in their administrative areas, respectively. The following table 1.1 represents both the city corporation at a glance.

Table 1.1: DNCC and DSCC at a Glance

Name	DNCC	DSCC
Zone	10	10
Ward	54	75
Area	196.22 sq. km	109.25 sq. km

(Source: DNCC and DSCC Website)

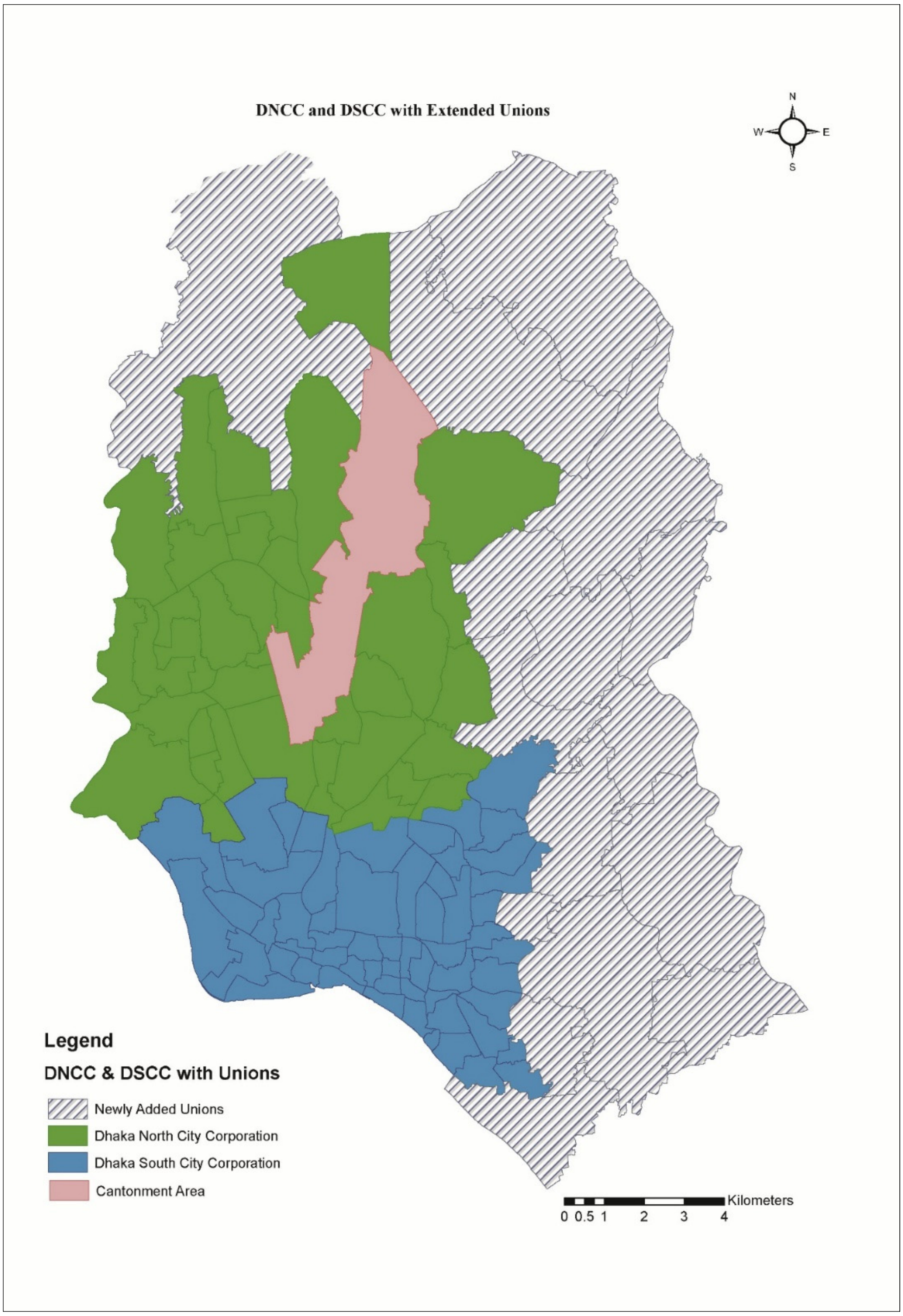

Figure 1.6: Dhaka North and South City Corporation with Extended Areas
(Source: Developed by Author after DAP)

The population of Dhaka is proliferating. In 2001 the population of this city was 5.3 million. However, in the next ten years, the size of the population has increased almost double 8.9 million. Although, it is assumed that the population is substantially more than that reported by the BBS. World urbanization prospects have claimed Dhaka's population was over 19 million in 2018, and the projected population will be 28 million by 2030 [17].

Nevertheless, the developable land is not increasing to accommodate the vast population, and the city is now growing vertically [2]. Since there is a severe land crisis in Dhaka and due to its vertical growth, the density of this city is very high. This study used the DAP database to calculate the population and density by using the dwelling unit and average household size (4.35) from BBS 2011. The following table 1.2 shows that the total population by Household is over 13 million, and the density is 42995.24 per sq. km. The maximum population in a ward/union is 791643 in Dania Union, and the area of this union is 3.33 sq. km. On the contrary minimum population is 3023 in DSCC ward 20.

Table 1.2: Population and Density of Dhaka (DAP)

Total Area	303.98 sq. km
Total Population	13069876
Maximum Population in a Ward/Union	791643
Minimum Population in a Ward/ Union	3023
Density	42995.24 sq.km

(Source: DAP)

Figure 1.7 shows the density map of both the city corporation areas with extended wards. Every ward has been assigned a unique ID for illustration, and the details tabulation is given in Annexure 1. Old town areas are the most densely populated areas in Dhaka city. It is also found that the planned urban areas like Gulshan, Dhanmondi, Banani, Baridhara are comparatively less dense except Uttara Model town. This study has found that the DSCC Ward-52 is the most densely urban area in Dhaka. The area of this ward is 0.3067 sq. km. and the density is 518781 sq. km. On the other hand, the least dense area is the Dumni union having an area of 13.31 sq. km, and the density is 2075 sq. km. However, these results are the outcomes from the DAP database where the unions are not updated into wards. On that note, the density map may vary from figure 1.7.

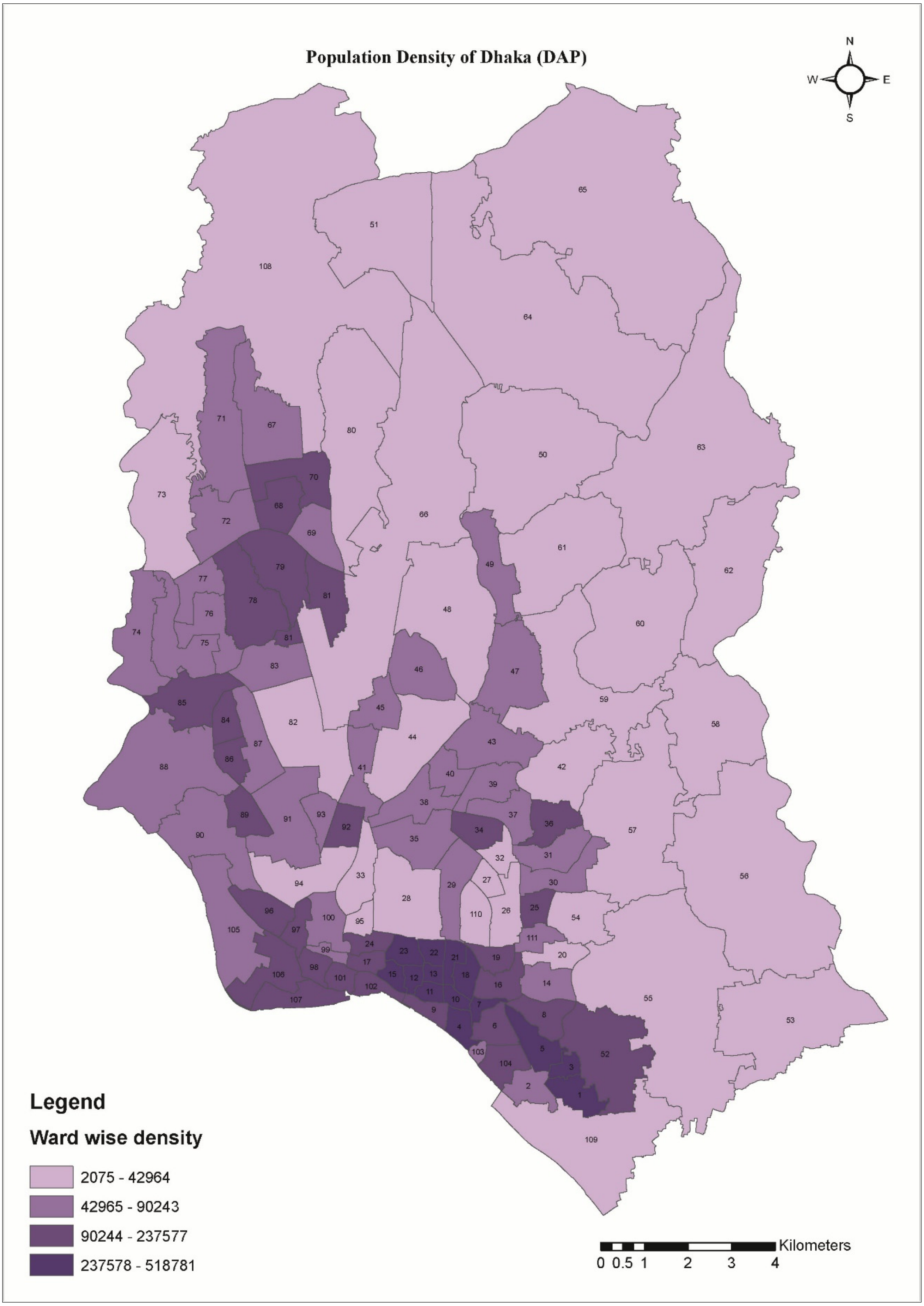

Figure 1.7: Population Density of Dhaka Ward Wise

(Source: Developed by Author after DAP)

1.5 Towards Urban Resilience

Ensuring urban resilience is a big challenge for any country, especially for the least developed countries like Bangladesh. It is almost impossible to carry out research activities without any strategy or definite methodology. In this study, defining the strategies were a big challenge for the researchers. The working scope of disaster management is enormous, and all the aspects were not covered in this study for time limitations and unavailable resources.

This study followed a hierarchy from the macro/city level to the micro/ward level. The organization of this guidebook is divided into six (6) different parts as follows:

Part A: Introduction

In this part in *Chapter 1*, the background of the study area is described. It contains the development of Dhaka city from different eras, its growth and development pattern, landuse changes, population and density.

Part B: Area Assessment at City Level

Part B has two chapters, *Chapter 2: Geology, Geomorphology, Engineering Geology, and Geotechnical Aspects Of Dhaka City, where soil type, seismicity, and soil classification and amplification of Dhaka city are* briefly described.

Chapter 3: Comprehensive Vulnerability Assessment, where the whole Dhaka city was under consideration for seismic vulnerability. The city was assessed based on the building vulnerability and risk classification by emergency response difficulties.

Part C: Area Risk Assessment at Ward Level

A detailed assessment methodology was used for micro/ward level assessment. This part is divided into two chapters 4and 5. *Chapter 4: Building Assessment*; in this chapter, the visual rating method was applied in sample buildings and categorized into different risk classifications. *Chapter 5: Emergency Response and Rescue* contain the road network vulnerability at the ward level and assess emergency evacuation preparedness for seismic hazard.

Part D: Prioritization of Building Retrofit (Individual Building Level)

In chapter 6, buildings were categorized using Analytical Hierarchy Process, commonly known as the AHP method, to prioritize the buildings to be retrofitted first according to the expert opinions.

Part E: Public Awareness

Chapter 7: The Improvement in Citizen Awareness of Low-Frequency Hazards After A Disaster Risk Reduction Town Walk – A Case Study In The Tejturi Bazar Area of Dhaka City, in this chapter, the public awareness level were assessed under the town watching programme and described the awareness level before and after consultation.

Part F: Conclusion and Recommendation

Chapter 8 contains the existing legal framework of Bangladesh to deal with disasters. Different acts, rules, regulations, policies and plans were briefly described and identified the gap to achieve urban resilience. Some recommendations were suggested to make cities more resilient against the seismic hazard. Figure 1.8 shows the workflow and organization of this guidebook

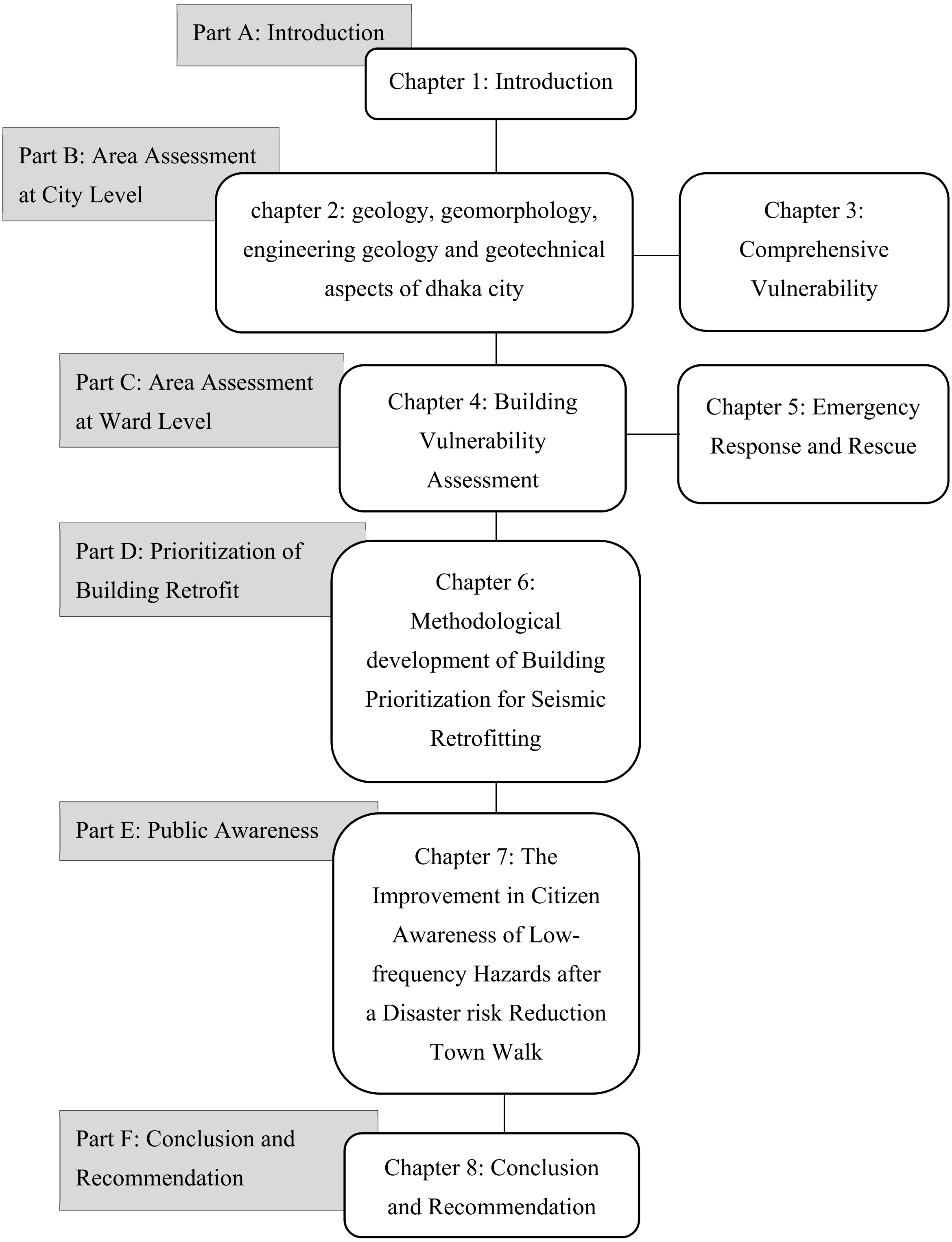

Figure 1.8: Organization of the Guidebook

1.6 Conclusion

Dhaka is one of the most important cities in Bangladesh. It has a long historical background and has been playing a significant role since the Mughal era. Dhaka was developed based on its commercial activities and its accessibility, especially for its water routes. The development pace has accelerated after the independence of Bangladesh in 1971. It was started growing towards the north and eventually occupied the north, west and southern part of Dhaka. Now the development trends clearly show that the city is pushing towards the east. The peripheral areas of Dhaka once were water bodies, wetlands and flood plains land. Due to rapid growth and urbanization, the khals, canals, and water bodies were changed into urban areas. Land crisis and ever-growing population forced Dhaka to go vertically. High rise buildings are built in an unplanned way, and on top of that majority of these structures are non-engineered. Such non-engineered building stocks are acting as a potential threat for earthquakes and are very much prone to collapse due to soil amplification and liquefaction. The density of Dhaka is very high compared to other cities in Bangladesh, and it is assumed that any collapse of the building can cause high casualties in the capital city.

Moreover, other aspects are directly interlinked to such incidents as the health facility, road network vulnerability, emergency response, and rescue might create colossal damage to this country's life and economy. Proper planning and regulations must be ensured and enforced by introducing new rules and regulations. The central government and local governments are the key institutes to take necessary actions to reduce the risk and damage by incorporating risk-sensitive urban planning. Identifying vulnerable buildings is one of the major tasks that should be done as early as possible. Road network vulnerability must be assessed and increasing the earthquake knowledge among the inhabitants by raising public awareness. Retrofit techniques developed under this project should be disseminated among the practitioners and building owners to reduce the vulnerability. However, it is understandable that the work volume is exceptionally high; despite all this, it is time to start the initiatives to eradicate or reduce the threat at the minimum level.

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Annexure 1

ID	Ward	Population	Area	Density
1	DSCC_Ward-53	387911	0.763405	508133
2	DSCC_Ward-54	40646	0.745125	54549
3	DSCC_Ward-52	159175	0.306825	518781
4	DSCC_Ward-43	156500	0.457133	342351
5	DSCC_Ward-51	285586	0.892535	319972
6	DSCC_Ward-45	91045	0.693205	131339
7	DSCC_Ward-44	91976	0.239022	384801
8	DSCC_Ward-50	108689	0.858941	126538
9	DSCC_Ward-37	69112	0.401801	172006
10	DSCC_Ward-42	110246	0.236496	466164
11	DSCC_Ward-36	110942	0.264571	419328
12	DSCC_Ward-32	102868	0.242391	424389
13	DSCC_Ward-35	82615	0.185396	445614
14	DSCC_Ward-48	74998	0.896707	83637
15	DSCC_Ward-31	107392	0.305181	351896
16	DSCC_Ward-40	91672	0.753375	121682
17	DSCC_Ward-28	48285	0.367205	131493
18	DSCC_Ward-41	169406	0.465561	363875
19	DSCC_Ward-39	49524	0.507341	97615
20	DSCC_Ward-49	15334	0.653728	23456
21	DSCC_Ward-38	134189	0.369464	363199
22	DSCC_Ward-34	119712	0.312448	383142
23	DSCC_Ward-33	239842	0.463627	517317
24	DSCC_Ward-27	72072	0.434256	165967
25	DSCC_Ward-06	56906	0.517588	109945
26	DSCC_Ward-08	31985	1.06141	30134
27	DSCC_Ward-10	8382	0.40404	20745
28	DSCC_Ward-20	33095	2.67274	12382
29	DSCC_Ward-13	76468	1.32571	57681
30	DSCC_Ward-05	76799	1.1142	68927
31	DSCC_Ward-04	96009	1.0639	90243
32	DSCC_Ward-11	19988	0.488525	40915
33	DSCC_Ward-21	18448	1.13177	16300
34	DSCC_Ward-12	86199	0.761847	113145
35	DSCC_Ward-19	89653	1.67332	53578
36	DSCC_Ward-02	88092	0.937611	93954
37	DSCC_Ward-01	56693	0.98888	57331
38	DNCC_Ward-35	87504	1.22897	71201
39	DNCC_Ward-23	72706	0.993529	73180
40	DNCC_Ward-36	57046	0.749416	76121
41	DNCC_Ward-26	52691	1.17119	44989
42	DNCC_Ward-03	111168	2.60886	42612

43	DNCC_Ward-22	140100	1.9458	72001
44	DNCC_Ward-24	48946	3.10538	15762
45	DNCC_Ward-25	66150	0.947308	69829
46	DNCC_Ward-20	89953	1.78464	50404
47	DNCC_Ward-21	165500	2.46357	67179
48	DNCC_Ward-19	151902	5.43759	27936
49	DNCC_Ward-18	74128	1.66597	44495
50	DNCC_Ward-17	274272	8.4537	32444
51	DNCC_Ward-01	246336	5.73355	42964
52	Dhania Union	791643	3.33215	237577
53	Saralia Union	151806	6.18222	24555
54	Manda Union	58573	1.49036	39301
55	Matuail Union	263797	12.2202	21587
56	Demra Union	96348	12.2855	7842
57	Dakshingaon Union	124923	7.12342	17537
58	Nasirabad Union	27735	5.45081	5088
59	Badda Union	105709	5.62437	18795
60	Satarkul Union	23725	6.56003	3617
61	Bhatara Union	156922	5.19781	30190
62	Beraid Union	39293	5.76061	6821
63	Dumni Union	27622	13.3122	2075
64	Dakshinkhan Union	415264	16.7569	24782
65	Uttar Khan Union	190386	20.316	9371
66	Cantonment Union	77591	15.4606	5019
67	DNCC_Ward-02	204537	2.64581	77306
68	DNCC_Ward-03	132723	1.03963	127664
69	DNCC_Ward-04	71001	1.11693	63568
70	DNCC_Ward-05	210518	1.48683	141588
71	DNCC_Ward-06	193549	3.40284	56879
72	DNCC_Ward-07	154608	1.83776	84129
73	DNCC_Ward-08	134576	4.35348	30912
74	DNCC_Ward-09	101285	2.22263	45570
75	DNCC_Ward-10	96370	1.87205	51478
76	DNCC_Ward-11	111116	1.34321	82724
77	DNCC_Ward-12	81262	0.901105	90180
78	DNCC_Ward-13	255027	2.41444	105626
79	DNCC_Ward-14	196485	1.9698	99749
80	DNCC_Ward-15	241303	6.45529	37381
81	DNCC_Ward-16	160419	1.43219	112010
82	DNCC_Ward-27	115523	3.44985	33486
83	DNCC_Ward-28	117237	1.48811	78782
84	DNCC_Ward-29	57990	0.618134	93815
85	DNCC_Ward-30	178089	1.69131	105296
86	DNCC_Ward-31	57259	0.57021	100417

87	DNCC_Ward-32	74933	1.3976	53615
88	DNCC_Ward-33	262335	5.09383	51501
89	DNCC_Ward-34	80753	0.803269	100530
90	DSCC_Ward-14	151523	2.63583	57486
91	DSCC_Ward-15	124471	2.64673	47028
92	DSCC_Ward-16	82276	0.690577	119141
93	DSCC_Ward-17	41973	0.599905	69966
94	DSCC_Ward-18	60104	1.90279	31587
95	DSCC_Ward-20	3023	0.392541	7701
96	DSCC_Ward-22	89362	0.90535	98704
97	DSCC_Ward-23	63988	0.508598	125813
98	DSCC_Ward-24	52674	0.436084	120789
99	DSCC_Ward-25	16987	0.214733	79108
100	DSCC_Ward-26	51717	0.98441	52536
101	DSCC_Ward-29	43021	0.383221	112262
102	DSCC_Ward-30	41290	0.430438	95926
103	DSCC_Ward-46	6725	0.145467	46230
104	DSCC_Ward-47	83194	0.76522	108719
105	DSCC_Ward-55	176092	2.63921	66721
106	DSCC_Ward-56	166448	1.40448	118512
107	DSCC_Ward-57	105653	0.984729	107291
108	Harirampur Union	347169	27.4921	12628
109	Shyampur Union	153229	5.51108	27804
110	DSCC_Ward-09	29123	0.884568	32923
111	DSCC_Ward-07	42743	0.499962	85492

Chapter 2 Geology, Geomorphology, Engineering Geology and Geotechnical Aspects of Dhaka City

2.1 Introduction

The following sections of this chapter are prepared from an urban planning perspective and can be used only for urban planners and decision-makers. General academic and scientific discussions are derived from existing literature, CDMP, and relevant information from the Geological Survey of Bangladesh. Maps and figures are used only for illustration purposes to make technical sections more user-friendly for the reader. This chapter is divided into four sections- *Geology and Geomorphology of Dhaka city*, *Engineering Geology of Dhaka city*, *Soil Amplification Study of Dhaka city*, and *Soil Liquefaction Study of Dhaka city*. Because of this project's limited scope and resources, most of the data are collected from secondary sources, technical reports, books, and academic journals. Only the soil amplification study is conducted by the researchers of this project based on the borehole data collected from GSB. It is strongly suggested not to take any structural decision based on this report. Detailed sub-soil investigation is required for constructing any civil engineering structures.

2.2 Geology and Geomorphology of Dhaka City

The Geological evaluation of Bangladesh has been associated with the uplift of the Himalayan and the outbuilding of large deltaic landmass by major river systems originating from the uplifted Himalayas [1]. Thus, Bangladesh is considered the largest delta in the world. The deposition through sedimentation via the major river system is not evenly distributed. The oldest deposit is the Plio-Pleistocene Barend clay, Madhupur clay, and Lamaic region clay. Hence, Bangladesh can be divided into three major physiographic units, namely, (i) the tertiary hill formations, (ii) the Pleistocene terrace, and (iii) the recent flood plains [2].

Dhaka is situated on the southern tip of a Pleistocene Terrace, called the Madhupur Tract. Two characteristics units cover the city and its surrounding areas, namely Madhupur clay of Pleistocene age and alluvial deposits of Recent age. The Madhupur tract has a maximum rise of 14m and is partially on the Holocene floodplains with a minimum elevation of 2m [3][4].

The Madhupur clay is the oldest sediment of the Pleistocene age and alluvial deposits of recent age. A significant portion of this city is composed of upper and lower Madhupur Terraces, the high land of Dhaka. On the other hand, low land, floodplains, depression, and abandoned channels are the low-lying areas in and around the city (Figure 2.1) [23].

The subsoil sedimentary formation up to the depth of 300m shows three distinct types of earth matters: the first one is the Madhupur clay of the Pleistocene age. It is characterized by reddish plastic clay with very fine sand particles. The second one is the Madhupur clay that overlies the DupiTila formation of the Plio-Pleistocene age and is composed of medium to coarse yellowish-brown sand and infrequent gravel. Furthermore, the third one is that the incised channels and depression within the city are developed by recent alluvial floodplain deposits and are additional subdivided into- lowland alluvium and highland alluvium. Madhupur clay is characterized as stiff to very stiff soil covering the city's central part from north to south. On the other hand, Holocene Alluvium is characterized from very soft to medium stiff silty clay, clayey silt, and very loose to loose soil covering the eastern, south-eastern, southwestern, and north-western parts of the city [3][4].

The geomorphological map of Dhaka (Fig 2.1) has categorized the Madhupur Terrace into three different parts i) upper Madhupur terrace, ii) Madhupur slope, and iii) lower Madhupur terrace. A significant portion of this city is developed on the upper Madhupur terrace (middle part of Dhaka). Lower Madhupur terrace is also found in the upper north-eastern side of Dhaka. The rest of the area is covered with flood plains in the south-eastern part, and swamps and back swamps in the east and western part of Dhaka can be identified [23].

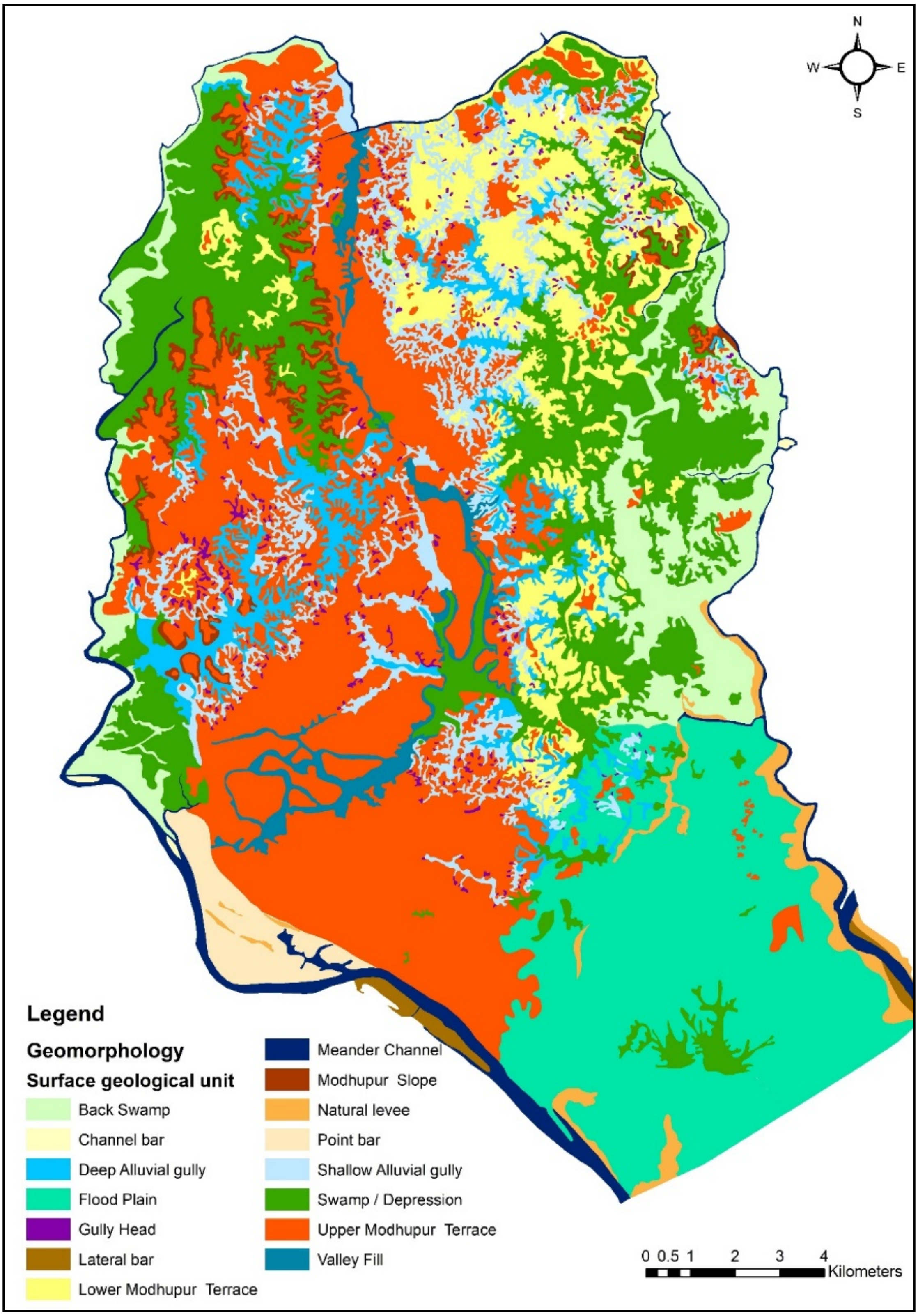


Figure 2.1: Geomorphological Map with the surface geological unit of Dhaka City [23].
(Source: CDMP 2009)

2.3 Engineering Geology of Dhaka City

Engineering geological map of Dhaka city was collected from Geological Survey of Bangladesh. The general engineering geological base map (Fig: 2.2) was prepared using 814 nos. of subsurface geotechnical investigation boreholes. This map was developed to aid in urban planning and the decision-making process. From the database of GSB, it was found that five geological units comprise more than 72% land of Dhaka cities such as Madhupur Terrace (High), High Floodplain, Low Floodplain, Madhupur Terrace (Middle), and Madhupur Terrace (Low). Table 2.1 shows the area of these geological units in sq. km and their percentage from higher to a lower value. In the following sections, the characteristics of the geological units are briefly described according to the GSB report [5].

i) High floodplain deposits: This unit is generally flat, situated above the annual flood level (> 4.0 m AMSL). The lop layers are mainly alternating silty clay and clayey silt with occasional thin sand layer, light grey to light yellowish-brown colour. Worm burrows, root tubas, and vegetal matters are also typical. The sand, silt, and clay percentage range between 7-10, 70-78, and 15-20, respectively. It is naturally medium compacted and low-plastic with moderate PGA (Peak Ground Acceleration) potential.

ii) Low floodplain deposits: This unit is extended flat, annually flooded, poorly drained land. It consists of alternating silt, clay, fine sand, peaty clay, and occasionally layers of peat. Alternating blackish-grey organic clay and blackish-brawn silty clay are generally present in downslope areas near marshy land. The thickness of peat layers ranges from a few to 30 centimetres. Occasional thick layers of light grey to yellowish-brown silty clay with mottling and ferruginous concretions are present in greater depth. Partially decomposed roots and warm burrows are expected at the upper part. This unit is generally loose and soft with high PGA potential.

iii) Marsh silty and peaty clay: This unit is the deepest part of the area, situated between 1.3-2.0 meters AMSL. Most of the site remains underwater except during the winter season. The deposit consists mainly of grey to light-grey organic clay, dark grey peaty clay, and dark-brown peat. At places, the organic clay and peat are intercalated by sandy silt. Vertically erected and fallen-down wooden logs are present at places. Sporadical patches of reddish to yellowish-brown silty clay with orange-red mottling are present. The sediments are highly plastic end sticky with high moisture content. It behaves like a liquid and collapses with a small load. This unit is highly susceptible to liquefaction with vary high PGA potential.

iv) Abandoned channel deposits: This unit consists mainly of silty clay and clayey silt, dark grey to brownish-grey in colour with occasional yellowish-brown mottling. Organic clay and peat layers, lances of partly decomposed broken shells, and very fine sand interbedded with clay are also common at places. The sub-surface layers are very soft. Very high PGA end very high flood and other natural hazard potential.

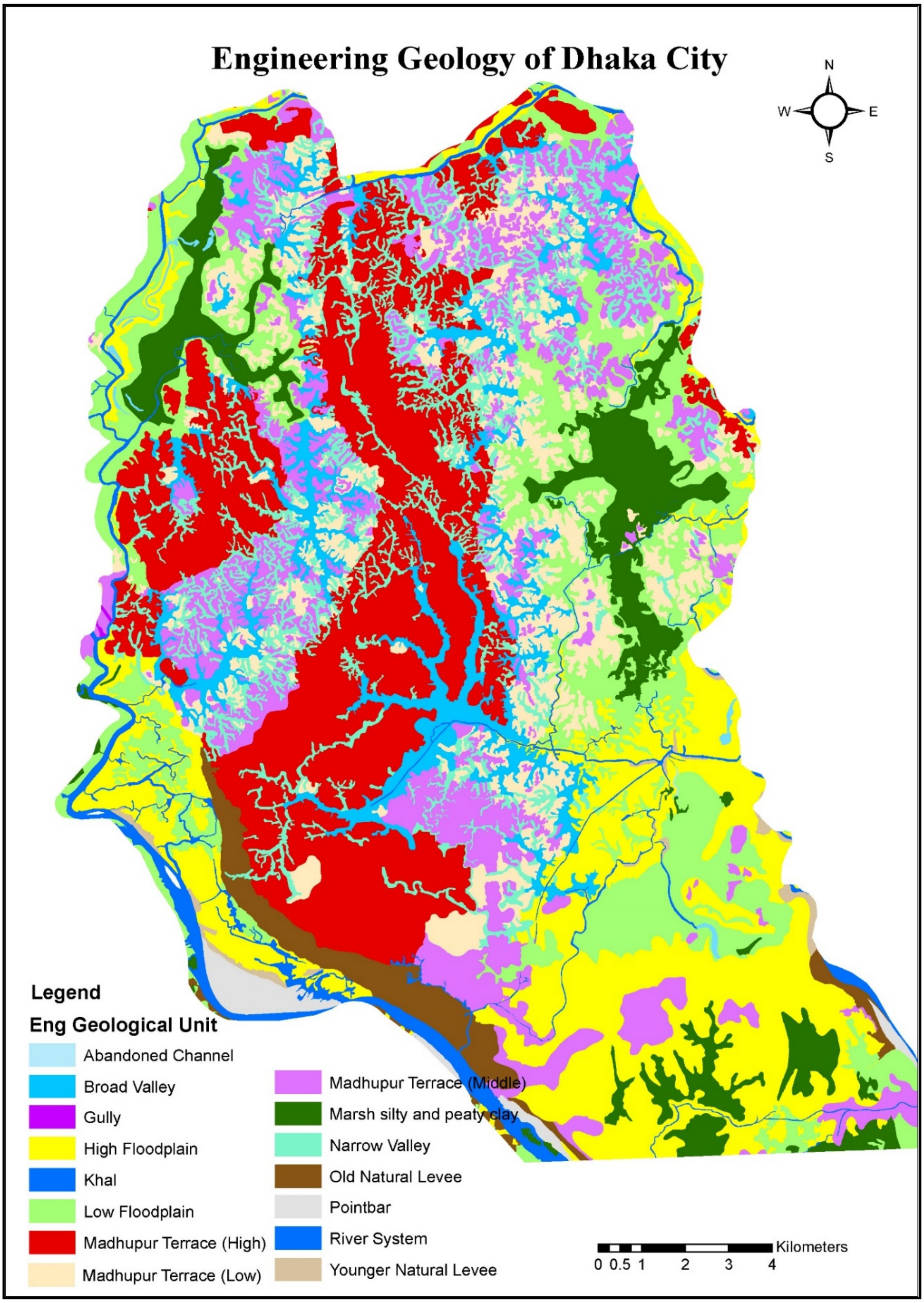


Figure 2.2: Engineering Map of Dhaka City.
(Source: GSB, 2011)

v) Old natural levee deposits: Natural levees formed by the channels mainly of Buriganga River depositing dominantly of fine to coarse-grained grey to brownish-grey sand and clayey silt on top of Madhupur Clay terrace. This unit is moderately compacted and low plastic. This unit has a higher elevation than its surroundings.

vi) Younger natural levee deposits: The active minor channels form natural levees consisting dominantly of alternating layers of grey-coloured fine sand and clayey silt of various thicknesses deposited over the flood plain sediments. Generally, it is low plastic and loses to moderately compacted with moderate PGA potential. This unit has a higher elevation than its surroundings.

vii) Point bar deposits: These deposits consist mainly of loose and fresh medium lo line grained grey-coloured sand and silty sand. A few thin laminations of silty clay are expected at various depths. The general elevation of this unit is lower than the surroundings. The loose subsurface layers with high to moderate PGA and other natural hazard potential.

viii) Broad valley deposits: The sediment consists mainly of light-grey to dark-grey sticky clayey silt. Thin layers of yellowish-grey to yellowish-brown clayey silt washed out from Madhupur Clay units, and blackish-grey organic clay is present at various depths. Thin layers of grey loose fine sand are also common. The sediments are plastic and medium compacted. Generally, it overlies the eroded Madhupur Clay surface with variable thickness. This unit has highly variable sub-surface strata as well as high to moderate PGA potential and hazard susceptibility.

Table 2.1: Engineering Geological Unit Distribution of Dhaka City [5].

Geological Unit	**Area (sq. km)**	**Percentage**
Madhupur Terrace (High)	64.588	19.91
High Floodplain	51.866	15.99
Low Floodplain	50.050	15.43
Madhupur Terrace (Middle)	39.880	12.29
Madhupur Terrace (Low)	28.662	8.83
Narrow Valley	23.131	7.13
Broad Valley	21.511	6.63
Marshland and Depression	21.280	6.56
River System	9.673	2.98
Old Natural Levee	8.211	2.53
Pointbar	3.191	0.98
Younger Natural Levee	1.351	0.42
Oxbow lake	0.552	0.17
Khal	0.309	0.10
Channelbar	0.089	0.03
Gully	0.050	0.02
Abandoned Channel	0.026	0.01

(Source: GSB, 2011)

ix) Narrow valley deposits: The sediments mainly consist of light grey to dark-grey sticky clayey silt. It deposits primarily in the eroded gullies nearby narrow valleys formed by several dendritic drainage channels of Madhupur Clay terrace. A few thin layers of yellowish-brown, fine sand and blackish-grey organic clay are also common. Generally, the sediments are low plastic and medium compacted, deposited on top of the eroded Madhupur Clay surface. The PGA potential is high to moderate, and other natural hazard potential is low.

x) Madhupur Clay (Upper terrace): This is the highest elevated, flattened and low dissected part of Madhupur Clay terrace. This unit is characterized by over consolidated brick red to reddish-brown highly oxidized clayey silt with orange-red mottling and metallic-black to brown ferruginous nodules. A small amount of medium to fine-grained sand with mica is also present. Secondary light bluish-grey plastic silty clay is deposited along with fractures and animal burrows. Accumulated iron oxides formed the nodules having a nucleus. The redden or colour increase with depth. The clays are mainly Kaolinite. The sediments are highly compacted, plastic, and sticky. It is resistant to erosion with low infiltration potential and very hard when dry. This top layer is mainly weathered residuum part altered during the Pleistocene period, underlaid by compacted yellowish brown fine sandy silt with occasional discontinuous layers of cohesive sand and clean sand. At places, this underlaid fine sandy silt layer is not present. The over consolidated yellowish-brown medium underlays these layers to coarse-grained sand of the Dupi Tila Formation of Pio-Pleistocene age, the best available foundation layer in this city. It is recommended that the foundation of all heavy and high-rise civil infrastructures is preferably placed on this layer. Madhupur Clay unit is also a perfect foundation layer for moderately high civil infrastructures with low PGA. Still, it requires a deep foundation for tall structures based on the detailed subsurface geotechnical investigation.

xi) Madhupur Clay (Middle terrace): This unit is the rugged, highly dissected, and eroded part of the Madhupur Clay terrace, which has a lower elevation than the upper terrace. The litho-characteristic of this unit is almost the same as Madhupur Clay (upper terrace), but the colour varies from yellowish-brown to reddish-brown. The redden of colour increase with depth, but it is lighter than the upper terrace. It is equally resistant to erosion with low infiltration potential and is very hard when dry. This unit is the typical weathering zone of fluctuating water table. In this unit, the top residuum part is underlaid by a fine sandy silt layer with few exceptions and followed by the Dupi Tila Formation. The PGA and other natural hazard potentials are also low, but the flood hazard is relatively higher than the upper terrace due to lower elevation.

xii) Madhupur Clay (Low terrace): This unit is flattened and highly eroded part of Madhupur Clay terrace, which is situated almost at floodplain level, mainly along the extreme edges, also present as individual knobs in the floodplains. The lithological characteristics of this unit are nearly the same as Madhupur Clay (middle terrace), but the colour varies from yellowish-grey to yellowish-brown. An Increase of reddening of colour with depth is not prominent. It is equally resistant to erosion with low infiltration potential and is very hard when dry. In this unit, the top residuum part is underlaid by a fine sandy silt layer with few exceptions and followed by the Dupi Tila Formation. The PGA and other natural hazard potentials are also low, but the flood hazard is high as of floodplains.

2.4 Soil Amplification

2.4.1 Seismotectonic of the study area

From the locational aspect, Bangladesh is an earthquake-prone country due to its tectonic setup. It lies in the north-eastern Indian Plate near the edge of the Indian craton and at the junction of three tectonic plates- the Indian Plate, the Eurasian Plate, and the Burmese microplate [6]. The impact of the Indian Plate with the Eurasian Plate in a northward direction has created the Himalayan Ranges between these plates and also created the Bengal Basin in the north-eastern part of the Indian Plate [7][8][9]. From literature, it was found that the Indian Plate is continuing its motion towards the north at approximately 4-6 centimetres per year approximately [6][10]. Two major active tectonic belts are responsible for large and damaging earthquakes in Bangladesh, Northeast India, Nepal, Bhutan, and Myanmar [7].

Bangladesh is divided into four seismic zones in the national building code (BNBC 2020), where Dhaka city and its surrounding areas are situated in seismic zone 2 with a basic seismic coefficient, Z=0.20 [11]. Dhaka might encounter two potential epicentres of magnitude 6 and 7 from the Madhupur and Bansi fault [12][13]. Dhaka is seismically active with multiple potential earthquake sources within 50 to 500 km distance. It is evident that the metropolis and its surrounding areas have a high probability of seismic hazard [6][8]. It is perceptible from the literature that alluvium deposits usually amplify the seismic wave more than hard rock terrains during an earthquake [14]. From the geomorphological map (Figure 2.2), flood plain and depression areas surrounding Dhaka city to its peripheral areas can be subdivided into lowland alluvium and highland alluvium, which indicates the probability of soil amplification of these areas.

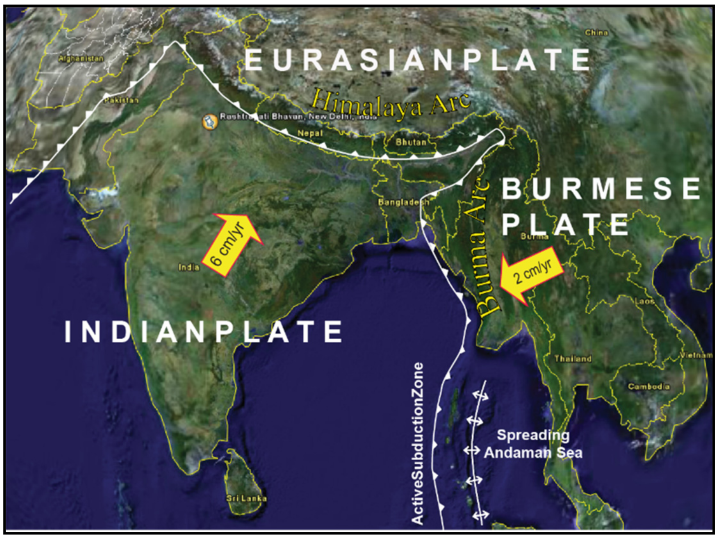


Figure 2.3: Tectonic setup of Bangladesh and Plate Boundaries.
(Source: Akhter, 2010)

2.4.2 Fault model of the study area

CDMP previously did time predictable fault modelling for scenario earthquakes. In Figure 2.4, the shaded area is the surface projection of the faults, and the line closest to the area indicates the intersection of the fault surface extended to the ground Surface. Table 2.2 shows the parameters of the faults.

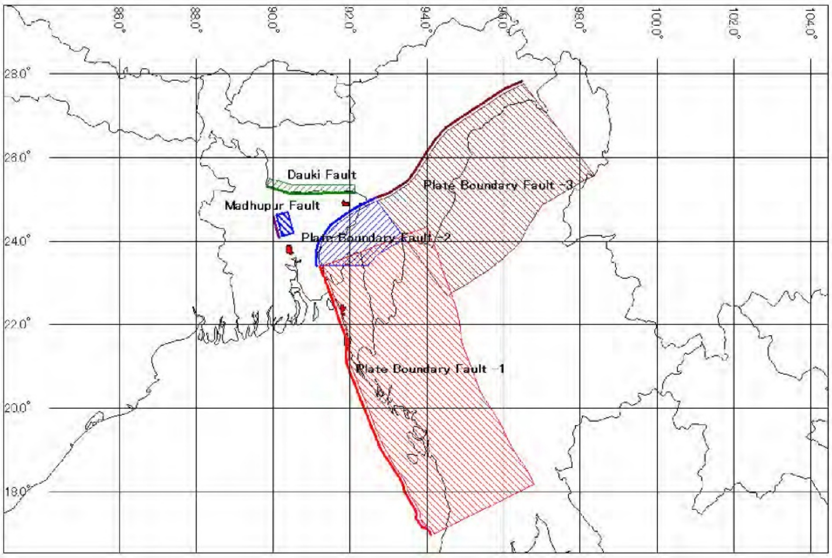


Figure 2.4: Scenario Earthquake Fault Model (Source: CDMP)

Table 2.2: Fault Parameters for Empirical Attenuation Analysis

Fault	Coordínate of Epicentre		Mw	Depth to top of fault (km)	Dip Angle (degree)	Fault Type
	Latitude	Longitude				
Madhupur Fault (MF)	24.3	90.1	7.5	10	45	Reverse
Dauki Fault (DF)	25.1	91.2	8.0	3	60	Reverse
Plate Boundary Fault -1 (PBF-1)	21.1	92.1	8.5	17.5	20/30	Reverse
Plate Boundary Fault -2 (PBF-2)	23.8	91.1	8.0	3	20	Reverse
Plate Boundary Fault -3 (PBF-3)	25.7	93.7	8.3	3	20/30	Reverse

(Source: CDMP)

2.4.3 Data and methodology

This study is based on secondary data sources, especially from the Comprehensive Disaster Management Programme (CDMP) and the Geological Survey of Bangladesh (GSB). Geological data was used to prepare the geomorphological map (Figure 2.2) from the GSB database. The working methodology of this study can be divided into three sections for the soil amplification factors in Dhaka city. Firstly, the amplification factors were calculated from average shear wave velocity at site by empirical correlation based on the relation with SPT-N value and shear wave velocity from literature. Secondly, Landsat imagery was used to analyze the normalized difference water index (NDWI) to detect the encroachment of water bodies from the last 30 years. And finally compared with geomorphological map and overlap the soil amplification map later to assume the vulnerable areas in Dhaka city. Due to time constrain and limitations of resources, only secondary data were used in this study.

2.4.4 Geophysical exploration of Dhaka City

In a previous study by CDMP, PS-logging and Multi-channel Analysis of Surface Wave (MASW) was used to check the shear wave velocity (Vs) at shallower part and combined the result obtained by using Small Scale Micro-tremor Measurement (SSMM). The geological/geotechnical ground model for each 250 meter square grid and SSMM was used to check the shear wave velocity up to 30m for reference. Finally, the average shear wave velocity for up to 30m depth (AVS_{30}) was calculated by the following equation.

$$T_{30} = \Sigma \frac{Hi}{Vi} \qquad (1)$$

$$AVS_{30} = \frac{30}{T30} \qquad (2)$$

Where, T30: Travel time for 30m depth, *Hi*: Thickness of *i* layer and 30= $\sum \boldsymbol{Hi}$; Vi: S-wave of *i* th layer.

For analyzing the amplification factor, the whole Dhaka city was divided into 250 meter square grids. Amplification factor was calculated by PGA at the bedrock divided by PGA on the surface. Shear wave velocity at the bedrock was determined as 900 m/s (CDMP was 760 m/s). The bedrock was considered at 30m. Later on, the interpolation method was used to assume the amplification factor for Dhaka city. The nearest fault for Dhaka city is the Madhupur fault.

2.4.5 Normalized difference water index

A simplified method is used to identify the continuous encroachment of water bodies in Dhaka city. Normalized Difference Water Index, popularly known as NDWI, is a remote sensing analysis method to monitor the changes of water bodies by using green and near-inferred wavelengths [15]. The following equation is used on the Landsat image to identify the water content changes in Dhaka last 30 years from 1989 to 2019.

$$NDWI= \frac{Xgreen-Xnir}{Xgreen+Xnir} \qquad (3)$$

Here, Xgreen is the green wavelengths and Xnir is near-inferred rays.

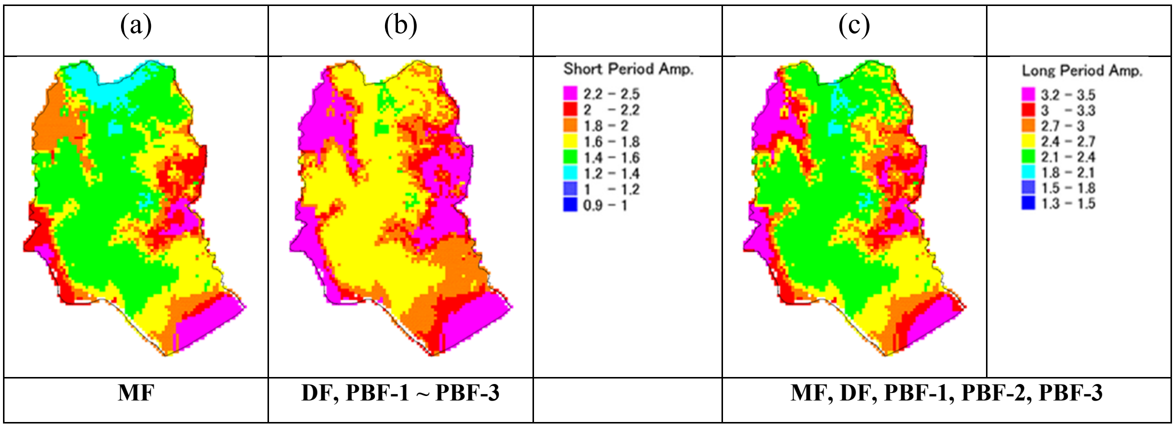


Figure 2.5: Amplification factors based on the AVS30 for short and long period Sa in Dhaka

(a) amplification factor of PGA and Sa (T=1.0 sec) for MF scenario earthquake (b) amplification factor of PGA and Sa (T=1.0 sec) for DF and PBF1 to 3 scenario earthquakes (c) amplification factor of PGA and Sa (T=0.3 sec) for all scenario earthquakes. (Source: CDMP)

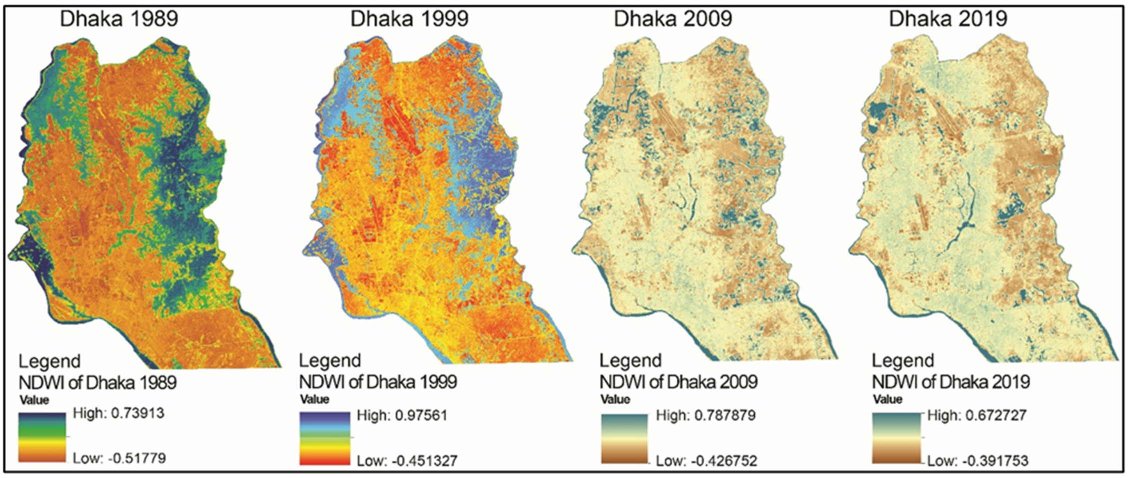


Figure 2.6: Normalized Difference Water Index of Dhaka city from 1989 to 2019.
(Source: Developed by Author)

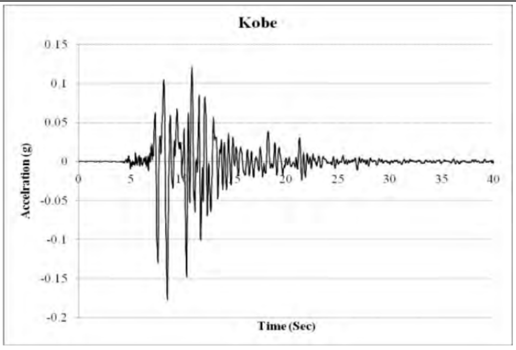
Figure 2.6 shows that in 1989 the blue shaded areas in the eastern, north-western, some part of the western of Dhaka city was covered by water bodies, marshland, and depression area. Over time to accommodate the excessive population, these peripheral areas were developed by sand filling. From 1999 to 2009, the water content in Dhaka city dramatically reduced. The amplification map (Figure 2.5) produced from the CDMP shows that those areas are also amplifiable from different earthquake scenarios.

2.4.6 Shear wave velocity (Vs)

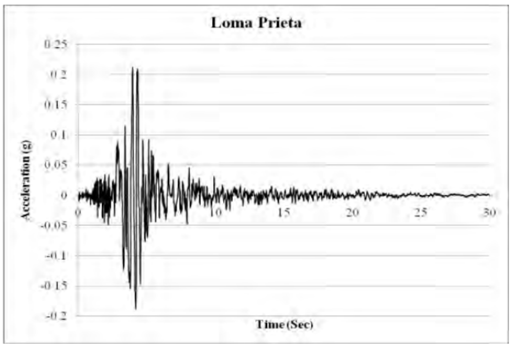
Shear wave velocity (Vs) is one of the most important input parameters to represent the stiffness of the soil layers. Total 87 locations have been selected for Site Amplification Analysis in Dhaka city in this research. Shear wave velocity (Vs) is measured in every location of Dhaka city by using standard penetration test. In Dhaka city, the depth of bedrock was unavailable due to the lack of deep boreholes. In DEEPSOIL [16], bedrock depth is assumed to be below the last layer, so to prevent erroneous results, the last layer was considered the same up to a depth of 100m.

For site response analysis by the equivalent linear method, the results are considered to be accurate for estimating PGA up to 3sec for general projects [17][18][19][20][21]. The selection of a ground motion for dynamic analysis is tedious. Input ground motions have to be selected to represent the regional seismicity and incorporate the anticipated earthquakes.

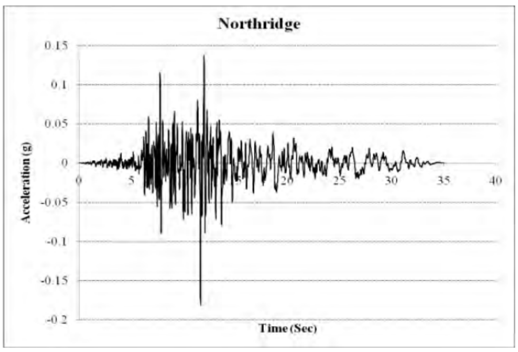
Ground motion selection can be done based on expected magnitude and distance, soil profile, strong motion duration, seismotectonic environment, acceleration to vertical ratio, spectral matching, etc. In this study, Kobe earthquake (Mb = 6.8) of 17th January 1995, Loma Prieta earthquake (Mb = 6.9) of 17th October 1989, Northridge earthquake (Mb = 6.7) of 17th January 1994, Sikkim earthquake (Mb = 6.9) of 18th September 2011, is selected as the input ground motions (Figure 2.7). The input rock motion for Dhaka is scaled to 0.19g value [22]. The magnitude of the earthquake is almost similar to that expected in Dhaka City. So, the rock properties have been defined, and the shear modulus has been considered, which is frequency independent. During the analysis, the number of iterations also affects the results. It summarizes the surface PGA evaluated at different locations and shows the Site amplification factor at different locations of Dhaka City. For better understanding and making this report simple for the reader among urban planning disciplines, this study discussed and illustrated only the Kobe earthquake input ground motion in the following sections.



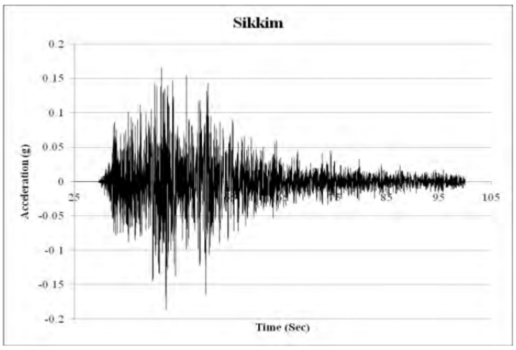
(a) Kobe earthquake, 1995; Mb= 6.8



(b) Loma Prieta earthquake, 1989; Mb=6.9



(c) Northridge earthquake, 1994; Mb=6.7



(d) Sikkim earthquake, 2011; Mb=6.9

Figure 2.7: Scaled Input Ground motion (a) Kobe earthquake, (b) Loma Prieta earthquake, (c) Northridge earthquake and (d) Sikkim earthquake (Source: DEEPSOIL)

2.4.7 Maximum Peak Ground Acceleration (PGA)

Maximum Peak Ground Acceleration (PGA) at different depths of Kobe earthquakes for this site is shown in (Figure 2.8). PGA at the surface and that at bedrock are obtained from the analysis. The peak ground acceleration values at the surface are observed to be in the range of 0.214g (Sikkim) to as high as 0.295g (Kobe), and that of the bedrock was followed to vary from 0.177g (Kobe) to 0.212g (Loma Prieta).

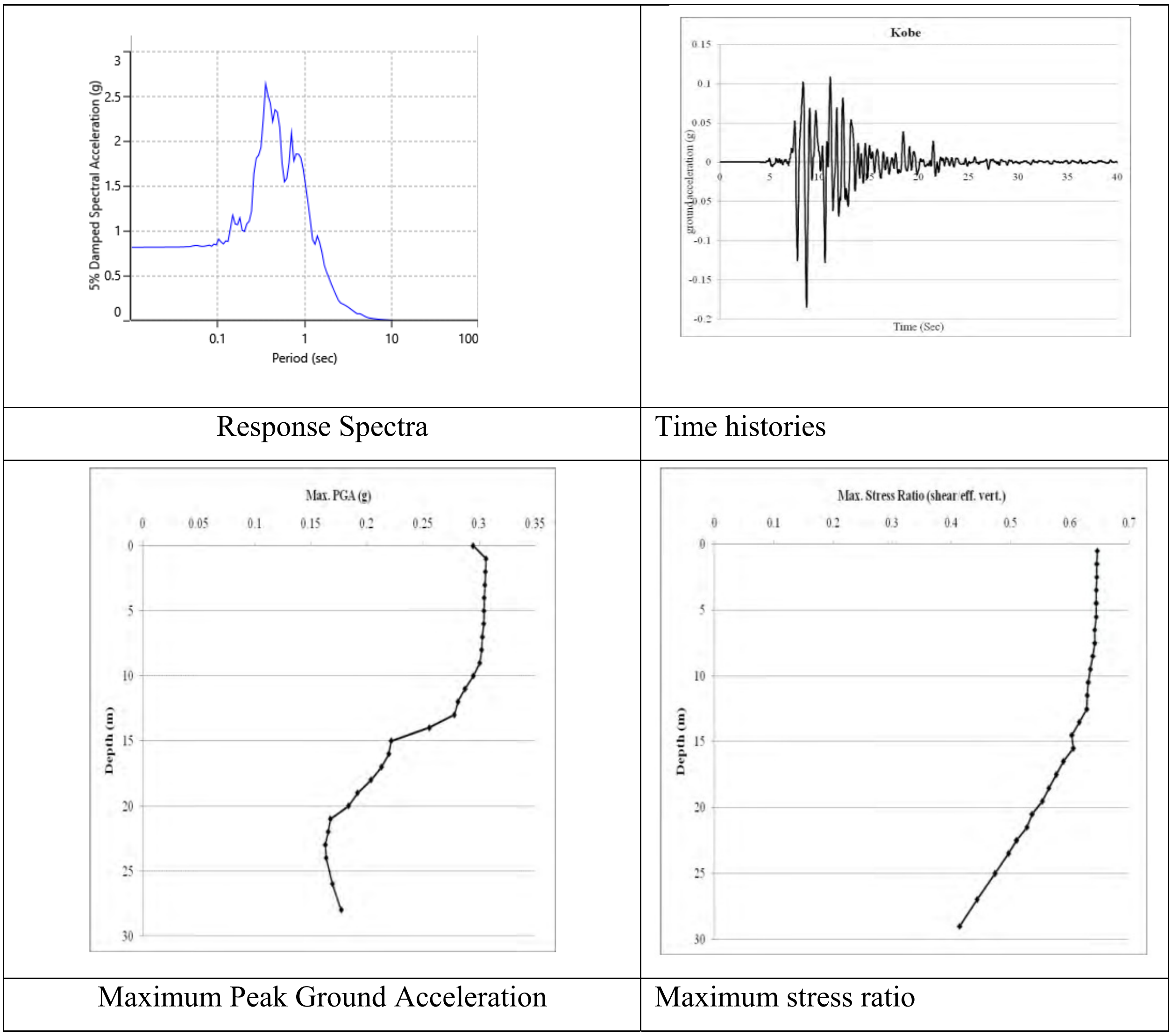


Figure 2.8: Time histories for local site effects. (Source: DEEPSOIL)

Site amplification factors at subsurface layers are often used as one of the parameters for the estimation of ground response. The amplification factor is the ratio of peak ground acceleration at the surface to acceleration at hard rock. The amplification factors are determined as;

Amplification Factor = PGA recorded at ground surface / PGA recorded at hard rock

Therefore, the amplification factors have also been computed, and it has been identified that similar to the peak ground acceleration values, the variation is between 1.12 (Loma Prieta) and 1.67 (Kobe).

National Earthquake Hazards Reduction Program (NEHRP) has developed a site classification system representing the soil types and classes. It is an internationally well-established site classification to date. Following Table 2.3 is reproduced from NEHRP to classify the soil type and soil class of Dhaka city.

Table 2.3: NEHRP Site Classification

Soil Type	**Brief Description**	**Average shear wave velocity at 30m (m/s)**
A	Hard Rock	Vs >1500
B	Rock	760 <Vs ≤1500
C	Hard soil, stiff/very stiff soil, mostly gravels	360 <Vs ≤760
D	Sand, silts, stiff or very stiff clay, some gravels	180 <Vs ≤360
E	Soft clay	Vs < 180
F	Need specific calculations	--

All the 87 borehole locations were analyzed, as shown above. The results are as follows:

Table 2.4: Amplification Factor and Average Shear Wave velocity data of Dhaka.

No	Borehole	Average Shear Wave Velocity	Amplification Factor	Soil Type	Soil Class
1	DK_BM2948	131.34	1.92	Soft Soil	E
2	DK_BM2897	160.47	2.87	Soft Soil	E
3	DK_BM2914	167.42	3.2	Soft Soil	E
4	DK_BM1866	181.73	3.35	Stiff Soil	D
5	DK_BM2969	188.72	3.08	Stiff Soil	D
6	DK_BM2971	189.17	2.38	Stiff Soil	D
7	DK_BM2976	195.27	2.93	Stiff Soil	D
8	DK_BM1863	195.64	2.65	Stiff Soil	D
9	DK_BM2952	206.3	2.63	Stiff Soil	D
10	DK_BM3276	207.72	3.07	Stiff Soil	D
11	DK_BM3282	208.03	3.53	Stiff Soil	D
12	DK_BM2905	208.45	2.82	Stiff Soil	D
13	DK_BM2917	208.45	2.82	Stiff Soil	D
14	DK_BM2931	210.55	2.67	Stiff Soil	D
15	DK_BM2994	211.47	2.56	Stiff Soil	D
16	DK_BM3293	212.33	3.41	Stiff Soil	D
17	DK_BM3284	215.28	3.48	Stiff Soil	D
18	DK_BM2890	215.69	2.66	Stiff Soil	D
19	DK_BM3266	219.31	3.45	Stiff Soil	D
20	DK_BM2978	219.56	2.49	Stiff Soil	D
21	DK_BM2993	219.62	2.44	Stiff Soil	D
22	DK_BM2921	220.47	2.41	Stiff Soil	D
23	DK_BM2956	222.23	2.42	Stiff Soil	D
24	DK_BM3272	224.82	2.81	Stiff Soil	D
25	DK_BM2981	226.76	2.31	Stiff Soil	D
26	DK_BM3277	227.53	2.72	Stiff Soil	D
27	DK_BM2962	228.3	2.38	Stiff Soil	D
28	DK_BM3290	229.94	3.2	Stiff Soil	D
29	DK_BM3271	230.17	2.87	Stiff Soil	D
30	DK_BM2922	231.79	2.36	Stiff Soil	D
31	DK_BM2911	232.03	2.33	Stiff Soil	D
32	DK_BM3278	233.42	2.88	Stiff Soil	D
33	DK_BM3279	233.67	2.95	Stiff Soil	D

No	Borehole	Average Shear Wave Velocity	Amplification Factor	Soil Type	Soil Class
34	DK_BM2913	234.01	2.44	Stiff Soil	D
35	DK_BM3270	234.98	2.96	Stiff Soil	D
36	DK_BM3288	236.49	3.07	Stiff Soil	D
37	DK_BM3297	236.75	2.63	Stiff Soil	D
38	DK_BM2972	238.1	2.28	Stiff Soil	D
39	DK_BM3296	239.97	3.01	Stiff Soil	D
40	DK_BM3280	241.3	3.25	Stiff Soil	D
41	DK_BM3274	241.57	2.89	Stiff Soil	D
42	DK_BM2979	243.28	2.23	Stiff Soil	D
43	DK_BM2974	244.3	1.94	Stiff Soil	D
44	DK_BM3275	244.44	2.81	Stiff Soil	D
45	DK_BM3295	246.26	2.98	Stiff Soil	D
46	DK_BM2891	246.74	2.19	Stiff Soil	D
47	DK_BM3291	246.87	2.92	Stiff Soil	D
48	DK_BM2906	247.21	2.23	Stiff Soil	D
49	DK_BM3292	247.27	2.95	Stiff Soil	D
50	DK_BM3294	247.66	2.81	Stiff Soil	D
51	DK_BM2918	249.25	2.2	Stiff Soil	D
52	DK_BM3312	250.77	2.73	Stiff Soil	D
53	DK_BM3283	251.68	2.62	Stiff Soil	D
54	DK_BM2959	256.06	2.26	Stiff Soil	D
55	DK_BM2849	256.27	2.2	Stiff Soil	D
56	DK_BM3285	258.19	2.84	Stiff Soil	D
57	DK_BM2950	258.42	2.48	Stiff Soil	D
58	DK_BM2975	261.93	2.12	Stiff Soil	D
59	DK_BM2942	264.57	2.03	Stiff Soil	D
60	DK_BM2899	264.92	2.1	Stiff Soil	D
61	DK_BM3273	265.07	2.65	Stiff Soil	D
62	DK_BM2904	265.39	2.09	Stiff Soil	D
63	DK_BM3267	267.16	2.08	Stiff Soil	D
64	DK_BM2910	267.27	2.12	Stiff Soil	D
65	DK_BM2951	267.57	1.99	Stiff Soil	D
66	DK_BM1865	268.47	1.92	Stiff Soil	D
67	DK_BM3281	268.61	2.75	Stiff Soil	D

No	Borehole	Average Shear Wave Velocity	Amplification Factor	Soil Type	Soil Class
68	DK_BM2943	272.26	2.09	Stiff Soil	D
69	DK_BM3286	274.38	2.6	Stiff Soil	D
70	DK_BM2947	279.61	1.97	Stiff Soil	D
71	DK_BM3287	279.65	2.58	Stiff Soil	D
72	DK_BM3303	279.86	2.55	Stiff Soil	D
73	DK_BM2903	283.55	2.9	Stiff Soil	D
74	DK_BM2919	283.73	1.98	Stiff Soil	D
75	DK_BM3269	283.93	2.12	Stiff Soil	D
76	DK_BM3268	290.19	1.94	Stiff Soil	D
77	DK_BM2963	303.74	1.8	Stiff Soil	D
78	DK_BM2977	304.32	1.8	Stiff Soil	D
79	DK_BM2900	304.69	1.58	Stiff Soil	D
80	DK_BM2902	310.41	1.78	Stiff Soil	D
81	DK_BM2973	321.33	1.41	Stiff Soil	D
82	DK_BM2961	323.2	2.13	Stiff Soil	D
83	DK_BM2912	327.02	1.9	Stiff Soil	D
84	DK_BM2958	332.19	1.69	Stiff Soil	D
85	DK_BM3309	339.72	2.18	Stiff Soil	D
86	DK_BM3309	339.72	2.18	Stiff Soil	D
87	DK_BM3311	345.7	2.03	Stiff Soil	D

2.4.8 Average shear wave velocity scenario

Previously, CDMP used the estimated average shear wave velocity at each 250 meter square grid by produced soil model based on only 53 borehole data with PS logging and microtremor data to predict the soil amplification of Dhaka city. Though the number of borehole data is small, different analysis methods were used to validate the data and reduce the margin of error. Later on, the Geological Survey of Bangladesh (GSB) did the 3D soil modelling using 317 boreholes and geological knowledge in greater Dhaka city for different projects, namely, Geo-Information for Urban Development Project. For this study, 87 borehole data of Dhaka were collected from GSB. In 2018, Rahman et al. [4] estimated the near-surface shear wave velocity of Dhaka city from SPT-N data by using empirical correlation and proposed correlations between the Vs and uncorrected SPT-N by using nonlinear regression of power-law model are given below:

$Vs = 97.3062\ N^{0.3393}$ ($r = 0.7496$ and $R^2 = 0.5618$) for all soils (4)

$Vs = 82.01\ N^{0.3829}$ ($r = 0.6689$ and $R^2 = 0.4474$) for all sandy soils (5)

$Vs = 100.58\ N^{0.341}$ ($r = 0.7304$ and $R^2 = 0.5334$) for all clayey soils (6)

Equations (5) and (6) were used to predict the shear wave velocity for each soil layer if the 87 borehole sites in Dhaka. The average depth of the boreholes is 40m, and the shear wave velocity for bedrock was considered 900 m/s.

This research aims to estimate the site amplification of Dhaka city based on shear wave velocity. This research includes secondary borehole data to estimate the site amplification. The shear wave velocity is computed by using the SPT-N value. The depth of sand filling in areas varies from 2.0 to 6.0 m from the existing ground level (EGL). The depth of the clay layer varies from 4.0 m to 30.0 m. The depth of the silty clay layer varies from 4.0 m to 6.0 m. The depth of the clay layer varies from 4.0 m to 26.0 m. The depth of the fine sand layer varies from 4.0 m to 20.0 m. The depth of the dense sand layer varies from 4.0 m to 20.0 m from EGL. The maximum value of shear wave velocity varies from 300 m/s to 810 m/s. The minimum value of shear wave velocity varies from 80 m/s to 100 m/s. The average value of shear wave velocity varies from 164 m/s to 320 m/s.

Based on the analyzed data from GSB, the Shear Wave Velocity Map of Dhaka was prepared with 87 Borehole data (Figure 2.8). After that, the data was distributed by using interpolation tool of ArcGIS software for the detailed area mapping for Dhaka (Figure 2.9). This shows the area categorized as the vulnerable, less vulnerable and more vulnerable and the most vulnerable. This classified areas for the determining of the areas in terms of the seismic vulnerability. The lower the shear wave velocity value, the lesser vulnerable areas; the higher the value, the more vulnerable areas.

Figure 2.8 and 2.9 show that the peripheral areas of Dhaka are more vulnerable in terms of shear wave velocity. It happened because of landfilling, which was previously low land and wetland, and developed without proper maintenance of rules and regulations, making the areas more vulnerable to seismic hazards and disasters.

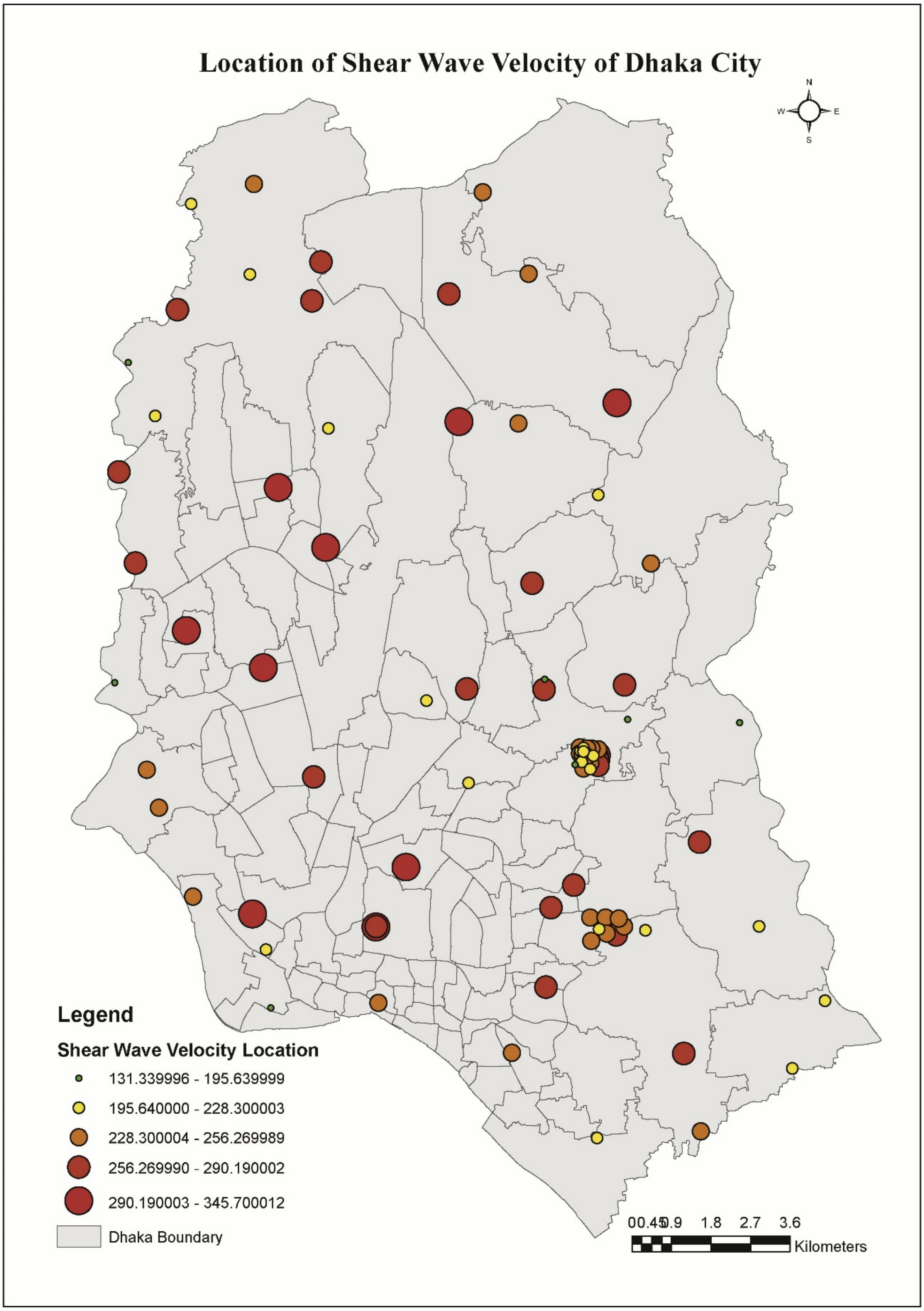


Figure 2.9: Shear Wave Velocity Map of Dhaka

(Source: Prepared & Analyzed by Author, 2020)

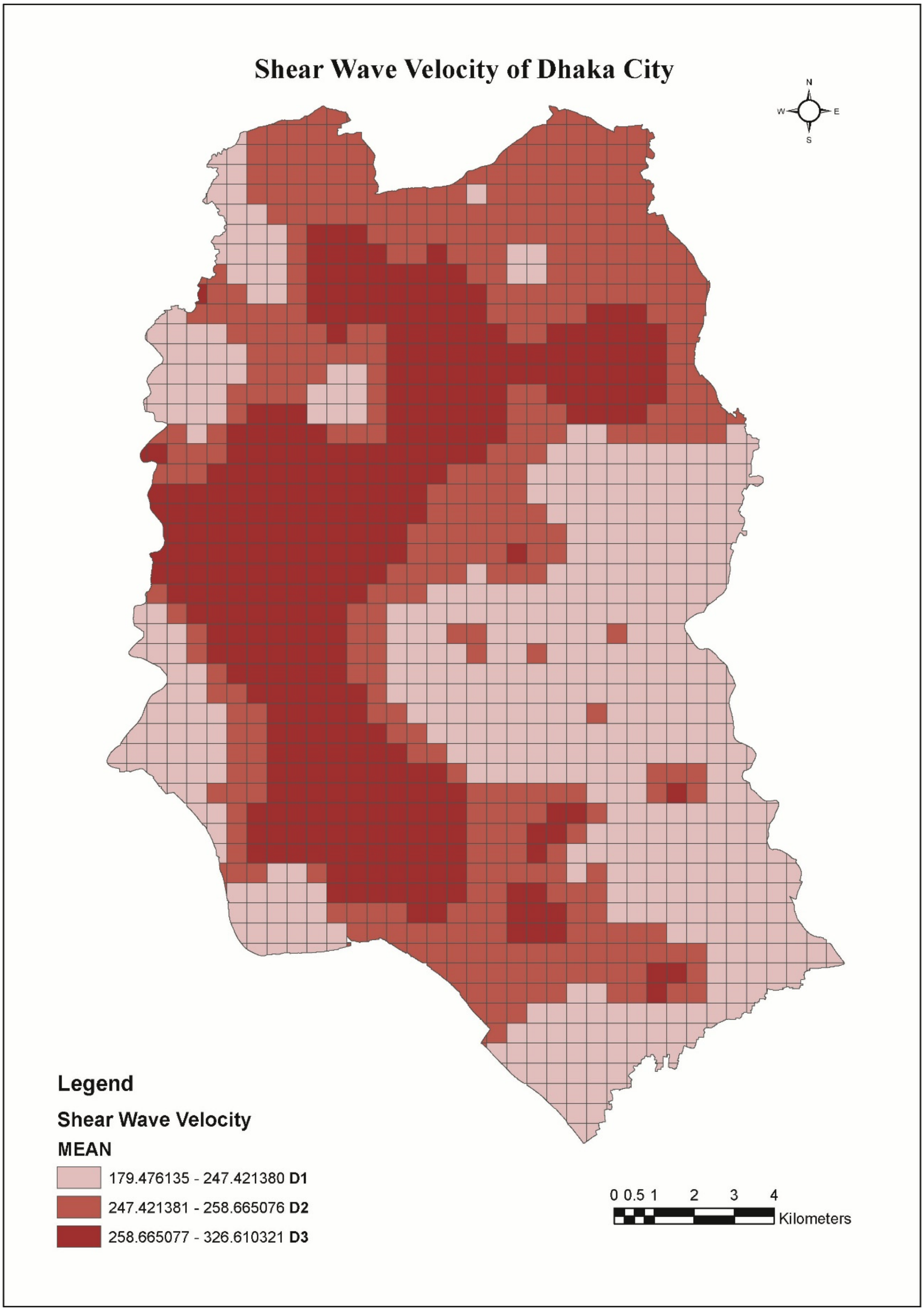


Figure 2.10: Distributed Shear Wave Velocity Map of Dhaka
(Source: Prepared & Analyzed by Author, 2020)

2.4.9 Amplification factor scenario

For simulation, DEEPSOIL software was used. The Kobe earthquake was selected for input motion based on the soil characteristics and a large number of recorded data to calculate the PGA. The soil amplifications at all the sites were calculated by ratio between PGA at ground surface and PGA at bedrock.

Based on Figure 2.10, the 87 boreholes data of site amplification, it shows that the amplification factor varies from 1.41 to 3.45, whereas CDMP data shows the amplification factor ranges from 1.37 to 3.4. The eastern part of Dhaka shows the amplification factor is between 2.6 to 2.8, and the western part is more amplifiable. It represents the opposite scenario where the southern and north-eastern part is more amplifiable than the western part. The result of these two different databases varies due to different empirical correlation equations and different input motions. On the other hand, 87 borehole data were used to analyze the amplification factor. From a geomorphological perspective, this area's geomorphological classification was dominated by high and low floodplain zone with some Lower Madhupur Terrace. Considering the geomorphological classification with the CDMP result, a profound similarity is found. However, the geomorphological classification is determined by the surface soil and its formation and characteristics; subsoil investigation may show different results than the surface. In addition, the average depth of the GSB borehole is 40 m. The bedrock motion is considered to be 900 m/s, which could cause the variation of the amplification factors between the two databases.

Figure 2.11, for which the amplification factors are interpolated to grids in Dhak city area, shows that some of the peripheral areas of Dhaka are more vulnerable in terms of amplification factors, making the areas more vulnerable to seismic hazards and disasters. It shows that some parts of the north-western region of Dhaka are most vulnerable; Figure 2.6 shows that in the late 80’s it was primarily wetlands. It is also applicable for the eastern part and south-eastern part of Dhaka. The amplification factor also shows that Dhaka's areas are not evenly distributed in terms of soil amplification.

The stratified areas showing some of the areas are vulnerable, and some are less vulnerable, but the average value indicating the amplification situation is not safe enough for generalization. There needed the most crucial intervention for making the planning rules and regulations for Dhaka.

2.4.10 Findings and results

The average shear wave velocity at site was calculated for each borehole location using the empirical equations (1), (2), (5), (6). It was found that most of the area of Dhaka city can be classified as D according to NEHRP soil classification (Table: 2.3). Only three locations were found as E where the average shear wave velocity was below 180 m/s. However, this study used the Inverse distance weighted (IDW) interpolation method to distribute the total 87 borehole values to Dhaka city. Because of the small number of the mean shear wave velocity, the IDW method of interpolation took the average value of those three particular locations, and the values were significantly changed. For instance, DK_BM2948 (131.34 m/s), DK_BM2897 (167.42 m/s), DK_BM2914 (160.47 m/s) each borehole has a velocity less than 180 m/s. However, the lowest velocity recorded in the IWD method is 179.48 m/s. Such results occur due to the unavailability of sufficient borehole data. For a better understanding, the shear wave velocity map was categorized into three sections D1, D2, and D3 as shown in Figure 2.9.

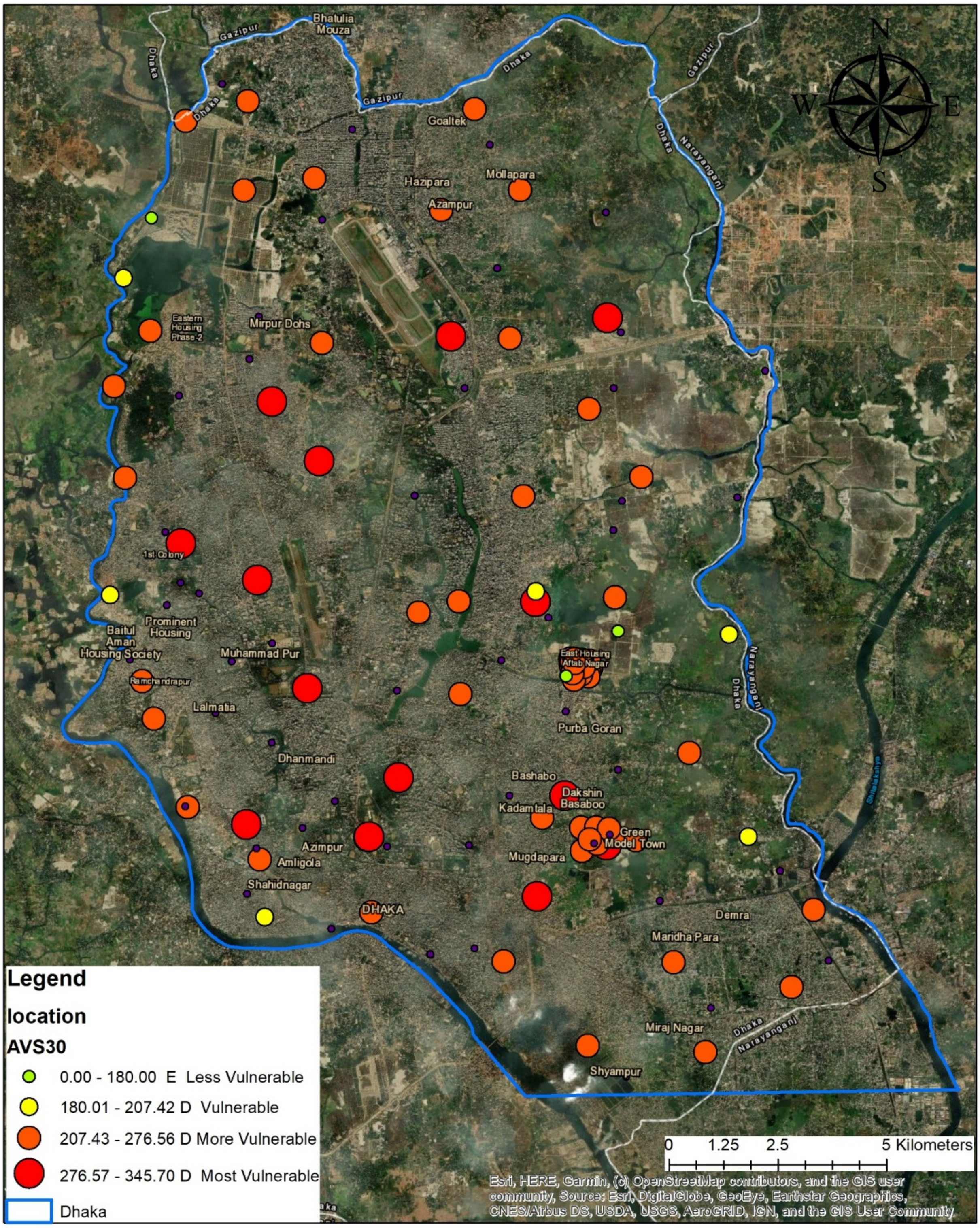


Figure 2.11: Amplification Factor Map of Dhaka

(Source: Prepared & Analyzed by Author, 2020)

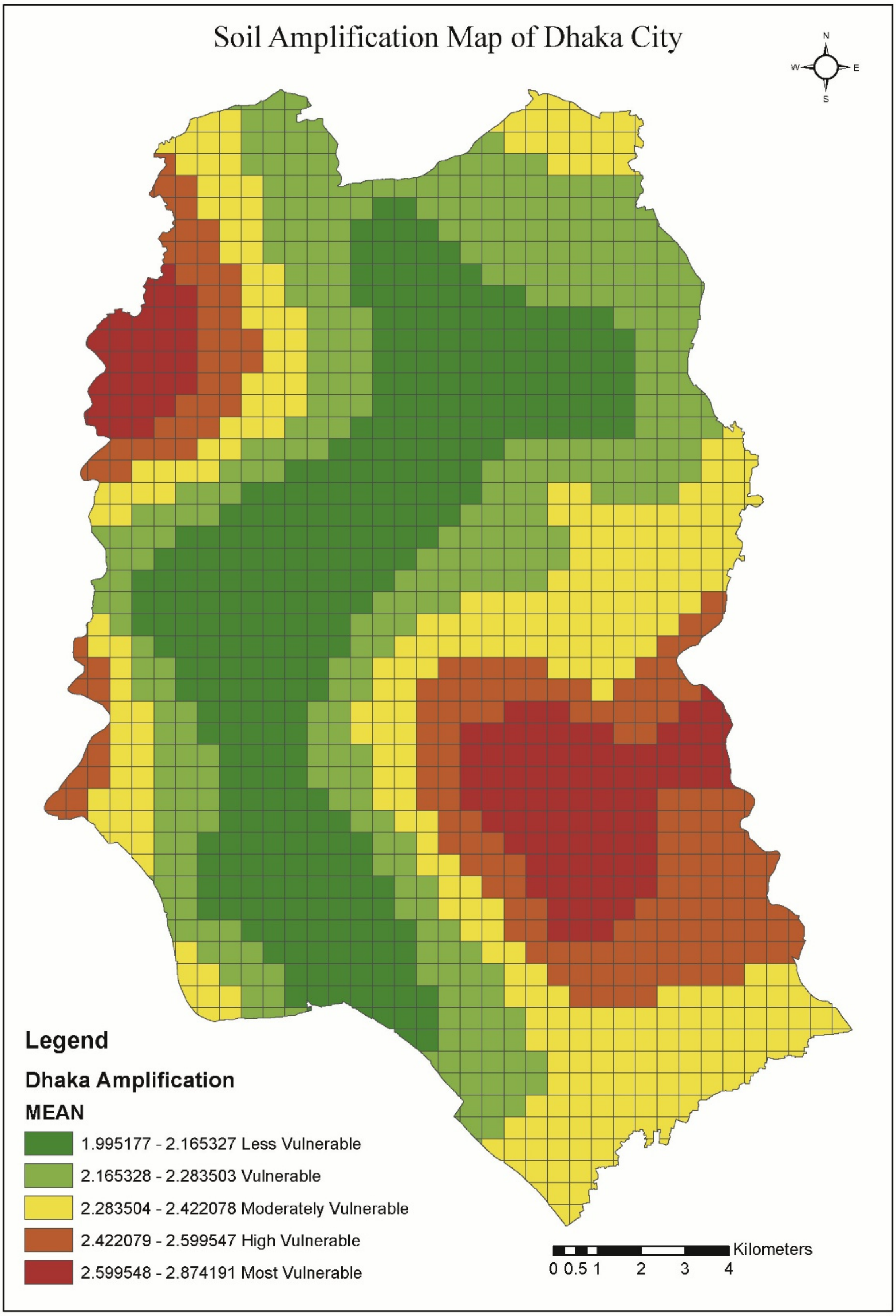


Figure 2.12: Distributed Amplification Factor Potential Map of Dhaka
(Source: Prepared & Analyzed by Author, 2020)

Figure 2.11 shows that the eastern part, north-western part and some western part has low shear wave velocity rather than the middle part, north-western and some western parts have low shear wave velocity rather than the middle of Dhaka city. From the geological aspects of Dhaka, type D2 represents the Upper Madhupur Terrace (Figure: 2.2). Type D1 primarily indicates the low wetland and high flood plain areas. The amplification map (Figure 2.11) also shows that areas of Type D1 and D2 in Figure 2.9 are more amplifiable than Type D3.

2.5 Conclusion

Bangladesh is one of the most seismically vulnerable countries in the world for its geological location. It lies at the junction of two active plates, the Eurasian Plate and the Indian Plate. Dhaka is also considered one of the most vulnerable megacities in terms of seismic hazards. According to the BNBC, Dhaka is situated on seismic zone 2 (with seismic coefficient Z=0.02). Besides, two tectonic fault lines, like the Madhupur fault and the Dauki fault, lie close to the city, along with three plate boundary faults. The geological formation of Dhaka and its adjacent areas can be divided into two primary units, such as Madhupur clay of Pleistocene age and alluvial deposits of recent age.

The central part of this city consists of upper, middle, and lower Madhupur terraces. The peripheral areas have consisted of high floodplains and low floodplains with wetland, marshland, and water bodies. Over the year, to manage the enormous population pressure, Dhaka started expanding towards the peripheral areas. Land development turned into a necessity for the inhabitants as well as for the government. Unplanned development without monitoring made this city seismically more vulnerable. After analyzing 87 borehole data, it was found that the soil type of Dhaka is ‘D’ according to the NEHRP soil classification system. On the other hand, the amplification factor of this city is also considered very high. Especially the eastern part, north-western part and some portions of the western part are considerably high amplifiable areas. More in-depth studies in the geotechnical area are required for more accurate and reliable results from academicians and professionals.

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Chapter 3 Comprehensive Seismic Vulnerability Assessment

3.1. Introduction

This chapter attempts to provide a pictorial overview of overall city focusing on vulnerability condition based on earthquake consideration. It is developed considering structural aspect of a building along with aspects related to emergency response capacity. The work progress for this chapter started from understanding the necessity of delineating the administrative units requiring attention for improvement to reduce seismic damage. The procedure begins with making an important assumption for the research to match the method with the context of the study. The assumption validates the further progress of the research. After deciding on the assumption, data used for this research was summarized to have a better understanding of the work process. Then, the methods to estimate seismic capacity index (I_s) were tried to determine by using a number of methods. Eventually, two alternative methods have been determined for the estimation process. One of the methods were finally determined which has been used to create the vulnerability scenario of Dhaka city. Evacuation to main roads, safe evacuation open space, rescue by firefighters are the other factors considered for the comprehensive vulnerability scenario of the city. The final result of this chapter presents the administrative units (wards) that can be taken into consideration for improving their condition to reduce vulnerability of those areas.

3.2. Data and Sample data

The GIS database (RAJUK) used for this research contained information about 692,501 buildings. A number of buildings/structures has been removed from further process to maintain the relevancy of the study. Apart from this, building data for 12 wards/unions of the city were not available in the database. This number sums up to around 54,000. After considering this number, the total number of RC buildings become 106,093. This research is carried out by using information of these 106,093 buildings.

A sample dataset [2] has been used for estimating I_s index. The sample dataset contained information of 582 buildings. This dataset contained general building info like floor area, number of stories, building occupancy, dwelling units for some buildings etc. There was no construction year/ building age data included in the dataset. Building age data is considered as an important data as it is related to defect issue of a building. Another GIS database (CDMP) has been used to retrieve the data related to building age for the sample buildings. Age data couldn't be retrieved for some buildings. So, estimation process that concerns building age has been proceeded with 402 buildings. According to a Godden (2004), for an infinite population (population> 50,000) sample size can be calculated by the following formula [9]. If it is applied, the desired sample size becomes 384. Sample building size applied in this research can be justified by this.

$$SS = \frac{Z^2 P(1-P)}{C^2} = \frac{1.96^2 \times 0.5 \times (1-0.5)}{0.05^2} = 384$$

where,

SS = Sample Size

Z = Z-value (1.96 for a 95% confidence level)

P = Estimated proportion in the population to have a specific attribute (generally 0.5 when no estimate is available)

C = Confidence interval or precision level (normally 0.05)

3.3. Assumption

The database obtained from RAJUK contains information of more than 692 thousand built structures from both DNCC and DSCC. Generally, there are three types of structures that can be found in Dhaka city. They are typified as ‘kutcha’, ‘semi-pucca’ and ‘pucca’. The kutcha houses can be simply described as the houses constructed with non-durable materials. Generally, material for kutcha house is tin sheet, bamboo etc. Pucca houses are the ones constructed with durable materials like bricks, cement, concrete, aggregate etc. The semi-pucca are the ones in which generally the walls are constructed with durable materials that are used for pucca construction and the roofs are constructed with the materials of kutcha type houses. In Dhaka, not all of the pucca constructions are reinforced concrete buildings. Some of them are masonry type construction. Table 3-1 gives an easy understanding of the construction types available in Bangladesh. Also, figure 3-1 presents pictorial view of these structure types.

Table 3.1: Structure types by construction materials

Structure type	Pucca	Semi-pucca	Kutcha
Floor	Brick and concrete	Earthen/ polished	Earthen
Wall	Brick	Brick	Thatch/bamboo/tin
Roof	Concrete	Tin/Bamboo	Tin/bamboo/straw

Source: Author

a) Pucca b) Semi-pucca c) Kutcha

Figure 3.1: Structure types (Source: Google)

For this study purpose, only the pucca structures shall be considered. In the base GIS dataset (RAJUK), the mentioned structure types are, pucca, semi-pucca, kutcha. Also, the structures that are under construction are also mentioned. Along with kutcha and semi-pucca structure types, ‘under-construction’ structures won’t be considered throughout the study. Even if they are pucca structures, they are not provided with some other data (household size, building use etc.) that might be needed further. Hence, they shall be deducted. Around 57.17%

of structures are removed from the process. Table 3-2 shows the distribution of the structure all over the city by their construction type.

Table 3.2: Structure type distribution for all over the city.

Structure type	Number of structures	% distribution
All types	692,509	100%
Kutcha structures	121,421	17.5%
Semi pucca structures	267,128	38.57%
Under construction	7,619	1.1%
Pucca	296,341	42.8%

Also, it is required to determine only the RC (reinforced concrete) buildings of the city among the pucca structures in order to estimate index values for the buildings by using the Japanese standard for seismic evaluation. This is because the Japanese standard is supposed to be applied on the RC buildings. The available data stock from the GIS database does not contain any detailed structural construction information regarding the detail of structure types. The database specifies only if a building is pucca or kutcha. However, if a building is pucca, more details (i.e. either masonry type or RCC type) are not provided so that the buildings can be classified based on their construction type. So, an assumption has been taken to define the RC buildings for this study to make it fit for the application of Japanese standard.

To make the assumption, available data from CDMP containing details of limited number of buildings was studied to understand building share by construction type. The CDMP sample database contained mostly pucca buildings. According to CDMP (2009), "It was observed that most engineered buildings is mid-rise (65.9%) and low-rise (22.1%) concrete frame with masonry infill wall and most non-engineered buildings (30%) is low-rise masonry buildings with flexible roof." Here, low-rise buildings are defined as the buildings storied from 1 to 3 stories. Another study stated that about 21% buildings of total share fall under un-reinforced masonry construction type [8]. So, following the reference, it is assumed that masonry buildings are generally low-rise. If the distribution of pucca structures is analyzed, it can be seen that around 45.86% of the buildings are storied within 1 to 3 stories. Table 3.3 shows the overall distribution of the buildings according to floor number that are pucca.

Table 3.3: Distribution of low-rise pucca buildings

Distribution type	No. of buildings	Individual %	Cumulative percentage
Pucca and 1 storied	50,661	17.09%	17.09%
Pucca and 2 storied	54,068	18.25%	35.34%
Pucca and 3 storied	31,188	10.52%	45.86%
Pucca and 4 storied	84,574	28.54%	74.4%

If the buildings under 4 stories are assumed as masonry buildings, then it is about 45.86% and if 4 storied buildings are also considered as masonry buildings then it becomes 74.4%. If 4 storied buildings are assumed as masonry structures then it is possible that a large share of RC buildings will be out of consideration. It is true that there are many RC buildings among 1-3 storied buildings. Still, assuming 1-3 storied buildings as masonry buildings lessen the affect. Even if there are RC buildings within 1-3 storied buildings, they can be kept out of consideration because retrofitting low-rise buildings might not be as effective from the viewpoint of cost.

Considering all these, it is assumed that all buildings over 3 stories are reinforced concrete buildings. That means, apart from the kutcha, semi-pucca and buildings under constructions, buildings under 4 stories are deducted from this study to carry out further analysis. It is well understood that deduction of the buildings under 4 stories can cutdown a good amount of building stock from the damage scenario. Lack of information to determine the RC buildings, recent growing tendency to demolish low-rise constructions to make high-rise structures and effectivity in case of retrofitting purpose are the main driving factors to make this assumption.

3.4. Determination of estimation method

It is important to evaluate the seismic performance of a building to assess the structural condition as a whole. In Bangladesh, there is no such way by which the buildings can be seismically evaluated to determine their structural strength. But, this kind of evaluation helps to know more about structural ability of buildings to withstand seismic loads. It is necessary to figure out the seismic performance of buildings to find out the ones that are highly susceptible to seismic occurrence. In Japan, this kind of evaluation is done by following the Standard for Seismic Evaluation of Existing Buildings [5]. To estimate the seismic performance of the buildings of Dhaka city, the Japanese evaluation system has been taken as a standard to observe the seismic performance of the assumed RC buildings of the city.

The standard shall be applied for the seismic evaluation of the existing RC (reinforced concrete) buildings. In Japan standard, structural seismic performance of a building is denoted by seismic capacity index, Is. This procedure is applied for the evaluation of seismic performance, the determination and verification of RC buildings for retrofitting purpose. There are three levels of screening procedure associated with this standard; namely the first level, the second level and the third level. Depending on the purpose of assessment, any level of these three may be used.

The first level screening procedure of Japan has been taken as the base for the estimation of seismic performance of the existing RC buildings. Seismic capacity index, Is has been estimated by using statistical approach for the subjected buildings within the study area rather than performing structural calculation. Simplicity of the first level procedure and data availability in the context of Dhaka were the driving factor to use the first level screening procedure for this study.

According to Japanese Standard of Seismic Evaluation, seismic capacity index, Is should be calculated by equation (1). The higher the value of the index, the better performance a building shows in terms of seismicity (JBDPA, 2001).

$$Is = Eo \times SD \times T \tag{1}$$

where,
Eo = Basic seismic index
SD = Irregularity index

T = Time index

In Japan standard, buildings are classified in three classes based on their index value [6]. This classification will be applied to this study as well. According to this standard,

0 – 0.3 : High risk

0.3 – 0.6: Moderate risk

> 0.6 : Low risk

To apply the standard appropriately in the context of Bangladesh, certain assumptions has been applied to suit the purpose of the research. Initially, two different alternative models were formed to estimate I_s index. The first alternative made use of some very general kind of variables like number of stories, floor area and building age. On the other hand, estimation of I_s by the second alternative followed the regular equation of deriving seismic capacity index. From these two, the best suited model was selected for the overall estimation process. The most suitable model, for developing an overall vulnerability map, was selected on the basis of error estimation considering that lower error percentage provide more accurate result.

The Japanese standard for seismic evaluation is a method that is generally applied to buildings by physically inspecting them and it is a time-consuming process. However, it might be impracticable to carry out physical building inspection for evaluating seismic capacity on all buildings in the context of Dhaka city. Therefore, to create a vulnerability map considering seismic performance of buildings, it is indispensable to determine the seismic capacity index of the buildings. Keeping that in consideration, it has been tried to estimate seismic capacity of buildings by a number of methods. From all the trial methods, two alternative methods were finalized to measure seismic capacity index.

3.4.1. The first alternative: Variable

Multiple regression analysis is employed for the derivation of I_s value in the first alternative. This analysis is a statistical process which is actually an extension to simple linear regression. Multiple regression analysis is used in the cases when value of a variable is needed to be predicted from two or more variables. Any regression analysis consists of two components; dependent variable and independent variable. Dependent variable is the 'value to be predicted' variable. Independent variables are the ones that are used for predicting the value of the dependent variable.

In this approach, seismic capacity index, I_s is denoted as the dependent variable. As for the independent variables, this approach was proceeded by using number of stories and floor area as the independent variables in the first place, which is denoted by equation (2). Since, condition of a building can deteriorate with progression of aging, building age was added as another independent variable to observe the effect of aging in seismic performance as modelled by equation (3). Table 3-4 describes the details of equation (2) and (3).

In former approach, the derivative equation for I_s becomes for two variables,

$$y = 0.574 - 0.057x_1 - 0.050x_2 \tag{2}$$

In later approach, the derivative equation for I_s becomes for three variables,

$$y= 0.3440 - 0.020x_1 - 0.039x_2 - 0.030a_1 - 0.011a_3 - 0.062a_4 + 0.002a_5 \quad (3)$$

Table 3.4: Details of estimation models

Item		Equation (2)	Equation (3)
R^2 value		0.371	0.248
Sample no.		582	402
Dependent variable		y	y
Independent variable	Number of stories	x_1	x_1
	Floor area (standardized value)	x_2	x_2
Categorical variable	Age group of 0-10		a_1
	Age group of 21-30		a_3
	Age group of 31-40		a_4
	Age group of 41-50		a_5

For Eq. (3), age group of 11-20 has been taken as reference as categorical variable to avoid multicollinearity within the variables. Yet, there was some trace of multicollinearity within the categorical variables.

3.4.2. The second alternative: Basic equation

In this method, seismic capacity index has been derived by the basic equation of first level screening procedure. Equation (1) is used in Japan for determining seismic capacity index. Since, conditions or standards in Bangladesh might differ from the condition of standards from Japan, the same equation might not be appropriate in the context of Bangladesh. The equation was modified to address this issue by another researcher for SATREPS-TSUIB project [1]. The modified equation is as follows,

$$I_s = \frac{1\times CI+0.2\times WI}{1.1} \quad (4)$$

where,

$$CI \text{ (column area ratio)} = \frac{\text{Column area}}{\text{Total floor area}}\times 100 \quad (5)$$

$$WI \text{ (wall area ratio)} = \frac{\text{Minimum wall area between x and y axis}}{\text{Total floor area}}\times 100 \quad (6)$$

It should be mentioned that; total floor area is derived by multiplying floor area of one storey with number of stories of a building.

The unknown variables to derive I_s from equation (4) is column area and minimum wall area between x and y axis. These two variables are generally acquired from field survey/as built drawing of the buildings. Since, there is no specific data of this kind for all the buildings of the city; this method started by estimating these two variables statistically. These two variables were estimated against storey numbers of the buildings. The prediction equation for estimating column area and minimum wall area is expressed by equation (7) and equation (8).

$$A_c = 0.3639N^{1.1046} \quad (7)$$

$$A_w \text{ (min)}= 2.9063N^{-0.888} \quad (8)$$

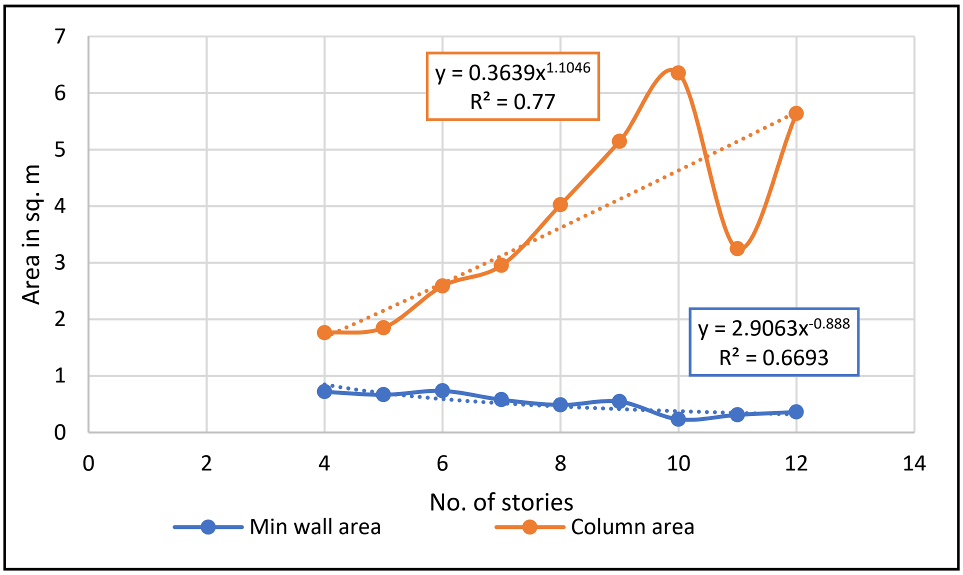
where,

A_c = column area

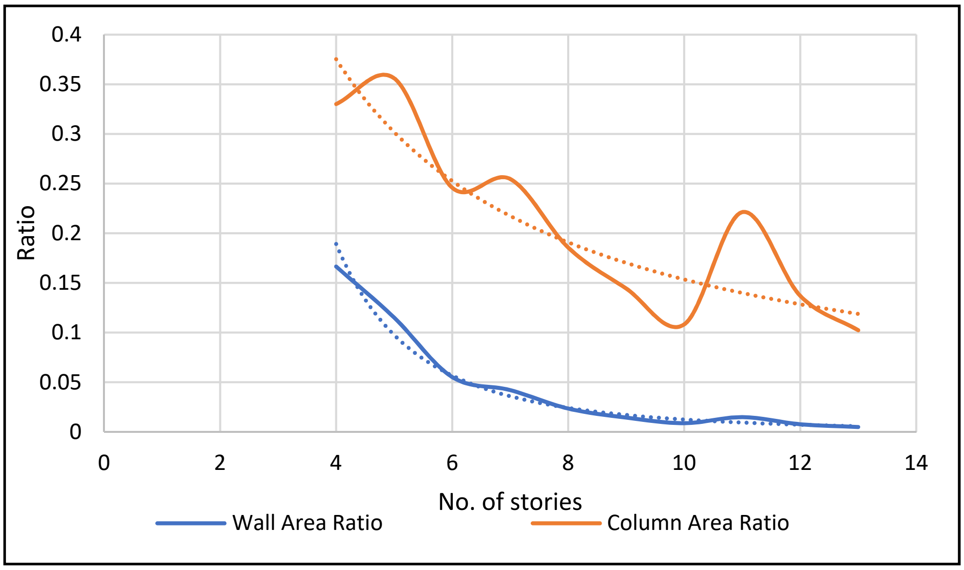
A_w (min)= minimum wall area between x and y axis

N= number of storeys/number of floors

In both equation (7) and (8), the independent variable is number of stories (f) and the dependent variables are column area (A_c) and minimum wall area (A_w) respectively. The estimation of column and wall area led to the derivation of column area ratio by using (5) and wall area ratio by using (6) which eventually lead to the derivation of I_s by using equation (4). Figure 3-2 depicts the relation of column and wall area with column and wall area ratio.



(a): Trend line estimation to determine minimum wall and column area



(b): Derivation of wall area ratio and column area ratio

Figure 3.2 (a,b): Derivation of CI and WI from column and wall area

Figure 3-2(a) shows the estimation of column and wall area for each corresponding storey. Despite the uniform value of column and wall area for each storey, change of column area ratio and wall area ratio is visible in Figure 3-2(b).

3.5. Application

The intention of estimating seismic capacity index, I_s was to be able to apply it to any building with very simple information that is readily available. This facilitates the wide applicability of seismic capacity index, I_s to all the RC buildings of Dhaka city.

3.5.1. The first alternative: Variable

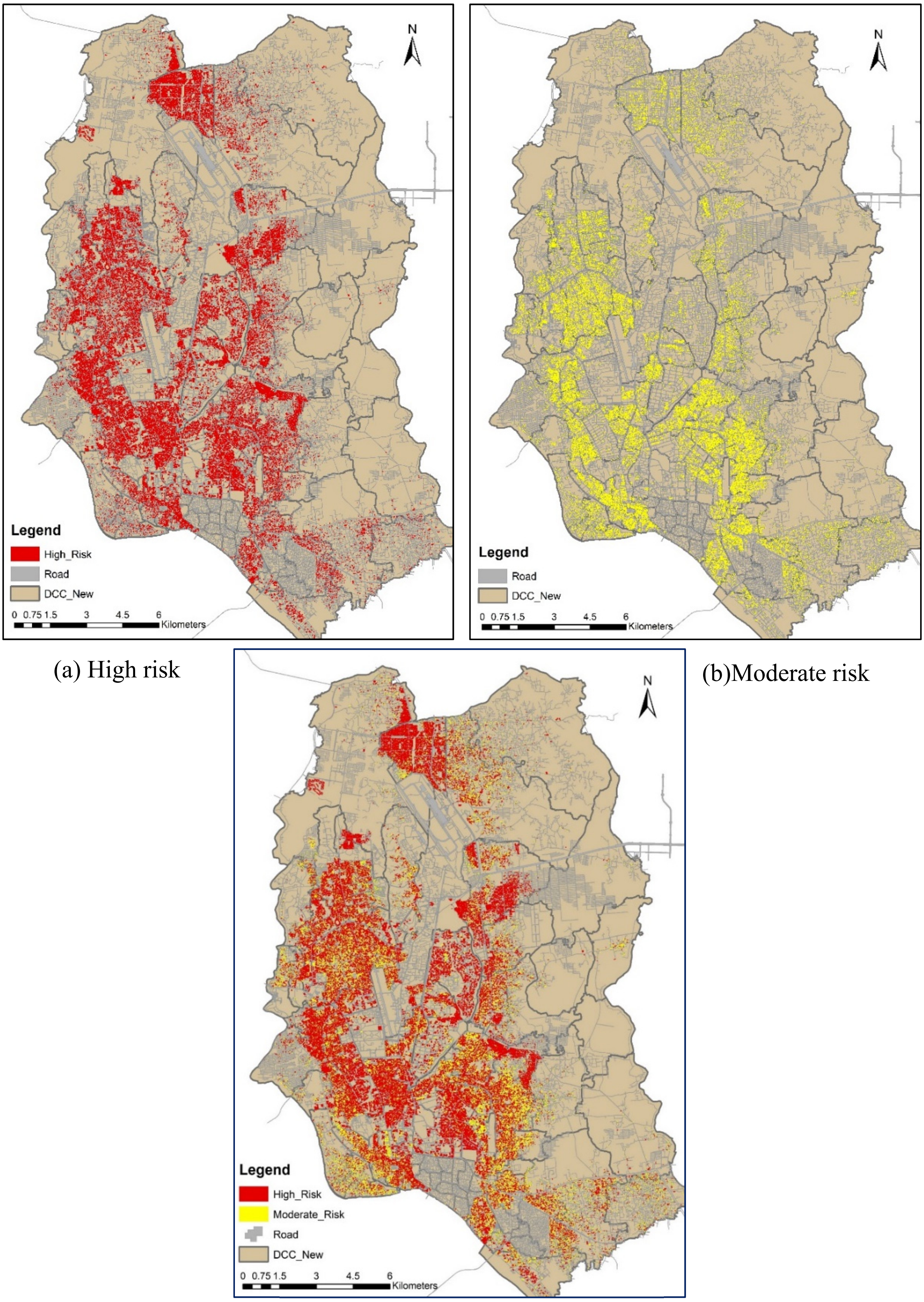
Both of the regression equations deliver negative values for some buildings after applying to the building portfolio. Regardless, the gradation of values from negative to positive actually represents the condition of buildings from high risk to low risk. Considering the negligible percentage of negative values (2.69% for the first equation and 1.02% for the second equation), they have been considered for this research.

Risk scenario for these two equations shows a quite different outcome. Table 3-5 shows the distribution of buildings according to the risk classification for the two regression equations. The risk classification is modified to fit the context of the equations that provides negative values.

Table 3.5: Distribution of RC buildings according to risk classification for Alternative 1

Category	Classification range	Eq. 2	Eq. 3
High risk	<0.3	53.9%	99.96%
Moderate risk	0.3-0.6	46.1%	0.04%
Low risk	Above 0.6	0%	0%

Since, application of both of the equation for this alternative provide some negative values, the classification range for 'high risk' has been modified to fit the study. Ideally, it should be 0-0.3 for high risk buildings. For this alternative, range for high risk classification is set to <0.3. No building falls in low risk class after applying both of the equations to all the buildings. It was hypothesized that, consideration of building age as a deteriorating factor in the estimation method might show greater variation. However, application of equation 3 that considers building age, shows that almost all the buildings falls under high risk, which might not be a true depiction of real situation. Incorporation of age in the estimation should have provided a better result as per hypothesis. Low R^2 value for this model might contribute to the fact that, data type of age group as a categorical variable might not be effective in this model. Considering these issues, equation 3 has been nullified from the study and only equation 2 will be addressed as alternative one. The risk classification map for alternative one is shown in Figure 3.3. And the risk classification map for alternative two is shown in Figure 3.4.

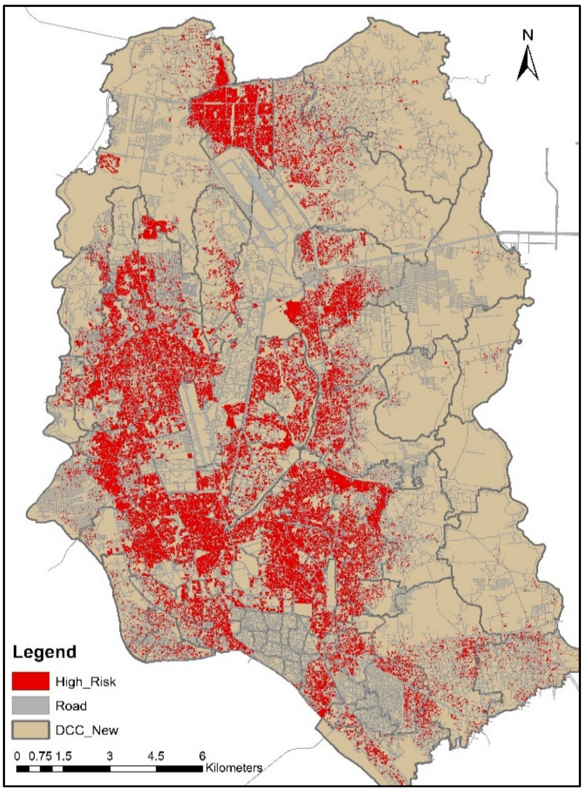


(a) High risk

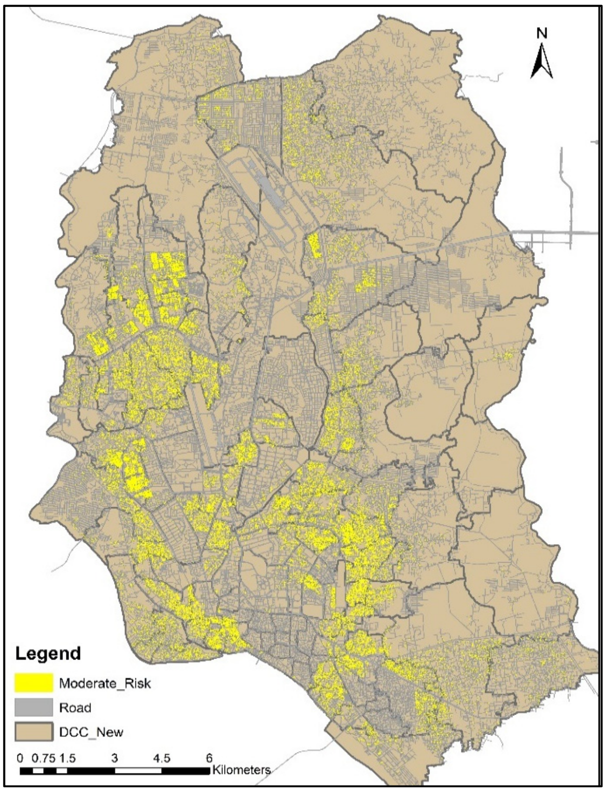
(b)Moderate risk

(c) Overall scenario

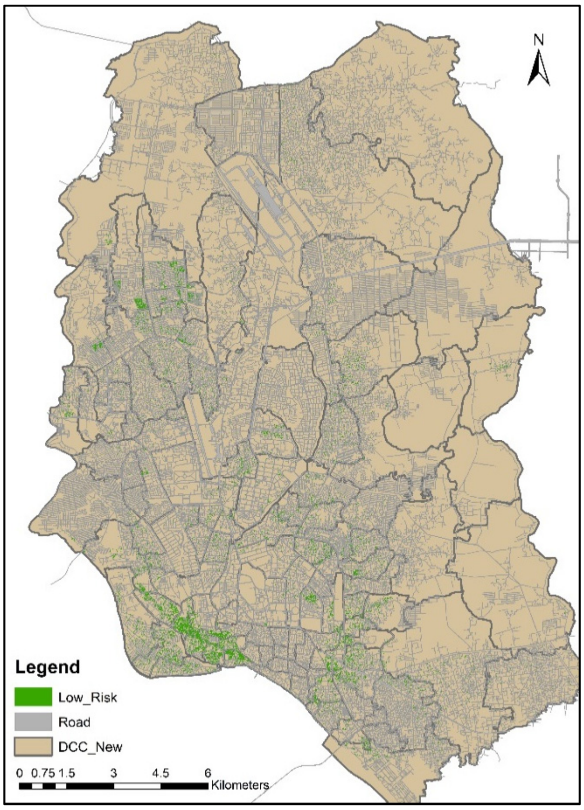
Figure 3.3: Seismic risk map in each risk level for Alternative one



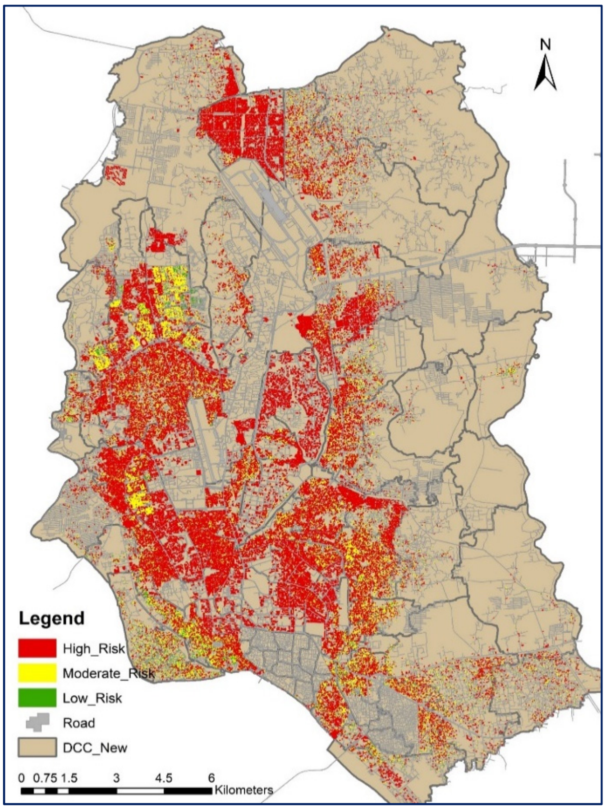
(a) High risk



(b) Moderate risk



(c) Low risk



(d) Overall scenario

Figure 3.4: Seismic risk map in each risk level for alternative two

3.5.2. The second alternative: Basic equation

The equation for this alternative was also been applied to the building stocks of Dhaka city as alternative one to predict seismic capacity index for all the buildings. At first, column area ratio and wall area ratio were predicted for each building by using equation (7) and (8). Then equation (4) is applied to the building stock. After the application of equation (4), I_s value for this alternative showed a variation of values ranged from 0.001 to 11.731. Value above 1 can be considered as outlier value. There are about 2500 buildings with I_s values above 1 which is about 2.35% of the total share of buildings. Unlike alternative 1, there are no negative values associated in this alternative. Table 3.6 shows the classification range of the buildings based on I_s values along with their distribution in each category, where buildings fall under three different classification ranges from high to low risk.

Table 3.6: Distribution of RC buildings according to risk classification for alternative 2

Category	**Classification range**	**% of buildings**
High risk	0 - 0.3	56.26%
Moderate risk	0.3 - 0.6	36.87%
Low risk	Above 0.6	7.87%

3.6. Discussion for Estimation Method

3.6.1. Determination of suitable method

Application of the two different alternatives shows varied result from each other despite having some similarities. Both of the alternatives show higher percentage (alternative 1- 53.9%, alternative 2- 56.26%) of buildings under high risk throughout the city, although alternative 2 shows greater variation than alternative 1. Unavailability of any hands-on way to check the reliability of the methods leads to the confusion in determining the better model among the two. With this limitation, the most fitting method to estimate I_s can be determined by considering R^2 and standard error of estimates for both of the models.

The difference in modelling the two applied methods to estimate I_s do not facilitate the application of R^2 value to measure the precision of the models. Hence, standard error of estimate became the deciding factor to determine the better estimation method for I_s. Standard error of estimates, generally denoted as S, is a measure to understand the approximate size of estimation errors in a dataset. Smaller value of S is supposed to provide with better estimation.

For the purpose of the study, standard error of estimates, S has been determined by considering the residuals of the data set. Table 3.7 shows the error values for both of the alternative methods. The values of S for both of the methods imply the fact that alternative 1 provides more precision for the estimation of seismic capacity index, I_s with a lower value of S than alternative 2. Therefore, alternative 1 is the method that can provide a better vulnerability scenario of Dhaka city for the purpose of the study.

Table 3.7: Determination of precision using S

Alternatives	Standard Error of Estimates, S
Alternative 1- Estimation by variable	0.118
Alternative 2- Estimation by using basic equation	0.144

3.6.2. Suitability of the method

The selected alternative to estimate seismic capacity index was estimated by applying regression analysis. Before accepting the model, it requires to be evaluated. For further acceptability, there are certain assumptions that are needed to be met. The regression model for this research was generated by using SPSS, a statistical software that allows the model to be evaluated as well as facilitates the checking of assumptions.

3.6.2.1. Evaluation of the model

Easier way to evaluate the model is to check R^2 value and P-value. R^2 is a statistical measure that explains the variability of the independent variables to the dependent variable. Range of R^2 value is between 0% to 100%. Lower value indicates lesser variability of the model to the explain data and vice versa. This model generates R^2 value of 0.371, which means the independent variables expresses the dependent variable by 37%. And, there might be other variable that might express the dependent variable by rest of 63%.

And, P-value is generally express the significance of the model. If P-value is less than 0.05, the model can be considered statistically significant. It expresses the likelihood that the independent variables are able to provide a true prediction which is more than a chance. In this case, P-value is 0.000, that expresses statistical significance of the model. P-value is observed from an ANOVA table which is table 3-8.

Table 3.8: ANOVA table

ANOVA[a]						
Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	9.865	2	4.933	170.578	.000[b]
	Residual	16.743	579	.029		
	Total	26.608	581			
a. Dependent Variable: Seismic Capacity Index						
b. Predictors: (Constant), No. of floors, Zscore: Area covered in m2						

3.6.2.2. Assumption testing

- <u>Assumption 1: No multicollinearity associated with the variables</u>

  The word ‘multicollinearity’ denotes a condition where the independent variables (two or more) in a multiple regression model are highly interrelated or corelated with each other. Here in this research, Pearson correlation and tolerance, VIF has been checked to identify if multicollinearity is present between the independent variable.

  Table 3.9 shows the degree of correlations of the variables with each other. It shows that both of the independent variables are related with each other to some extent. Despite having some relation with each other, this does not imply multicollinearity. Because, the value of correlation between the independent variables need to exceed 0.7 to be implied as multicollinearity. In short, there is no multicollinearity between the independent variables that might affect the regression model.

Table 3.9 Correlation of the variables

Correlations				
		Seismic Capacity Index	Zscore: Area covered in m2	No. of floors
Pearson Correlation	Seismic Capacity Index	1.000	-.421	-.571
	Zscore: Area covered in m2	-.421	1.000	.395
	No. of floors	-.571	.395	1.000

Another way to check multicollinearity is by checking on tolerance and VIF. Tolerance value for an independent variable indicates how much variability of that specified variable is not explained by other independent variable in the model. If tolerance value for an independent variable is very small (<0.1), then it is assumed that there is high multicollinearity. As for VIF, if its value is higher (generally >10), then it indicates multicollinearity. Collinearity statistics of Table 3.10 represents tolerance value and VIF for each independent variable where it is clear that this model does not have issues related to multicollinearity.

Table 3.10: Coefficients table for the model

Model	Unstandardized Coefficients		Standardized Coefficients	Sig.	Correlations			Collinearity Statistics	
	B	Std. Error	Beta		Zero-order	Partial	Part	Tolerance	VIF
(Constant)	.574	.023		.000					
Zscore: Area covered in m2	-.050	.008	-.231	.000	-.421	-.259	-.213	.844	1.185
No. of floors	-.057	.004	-.479	.000	-.571	-.485	-.440	.844	1.185

- Assumption 2: The values of the residuals are independent

  This assumption checks the independency of the residuals. For this research, it has been checked by Durbin-Watson statistic test. The value for this statistic can vary from 0 to 4. If the value is below 1 and over 3, then generally it is a concern about the validity of the model. Value of Durbin-Watson statistic for this model is 1.666. So, there is no concern with this assumption as well.
- Assumption 3: Homoscedasticity

  This assumption implies that the variance of residual value or error should be the same across the points of independent variable. It can be understood by the scatterplot where the standardized predicted values are plotted against standardized residual values. Figure 3.5 presents the scatterplot that shows slight heteroscedasticity. It might have a little effect on significance tests [7].

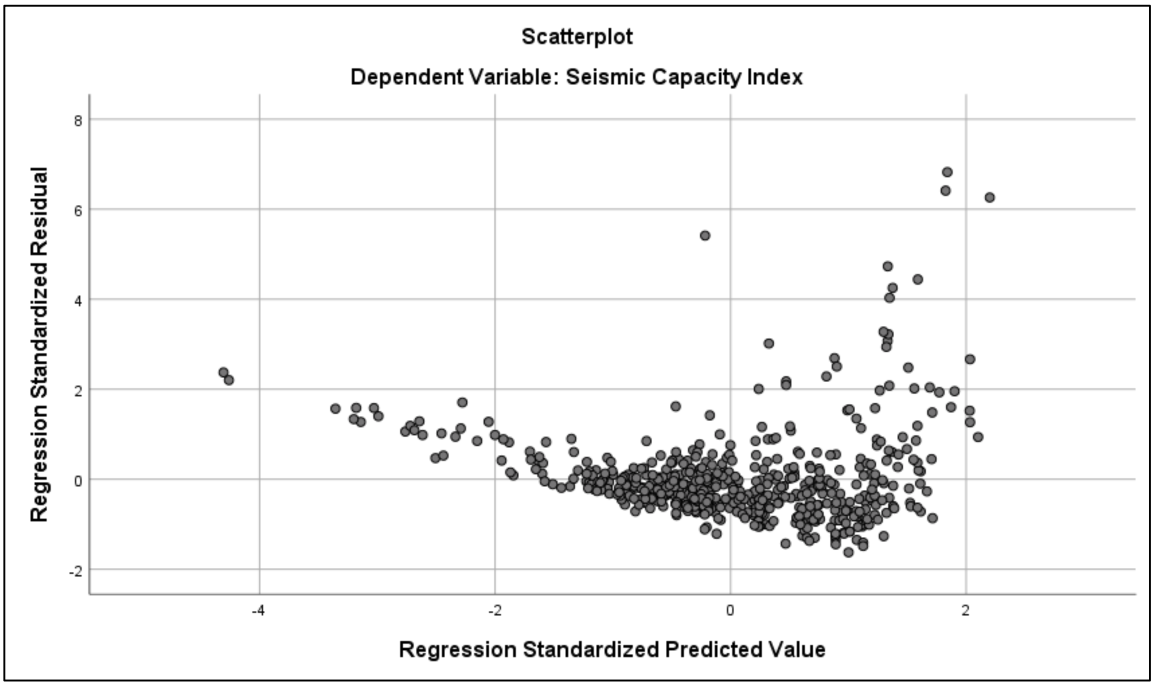


Figure 3.5: Scatter plot of the model

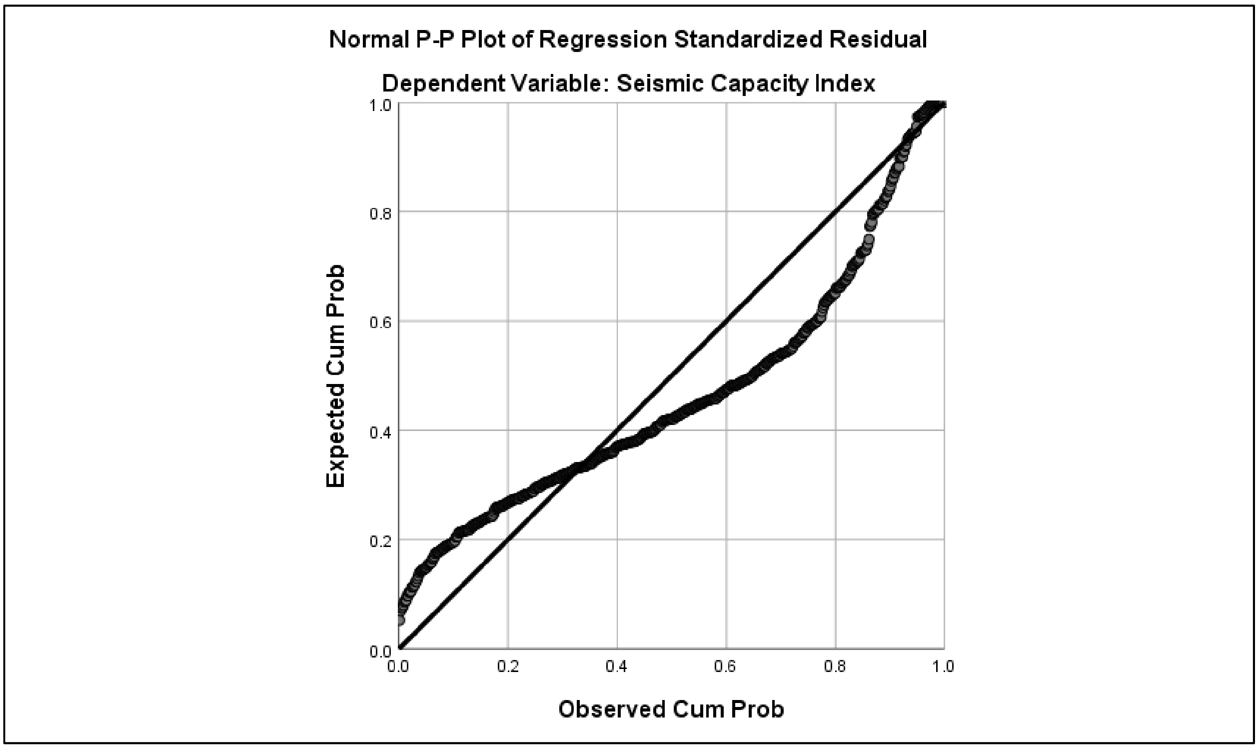


Figure 3.6: P-P plot

- Assumption 4: Normal distribution of residual values

  Another assumption for multiple linear regression model is that residual value of a regression model will be normally distributed. It can be observed by a P-P plot. In the plot, the dots need to be closer to the diagonal line for the distribution of residual values to be normal. The closer the dots are to the diagonal line, the more it implies the facto of the residuals being normally distributed. In Figure 3.6, which shows the P-P plots, it can be seen that the lines are not touching the line but they have the tendency to remain close to the line.

- Assumption 5: No cases that influence or create bias within the model

  This assumption points out the presence of any case in the dataset that might influence the model. If such case in presented, then those case must be eliminated for the model to be more accurate. This can be checked by using Cook's distance. Any value over 1 indicates the likeliness to be a significant outlier that might be influential for the model. In this research, the value minimum value is 0 and maximum value is 0.144. So, there is no specific cases that might require to be removed.

3.7. Vulnerability Scenario of Dhaka City

Vulnerability scenario has been developed in two ways. Firstly, buildings are classified at different risk levels according to their seismic capacity index. Secondly, the wards are classified into different risk levels by the distribution of buildings.

3.7.1. Risk classification by buildings and their density

3.7.1.1. Building performance

Vulnerability scenario by risk classes can provide a better understanding of the risk condition of built-up spaces for the city. Figure 3-8 shows the overall risk condition for RC buildings of Dhaka city according to alternative 1 which is decided to be the final estimation model. This map is a composite map showing risk condition of buildings by the classification groups.

As shown in table 3-5, there is no building that falls under low risk according to the Japanese classification method. This might suggest that, the buildings are actually weaker to withstand a high magnitude earthquake in the context of Dhaka city.

The visual presented by figure 3.7 suggests a northward distribution of buildings under both of the risk conditions. Historical growth of the city suggests that Dhaka started to traverse from the southern part and gradually expanded towards the northern part. Similarly, distribution of buildings by risk classifications across the city almost shows the gradual high to low degradation. Exception can be seen in the northmost ward. Another observation is that, high risk buildings are mostly located along the main arterial roads which is also similar to the city's general tendency of construction growth along the main arterial roads. It is worth mentioning that, the trend of the city's expansion towards northward direction is because of the tendency to follow the roads.

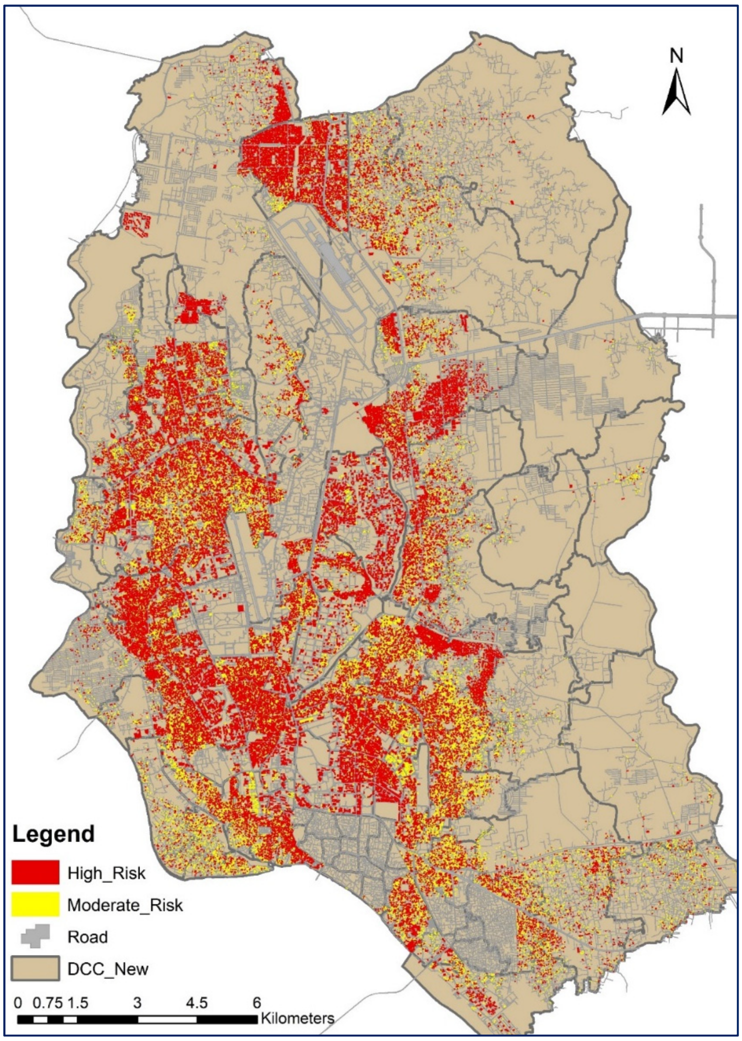


Figure 3.7: Risk classification map of Dhaka city

3.7.1.2. Classification of wards by risk level

To understand the risk from spatial point of view, it is necessary to assess risk by the city's administrative level. Hence, creating a choropleth map can help in assessing the overall vulnerability of the at ward level. Figure 3-8 represents the formed choropleth map that helps to understand the vulnerability condition of the map at a glance. Some specific considerations were applied in the creation of the map.

1. Risk is classified according to building density of the buildings that falls under high risk according to alternative 1. Here, building density is defined by the number of buildings per unit area.
2. The wards are classified into four categories with a color gradation depicting 'low' to 'very high' risk. The 'low' and 'moderate' risk areas are the less vulnerable wards that contain lesser number of buildings that are estimated to be under high risk. 'Very high' and 'high' risk areas are the vulnerable wards with comparatively greater number of buildings that falls under high risk.
3. Each of the four classes contains an equal number of features so that the proportion of buildings to ward area remains uniform.
4. It needs to be mentioned that, there are some wards with no color as they are the ones that do not have any building information in the current dataset (also applicable for figure 3-7).

The figure shows the distribution of wards under differing risk condition. It depicts that the eastern part of the city is safer, while rest of the city falls under damage risk. However, figure 3-8 contains the unions that are added newly and those unions are not distributed into wards while the database was received. To go on in further analysis, the old city corporation area has been considered and the distribution of wards has been shown in figure 3-9.

Table 3.11 represents the wards that falls under high risk for both of the city corporation areas. Both of the city corporations share almost the same number of wards under high-risk condition. The wards listed in the table are the ones with higher density of buildings within their areas. So, in the occurrence of an earthquake, these wards would be the most vulnerable under area wise assessment. To reduce the probable earthquake damage risk, the buildings of these wards can be considered first for the purpose of retrofitting with further progression.

The wards that are vulnerable to high building damage risks are mostly located in the functional region of Dhaka city. The wards that are newly added to the city corporation areas are mostly under relatively low vulnerable areas.

Table 3.11: Distribution of wards under high risk condition

Name of city corporation	**Ward no.**	
	Very high risk	**High risk**
DNCC	01, 03, 07, 12, 14, 22, 29, 30, 31, 32, 34, 35	02, 05, 11, 13, 16, 18, 19, 21, 23, 25, 26, 36
DSCC	01, 12, 13, 16, 17, 23, 25, 26, 28, 29, 30, 44	02, 03, 04, 06, 07, 09, 15, 19, 27, 39, 45, 47, 48

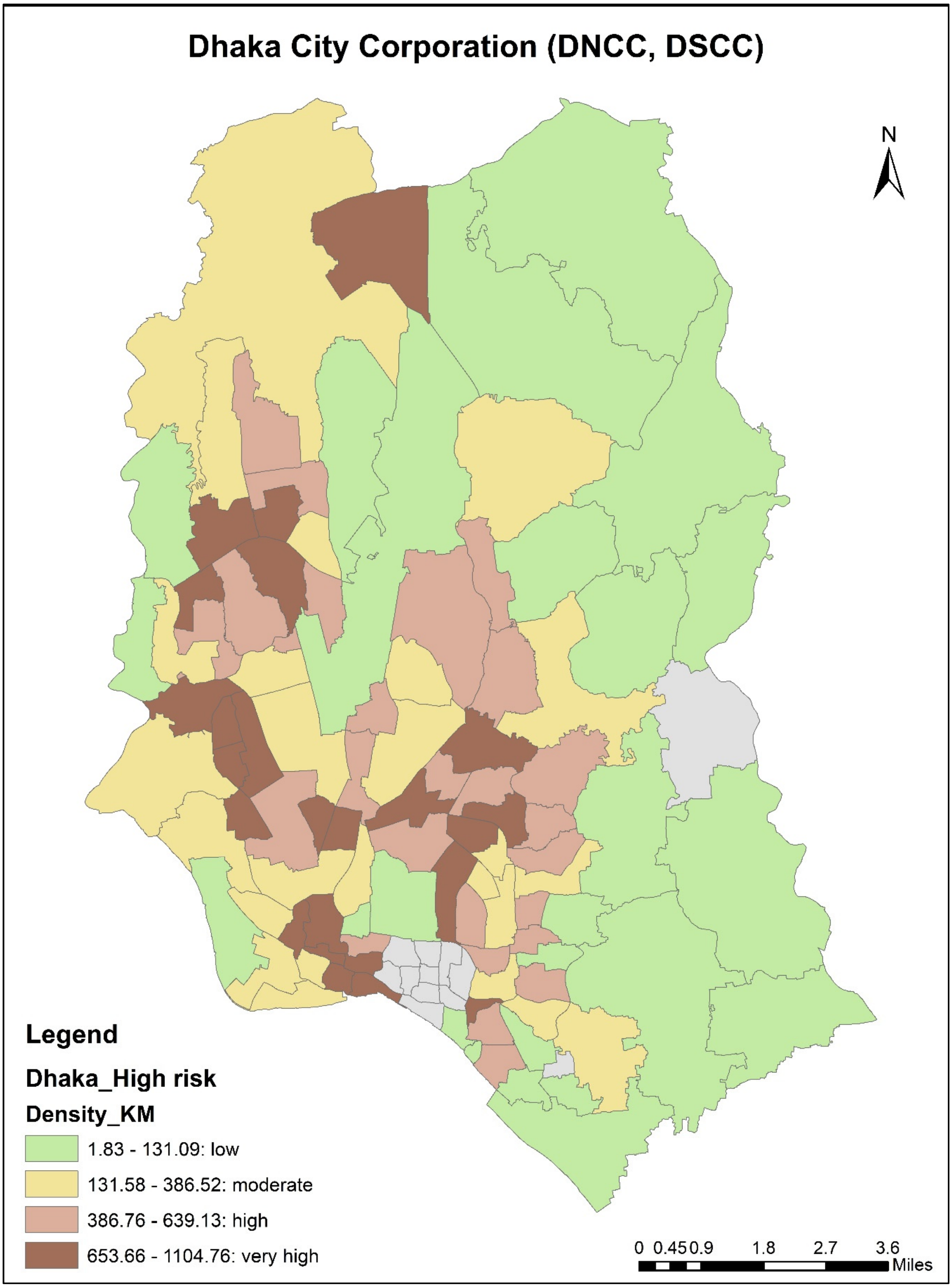


Figure 3.8: Vulnerability at ward level for the high-risk buildings of Dhaka city

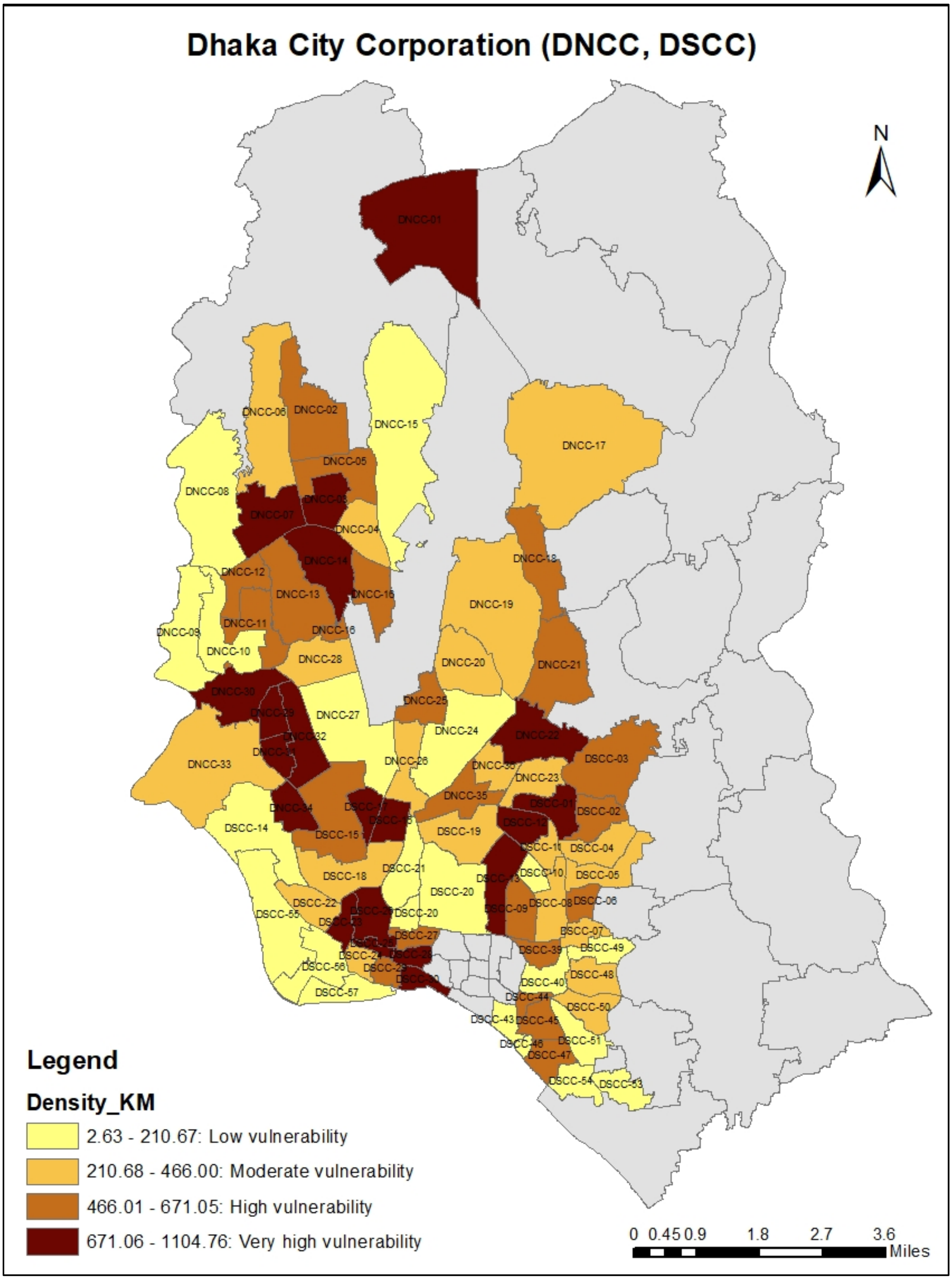


Figure 3.9: Vulnerability at ward level for the high-risk buildings of old Dhaka City Corporation area

3.7.2. Risk classification by emergency response difficulties

Seismic vulnerability of a city depends not only on structural performance of the buildings of the city, but also on other facilities related to city. Especially, Dhaka city is under high vulnerability for housing a large population and buildings for accommodation within its small area. The constructed buildings not always followed the building construction rules by BNBC causing concern in terms of seismic safety. Apart from this, lack of awareness among people is also a rising concern for the after effect of earthquake as it is directly related to a city's emergency response system. Accessibility, evacuation capacity, rescue activities, disaster response of medical facilities are also some of other important issues that define a city's resilience spectrum.

A new methodology has been proposed under this project [3] to figure out the process of simplifying seismic response capacity issues of Dhaka city. They shaded light on this problem and intended to assess Dhaka's physical seismic emergency response capacity, identifying places where emergency seismic response capacity is lacking and mitigating actions such as emergency risk response, evacuation, and rescue are required. The author tried to assess this aspect of emergency response capacity using five defining indicator that are mentioned below:

1. rescue and evacuation accessibility,
2. emergency evacuation capacity in open space,
3. rescue capacity by firefighters and community volunteers,
4. availability of emergency medical facilities, and
5. evacuation capacity of temporary shelters

The above indicators address emergency response spectrum at widespread urban level. Each of these indicators can be considered crucial for post disaster response comprehensively. In the above-mentioned study, rescue and evacuation accessibility is ideally a measure of road width, emergency evacuation capacity in open space is a measure of population coverage in open space, rescue capacity by firefighters and community volunteers is a measure of locally available resources for emergency rescue works, availability of emergency medical facilities is a measure of surrounding medical help available and evacuation capacity of temporary shelters is a measure of nearby public buildings as temporary shelters.

Five maps has been prepared showing risk level of each corresponding indicator[3]. The considered indicators were combined in a comprehensive emergency response map.

Two units of study for assessment was used in that research. The authors divided Dhaka City Corporation area into 666 grids in the first unit. Each grid has an area of 500 m × 500 m. These grids were used to analyze seismic emergency response capacity of the city and make prioritization of areas that needs attention to receive resources for improving their infrastructure regarding emergency response. In the second unit, the DCC area were divided based on the sub-districts of the city into 32 'area's; locally known as 'thana'. All of the indicators were assessed in the grid assessment and comprehensively a risk assessment map of the city has been developed by the authors.

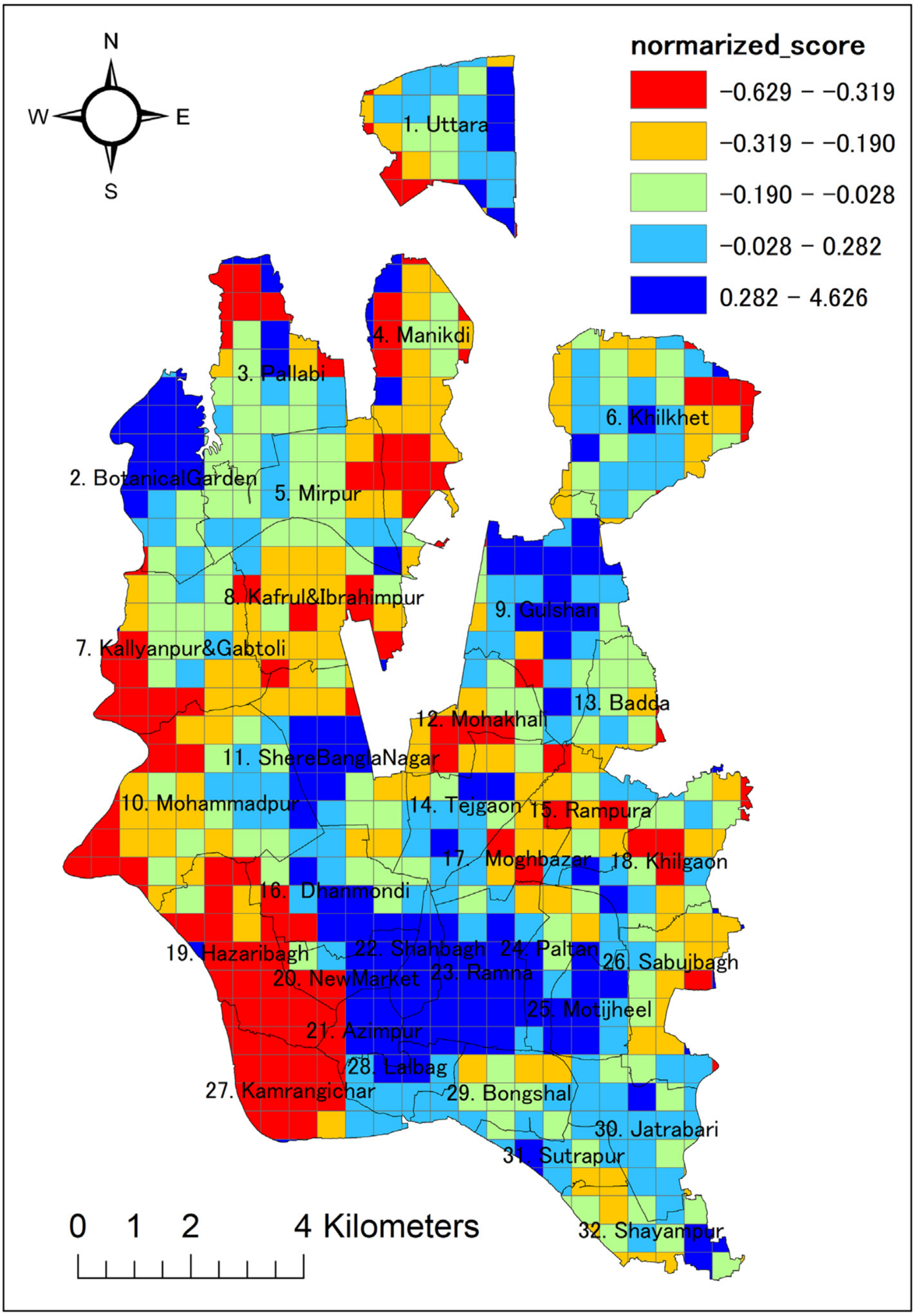


Figure 3.10: Comprehensive risk assessment based on emergency response capacity-grid (Omar, Matsuyuki, Das and Ubaura, 2021)

Figure 3-10 shows the comprehensive risk map of the city's emergency response capacity to envisage risk of grids/areas combinedly. Color gradation shows the condition of each grid; red color depicts the areas with lower overall capacity while blue color represents higher overall capacity. This map is a combination of figure 3-11, 3-12, 3-13, 3-14 and 3-15.

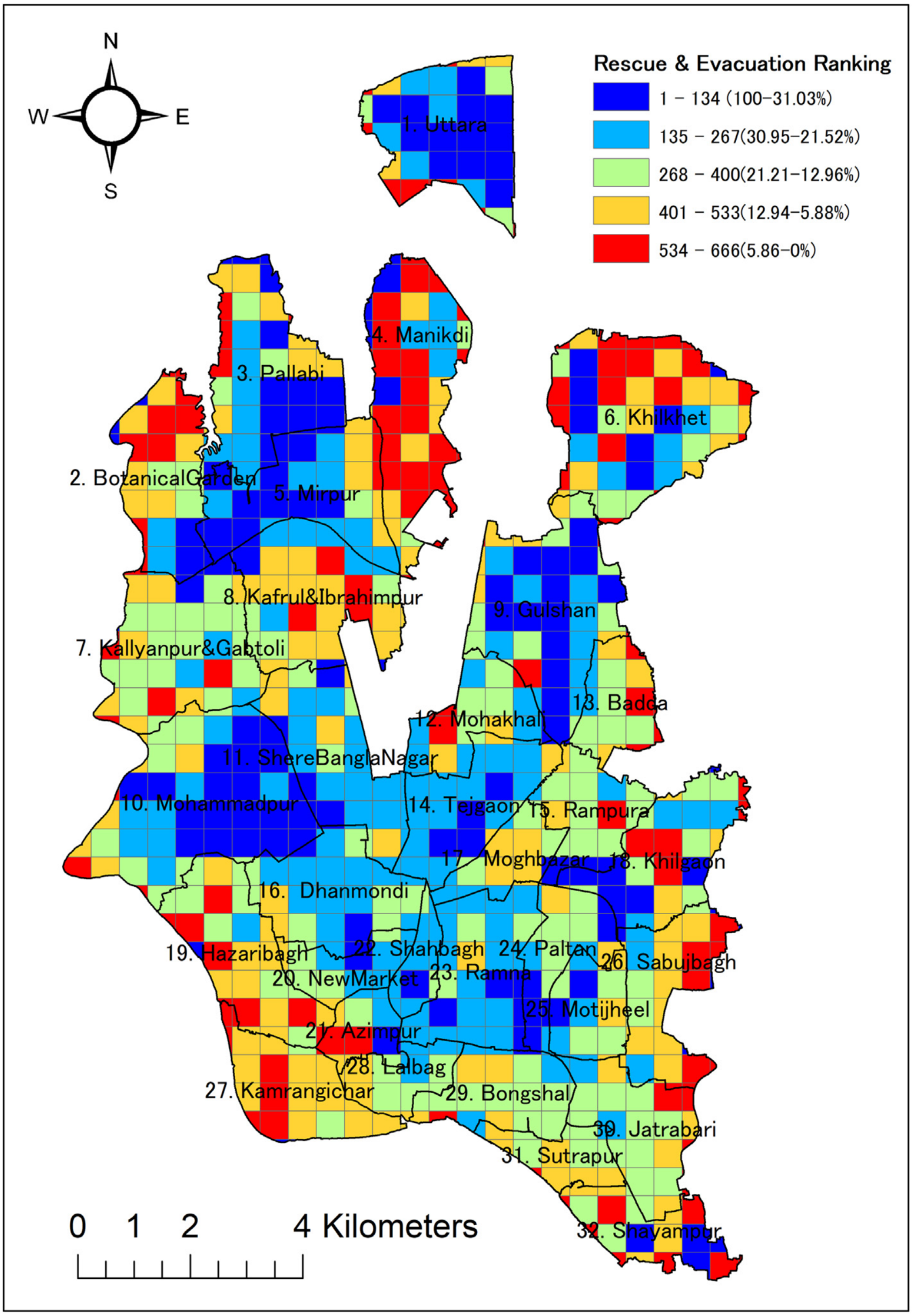


Figure 3.11: The accessible area ratio (AAR); (Omar, Matsuyuki, Das and Ubaura, 2021)

The accessible area ratio map shown in figure 3-11 provides the vision on accessibility condition of the grid areas considering road width. According to the author, Sabujbag, Kamrangichar, and Hazaribagh, in the southern part of Dhaka, have the lowermost accessible areas which are represented by the grids AAR value. On the other hand, Uttara, Mohammadpur, and Gulshan are the less risky areas in terms of accessibility.

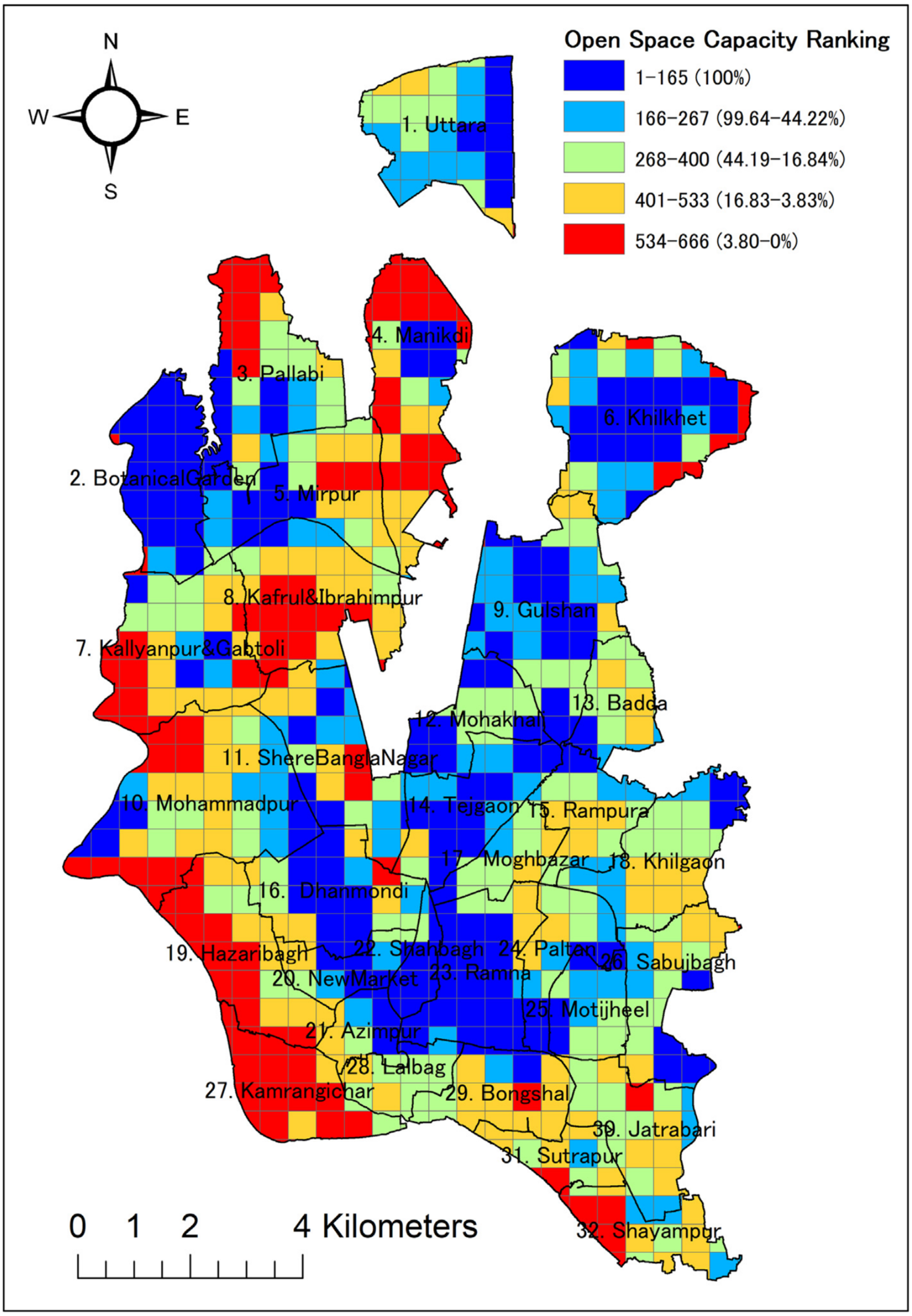


Figure 3.12: Population coverage ratio (PCR) by open space (Omar, Matsuyuki, Das and Ubaura, 2021)

The map in figure 3.12 shows population coverage ratio with open space as an indicator. Acoording to the author's opinion, Sutrapur, Shayampur, Hazaribagh, and Kamrangichar in the southern part of Dhaka possess high risk. On the contrary, middle part of the city that includes Ramna, Shahbagh, and Azimpur, have spacious parks and open spaces, making them lower-risk areas.

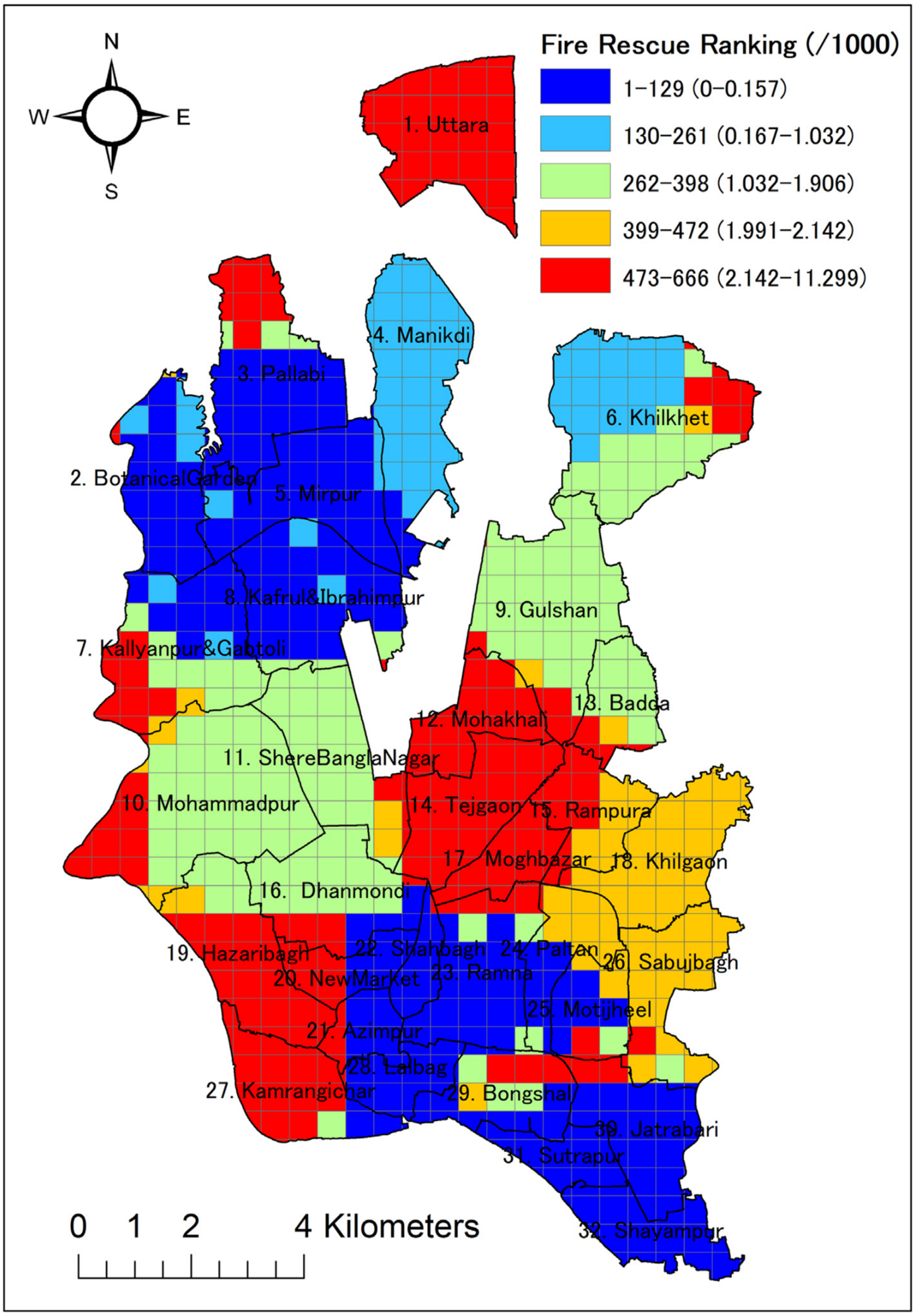


Figure 3.13: Population coverage ratio (PCR) by firefighters and community volunteers (Omar, Matsuyuki, Das and Ubaura, 2021)

The map in figure 3.13 shows population coverage ratio with firefighters and community volunteers as an indicator. Kamranguchar in the western part of Old Dhaka, is a high-risk area because of existence of no fire station and high population density. Lalbag, Bongshal, and Sutrapur in Old Dhaka, are low-risk areas.

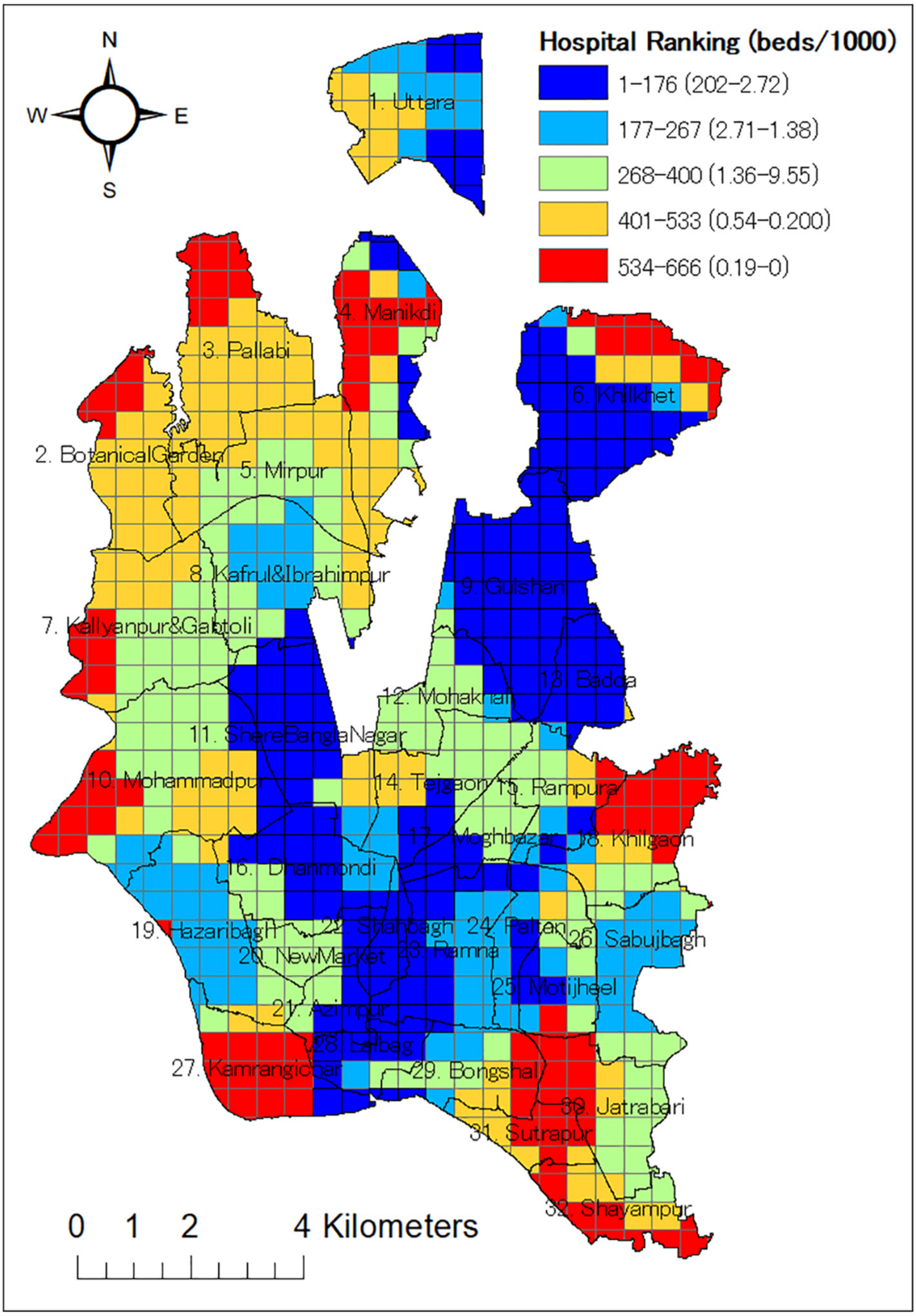


Figure 3.14: Population coverage ratio (PCR) by hospitals (Omar, Matsuyuki, Das and Ubaura, 2021)

Figure 3.14 shows population coverage ratio with hospitals as an indicator. This was done by finding out beds available for 1000 person. Shahbagh, Sher e Bangle Nagar, Dhanmondi areas are at lower risk because of a number of large government hospitals and private hospitals. Shayampur, Pallabi, and Sutrapur are at high risk due to opposite reasons.

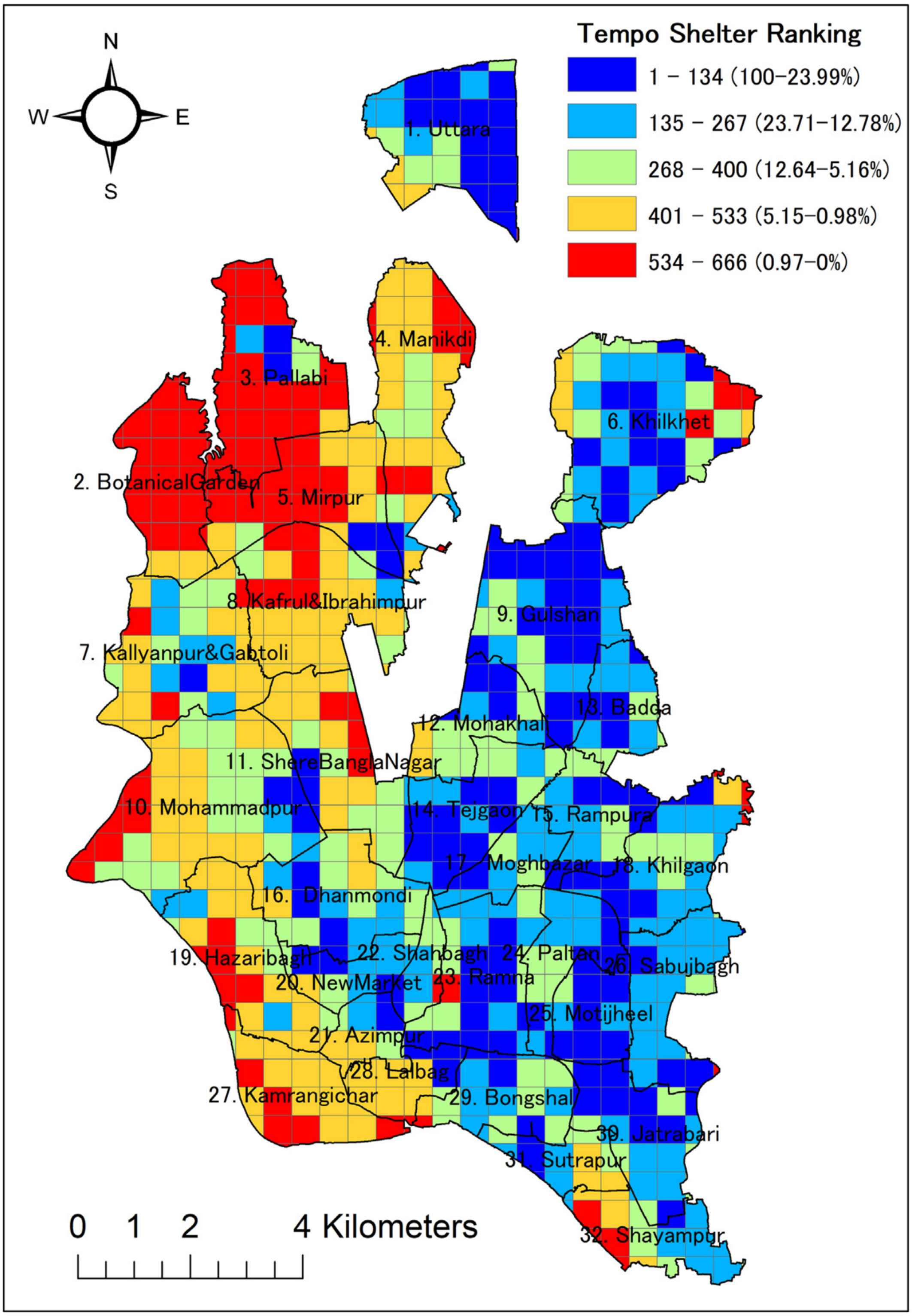


Figure 3.15: Population coverage ratio (PCR) by temporary shelters (Omar, Matsuyuki, Das and Ubaura, 2021)

Figure 3.15 shows a map showing PCR by means of the proposed evacuation shelters. According to the author, "the eastern part of Dhaka has a greater evacuation shelter capacity than the western part."

All these five indicators were combined to produce a comprehensive risk map as it is already shown in figure 3.10. According to the comprehensive result of the indicators, Shahbag, Ramna, Azimpur, Lalbagh, New

Market and Motijheel are the areas that can be considered safe. Mohammadpur, Kallyanpur, Gabtoli, Kamrangichar, Hazaribagh, Uttara and Manikdi are the risky areas; in other wards they are the least safe areas. In an attempt to compare the result of the analysis to real time scenario, the author gathered opinions from experts. These opinions helped in understanding the similarities and differences between methodological result and how the original scenario is perceived.

3.7.3. Comprehensive vulnerability scenario

Vulnerability of a city is not to be considered single-dimensionally. Vulnerability, as it is defined by UNDP, is "the entity of conditions, which are defined by physical, social, economic, and environmental factors and processes, that increases the sensitivity of the societies against the impact of the hazards" [4]. The very basic concept of seismic physical vulnerability expresses seismic performance of a physical element; which can be an individual building of an infrastructure. Social vulnerability expresses vulnerability related to human beings, economic factors express vulnerabilities that are related to probable economic loss related to human and infrastructure and environmental factors expresses the potential impacts on the environmental components upon the occurrence of a disastrous event.

It might be ideal to consider the above mentioned factors while developing a seismic vulnerability scenario for a city. However, the prime emphasis of this chapter is to provide a comprehensive vulnerability scenario that will facilitate decision making aimed at enhancing seismic resiliency by means of improving seismic performance of buildings using retrofitting procedure. A comprehensive vulnerability scenario is expected to provide a probable vulnerability condition of Dhaka city considering multiple factors and variables. These factors and variables should address seismic safety of the urban dwellers from different aspects and help the decision makers in taking optimum level decision related to reduction of seismic damage.

From this viewpoint, density of theoretically structurally weak buildings has been incorporated with factors like evacuation capacity to a wide road, the coverage ratio of evacuation place, evacuation shelter, rescue activities by firefighters and volunteers, emergency medical facilities, accessibility by rescue to develop a comprehensive vulnerability map. This has been done in ward level to advocate some wards or localities that might need more attention to improve seismic resiliency of the city. One of the approaches to improve seismic resiliency of the city is to retrofit the buildings of the wards that are deemed to be more vulnerable in the vulnerability scenario.

The process of preparing this comprehensive map involved the interpretation of grid-based results from a research under this project[3] to ward level outcome. It is necessary to understand the emergency capacity result in ward level to prepare a map that represents the city's condition at a glance in the smallest administrative units of the city. This will provide an outline to the policy makers in order to carry out capacity improvement activities at ward level. Figure 3.16 represents the grid-based comprehensive risk assessment map based on emergency response capacity in figure 3-10 to ward based comprehensive risk assessment map.

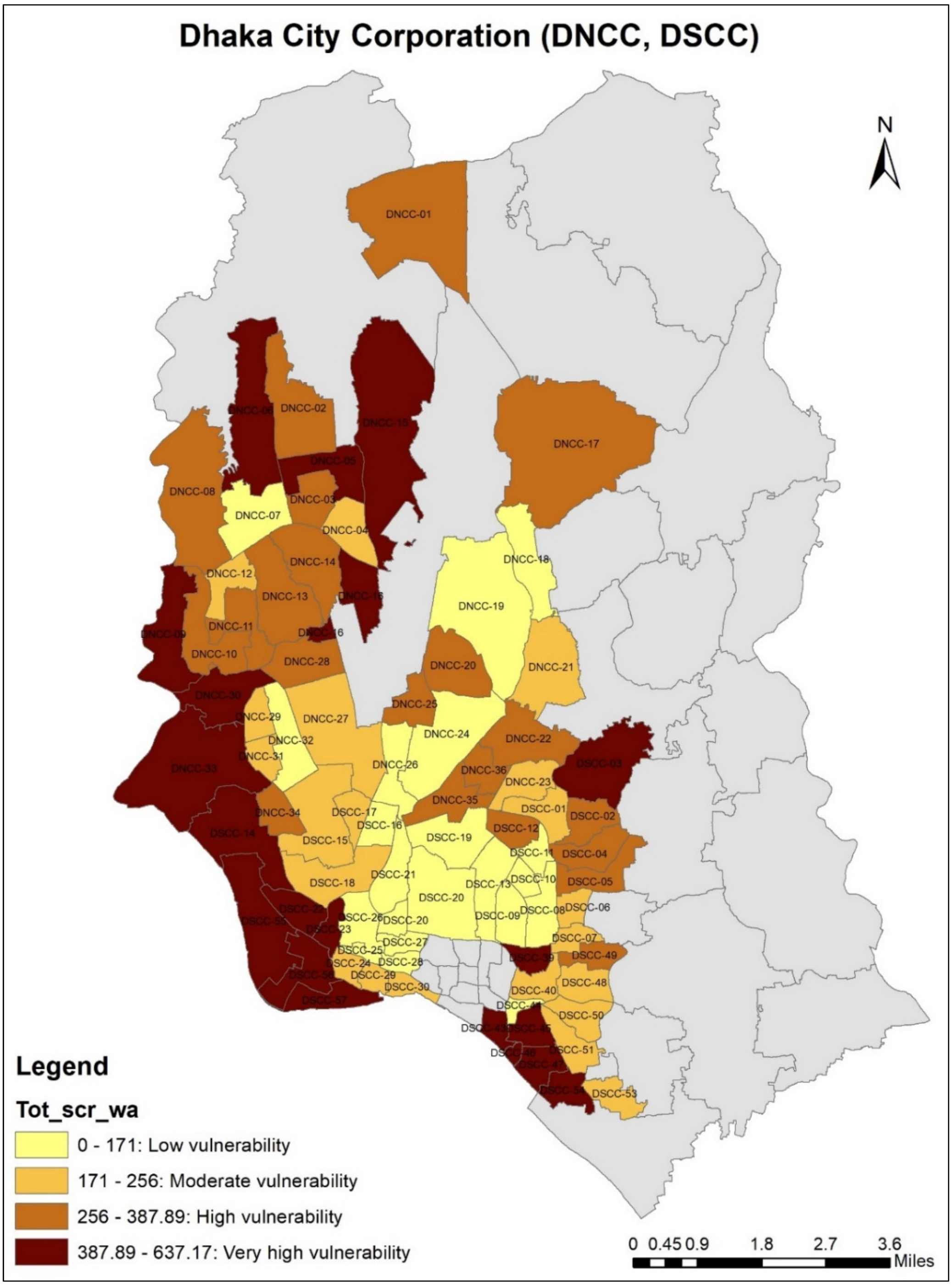


Figure 3.16: Comprehensive risk assessment map at ward level based on emergency response capacity

The development of comprehensive map has been developed by giving equal weightage to building density of the buildings under high risk and the indicators of emergency response facilities. This has given more weightage to building related parameter. In both cases, wards have been categorized in four vulnerability categories. This facilitated easier distribution of weightage for the categories. This overall ward level vulnerability scenario has been developed to facilitate the policy makers in making retrofitting decisions for the buildings in urban level considering multiple aspects.

In the comprehensive map, vulnerability of each ward is determined by a score that represents level of vulnerability of a specific ward. The new comprehensive map divided the wards into three different categories based on their level of vulnerability; high vulnerability, moderate vulnerability and low vulnerability.

The overall comprehensive map has been developed based on the ward formation before bifurcation. This has been done to unify the two vulnerability maps based on their data availability. Among these 83 wards (reduced from 112 wards), there are 14 wards under high vulnerability, 41 wards under moderate vulnerability and 28 wards under low vulnerability as it is shown in figure 3.17.

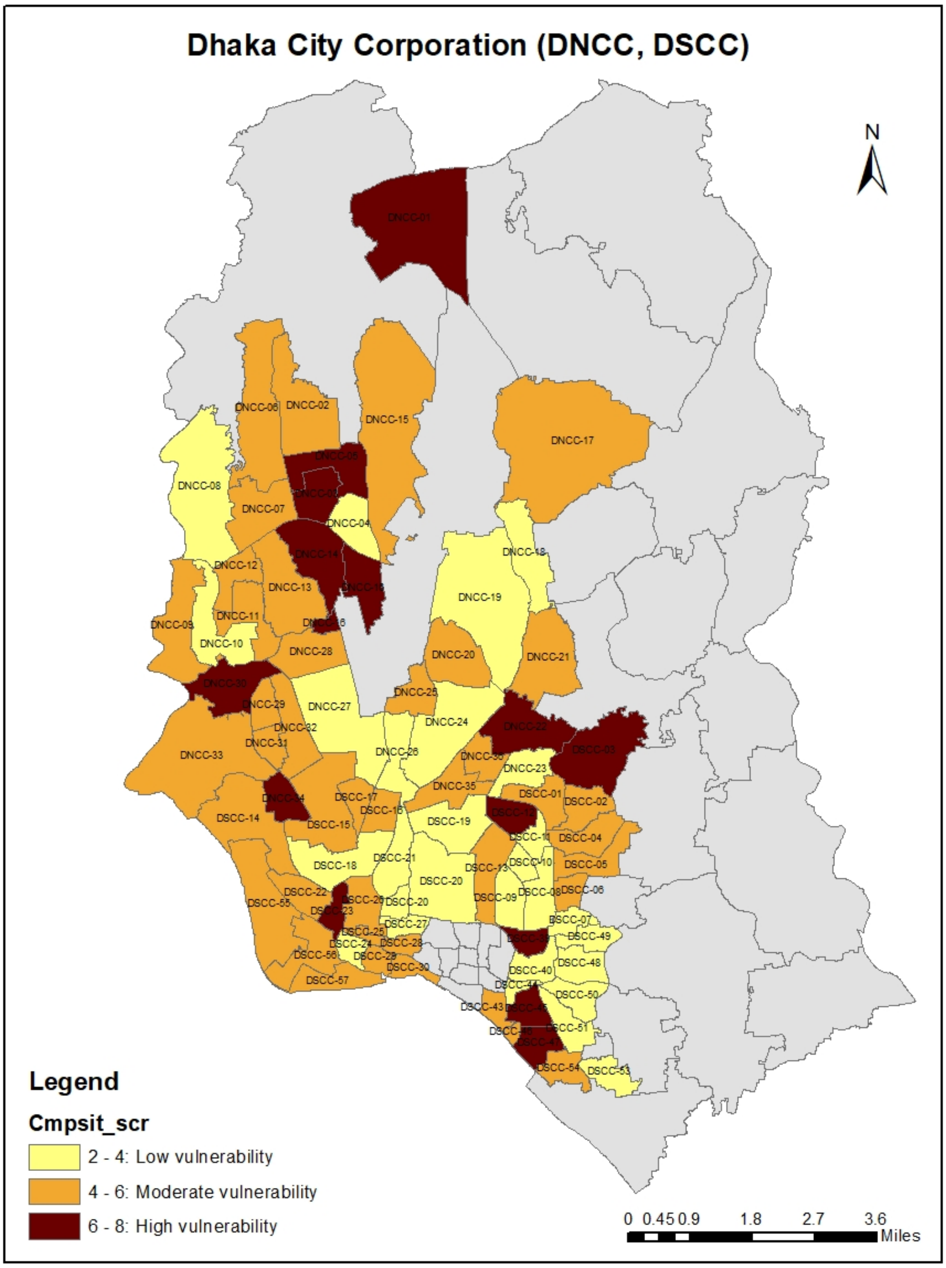


Figure 3.17: Comprehensive vulnerability assessment map

3.8. Limitations

This study has attempted to develop a model that provides a tentative idea about seismic performance of a building. To have an outline about the seismic performance of the city's buildings to improve resiliency of the city by using retrofitting technique, it is needed to know the seismic performance of the buildings. And it is nearly impossible to put all RC buildings of Dhaka city under screening procedure to determine their seismic performance. In the process of developing the vulnerability scenario, a statistical method has been applied. The result of the scenario cannot be stated as accurate. However, this research is not beyond limitations. There are a number of limitations associated with the progress of the research. The following are the major limitations encountered during the progress of the research.

a. All buildings over 3 stories have been considered as RC buildings:
   There are approximately 600,000 buildings in Dhaka city and there is no database that provides with the information of each buildings structure type (eg: URM, masonry etc.). And there has been no other effective way to figure out the RC buildings in the existing database. Hence, this assumption has been taken. This has facilitated working with the assumed RC buildings. On the other hand, this has also eliminated a number of low-rise RC buildings. Lack of details in building database limited the scope of a more detail-oriented building study while considering the performance of buildings during earthquake.

b. A relatively small size of sample:
   According to statistics, 582 sample buildings are adequate for further statistical analysis. Despite this, it has been observed that with a greater number of samples, the derived model shows more acceptability. Since, the samples are scattered throughout the city, distribution of the samples are not uniform. Also, for storey-based analysis, some specified types of buildings have a really small number of samples. Distribution of buildings based on storey also effected the analysis process.

c. Inconsistency in some building data:
   While exploring the buildings of the dataset, it was found that a good number of buildings held the same information under them. As a result, some wards of Old Dhaka couldn’t be considered for vulnerability scenario. And, for other wards, those identical building data couldn’t be considered in the process which in fact affected the result.

3.9. Conclusion

The fact that Dhaka is highly vulnerable to earthquake in the present context of Bangladesh, is becoming a rising concern. It is important to try and reduce the probability of damage as much as possible by seismic retrofitting; as it is proved more effective that demolishing and rebuilding. Prioritization strategy for seismic retrofitting can help in finding the buildings in need of retrofitting. This research provides a prioritization framework to start with seismic risk mitigation attempt. Understanding seismic performance of a building can provide only a single dimension approach in seismic retrofitting which might not be efficient as an approach prioritization. Considering these issues, this research attempt to develop prioritization framework of buildings while considering the effect of damage at city-wide level and also on each kind of building occupancy. Development of a method to find out seismic capacity of buildings with easily available data, understanding damage potential within the administrative areas of the city and recognizing the importance of buildings by occupancy classes are the foundation of preparing a prioritization framework in the context of Dhaka city.

Understanding the damage condition of the buildings at city-wide level might help in order to take necessary steps to reduce probable tangible and intangible losses caused by a potential high magnitude earthquake. This research presents an estimation procedure to determine seismic performance of the RC buildings across two parts of the city; DNCC and DSCC. Japanese standard for seismic performance has been considered as the base for this purpose. With very general information like floor area and number of stories, this procedure estimated the seismic capacity of all the buildings of the city by deriving a regression equation. Determination of performance condition of those buildings helped to understand the damage condition of the city by contributing to a bigger scenario. Damage condition has been traced at ward levels of the two city corporation areas, where wards are the lowest urban administrative unit in the context of the country. This helped to understand and identify the highly vulnerable wards. It has been found out that, there is no building under low risk according to the estimated seismic capacity index which might point to the weaker condition of the buildings of Dhaka city.

A comprehensive vulnerability scenario has been developed to understand vulnerability situation of the city. By considering other variables related to improve resilience of the city, the vulnerability map encompassed a greater view of the city. The comprehensive vulnerability map divided the city in three vulnerability categories; high, moderate and low.

The vulnerability map can provide ground for the policymakers to decide on carry out activities to improve resiliency to reduce probable damage caused by earthquakes. The process has its own limitation which leaves room for improvement and make the map more accurate. However, the proposed map in this research can play the role of a stepping stone to develop an accurate vulnerability scenario of the city.

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Chapter 4 Building Vulnerability Assessment

4.1 Introduction

An earthquake is a sudden event below the surface of the earth, resulting in vertical and horizontal waves that cause destruction. Records of earthquakes show that Bangladesh and surrounding areas experienced at least 1000 earthquakes having a magnitude bigger than or equal to 4 in the last 100 years [1]. The risk of severe damage from earthquakes increases considering the development pattern of Dhaka city.

The seismic hazard assessment of urban areas is related to the degree of earthquake hazard, construction vulnerability, and exposure level [2]. Seismic risk for building vulnerability is from all three variables, which assumes exceptional significance no longer solely due to its apparent physical consequences in the incidence of a seismic event. However, it is the potential aspect for which the engineering research can intervene, enhance and even manage seismic behavior of existing buildings, decreasing the degree of vulnerability and, therefore, the degree of physical damage, life loss, and economic loss [3][4]. Development of vulnerability research in urban areas can be performed to identify building risk and minimize the seismic risk. The seismic hazard for Bangladesh has recently been identified to some extent [5].

On the other hand, the seismic vulnerability relies upon the building practice in the city and is associated with the quality of building inventory [6]. Vulnerability is the degree of loss to a given component or set of factors ensuing from the incidence of a natural catastrophe [7][8]. For a densely populated city like Dhaka, the situation is more significant at threat as the capital structures are built following the local practices and are now not much resistant to a robust natural hazard. Moreover, small to medium depth earthquakes shook the capital several times in these years [9]. The necessity to anticipate the seismic susceptibility of existing structures has sparked a surge in interest in research aimed at enhancing existing RC building seismic risk assessments.

4.1.1 Background of the study

With the concentration of job amenities and different investments, Dhaka city has been experiencing a population influx of 6.5% every year [1][10]. The city is recognized as an earthquake-prone city due to its geological and geomorphological setup. The indiscriminate and unplanned development of buildings is solidifying the potential threats of seismic hazards. According to a research, Dhaka city's Earthquake Vulnerability Index (EVI) ranks second among the world's 20 most vulnerable cities [1]. Estimating such vulnerability includes population density, unplanned urbanization, non-compliance of building codes, narrow road networks, lack of preparedness of the responding organizations, and insignificant consciousness amongst city dwellers and decision-makers. In current times, the collapse or tilting of a proper quantity of high-rise buildings is taking place in Dhaka city due to non-engineered constructions of the buildings. Even the Detailed Area Plan (DAP) did not incorporate hazard-sensitive land use planning [11].

Due to the rapid urbanization process, Dhaka city is emerging as a mega-city. Such development generates numerous economic and social externalities and social costs such as deterioration of environmental quality, increased pollution, and congestion. Dhaka is very much prone to seismic hazards. Especially, the older part of the city is relatively more vulnerable to disaster due to the high population density. According to Bangladesh Population Census 2011, ward no 30 at Dhaka North City Corporation is 186639, and the total area is 2.38 square kilometers (BBS, 2011). There have been both planned and unplanned residential areas in this area, and other land uses like institutional and commercial uses are very common like other urban areas in Dhaka. Having said that, the study area of Adabar is highly vulnerable to natural hazards like earthquakes due to the high density of population and unplanned infrastructure. This study followed the primary data collection method through the Visual Rating method to assess the vulnerability of buildings. This research intends to investigate the present context of increasing earthquake vulnerability. This study tries to reveal the causes of earthquake vulnerability, the impact of increasing earthquake vulnerability, and how we can reduce earthquake vulnerability in the aspect of urban planning. This research aims to bring into light the unplanned and non-engineered construction practices growing in urban areas.

4.1.2 Aim and objective of the study

This study aims to identify efficient and effective urban planning strategies to make cities safer and resilient against disaster, especially for earthquake vulnerability assessment in Dhaka. The following research question must be answered, “How the level of seismic vulnerability of existing structures can be assessed in the study area?” To answer the research question, the specific objectives of the study are as follows:

- ❖ To identify the building vulnerability of the study area.
- ❖ To assess the seismic risk of the study area in terms of building vulnerability.

4.1.3 Rationale of the study

Due to fast urbanization, population growth, and industrialization, Dhaka has recently experienced several artificial and natural hazards such as fire and inundation. Among them, earthquake is considered the most destructive catastrophe. The impact of modernization puts constant pressure on continuous development activities. The rapid growth of population and increased urbanization have created many urban environmental problems in Dhaka City. In this city, earthquake risk nowadays is an important issue. It is necessary to determine the inherent causes of increasing earthquake risk considering its associated impacts on human life. The present research is about to identify these causes and impacts of the earthquake on urban areas. This research tries to find out the risk of earthquakes in the study area, and the risk map will give a clear idea about all over the city's condition.

4.1.4 Scope of the study

The earthquake risk assessment will incorporate the urban area characteristics and the residential planning issues. This study will conclude with an integrated informative Risk Map for the study area that might be useful for reducing urban seismic risk for the decision-makers. Though the study focuses on a small portion of Dhaka, the methodology can be used for the entire Dhaka city to analyze the overall seismic vulnerability condition and risk. Thus, the research provides a great scope for disaster management in Dhaka City by identifying the level of risk and seismic vulnerability for urban area planning and decision making.

4.1.5 Expected outcome and limitations

The study will find out:

- ❖ The present scenario of building collapse risk and
- ❖ Vulnerability of earthquake in the study area.

Limitations of the Study

This study considers the existing buildings' earthquake vulnerability and building collapse risk using the Visual Rating method, which is very time-consuming. It takes a very long time to conduct a single survey. There was also a shortage of workforce and resources. Thus, it was not possible to survey all the buildings of the study area. Hence, this study is done with limited data. For conducting the surveys, household accessibility is required and needs a strong recommendation, which was unavailable. Building owners were not much cooperative for the privacy and security issues.

4.2 Past Studies on Building Vulnerability

Ansary, Jahan, Ara, & Islam (2011) [12], in their research, "Assessing Social Vulnerability to Earthquake Hazard in Old Dhaka, Bangladesh," describes that the urbanization process of Bangladesh has caused increased vulnerability to natural hazards like earthquakes. Dhaka is the primary centre for commerce, economy, education, politics, etc., and the city accommodates a large population. According to seismologists, a major earthquake is expected to impact Dhaka in the near future.

The guidebook "Dhaka Profile and Earthquake Risk Atlas" [13] shared various datasets by the Rajdhani Unnayan Kartripakkha (RAJUK: Capital Development Authority) and Bangladesh Bureau of Statistics (BBS) Census of 2011. It estimated potential damage and loss from the reports and scientific studies published by the Comprehensive Disaster Management Programme (CDMP). In this guidebook, the earthquake scenario was assumed 7.5Mw earthquake on the Madhupur Fault. Using UDRI produced some risk maps showed that Old Dhaka is less vulnerable than other parts of the city corporation.

Ferdous and Rahman (2015) [14], in thier study, look at earthquake risk indicators from the household to the city-region level. The study shows that the population of Old Dhaka is in great danger due to the ancient and old building structures they live in, while residents of developed Dhaka face a tremendous hazard from unlawful high-rise projects. The findings of this study show that massive filling of low-lying lands increases earthquake risk and may produce catastrophic liquefaction impacts for people from the newly developed areas. Overall findings of this study underline the importance of continuing public awareness campaigns, carefully following construction rules, and incorporating a disaster risk reduction method into landuse planning to decrease earthquake risk in Dhaka.

Radhikesh and Deepti (2014) [15] showed in their "Rapid Seismic Vulnerability Assessment of Building Stocks for Developing Countries" study, while dealing with large building stocks, it requires rapid visual screening procedures to identify buildings that are susceptible to earthquake damage. Relevant structural data is gathered and utilized to calculate a structural score, indicating whether a structure requires further investigation or not. This study outlines a method for fast visual inspection of building stock in developing countries. Score sheets are prepared for three seismicities: low, moderate, and high. Structural scores are related to damage grades I to V. The structural score <0.7 indicates high vulnerability requiring detailed evaluation and retrofitting.

The FEMA P 154 [16] has been proposed by the U.S. Federal Emergency Management Agency (FEMA) for seismic risk assessment and rehabilitation of existing buildings. This method provides a score that predicts the probability of collapse. However, the FEMA final score is the summation of the basic score and score modifiers due to other vulnerability parameters. FEMA considers a basic score for masonry infilled RC structure based on the lateral force-resisting system.

Jain et al. (2010) [17] proposed an RVS method for India based on the damaged database of the past earthquake. This method predicts the expected performance score, summating the basic, vulnerability, and vulnerability modifiers. The basic score also considers local soil type and seismic zone.

Sultan (2014) [18], in their study, presented a methodology to predict the seismic vulnerability of building by key statistical analysis using GIS (Geographic Information System) based on a number of structural parameters that are determined on the basis of engineering knowledge and observations. In this research, the building inventory survey was chosen as a method for rapid visual screening during a field survey to collect data for statistical analysis. They also observed that if one of the soft-story buildings under liquefaction fails, it will affect the others very easily because all the building structures are very close to each other.

In their research paper, Hejazi (2011) [19], the occurrence of soft at the lower level of high-rise buildings subjected to the earthquake has been studied and has been tried to investigate adding bracing in various arrangements of structure to reduce soft-story effect seismic response of the building.

Shafiul, Debasish, Hamood & Maeda (2019) [20], in their article, described, in Bangladesh, seismic evaluation of a massive stock of vulnerable masonry infilled RC buildings is necessary. Identifying the most vulnerable buildings by visual inspection would reduce the time and cost of detailed evaluation. Therefore they proposed a Visual Rating method in their study and applied it to several existing RC buildings at Dhaka city in Bangladesh. The Visual Rating Index has been then compared with detailed seismic evaluation results, which shows a good correlation.

4.3 Visual Rating method

This section of the chapter is extracted from Visual Rating Method manuals. For further study, readers can refer to the manual under SATREPS-TSUIB Project [21].

The simplified seismic capacity index is calculated considering column area ratio, RC wall area ratio, masonry wall area ratio, and average shear strength. Since the proposed method is based on visual inspection, this visual rating method approximately estimates column area ratio, RC wall area ratio and masonry infill area ratio in a more simplified way thorough visual investigation. Therefore, the simplified seismic capacity index of existing buildings is referred to as Visual Rating Index (I_{VR}), which is expressed by following Equation 1.

$$\mathrm{I_{VR}} = \frac{1}{\mathrm{n.w}}[\pi_c.\mathrm{I_c} + \pi_{inf}.\mathrm{I_{inf}} + \pi_{cw}.\mathrm{I_{cw}}] \qquad (1)$$

Where, $I_C = Column\ area\ ratio,\ I_C = \frac{A_c}{A_f} \approx \frac{b^2{}_c}{l_s^2}$

I_{Cw} =RC wall area ratio, $I_{Cw} = \frac{A_{cw}}{A_f} \approx \frac{t_{cw}}{l_s}.R_{cw}$

I_{inf} = Masonry infill wall area ratio, $I_{inf} = \frac{A_{inf}}{A_f} \approx \frac{t_{inf}}{l_s}.R_{inf}$

So, the Visual Rating Index (I_{VR}), the equation can be written as follow as equation 2

$$I_{VR} = \frac{1}{n.w}[\ \pi_c(\frac{b_c^2}{l_s^2})\ +\ \pi_{inf}(\frac{t_{inf}}{l_s}.R_{inf}) + \pi_{cw}(\frac{t_{cw}}{l_s}.R_{cw})] \qquad (2)$$

n= number of stories of the building

w= Average unit weight per floor area

b_c=average column size

l_s = average span length

t_{inf}=thickness of masonry infill

R_{inf}=Masonry infill ratio

t_{cw}= thickness of concrete wall

R_{cw}=concrete wall ratio

After considering the influence of some strength modification parameters, the VR index in the Equation 3 can be expressed as:

$$I_{VR} = \frac{1}{n.w}[\ \pi_c(\frac{b^2{}_c}{I^2{}_s})\ +\ \pi_{inf}(\frac{t_{inf}}{I_s}.R_{inf}) + \pi_{cw}(\frac{t_{cw}}{I_s}.R_{cw})]\ F_{IV}.F_{IH}.F_D.F_Y \qquad (3)$$

Where, F_{IV}, F_{IH}, F_D and F_Y are the modification factors for existence of vertical irregularity, horizontal irregularity, and deterioration of concrete and year of construction respectively.

4.3.1 Basic assumptions for the simplified seismic evaluation

The simplified method considers some basic assumptions for parameters such as material properties, buildings unit weight and thickness of masonry infill and structural wall, and seismic capacity modification factors. These assumptions might vary based on construction practices with different material properties in different countries. The following assumptions are considered for the Calculation of the VR index in Eqn. (5)

(a) Average shear strength of column (π_c)

The Japan Building Disaster Prevention Association (JBDPA 2001) proposed a seismic evaluation standard that considers the average shear strength of the column is 1.0 MPa for the first level screening procedure based on shear span ratio. Based on the analysis of existing buildings located at Dhaka, Bangladesh (SATREPS 2015) as a case study of developing countries, the average shear stress for columns could be assumed as 1.0 MPa.

(b) Average shear strength of masonry infill (π_{inf})

ASCE seismic guideline (ASCE/SEI 41-06 2007) prescribed 34 psi (0.24 MPa) for good masonry condition. Besides, the average lateral strength for the masonry infill wall is assumed to be 0.28 MPa based on past experimental studies in Nepal [23]. In this study, a value of shear strength of masonry infill, π_{inf}, is considered as 0.2 MPa, which is a conservative value for masonry.

(c) Average shear strength of concrete wall (π_{cw})

JBDPA standard (2001) proposed average shear strength of the concrete wall is 1 MPa considering without boundary column based on past damage investigation and experimental data. In this study, the average shear strength of concrete wall 〖(π〗 _cw) has been assumed 1.0 MPa for very preliminary evaluation.

(d) Thickness of masonry infill (t_{inf})

In general, the thickness of masonry infill is about 125 mm, which is common practice in masonry infill RC buildings in Bangladesh. Besides, the thickness of masonry infill varies within a range of 125 mm to 250 mm, as found in the field survey in Bangladesh (SATREPS 2015). Sometimes, for public buildings such as office buildings, the thickness of exterior and interior walls are 250 mm and 125 mm. However, this study assumes the masonry infill thickness (t_{inf}) as 125 mm for a single layer of infill panel.

(e) Thickness of concrete wall (t_{cw})

The thickness of the concrete wall ranges 200 mm ~300 mm as found in existing buildings in Bangladesh (SATREPS 2015) and Taiwan (Purdue University and NCREE 2016). In this study, the minimum thickness has been assumed to be 200 mm, considered lower boundary conservatively.

(f) Average unit weight per floor area (w)

The unit floor weight of existing buildings ranges from 10 to 12 kN/m2 based on the study of existing RC buildings located in Bangladesh (SATREPS 2015). Similarly, the unit floor weight has also been found based on the study on existing buildings in Taiwan (Purdue University and NCREE 2016). However, in this study, the average unit weight per floor area, w, is set as 11kN/m2.

4.3.2 Parameters of VR survey data sheet

(a) Number of Stories (n)

Number of stories is directly related to the total building weight. Surveyor will input the total story number at present. If there is a different story number in a building or set back in the same building, the surveyor will take the maximum story number excluding the “Chilekotha”.

(b) Average Column Size (b_c)

Columns surrounded by masonry infill are a common practice in Bangladesh. In this method, the cross-sectional area of column is simplified by using average column size (b_c). The average column size (b_c) represents all column dimensions of investigated buildings.

(c) Average Span Length (l_s)

Average span length, l_s is considered the size of equivalent square sized floor area, the load of which will be carried by the representative column. It is also difficult to measure floor area by visual inspection within short time. Because it requires as-built drawing preparation if architectural drawings are not available, it takes longer for building survey. However, the following method considers the average span length (l_s) of building in both directions to overcome the limitation.

(d) Masonry Infill Ratio (R_{inf}):

This section explains the simplification procedure of masonry infill area based on simple parameters depending on visual inspection. Generally, solid masonry infill, i.e. without opening and opening due to door, window, and high window, is common in RC buildings. Sometimes, partial masonry infills are also found in existing buildings. It is difficult to measure the length and width of each masonry infill, either solid or with opening, by visual inspection within short time. However, it is easy to count the number of masonry infill panels in each direction by visual inspection instead of measuring the dimension of each masonry infill.

(e) RC Wall Ratio (R_{CW}):

It is simplified by concrete wall ratio (R_{cw}), thickness of concrete wall (t_{cw}), and average span length (l_s) where, concrete wall ratio (R_{cw}) indicates the quantity of concrete wall expressed as the ratio of the total number of solid concrete wall panel in a direction to the total number of spans for that direction.

The example of the Survey Sheet of Visual Rating method is available in Annexture 1. The following figure 4.1 represents the methodloy flow diagram.

Methodology Flow Diagram

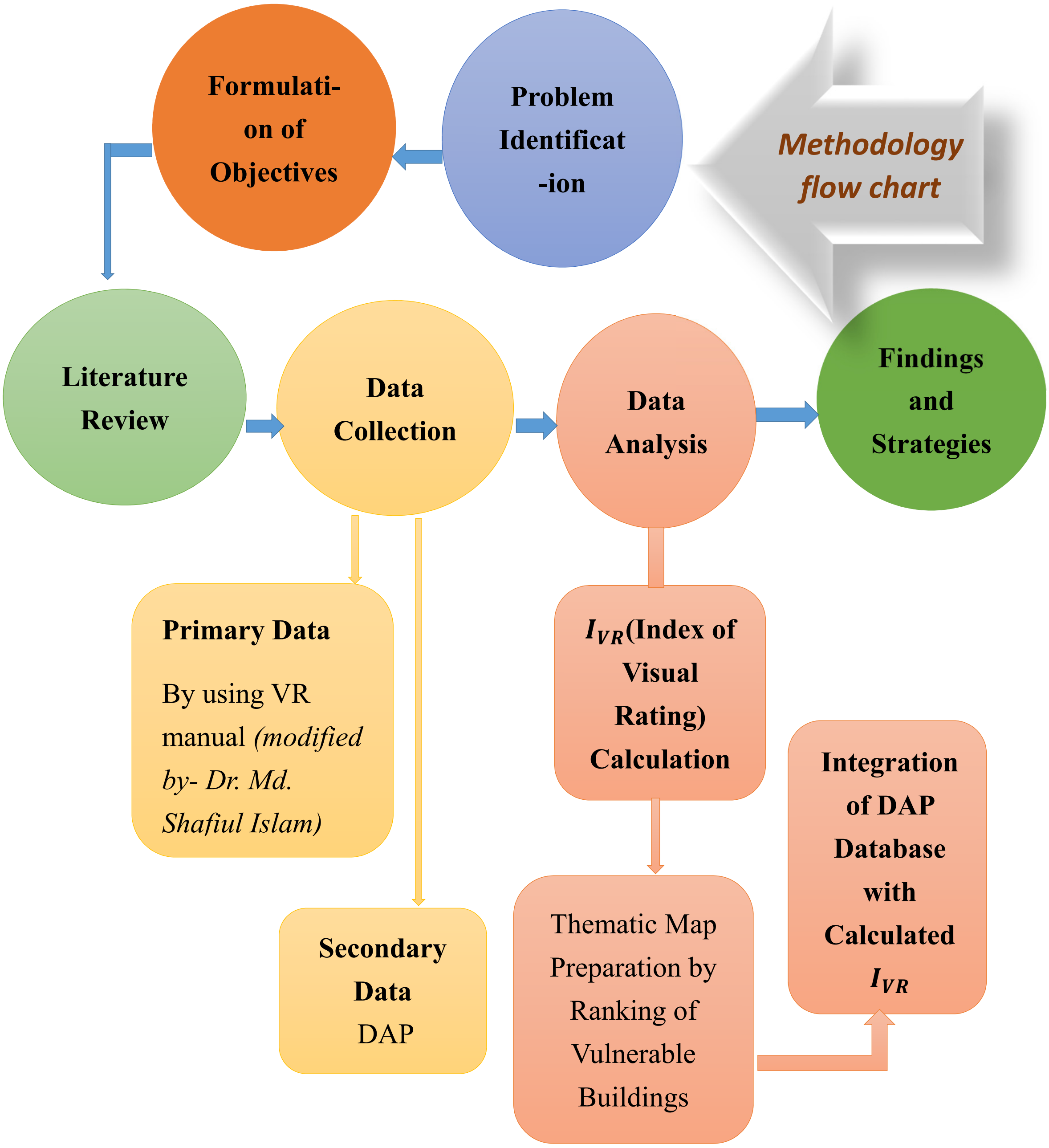

Figure 4.1: Methodology flow diagram

4.4 Location of the Study Area

The study area in Adabar ward no. 30 of Dhaka North City Corporation (DNCC) is situated in the middle of Dhaka city and is the most densely populated with 1,86,639 people [15]. It is one of the most densely populated wards covering residential and commercial areas. Total buildings in this study area are 7,467, covering an area of 2,338 square meters.

The city is currently being a target of the apartment developers and losing its old buildings. It's currently being called the "under-construction town." There had been a recent upsurge from the residents due to the open pits in the middle of streets, and un-repaired streets persisted for months at a time without being fastened. To add to the misery, it's repaired during the Monsoon, resulting in endless problems for the residents.

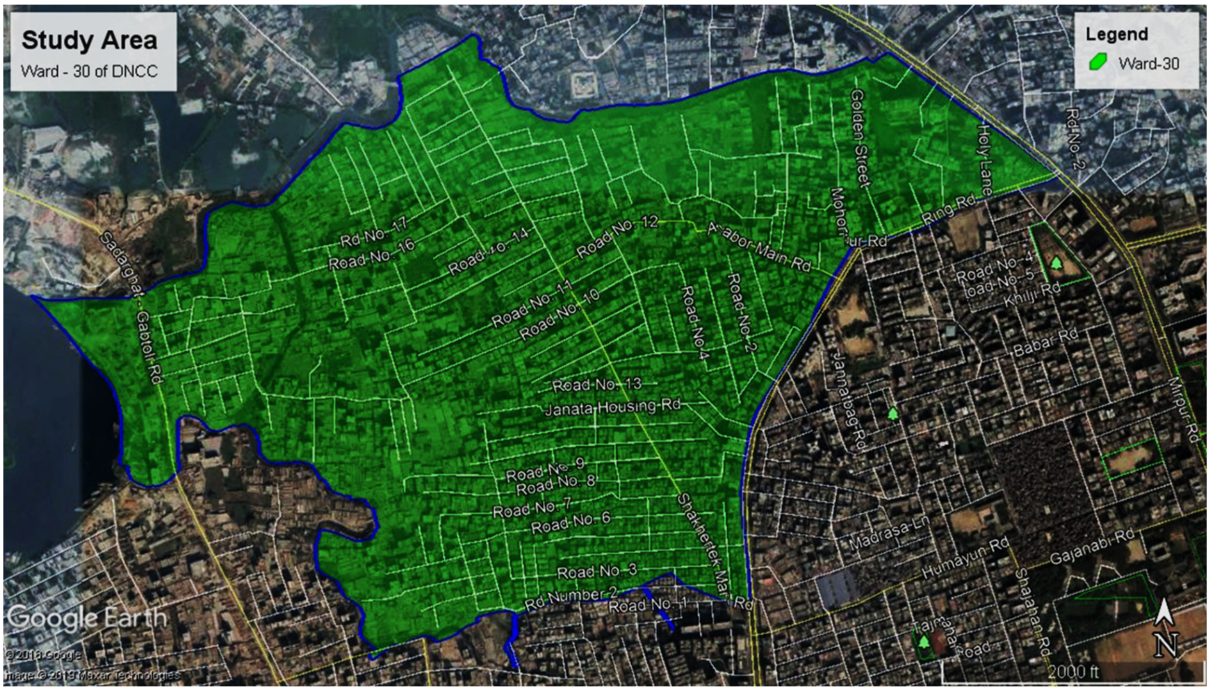

Figure 4.2: Location map of the study area.
(Source: DAP database, 2020: modified by Author, 2020)

4.4.1 Land use of the study area

From the DAP database, 2019, it has been found that different kinds of landuse exist in the study area as residential, commercial, educational, community services, service activity, recreational uses, and mixed uses. A typical scenario in the study area is that the first floor of the buildings are used for non-residential purpose where the upper floors are purely residential. Mixed landuse activity such as shops and industry on the ground floor and residence on the upper floor.

Developers have taken over Adabar, and the area's fast expansion contributes to landuse change. Privatization is one of the main factors of landuse change. Residential land use increases day by day. Now the residential land use is 78.55% of the total land of the Adabar area. The field survey reveals that Adabar is a residential area, and most of the structures are used as residential buildings. The second most used type is mixed-use, and then commercial. Table 4.1 presents the number of building with their use.

Table 4.1: Land uses of the study area.

(Source: DAP database, 2020.)

Use Categories	Land Use
Agriculture	0.15%
Commercial	5.89%
Community Facilities	0.48%
Education and Research	0.32%
Health Facilities	0.16%
Industrial	1.63%
Institutional	0.09%
Miscellaneous	1.86%
Mixed Use	8.57%
Residential	78.55%
Restricted	0.07%
Transportation & Communication	0.01%
Under Construction	2.21%
Total	**100.00%**

Landuse of Ward 30 DNCC

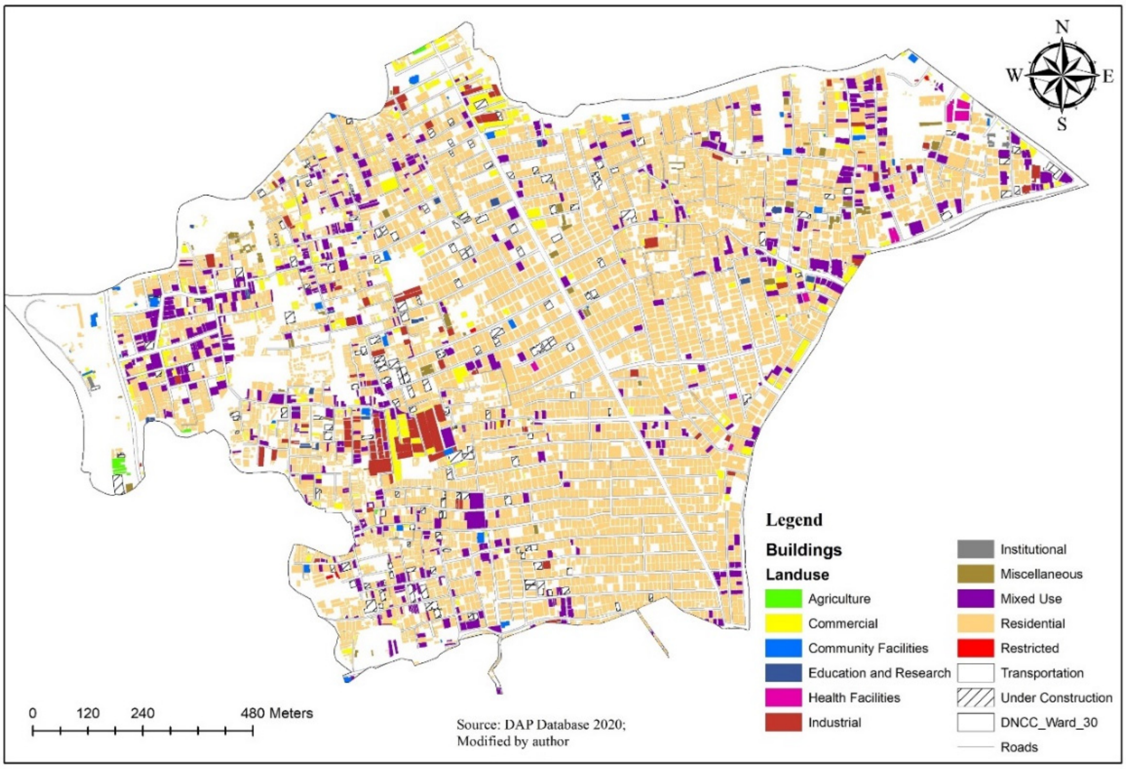

Figure 4.3: Land use map of the study area.

4.4.2 Height of the buildings in the study area

The Revised Detailed Area Plan (DAP) of Dhaka, prepared by Rajdhani Unnayan Kartipakkha (RAJUK), updated the Geographic Information System (GIS) database for the whole city. The base map was collected from that. From figure 4.3, it is clear that the study area has a good mixed storied building.

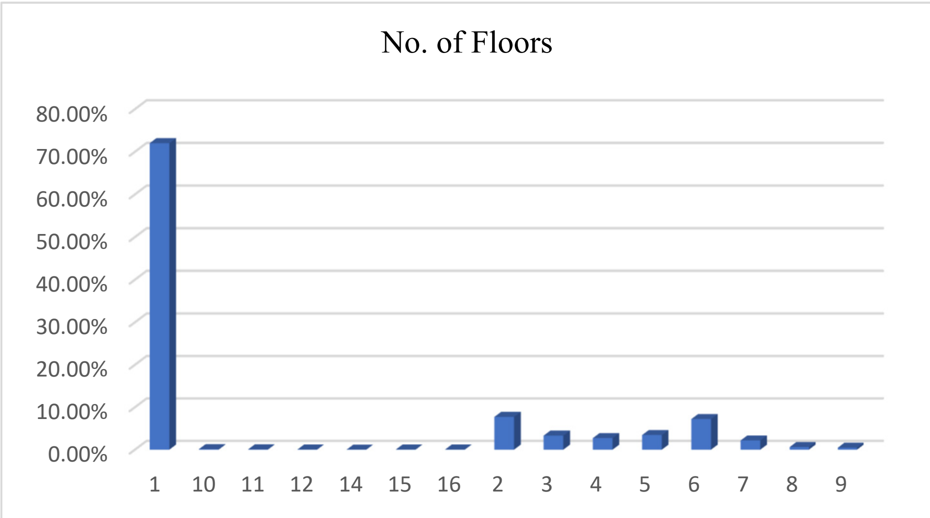

Figure 4.4: Chart of no of floors of the study area.

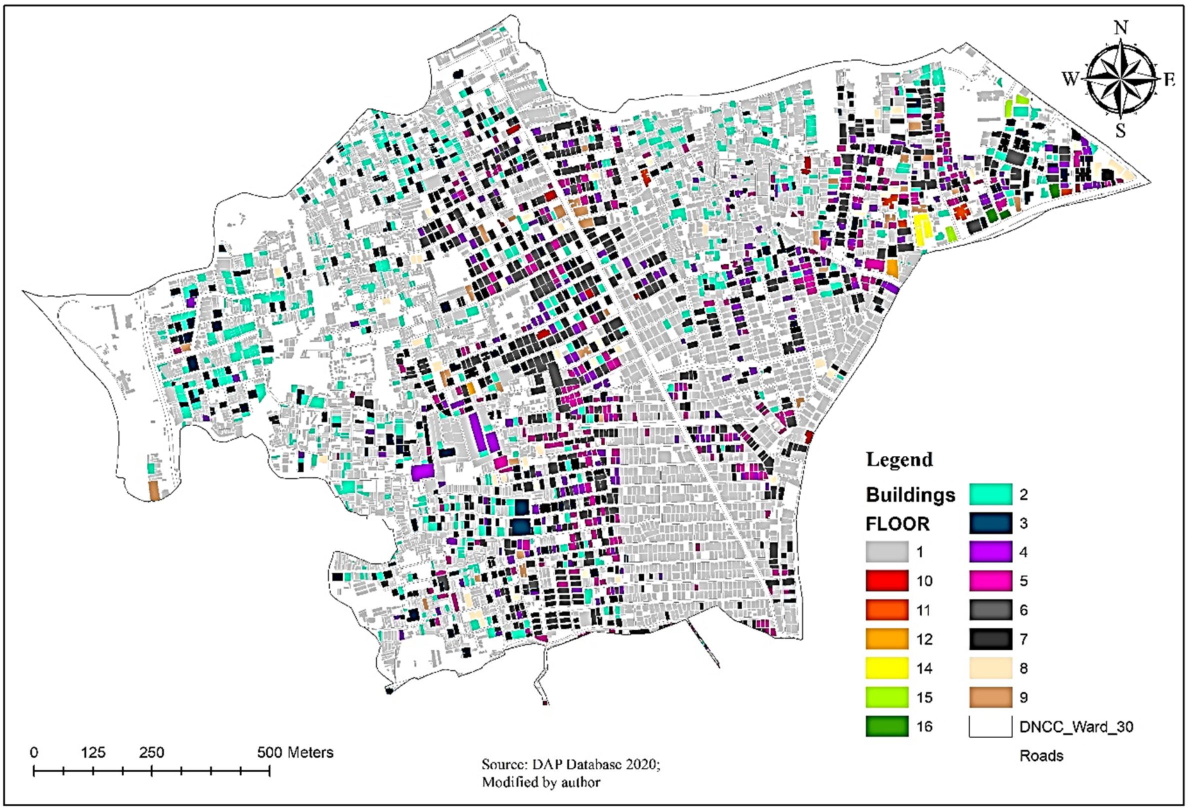

Figure 4.5: Building height map of the study area.

4.4.3 Age of buildings in the study area

As the study area is one of the oldest parts of Dhaka city, there are some buildings aged above 30 years. It has been revealed that most old structures have been demolished and reconstructed recently as the population grows very fast. In five (5) categories, the number of buildings is shown in Table 4.2.

Table 4.2: Age category of the buildings of the study area.

Age category	No. of Buildings
0-10	912
11-20	755
21-30	5771
31-40	25
41-50	4
Total	**7467**

Source: DAP database, 2020

After 2009 24.32% of buildings were constructed in the study area. 2.7% of the buildings are very old.

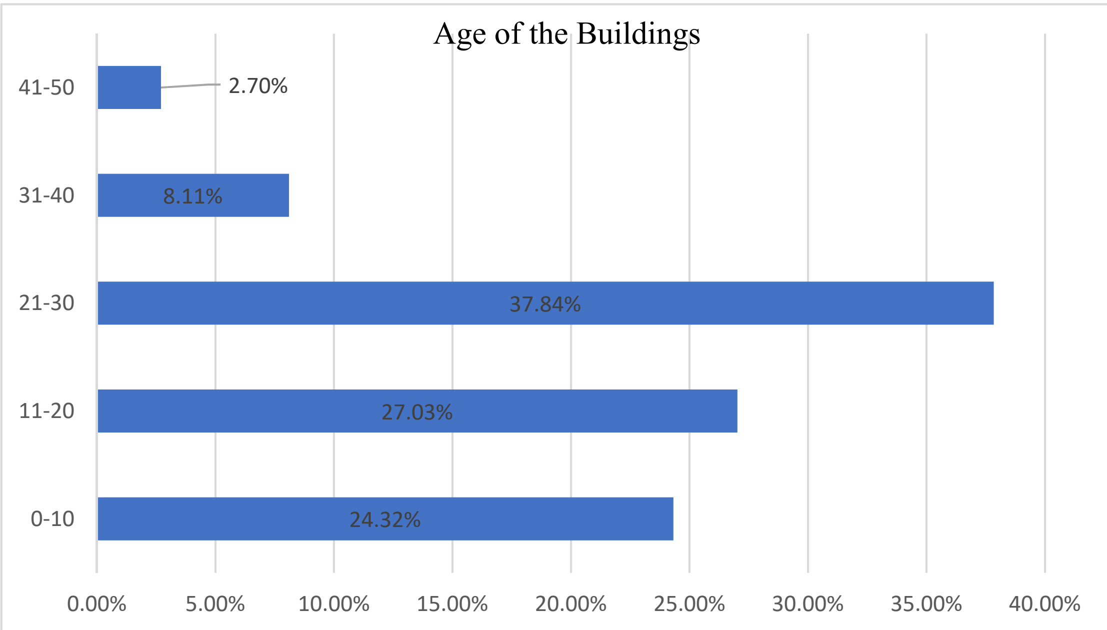

Figure 4.6: Chart of age category of buildings of the study area.
Source: DAP database, 2020.

4.4.4 Road network of the study area

Road width has great significance in the movement of emergency vehicles in the response and recovery phase after an earthquake. The road network has a deep relation with urban development because the easy communication system attracts all types of development. The development of road networks contributes to urbanization in this area. Road maps in the Adabar area are shown in figure 4.7.

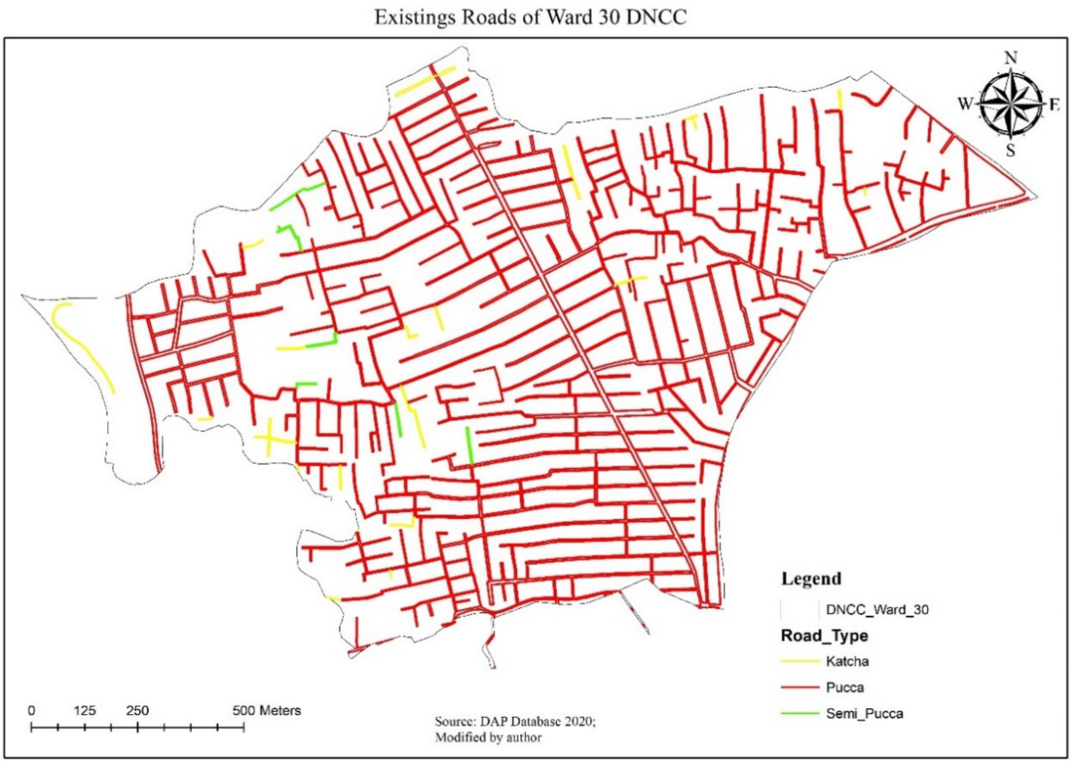

Figure 4.7: Road network map of the study area.

4.4.5 Type of buildings in the study area

Most of the old buildings were constructed in an unplanned way following no building construction rules. Some buildings also share a common wall; thus, finding open spaces between buildings is very difficult. Maximum buildings are found pucca here. Some are under construction, and a small number of structures are semi-pucca.

Figure 4.8: Terrace of a 2 storied building of the study area.
Source: Field survey, 2020.

Figure 4.9: Condition of the wall of a building of the study area.
Source: Field survey, 2020.

4.5 Assessment of Seismic Vulnerability of the Study Area

To analyze the existing building vulnerability of the study area, 37 buildings were selected based on the category of the number of floors. Such buildings were selected, including RCC, masonry, and other buildings having two to above six stories. A total of 37 buildings were selected as a sample size based on building height. The selected buildings are pucca in type.

4.5.1 Number of stories

This is a clear indication that the number of stories is a very significant, perhaps the most dominant, parameter in determining the seismic vulnerability of a typical multi-storey concrete building. For the VR survey, 37 buildings were selected. Among those, the number of 2 storey buildings is 5, and 6 storey is 12. There were also 3, 4 & 5 storey buildings.

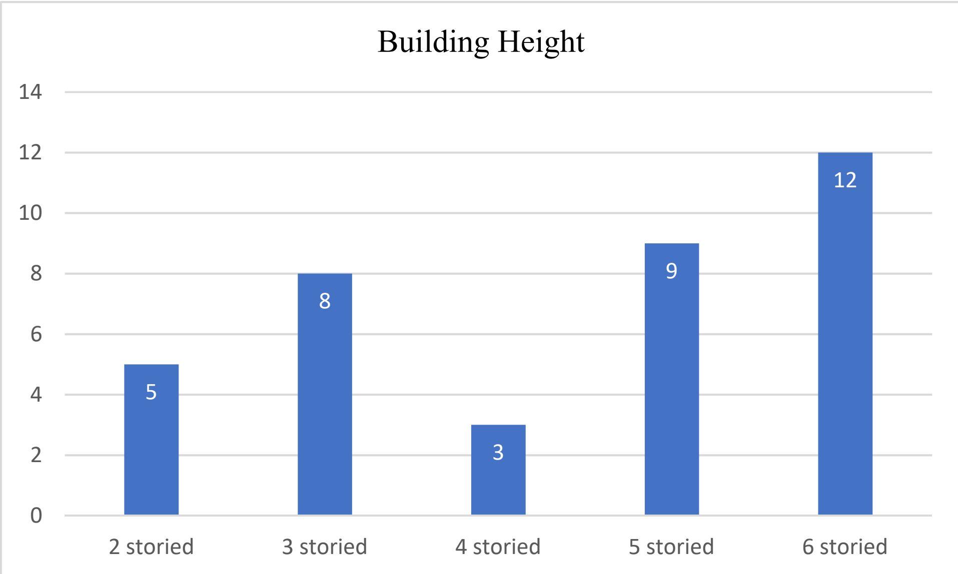

Figure 4.10: Chart of building height of surveyed buildings of the study area.
(Source: Field survey, 2020.)

4.5.2 Year of construction

Selected buildings have different ages. The buildings were categorized into 5 different ages. Among those, 38% of buildings were constructed before 1999. In this category, 38% of buildings were surveyed. In recent times 24% of buildings have been constructed, and the oldest buildings are 3%.

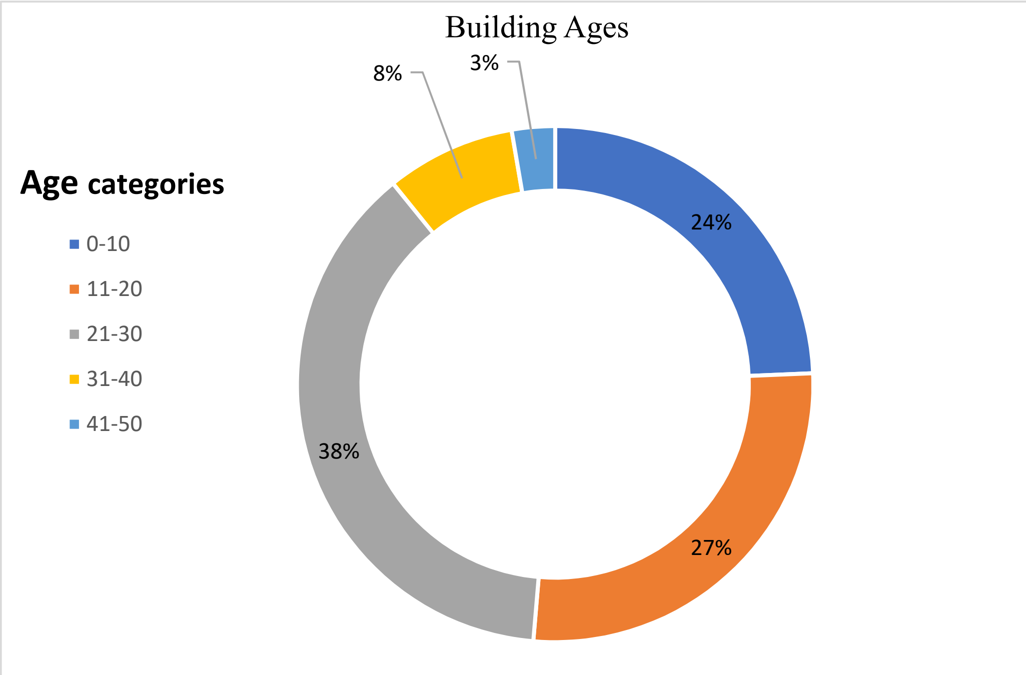

Figure 4.11: Chart of age category of surveyed buildings of the study area.
(Source: Field survey, 2020.)

4.5.3 Building use of the selected buildings

Surveyed buildings have 4 types of uses. They are residential, industrial, health facilities, and mixed-use. Among those 70% of buildings are residential, 22% mixed-use, 5% industrial, and 3% health facilities.

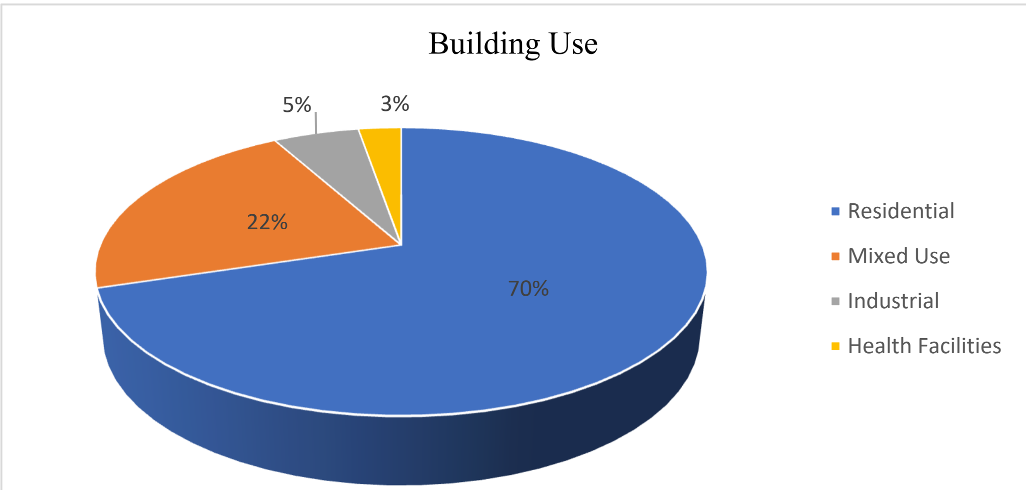

Figure 4.12: Chart of building use of surveyed buildings of the study area.
(Source: Field survey, 2020.)

4.5.4 Calculating Visual Rating index

Boundaries for the Visual Rating Method are shown below.

Table 4.3: Boundaries for visual rating index

Range of each category	Categories	Description
$\mathbf{0.26 \leq I_{VR}}$	A	No Possibility of Damage
$\mathbf{0.24 \leq I_{VR} < 0.26}$	B	Light Possibility of Damage
$\mathbf{0.16 \leq I_{VR} < 0.24}$	C	Less Possibility of Collapse to Damage
$\mathbf{0.10 \leq I_{VR} < 0.16}$	D	Moderate Possibility of Collapse
$\mathbf{I_{VR} < 0.10}$	E	High Possibility of Collapse

Calculation for one building to find out the $\boldsymbol{I_{vr}}$ is following

τ_c = The average shear strength of column = 1MPa

τ_{sw} = The average shear strength of shear wall = 1 MPa

τ_{inf} = the average shear strength masonry infill = 0.2 Mpa

n = Number of story = 6

w = Unit weight of buildings = 11 KNm^2

t_{inf} = Thickness of masonry infill = 125mm

t_{cw} = Thickness of concrete wall= No Concrete wall

Visual Rating Parameters:

b_c = Average column size = 509mm

l_s = Average span length = 5400 mm

R_{inf} = Masonry infill ratio, = 0/20, 2/16 (Consider the minimum value, 0/16)

R_{cw} = Concrete wall ratio, = 2/20, 1/16 (Consider the minimum value, 1/16) = 0.0625

The reduction factors are as follows:

F_{IV} = The modification factors for vertical irregularity = 0.6

F_{IH} = The modification factors for horizontal irregularity = 1

F_D = The modification factors deterioration of concrete = 1

F_Y = The modification factors for year of construction = 0.95

$\boldsymbol{I_{VR}}$ =1000/(6×11)[1×(509^2/5400^2)+0.2×((125/5400) 0)+1((200/5400)×0.0625)]×0.6×1×1×0.95

=15.1515 [1×0.00888+0+1×0.0023148] ×0.57

=15.1515×0.0111948×0.57

=0.09668

So I_{VR} =0.09668

The $\boldsymbol{I_{VR}}$ values for 37 surveyed buildings are shown in the following table.

Table 4.4: Calculated Visual rating Index for surveyed buildings

Surveyed Buildings	$\boldsymbol{I_{vr}}$	**Category**
1	0.261	A
2	0.216	C
3	0.152	D
4	0.138	D
5	0.247	B
6	0.165	C
7	0.201	C
8	0.085	E
9	0.073	E
10	0.088	E
11	0.183	C
12	0.321	A
13	0.181	C
14	0.318	A
15	0.331	A
16	0.172	C
17	0.159	C
18	0.167	C
19	0.097	D
20	0.083	E
21	0.143	D
22	0.217	C
23	0.076	E
24	0.185	C
25	0.211	C
26	0.093	E
27	0.149	D
28	0.215	C
29	0.178	C
30	0.248	B
31	0.164	C
32	0.194	C
33	0.133	D
34	0.142	D
35	0.162	C
36	0.205	C
37	0.125	D

(Source: Field Survey, 2020)

4.6 Major Findings

According to data collection, the building vulnerability of the area has been identified by using the VR method. This method only represents the vulnerability of pucca buildings in between 2-6 storied buildings.

Different building materials and related attributes cause differences in identifying the vulnerability. The vulnerability of buildings is classified into five vulnerable groups. These are shown in the following table with the findings of the study.

Range of each category	Categories	Description	Percentage
$\mathbf{0.26 \le I_{VR}}$	A	No Possibility of Damage	10.81%
$\mathbf{0.24 \le I_{VR} < 0.26}$	B	Light Possibility of Damage	5.41%
$\mathbf{0.16 \le I_{VR} < 0.24}$	C	Less Possibility of Collapse to Damage	43.24%
$\mathbf{0.10 \le I_{VR} < 0.16}$	D	Moderate Possibility of Collapse	21.62%
$\mathbf{I_{VR} < 0.10}$	E	High Possibility of Collapse	18.92%

Table 4.5: Percentages of earthquake vulnerability of the study area

From table 4.5, it shows that in this study area-

- 43.24% of buildings have less possibility of collapse,
- 21.62% of buildings have a moderate possibility of collapse.
- About 18.92% of buildings have the highest possibility of collapse during an earthquake.
- Almost 5.41% of buildings have been identified with light damage possibility and
- 10.81% has no damage possibility.

The Building Assessment Map of Adabar with $\boldsymbol{I_{VR}}$ values are following:

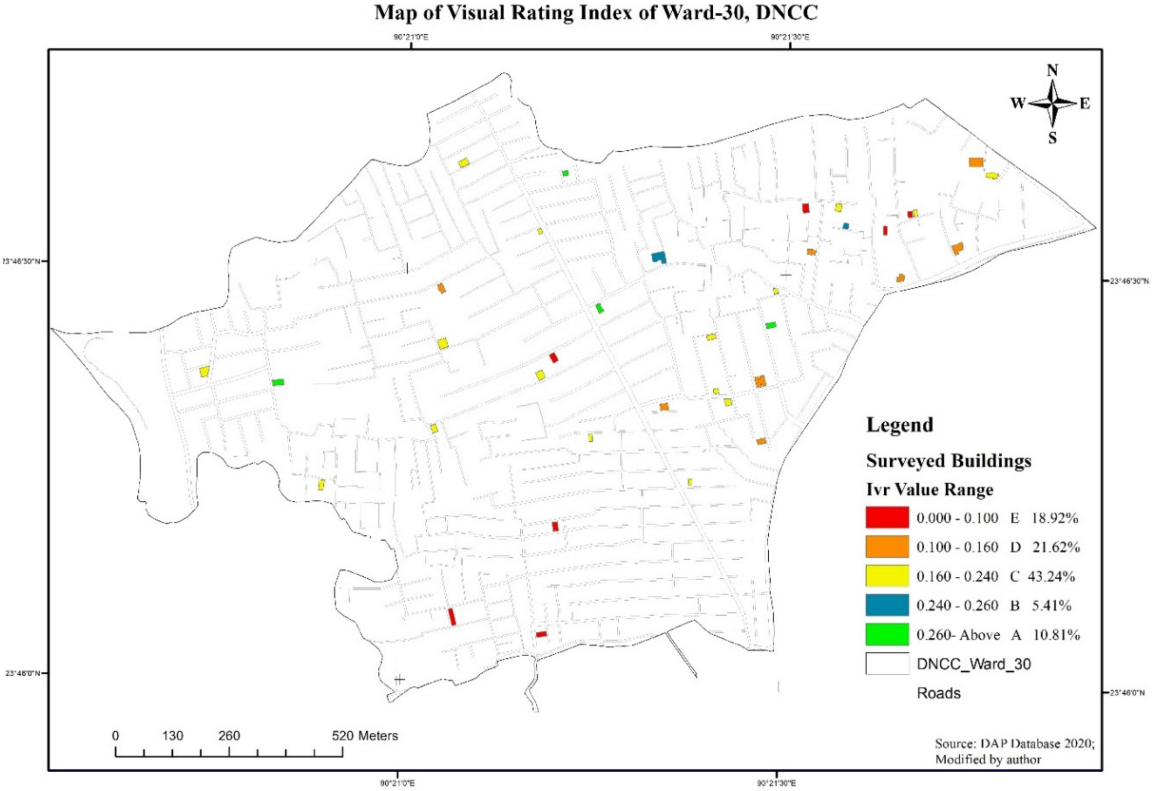

Figure 4.13: Map of Visual Rating Index of Ward 30, DNCC

4.7 Conclusion

Identification of vulnerable buildings seems to be the major challenge in the context of Bangladesh. Lack of data, resources, available methods, and techniques makes this challenge unbeatable. According to the Detail Area Plan of RAJUK, seven hundred thousand structures exist in the Dhaka city corporation area. Vulnerability assessment of this large building stocks required an extensive workforce and time. Detailed evaluation of an existing building takes more than two days to complete. The rapid screening method is the key to resolving this issue. The visual Rating method is developed considering the time limitation. Although it takes time considering other RVS methods, however, VR method shows a good result compared to Japanese first-level screening methods. This study is applied the VR method of 37 buildings in Adabar (DNCC Ward 30). From the analysis, it shows that 18.92% of buildings have a high possibility of collapse. These buildings need a detailed seismic evaluation to identify the seismic capacity and retrofit accordingly if required to reduce the risk and loss. Though, the sample size is very small to conclude. Further studies are required based on other parameters like ground condition, building age, building types, accessibility and road widths in a broader aspect.

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Chapter 5 Emergency Response and Rescue

5.1 Road Network Vulnerability Assessment <A>

5.1.1 Introduction

Vulnerability automatically reveals itself in hazardous situations [1]. It is characterized to express the degree to which a system is exposed to potential hazards and threats [2]. The vulnerability of critical infrastructure during critical hazards like an earthquake can pose a serious threat to life as well as increase the number of casualties. In this regard, numerous studies have been made for exploring structural vulnerability for seismic events [3][4][5]. However, these conventional studies on seismic hazard focus only on infrastructural construction requirement that lacks the potential involvement of network related issues. However, there are some other studies, which have illustrated the importance of transportation network reliability in terms of seismic threat [6]. Because the results from previous strong earthquakes have shown that damages in road network can considerably disrupt emergency responses like rescue and recovery operations, which may eventually lead to an extended traffic disruption [7].

The transportation network can be simply explained like veins for the human body, whereas roads are vital for the community life, connecting every single habitation, working and public unit independently of their size and role. It has a special importance among the lifelines as all the other utility and transportation systems are influenced by it, providing access to them. The role of a roadway network is more crucial in an emergency situation such as after a strong earthquake, when the needs for immediate transfer of rescue and first aid teams to the disaster areas and of injured people to the hospitals, are significantly increased. In addition, the transport of assistance and the establishment of settlements for homeless citizens, the progress of repair works of damaged lifelines and infrastructures and the other recovery activities during the restoration period, require a functional roadway network.

A pertinent question rises that, how to identify critical locations in a network. For example, the road network is large, wide and diverse in nature. Are there particular locations or facilities in that network where loss or degradation of certain road sections (links) will have significant impacts? How should such impacts be assessed? Thus there are needs for the development of methods to assess risk and vulnerability of transport networks. Decision support tools are needed that allow planners and policy makers to make rational assessments of threats to facilities and infrastructure; the consequences of network degradation and failure at various locations and under different circumstances; and what to do about these. Social and economic benefits flow from the ability to plan for and manage the impacts of transport network degradation to minimise wider consequences on economic, employment, trade and social activities in cities and regions.

The concept of network vulnerability is still new, and so it is important to define what is meant by vulnerability. For instance, there are several possible responses to the reduced performance of a degraded network, or in dealing with the perceived risks of degradation at different locations. In some cases, an appropriate response may be to upgrade key transport infrastructure [8]. But sometimes this simply makes the network more reliant on those key links and more vulnerable to their failure. An alternative approach is to add links to the network.

These links may normally be redundant but provide alternative routes when key network links are broken. At the urban network level there may already be many such latent alternative routes, but at the regional or national strategic network level this is less likely to be the case. Extra links would make the transport network more robust, but this may add unnecessary cost to the provision of transport infrastructure. Therefore, it becomes more important to have proper understanding to identify vulnerable locations in a network in order to reduce economical loss as well as social.

In terms of a sudden hazardous situation, an earthquake with a high intensity of ground motion can cause severe effects on both human losses as well as material damages [5][9][10][12]. While most of these misfortunes happen during or shortly after the earthquake, it is observed that a critical extent of human losses additionally occurs within the next hours or days. Those post breakdown losses can happen either by the limited capacity of emergency response resources or by not being able to send rescue support in the incident's location. That is why having a scientific understanding of network vulnerability assessment would help to initiate an effective and efficient evacuation as well as rescue operations for hazardous events like an earthquake within the shortest possible time. In this regard, this part of the report intends to present an integrated methodology that focuses on strengthening urban road network resiliency in seismic scenarios by evaluating two main dimensions: 1) building vulnerability and 2) road blockage. The first part considers Visual Rating (VR) method and Damage Probability Matrices (DPM) to evaluate building vulnerably due to seismic threat. The VR method focuses on the cross-sectional areas of columns and masonry infill in existing infilled masonry-RC buildings. On the other hand, DPM relates the outcome of VR method with respective damage states. Finally, to evaluate road blockage scenario, this research utilizes the integrated outcome of VR method and DPM to illustrate potential road blockage sites with the help of a correlation model.

5.1.2 Study area

The research has been conducted in Adabar area of Dhaka city, which is also known as Ward no 30 of Dhaka North City Corporation. Having a high density of inhabitants as well as structural entities, this area has been found very congenial to implement the developed mode (BBS, 2015). The total area consists of Shyamoli Ring Road, Adabar, Najrul Bagh, PC Culture Housing Society, Baytul Aman and Shekher Tek covering around 2.382 Sq. Km. The Shyamoli Ring road in the eastern side of the study area acts as the main entrance corridor for Ward 30. Later the road sub-divides into various tertiary roads among which the Shekher Tek road holds a remarkable amount of importance as it passes through the center of the whole area (Word 30) allowing access to its nearby vicinity. That means the connecting roads between Shyamoli Ring road and Shekher Tek road act as the main corridor to provide access to people towards the whole area. Also these are mostly the only roads through which people can exit the area. Therefore, in spite of being tertiary roads, these connecting roads play an important role in the functioning of DNCC Ward 30. Damages or any sort of blockages within these roads may lead to a severe traffic congestion hindering the access to perform any type of emergency services. To ensure the effective performance of the algorithms (in terms of computational time) as well as to collect detailed information concerning the model to work, a specific road (Road no. 7) has been selected within the study area (Fig 5.1.1). Though the road covers a small portion of the whole focusing area, yet, it works as an important connecting corridor to two major roads of Adabor area covering 42 buildings alongside it.

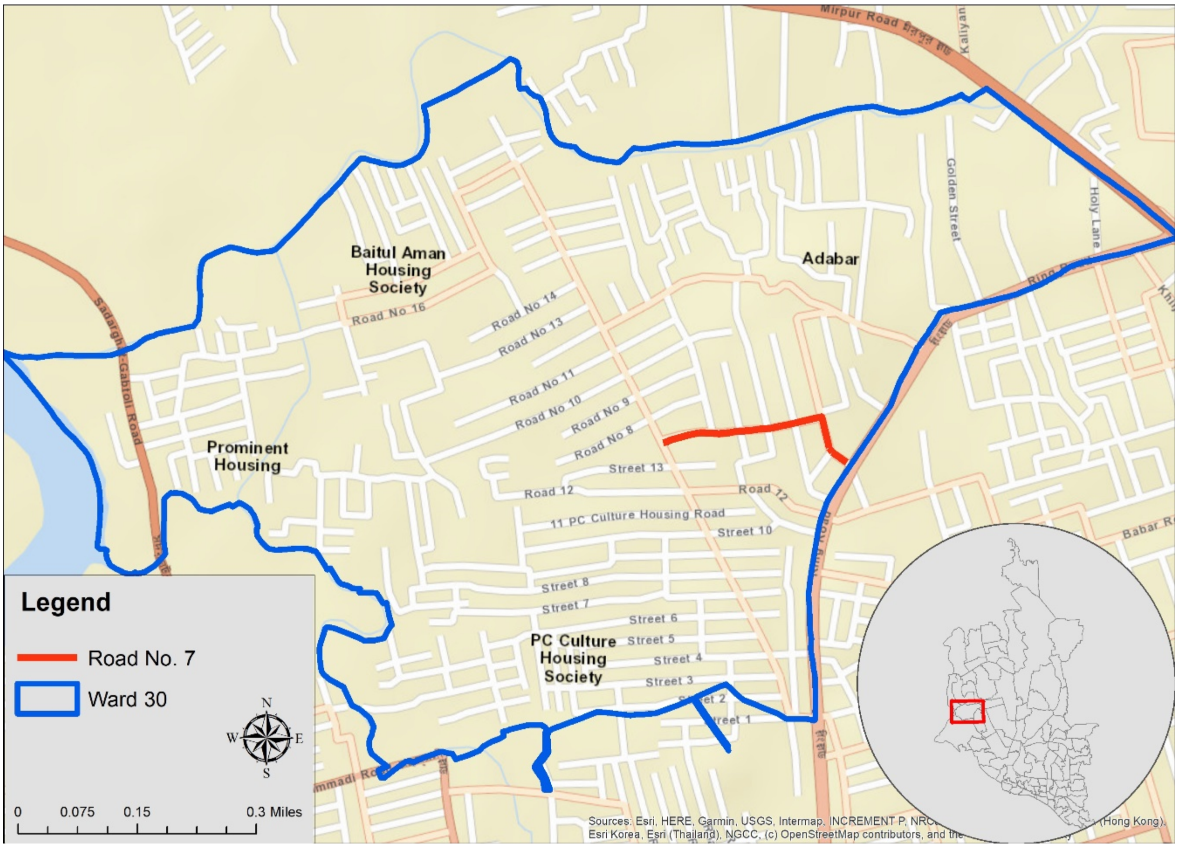


Figure 5.1.1: Study Area

Source: Developed by the Author, 2020

5.1.3 Objectives of the study

Followings are the objectives of the study:

- To explore building damage vulnerability scenario in terms of seismic threat; and
- To explore road network vulnerability for earthquake within the study area.

5.1.4 Conceptual issue: Urban road network vulnerability

Among different lifelines of an urban area road network is considered as the main lifelines. It plays a fundamental role in transportation and economic exchanges. During major disasters such as earthquakes, it allows emergency and recovery operations. Earlier a lot of researches about the vulnerability analysis of various large-scale systems have been conducted since 1970s, e.g., the computer networks, electric power grids as well as industrial production processes [13][14][15](Finn, 1988; Holmgren, 2006; Einarssonl & Rausand, 1998). Though the vulnerability of road network is the most basic and important issue in our daily lives and emergency evacuation, it did not draw our attention to research before 10 years. The research of road network vulnerability was originated after Kobe earthquake in 1995 and the September 11 terrorist attacks. In Kobe earthquake, the 7.2 Richter scale nearly destroyed all the surrounding transportation systems, making Kobe 90% of the berths paralysis with many roads, railways and high-speed inter-city rails damaged. The September

11 terrorist attacks expose not only the vulnerability to transportation network disruptions but also the lack of knowledge about the extent and impact of these disruptions [16] (Chen, Yang, Kongsomsaksakul & Lee, 2007). Since then, the vulnerability of road network has attracted widespread attention and great interest. There were catastrophic snowstorms and Wenchuan earthquake in China in 2008 which paralyzed local transportation systems. As a result many areas suffered extensive loss of life and property damage, which also exposed the vulnerability of road network. These events have highlighted the fact that disruptions in transportation systems, whether man-made or naturally inflicted, have huge impact on safety of the infrastructure, mobility and accessibility for people, the efficiency and the vitality of the economy [17](Srinivasan, 2002).

That is why this study focuses on exploring the vulnerability of road networks that is threaten by the very risks of building collapse due to earthquake.

5.1.5 Methodology of the study

5.1.5.1 Research method

This study focuses on finding the result on two aspects road network vulnerability. In such regard, this paper intends to present an integrated methodology that focuses on strengthening urban road network resiliency in seismic scenarios by evaluating two main dimensions: i) roadside building vulnerability and ii) road blockage.

To establish a well-coordinated connection among these two dimensions, this study follows a simple process of methodology that connects the results of building vulnerability to its nearby road network vulnerability. This whole procedure can be well illustrated in Figure 5.1.2,

where it expresses a flowchart of the whole method. The initial stage requires identification of vulnerable buildings that poses certain threat level during an earthquake. After identifying the vulnerable structures, the next step calculates the probable damage ratio for them. This type of damage probability articulates the path of exploring the volume or the ratio of a building that might collapse during a certain level of earthquake. After finding the damage ratio of each vulnerable building, the method calculates the probable amount of debris generating on the road due to the collapse portion of the structures. At the very ending point, the distribution of debris on the road gets calculated, which illustrates the overall road closure scenario within the study area.

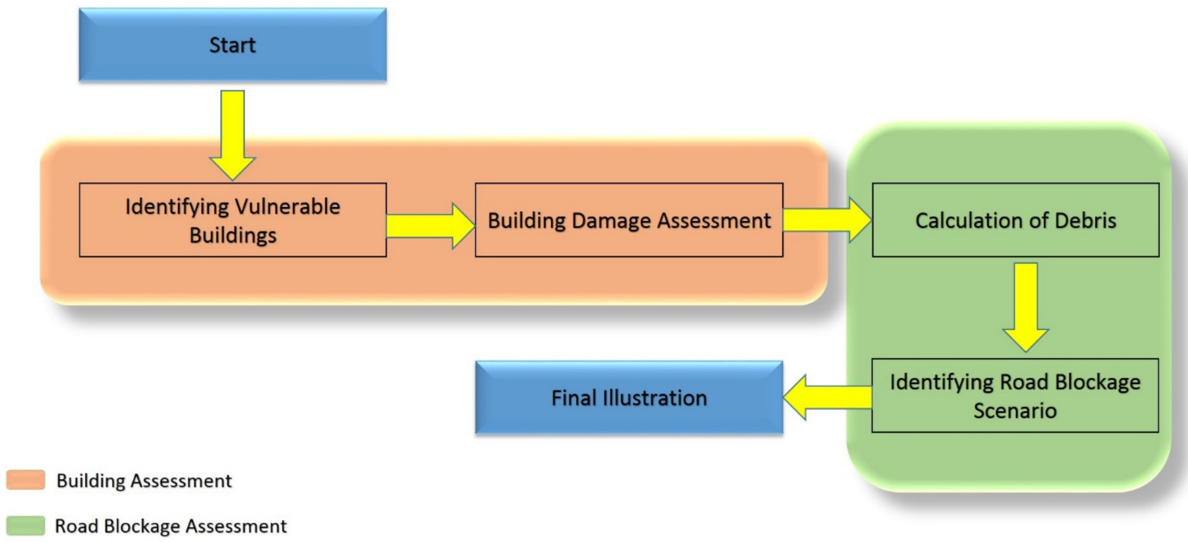


Figure 5.1.2: Flow Chart of Methodology

Source: Developed by the Author, 2020

In a summarized manner, the whole methodology integrates three distinctive methods to evaluate building as well as road network vulnerability. They are: i) Visual Rating, ii) Damage Probability Matrix (DPM) and iii) Road Closure Probability. These three individual methods have been used to identify three different circumstances eventually leading to explore the network vulnerability (Figure 5.1.3).

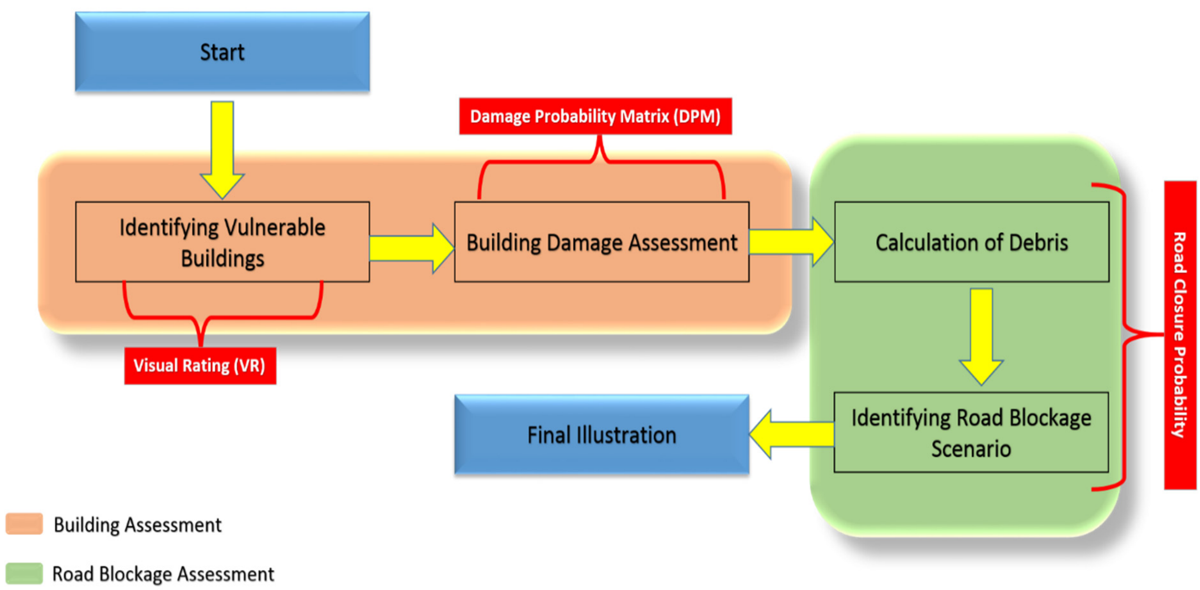


Figure 5.1.3: Integration of Different Methods

Source: Developed by the Author, 2020

Here, Visual Rating (VR) which is a part of Rapid Visual Screening (RVS) procedure has been utilized to evaluate each building within the study area for their possible vulnerabilities for earthquake. Later the vulnerability results of each structures lead to the calculation of building damage ratio, which is conducted through using Damage Probability Matrix (DPM). Finally the road closure probability gets identified through calculating induced debris width and analyzing their distribution by using interpolation tool in GIS. The details of these individual methods are discussed in the following sections, wherein the very applications of each methodology are reported.

i) Visual Rating (VR): Past earthquake damage in developing countries have been exhibiting the necessity of seismic evaluation and strengthening of existing buildings. In addition, enormous stocks of vulnerable buildings exist in those countries. Identifying vulnerable buildings using a quick and reliable evaluation procedure and prioritizing for retrofitting and/or strengthening would be of a great interest in terms of time and costs [18] (Islam, Alwashali, Sen & Maeda, 2019).

That is where Rapid Visual Screening or RVS procedure comes forward to rapidly evaluate bulk quantity of structural units. Though there lies various kinds of screening methods (e.g. FEMA P 154, Turkish RVS Method, Indian RVS method etc.) focusing on different aspects of a structures, yet most of them have limitation to provide seismic capacity because those methods do not consider the variation of cross-sectional area of structural elements (i.e. column, masonry infill and RC wall area etc. [18][19][20][21](Federal Emergency Management Agency, 2015; Sucuoglu, Yazgan & Yakut, 2007; Jain, Mitra, Kumar & Shah, 2010; Islam, Sen, Alwashali & Maeda, 2019).

To overcome such situation, a study has been made to establish a modified screening method that suits the structural environment of Bangladesh [18](Islam, Alwashali, Sen & Maeda, 2019). Where the screen method is known as Visual Rating or VR in short. This method of VR focuses on the cross-sectional areas of columns and masonry infills in existing infilled masonry-RC buildings. The method has been investigated by applying on existing RC buildings in Dhaka city, Bangladesh as a case study [18](Islam, Alwashali, Sen & Maeda, 2019). The effectiveness of the proposed method has been verified by comparing with detail seismic evaluation of investigated buildings.

This method proposes an equation that collects certain amount of data regarding the investigating building (Equation). This formula basically calculates the index value for VR, which is expressed as I_{vr}. The whole equation includes factors and variables like number of story (n), unit weight of building (w), thickness of masonry infill (t_{inf}), thickness of concrete wall (t_{cw}), average column size (b_c), average span length (l_s) and so on SATREPS – TSUIB, 2019 [22].

Equation 1: Formula for Visual Rating Inde

$$I_{VR} = \frac{1}{n.w}\left[\tau_c\left(\frac{b_c^2}{l_s^2}\right) + \tau_{\inf}\left(\frac{t_{\inf}}{l_s}.R_{\inf}\right) + \tau_{cw}\left(\frac{t_{cw}}{l_s}.R_{cw}\right)\right]F_{IV}.F_{IH}.F_D.F_Y$$

The notation of each items in equation are as follows:

τ_c= The average shear strength of column

τ_{sw} =The average shear strength of shear wall

τ_{inf}=the average shear strength masonry infill

n= Number of story

w=Unit weight of buildings

t_{inf}= Thickness of masonry infill

t_{cw}= Thickness of concrete wall

Visual Rating Parameters:

b_c=Average column size

l_s=Average span length

R_{inf} =Masonry infill ratio,

R_{inf} =Concrete wall ratio,

The reduction factors are as follows:

F_{IV}=The modification factors for vertical irregularity

F_{IH}= The modification factors for horizontal irregularity

F_D = The modification factors deterioration of concrete and year of construction

F_Y = The modification factors for year of construction

Figure 5.1.4: Description of VR Equation

Source: SATREPS-TSUIB, 2019

The output of this formula gives a decimal number as a result from the inspection of each building. To define each numeric value in a more simplistic manner this method proposes certain level of ranges which categorizes each building according to their vulnerability level. In the procedure, buildings are to be categorized into 5 (five) classes such as A, B, C, D, and E describing the different levels of seismic vulnerability depending on Visual Rating Index (I_{vr}). Category A and B indicate that the buildings located at these zones, are considered as less vulnerable buildings during earthquake. On the other hand, buildings located at category C, D and E is regarded as the most vulnerable buildings (Table 5.1.1).

Table 5.1.1: Boundaries for Visual Rating Index (I_{vr})

Range	Categories	Description
$0.26 \leq I_{VR}$	A	**No damage**
$0.24 \leq I_{VR} < 0.26$	B	**Light damage**
$0.16 \leq I_{VR} < 0.24$	C	**Less Possibility of collapse**
$0.10 \leq I_{VR} < 0.16$	D	**Moderate possibility of collapse**
$I_{VR} < 0.10$	E	**High possibility of collapse**

Source: SATREPS – TSUIB, 2019

The value of each boundary for each class is proposed based on simplified study and seismic evaluation of existing RC buildings in Bangladesh. The buildings with Visual Rating Index (I_{vr}) less than 0.24 are classified as C, D and E and those buildings are regarded as the seismically vulnerable and might be collapse during earthquake. Besides, the existing buildings consisting of much lower Visual Rating Index (I_{vr}) (such as I_{vr} <0.10) are classified into E category, have been categorized as the most vulnerable buildings. After identifying each building with their respective VR Index (I_{vr}) value as well as categorizing them considering the boundary range from Table 5.1.1, a relationship has been made with the boundary table of Visual Rating (VR) to their respective probability of collapse using the Damage Probability Matrix (DPM).

ii) Damage Probability Matrix (DPM) and integration of I_{vr}: : Introduced by Whitman in 1973 [23], a damage probability matrix (DPM) expresses the damage experienced by a particular type of building, designed according to some particular set of requirements, during earthquakes of various intensities. An element of this Matrix, *P* (DS, I) gives the probability that a particular damage state (DS) occurs when the structure under consideration is subjected to an earthquake of intensity, *I*. The sum of the probabilities in any column of this matrix is 1.0. In a damage probability Matrix, level of damage is described in terms of damage states, whereas the earthquake intensity is generally represented by the Modified Mercalli Intensity (MMI) scale. The general form of a DPM is given in Table 5.1.2. The intensity scale used in the damage probability Matrix is the MMI scale since the historical records of past major earthquakes are expressed in terms of MMI. Though in recent studies the damage rates can be expressed in terms of the ground motion parameters, there is a strong correlation between MMI and observed building damage for groups of buildings whose fundamental periods lie within an intermediate range, which makes the quantification of empirical DPMs more convenient.

Table 5.1.2: General form of a Damage Probability Matrix with Central Damage Ratios

Damage State (DS)	**Damage Ratio (%)**	**Central Damage Ratio (%)**	**MMI = V**	**MMI = VI**	**MMI = VII**	**MMI = VIII**	**MMI = IX**
None	0-1	0	*	*	*	*	*
Light	1-10	5	*	*	*	*	*
Moderate	10-50	30	*	*	*	*	*
Heavy	50-90	70	*	*	*	*	*
Collapse	90-100	100	*	*	*	*	*

Source: Gurpinar, Abali, Yucemen & Yesilcay, 1978 [24]

* Damage state probabilities, *P* (DS, I)

A damage state in a DPM defines the degree of structural and non-structural damage that would result to a typical building of a specific construction type under an earthquake of a specific intensity. Each damage state is described either qualitatively by a set of words or quantitatively in terms of a damage ratio. Damage ratio (DR) is defined as the ratio of the cost of repairing the earthquake damage to the replacement cost of the structure. In case information regarding actual cost of damage is not available, the verbal description is used. In order to use numerical values in DPMs, quantitative descriptions corresponding to each damage state are defined. On the other hand, even under the same seismic excitation, the damage that may result in a certain type of buildings may vary due to differences in soil conditions, material properties, workmanship and duration of excitation. Thus, DR takes values in between 0% and 100%. In order to set a consistent relationship between damage states and damage ratios and to make calculations easier, the range of the damage ratio corresponding to each damage state is represented by a single damage ratio which is called as the central damage ratio (CDR).

Different design strategies and damage distributions all around the world result in different correlations between damage states and damage ratios. In this study, the damage states are expressed as No Damage (N), Light Damage (L), Moderate Damage (M), Heavy Damage (H) and Collapse (C) states. Based on interviews with damage assessment experts and examining similar studies, a ranges of damage ratios and CDRs corresponding to the five damage states has been estimated which are shown in Table 5.1.2. Finally the output from Visual Rating Index classes has been related with their corresponding damage state considering the CDR values (Table 5.1.3).

Table 5.1.3: Relating VR Index with their Corresponding Damage State

VR			DPM		
Range	Categories	Description	Damage State	Central Damage Ratio	Range
$0.26 \leq I_{VR}$	A	**No damage**	**None**	0	0-1
$0.24 \leq I_{VR} < 0.26$	B	**Light damage**	**Light**	5	1-10
$0.16 \leq I_{VR} < 0.24$	C	**Less Possibility of collapse**	**Moderate**	30	10-50
$0.10 \leq I_{VR} < 0.16$	D	**Moderate possibility of collapse**	**Heavy**	70	50-90
$I_{VR} < 0.10$	E	**High possibility of collapse**	**Collapse**	100	90-100

Source: Developed by the Author, 2020

iii) Road Closure Probability: The prime concern of this study is to focus on the closure probability for individual road portion (obtained from the vulnerability of the structural urban components that, if damaged, may block those road portions). This is where the findings from the previous methods comes forward to articulate this study in finding probable road closure that might occur due to the induced debris from damaged buildings. Therefore, this final model follows a correlation between building's height and the width of the induced debris which is proposed by Argyroudis, et. al., 2005[11]. This correlation estimates the impact of collapsed buildings to the functionality of roads. Following partially the approach that has been proposed in the framework of RISK-UE project, simple, yet realistic, collapse shapes are assumed (Figure 5.1.6) in order to define that relationship [25]. These forms mainly correspond to buildings that are in contact with other buildings in two opposite sides.

In order to establish an average correlation between the initial height (H) of the building and the width of induced debris (W_d) for the various collapse shapes, the method proposes a model in which the volume (V^*) and the height (h) of the collapsed structure are a fraction of the original volume (V_o) (in other terms a short of an equivalent "void ratio"), and the width of debris (W_d) respectively. Considering the assumption of different building shapes, this method also proposes a formula to calculate the width of induced debris (Equation 2).

Equation 2: Width Calculation of Debris

$$\mathbf{V^* = kV_0} \qquad ; \qquad \mathbf{W_d = mh}$$

Where,

V^* = Volume of Debris

k = Constant to account the Air space in the Building (k = 0.3, 0.5)

V_0 = Initial Volume of the Building

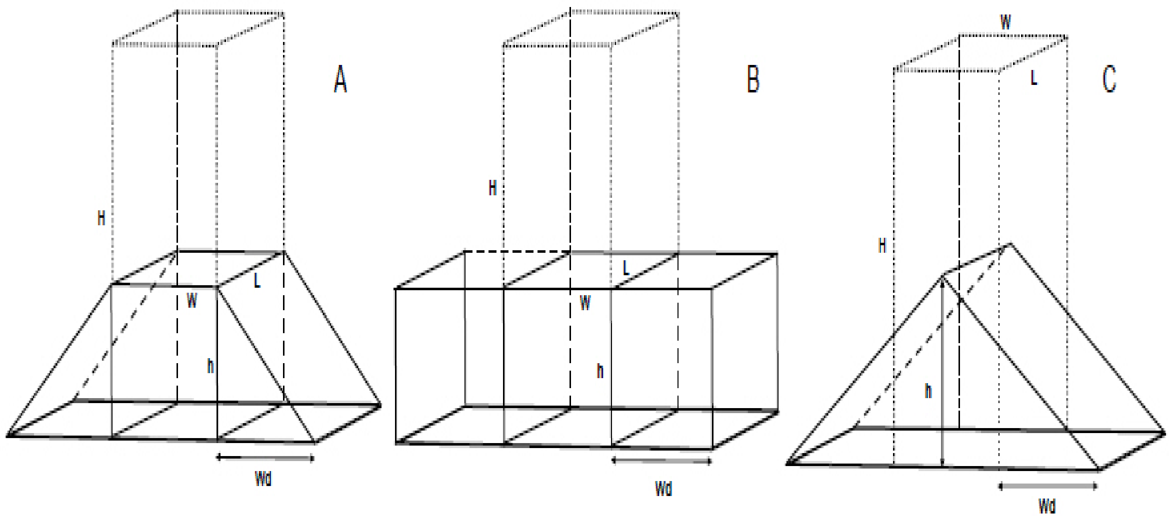
W_d = Width of Debris

m = Vegetative Cover Multiplier (m = 1.0, 1.5)

h = Height of the Collapsed Building

Source: Argyroudis, Pitilakis & Anastasiadis, 2005

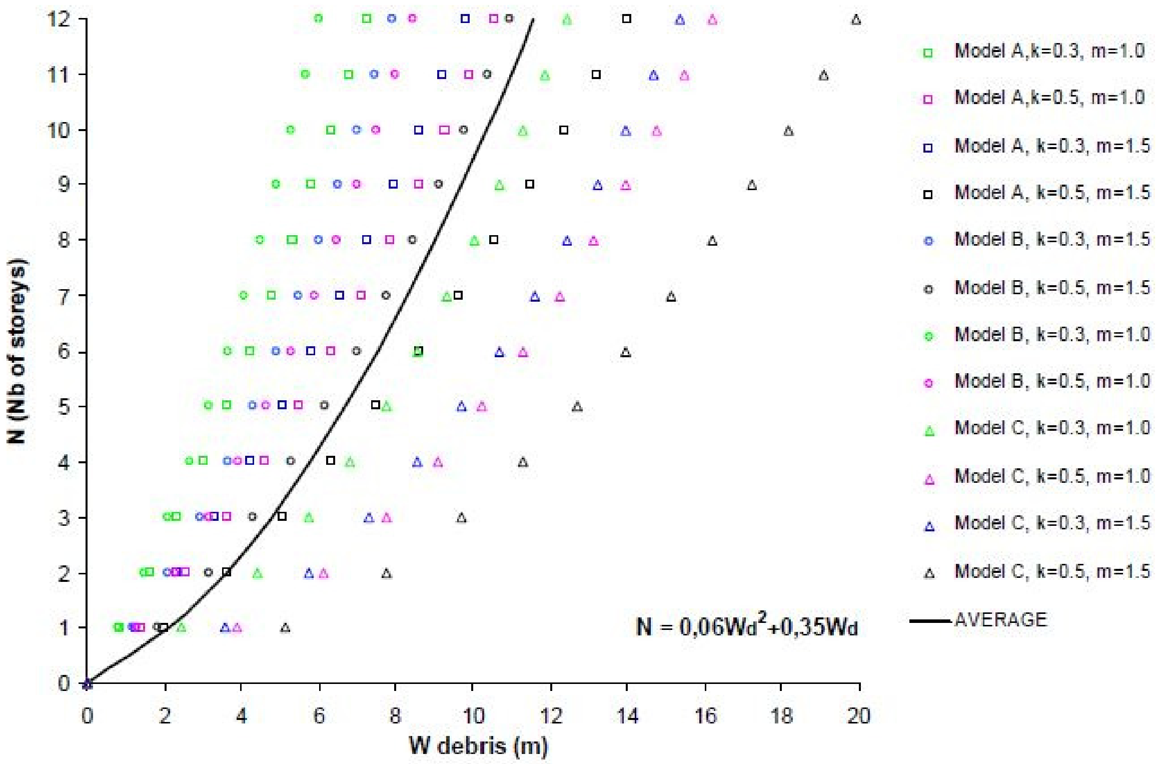
Figure 5.1.5: Description of the Equation of Width Calculation of Debris



Source: Argyroudis, Pitilakis & Anastasiadis, 2005

Figure 5.1.6: Probable Building's Collapse Shapes

This method provides an idea of the probability of building's collapse shape. Though it suggests three probable models, however, Argyroudis et al. 2005 [11], performed an analysis showing the mean value of the various solutions is estimated for each number of stores and the different models. The derived mean curve (Figure 5.1.7) is closer to model A, while model B gives lower and model C higher values of the average debris width. It is noted that the higher is the building the greater is the dispersion of the predicted values of debris width for the various models. Moreover, the change of the initial volume contributes more than the change of the height of the collapsed building to the induced debris width.



Source: Argyroudis, Pitilakis & Anastasiadis, 2005

Figure 5.1.7: Simple Collapse Shapes for the Definition of the Induced Debris Width

5.1.5.2 Data collection tools

This research follows an integrated methodology which combines three distinctive methods consisting of their own algorithms. However, for collecting necessary data for this study, only one of the methods required primary data of building vulnerability. Therefore, a necessary tool (building survey form) has been developed considering the evaluation factors of structural vulnerability. The calculation of Visual Rating (VR) method requires data on cross-sectional areas of columns and masonry infills. Therefore, such data has been obtained by following the established survey form of visual rating. This form includes real time measurements of masonry as well as concrete wall infill ratio, observation of horizontal and vertical irregularity and so on.

5.1.5.3 Data collection method

There are two major approaches to gather information about a situation, person, problem or phenomenon [26]. To conduct a research study, in most situations, it is needed to collect the required information; however, sometimes the information required is already available and need only be extracted. Based upon these broad approaches to information gathering, data can be categorized as: i) Primary Data and ii) Secondary Data.

i) Primary data sources: The primary data are those, which have recently been collected and for the first time and thus happen to be genuine in character [27]. Depending on the required data to fulfill this study, certain primary sources have been used. Such data have been collected through performing Visual Rating (VR) survey (Appendix A). This survey included inspection of individual buildings within the study area considering the respected factors that are needed for Visual Rating (VR) index calculation.

ii) Secondary data sources: Secondary data refers to those which have already been collected by someone else and which have already been passed through the statistical process [27]. In this study, data on land use as well as certain structural details (e.g. construction year, GIS database etc.) have been obtained from RAJUK [28]. Apart from that, demographic information has been collected from national census report [29]. There also lie some other secondary sources from which information on basic parameters of earthquake, previous articles on network vulnerability etc. have been collected.

5.1.5.4 Data analysis

The data analysis part of this study includes the whole integration process of the stated methods. Initially the generated data from VR survey were processed accordingly to perform the VR Index calculation using Equation. This results in identifying individual building's I_{vr} value. Each building holding their distinctive I_{vr} value represents their certain level of vulnerability n a more diversified manner. Therefore, to simplify the output of VR Index, all the I_{vr} values have been further subcategorized into five classes. Later on, these categories have been correlated with their respective damage states using Damage Probability Matrix (Table 5.3). With the demarcation of respective damage state of each building, further assessment has been made on identifying the probable amount of induced debris (Equation 2) that might generate during a building collapse scenario.

The final calculation of articulating the distribution pattern of road blockage scenario has been conducted using GIS tools. As there lies a relation of reflecting higher impact within the closest location comparing to distant point, therefore, a weighted method of inversely distance calculation has been used to determine the expansion of impacted area of road blockage.

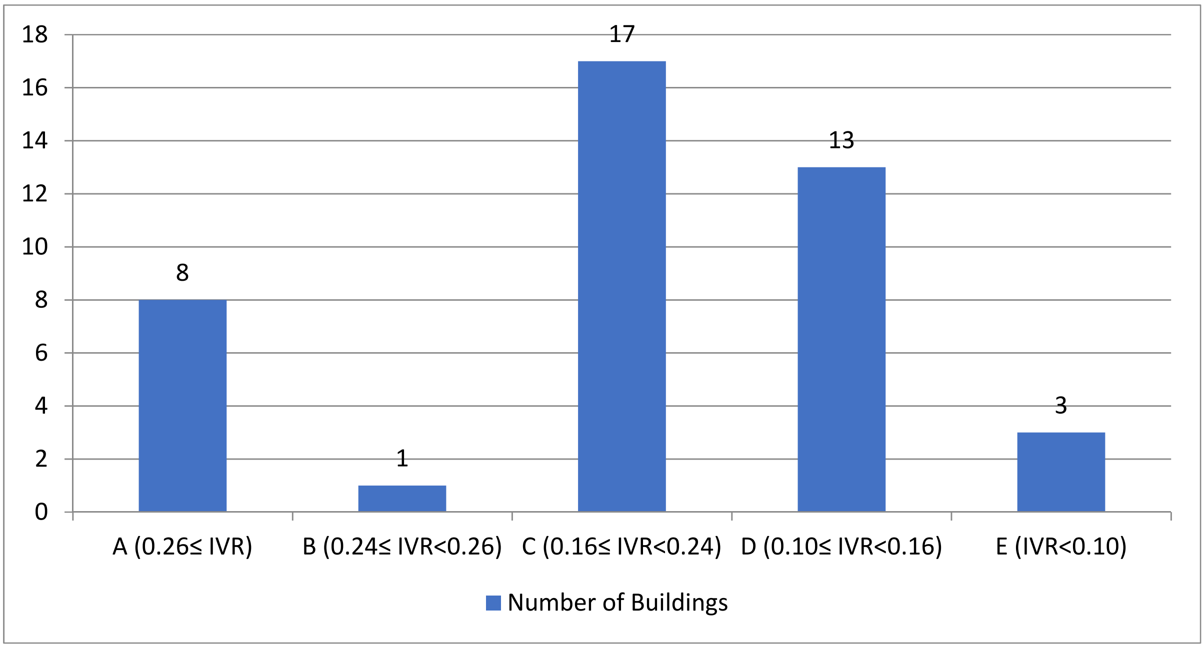
5.1.6 Road network vulnerability analysis in the study area

The prime concern of this research is to measure the potential impacts on road network performance in earthquake situations. These impacts are most detrimental to the functioning of emergency rescue services. Due to the substantial amount of delay in performing rescue services, the risk can drastically increase for the higher number of human casualties as well as material damages. In cases of post-earthquake responses, the functioning of road network disrupts because of road blockage scenario, which is mostly caused by induced debris from damaged buildings. Therefore, this research particularly focuses on vulnerable buildings that pose the potential probability of being collapsed during an earthquake event and generate a considerable amount of debris on their respective roads.

5.1.6.1 Result from building assessment

To evaluating building vulnerability for seismic threat, this research follows Visual Rating (VR) method with the integration of Damage Probability Matrices (DPM). At the initial stage, each building of the study area has been identified with their respective VR index (I_{vr}) using the formula developed by Islam, et. al., 2019 [18]. The results from VR index ranges from I_{vr}= 0.088 to I_{vr}= 0.331. Here, the lower index value represents greater risks for building vulnerability, whereas the higher VR index represents vice versa. Later, the I_{vr} values of all the investigated buildings have been reclassified into five categories and then correlated with their respective probable damage state (i.e. no damage 0-1%, light damage 1-10%, moderate damage 10-50%, high damage 50-90%, full collapse 90-100%) that each building might face during a strong seismic event.

According to the survey, most of the buildings have been identified as category C having 17 survey units (Figure 5.1.8). On the other hand, for the worst case scenario, 3 buildings have been identified as class E. As for the rest of the surveyed buildings, 8 buildings have been identified as class A, 1 as class B and 13 as class D.



Source: Field Survey, 2020

Figure 5.1.8: Statistics of VR Survey

After correlating the results from Visual Rating (VR) survey with Damage Probability Matrix (DPM) it shows a whole new scenario marking each inspected building with their respective damage state. The results from the application of this method are presented in Figure 5.9. The red color indicates a higher probability of building damage and following through the green color directs to a less probability. The following table has been established according to the obtained data from the field survey:

Table 5.1.4: Statistics on Building Damage

Damage State	Building Damage Range (in %)	% of Buildings
None	0-1	19.05
Light	1-10	2.38
Moderate	10-50	40.48
Heavy	50-90	30.95
Collapse	90-100	7.14

Source: Field Survey, 2020

Source: Developed by the Author with help of Field Survey, 2020

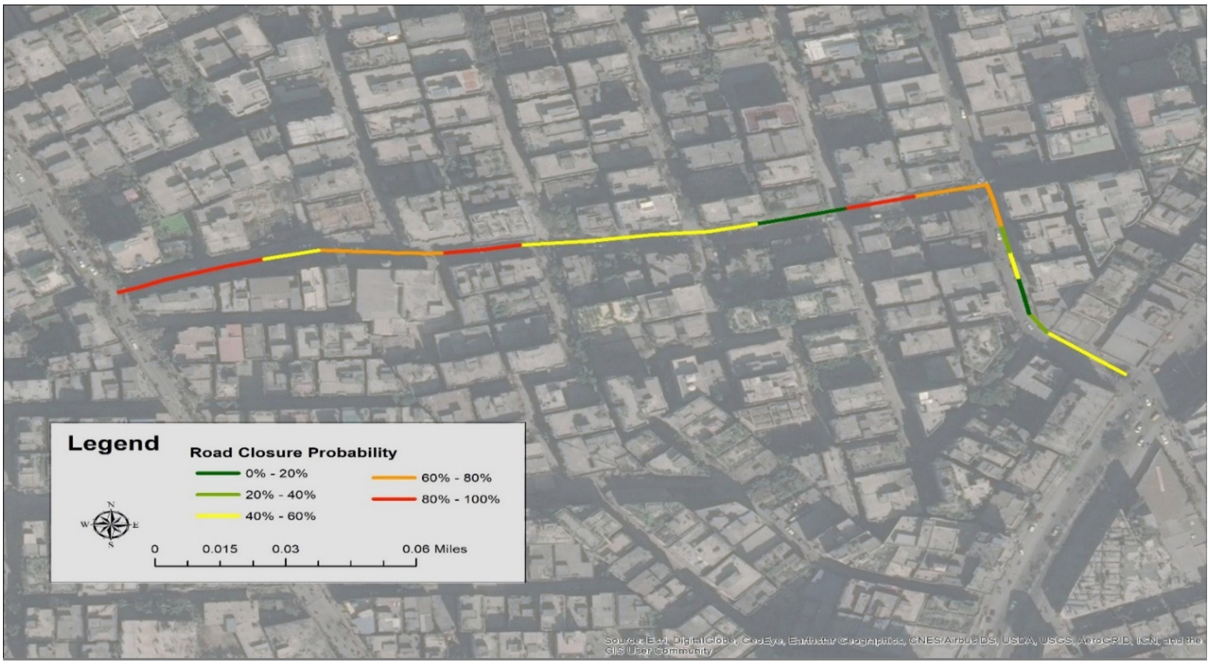
Figure 5.1.9: Building Damage Probability

The findings articulate that, around 7% of the buildings within the study area show the probability of getting 90-100% damage during an earthquake event. Apart from that, the majority of the buildings (around 40%) show probability of getting 10-50% damaged. But, the concerning fact highlights around 31% of the buildings poses a threat of getting 50-90% damage probability. However, it is also observed that buildings with greater height are most vulnerable to such damage threat. The risk minimizes as the number of building stories reduces.

5.1.6.2 Road blockage scenario assessment

The method of Damage Probability Matrix (DPM) performed in the previous section shows the probability of building collapse ratio for each unit of structures. This data helps to identify the amount of induced debris that might generate on the road after a building completely or a portion of it collapses. As each building holds different level of vulnerabilities or in other words, different damage probabilities, therefore, t he amount of induced debris on different section of the roads varies in volume or in length and width. As greater the portion of a building's damage ratio gets, the greater it produces debris. That means collapse of high rise buildings will generate larger amount of debris in volume resulting higher probability of road closure scenario.

Adabor is a residential area, with a high building density. Most of the buildings within this area are closely in contact with each other, leaving very narrow space in between. Also, lack of open areas, as well as short distance from building's facade to streets, leads to a higher risk potential to the transportation system in case of a strong earthquake. However, to evaluate the road blockage scenario within the study area, a simple but effective method by Argyroudis, et. al., 2005 [11] has been applied in this research. This method focuses on the damage ratio of a building, which might get revealed during a serious earthquake. Considering the results from building assessment, a correlation has been built with the height of the building to the potential width of induced debris from damaged structures. As a result, Figure 5.9 demonstrates the probable road blockage scenario within the study area.



Source: Developed by the Author with help of Field Survey, 2020

Figure 5.1.10: Road Closure Probability

The red color indicates a higher probability of road closure within that particular portion of the road as a greater amount of induced debris might concentrate within that area. Following the color sequence, the green color illustrates less concentration of probable induced debris. Though the concerning road is about 441m in length, yet it is exposed with a greater threat in terms of traffic functioning after a severe seismic event. This research has identified three major road portions where the blockage scenario might level up to 80-100%. In other words, within these three portions, the road might get completely blocked resulting in 100% inaccessibility through this road to its nearby areas. A sample of road blockage calculation is shown in Appendix B.

Table 5.1.5: Statistics on Road Blockage

Damage State	Road Blockage Range (in %)	Road Length (in m)	Road Length (in %)
None	0-20	51.3	11.72
Light	20-40	24.5	5.6
Moderate	40-60	156.6	35.79
Heavy	60-80	93.6	21.4
Collapse	80-100	111.6	25.5
Total		**437.6**	**100**

Source: Field Survey, 2020

According to the results from road closure probability, Table 5.1.5 shows 111.60 meters of roads are under greater threat of getting around 80-100% of road closure due to probable induced debris. It covers 25.5% of road length within the concerning roads of the study area. On the other hand, 93.60 meters of the road sections are under the threat of 60-80% road closure probability, which covers 21.4% of road length within the concerning roads of the study area. Though most of the roads have been threaten by moderate level (40%-60%) of road closure, the amount of high level of road closure probability is 156.60 meters which covers 35.79% of total road length is still a matter of big concern. Apart from that, 5.6% of road length falls under 20%-40% of road blockage probability. This covers 24.50 meters of road section within the study area. The rest 11.72% of road section falls within the range of 0%-20% of road blockage probability, which covers 51.30 meters of road section within the study area.

5.1.7 Conclusion

In recent years, network vulnerability assessment for seismic hazard is an evolving topic. And in the case of Bangladesh, which lies in a seismically active zone, it is very much important to anticipate all the possible risks due to earthquakes. That is why taking precaution on only building vulnerabilities leaves out the vital factors of network related issues.

In this research, the methodology focuses on defining the vulnerable routes of the network system for the purpose of improving the overall seismic risk management of the road network within an urban area of Bangladesh. As this type of research is almost new to this country, the result helps to identify appropriate mitigation actions for retrofitting vulnerable components as well as illustrating the importance of alternative routes in emergency situations. Though the recent researches have used different rapid screening methods to evaluate building vulnerability, this paper utilizes Visual Rating (VR) method for reaching towards more precision and detailed data on building vulnerability. Therefore, the accuracy increases for the final result of road network vulnerability which initially considers the outcome of VR method.

It is true that events like an earthquake are still unpredictable in terms of its occurrence frequency. However, knowing the vulnerable positions in a network route opens up the possibilities of achieving more effective and innovative retrofitting approaches to tackle and minimize road network related damages caused by hazardous situations like an earthquake.

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Appendix A

VR Survey Form

Name of Building: **Date:**

Address:

Please read carefully the selection criteria and put circle [○] in the appropriate items

No	Items	Selection Criteria	Categories of data								Please specify, If the value is found	Note
1	No of story (n)	Put story number										
2	Representative column size (b_c), (mm)	Please exclude the mortar/plaster thickness 50 mm, for tiles work exclude 75 mm	250 mm ~ 350 mm	350 mm ~ 450 mm	450 mm ~ 550 mm	550 mm ~ 650 mm	650 mm ~ 750 mm	750mm ~ 850 mm	850mm ~ 950 mm	950mm ~ larger	mm	
3	Average span length (l_s), (m)	The size of equivalent square floor area carried by a single column	2.50 m ~ 3.50 m	3.50 m ~ 4.50 m	4.50 m ~ 5.50 m	5.50 m ~ 6.50 m	6.50 m ~ 7.50 m	7.50 m ~ 8.50 m	8.50 m ~ 9.50 m	6.50 m ~ larger	mm	
4	Masonry infill ratio	Masonry infill Ratio, R_{inf}: $= \frac{\textit{No of infill panel in x or y dir.}}{\textit{Total no of span in x or y dir.}}$	X-direction:				Y-direction:					
5	Concrete wall ratio	Concrete wall Ratio, R_{cw}: $= \frac{\textit{No of Concrete wall in x or y dir.}}{\textit{Total no of span in x or y dir.}}$	X-direction:				Y-direction:					
6	Vertical irregularity, F_{IV}	Regular= No irregularity Nearly Regular= Small opening at ground floor Irregular= Ground floor nearly open/parking	Regular (1)			Nearly regular (0.8)			Irregular (0.6)			
7	Horizontal irregularity, F_{IH}	Regular= No irregularity Nearly Regular= Small projection exists with irregular shape Irregular= large projection with irregular shape	Regular (1)			Nearly regular (0.9)			Irregular (0.8)			
8	Deterioration of concrete, F_D	None= No deterioration Minor= Some crack in structrual element or minor spalling Severe= Major Spalling of concrete and major Crack	None (1)			Minor (0.9)			Severe (0.8)			
9	Year of construction (F_y)	after 2006 1993~2006 before 1993	New (1)			Middle (0.95)			Old (0.9)			

*numeral in parenthesis indicates corresponding weightage

Legends:
M.WALL W/OPENING
M.SOLID INFILL WALL

Please draw a sketch the RC column with Masonry infill

Y

X

Front View (Sketch)

Side View (Sketch)

Appendix B

Road Blockage Calculation (Sample)

Formula:

wd = M x H

wd = width of the debris

H = Damage (%) x Floor Height x 3.048

M = 1

Let us assume for the selected buildings B1 and B2,

The Damage Ratio is 50%

Number of Floors,

B1 = 3

B2 = 4

So Collapse height (ch) of the buildings,

ch (B1) = 1.5 x 3.048 = 4.572m (*as H = Damage (%) x Floor Height x 3.048*)

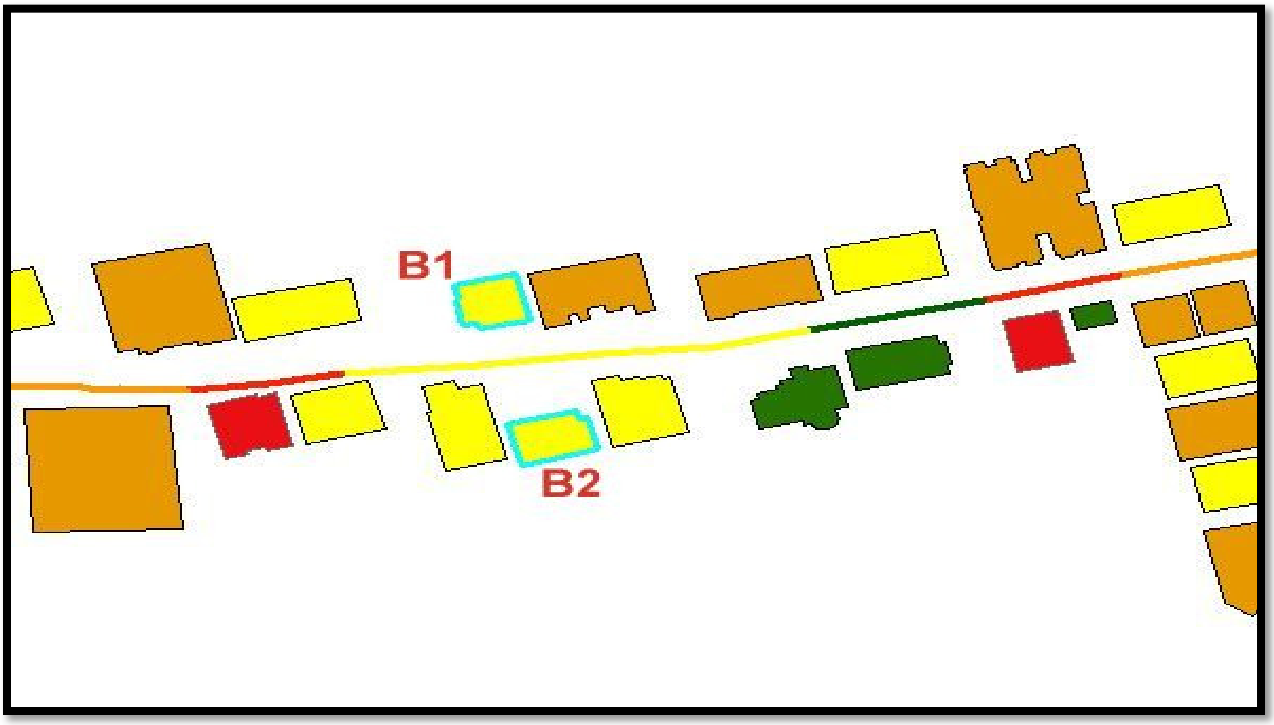
ch (B2) = 2 x 3.048 = 6.096m

Now width of debris,

wd (B1) = 4.572 x 1 = 4.572m

wd (B2) = 6.096 x 1 = 6.096m

Average wd (B1, B2) = 5.334m = **40%-60% road blockage** (*as the road's width is 9.144m)*



5.2 Road Network Vulnerability Assessment <B>

5.2.1 Introduction

The development of Dhaka city has largely happened in an unplanned way. Dhaka is growing rapidly, but urbanization is not appropriately planned. As urbanization is increasing, more people in cities face natural hazards. In Bangladesh, 37.405% of the total population lives in the cities [1]. In the last couple of decades, thousands of multi-story buildings have been built without any open spaces and have encroached on the streets and roadways. In addition, most of the natural water reservoirs, such as ponds and ditches, have been covered over with buildings. In many instances, building regulations have not been adequately supervised.

Furthermore, there are many industries, including garment factories, that are located within the capital. There are also buildings in the city that are poorly built, partly constructed with concrete, bamboo, or tin, and found in high-density slum areas [2]. The national building code was broken in 66 percent of the structures in the capital [3].

The Dhaka Structure Plan (2016-2035) [4] analyzes the scenario by the following points:

- The absence of critical public facilities (i.e., school, hospital, police station, sewerage system, etc.) and failure of their proper functioning may seriously impact the dwellers after the earthquake.
- City authorities are ill-prepared to face a high-intensity earthquake event because of little contemporary experience.

If an earthquake hits Dhaka, it will be difficult to provide emergency evacuation to its residents because of the unplanned development. The awareness level among the people will also play a significant role in determining the panic factor and overall preparation level. In case of emergency shelter [5], suggested that primary schools, high schools, colleges, community centers, and mosques can be used as temporary evacuation shelters.

5.2.2 Rationale of the study

An earthquake event in Dhaka city has the capacity of doing immense damage to the citizens living here, both economically and socially. The unplanned development happening in the city makes it even more vulnerable to the earthquake. The earthquake has various impacts on a city, including property loss, infrastructure damage, loss of lives, etc. These can lead to massive humanitarian crises, which may be very hard to manage by the government. The Disaster Management Act of 2012 [6] focused on mitigating disaster risk in Bangladesh, prioritizing the after-disaster management works and policies. It also mentions preparation for disaster, which includes increasing awareness and capability among the community. The National Plan for Disaster Management of Bangladesh (2016-2020) [7] moves from the after-disaster management concept to emphasize disaster resilience across communities. It also aligns with The Sendai Framework, which has prioritized understanding disaster risk and investing in disaster resilience.

Disaster resilience includes emergency preparedness for disasters, including earthquakes. Emergency planning is associated with a set of actions to be launched when the earthquake occurs. These should optimize the time of intervention (evacuation, rescue, hospital treatment, etc.) in the most efficient way to minimize the suffering of the populations [5].

A lack of planning for emergency evacuation preparedness and general awareness towards local level evacuation preparedness has been found. This study is concerned with these issues that influence the emergency evacuation preparedness of an urban area like Dhaka. This includes the people's perception of emergency evacuation preparedness and locating possible temporary evacuation shelters and their service area characteristics.

5.2.3 Research questions and objectives

5.2.3.1 Research questions

For conducting this research, the following research questions must be answered:

- What is the people's perception of emergency evacuation preparedness?
- What is the quality of emergency evacuation infrastructure?

5.2.3.2 Research objectives

The research objectives under the research question are:

- To assess the level of earthquake risk awareness and earthquake evacuation knowledge by people of different socio-economic backgrounds.
- To find out the availability and carrying capacity of emergency evacuation places in the study area.

5.2.4 Literature review and past studies

5.2.4.1 Concept of urban resilience

'Resilience is the ability of a system, community, or society exposed to hazards to resist, absorb, accommodate, and recover from the effects of a hazard promptly and efficiently' [8]. Urban Resilience is 'The measurable ability of any urban system, with its inhabitants, to maintain continuity through all shocks and stresses, while positively adapting and transforming toward sustainability.' [9]. Again, Gian Paolo Micellar, 2018 [10] describes 'Resilience is defined in terms of three stages: the ability of a system to reduce the probability of an adverse event, to absorb the shock if the adverse event occurs, and to quickly re-establish normal operating conditions. So, resilience thus encompasses the four characteristics of robustness, redundancy, resourcefulness, and rapidity. Are considered four types of resilience: technical; organizational; economic; and social.'

The disaster resilience concept describes resilience against several natural hazards; for example, disasters might be caused by earthquakes, flooding, volcanic eruption, landslide, hurricanes, wildfire, bushfires, tornadoes, avalanches, tropical cyclones, etc. Earthquake resilience is the focus of this study.

5.2.4.2 Components of urban resilience

Jha et al., 2013 [11] describe four components of urban resilience. They are Infrastructural, Institutional, Economic, and Social.

- Infrastructural resilience refers to the vulnerability of built structures, including property, buildings, and transportation systems. It also refers to sheltering capacity, health care facilities, the vulnerability of buildings to hazards, critical infrastructure, and the availability of roads for evacuations and post-disaster supply lines. Infra-structural resilience also refers to a community's capacity for response and recovery.

- Institutional resilience refers to the governmental and non-governmental systems that administer a community.
- Economic resilience refers to a measure of a community's economic diversity as well as to the overall employment, the number of businesses, and their ability to function following a disaster.
- Social resilience refers to the demographic profile of a community, including by sex, age, ethnicity, disability, socioeconomic status, and other key groupings and a community's social capital. Although it is difficult to quantify, social capital refers to a sense of community, the ability of groups of citizens to adapt, and a sense of attachment to a place.

5.2.4.3 Concept of seismic urban resilience

Bruneau et al., 2003 [12] describe, 'Seismic resilience is conceptualized as the ability of both physical and social systems to withstand earthquake-generated forces and demands and to cope with earthquake impacts through situation assessment, rapid response, and effective recovery strategies (measured in terms of reduced failure probabilities, reduced consequences, reduced time to recovery).' Also, a resilient system is a system that shows:

1. Reduced failure probabilities,
2. Reduced consequences from failures, in terms of lives lost, damage, and adverse economic and social consequences,
3. Reduced time to recovery (restoration of a specific system or set of systems to their "normal" level of performance)

5.2.4.4 Resilience and earthquake preparedness

According to Luisana Mariani, 2015 [9], Earthquake preparedness is a set of measures taken at the individual, organizational and societal level to minimize the effects of an earthquake. Preparedness measures can include securing heavy objects, structural modifications and storing supplies, insurance, an emergency kit, and evacuation plans.

California Department of Public Health, 2019 [13] has described components of earthquake evacuation. They are:

- Making a home evacuation plan
- Plan way to exit room or area
- Storage of emergency food, water, first aid kits, and fire extinguishers
- Identifying an emergency meeting place
- Emergency response telephone numbers (police, fire, paramedics, and medical centers)
- Bank or credit union's telephone numbers account types and numbers
- Health Insurance
- Secure heavy items in a home

Wu, Han, Xu, & Gong, 2018 [14] tell that there is a correlation between earthquake preparedness and place of residence, earthquake experience, earthquake risk, socio-economic variables, preparedness actions, participation in previous earthquake rescue events, homeownership, and sufficient resources available.

The disabled person's requirements have been explained by Pakjouei, Aryankhesal, Kamali, & Seyedin, 2018 [15]. According to them, disability needs for earthquake preparedness include:

- *House and Workplace Adaptation:* Due to movement constrictions, disabled persons need adaptive house and workplace conditions that enable them to escape from dangerous situations.
- *Spare Assistive Devices at Home and Workspace:* Assistive devices are absolute necessary for the disabled persons for movement.
- *Access to Vehicles:* The disabled persons require access to vehicles suitable for their needs for evacuation from unsafe areas.
- *Special Facilities for Emergency Evacuation:* The disabled persons need special facilities for emergency evacuation from buildings. It includes special exit routes, romps, and trained personnel for evacuation.
- *Adaptive Shelters:* The disabled persons require adaptive shelters for their evacuation, which can accommodate them according to their various disabilities.

Urban resilience and earthquake preparedness are related to each other. According to the U.S. Department of Health and Human Services, 2015[16], earthquake preparedness is highly benefited from community resilience because of is encourages actions that are required for earthquake preparedness. The elements under components of community resilience support these steps.

Clements & Ann, 2016 [17], describes the core characteristics of community resilience. According to them:

- Comprehensive local information, including knowledge of vulnerability and localized action for disaster, which they can take.
- People have taken steps to anticipate disasters and protect themselves, their assets, and their livelihood. Committed necessary resources and organized themselves before, during, and after a disaster.
- People work with local leaders to prepare for disasters using knowledge and resources.
- People work in partnership with emergency services, their local authorities, and other relevant organizations before, during, and after emergencies.
- Emergency management plans are resilience-based to build disaster resilience within communities over time.
- Core policies, products, and services of the locality are developed considering the resilience outcome.
- The emergency management volunteer sector is strong.
- Following Disasters, services functioning comes back to normal quickly.
- Businesses take steps and practice business continuity which considers emergency planning and community resilience.
- Land use planning controls land use and building development, so that community exposure reduces to known natural disasters to the community.

Cutter, Burton, & Emrich, 2010 [18] breaks down the components of community resilience:

- Social resilience: High social resilience depends on higher levels of educational equality, fewer elderly, disabled residents, high percentages of inhabitants with vehicle access, telephone access, and health insurance.
- Economic resilience: housing capital, equitable incomes, employment, business size, and physician access. The local economic base is diversified (more resilient) or primarily based on a single sector such as agriculture or fishing, making the community less resilient.
- Institutional resilience: It is affected by the capacity of communities to reduce risk, engages local residents in mitigation, creates organizational linkages, and enhance and protect the social systems within a community.
- Infrastructural resilience: It is mainly an appraisal of community response and recovery capacity (e.g., sheltering, vacant rental housing units, and healthcare facilities).

5.2.4.5 Concept of emergency evacuation

Emergency evacuation is the process of urgent escape of people from an area holding a threat on public lives or continuous hazard to lives and property. According to Zeigler, Perry, Lindell, & Greene, 1983 [19], evacuation is relocating people from a place of high threat to a relatively low threat area. The goal of an evacuation is to move as few people as needed the shortest distance to safety [20].

5.2.4.6 Concept of temporary evacuation shelters

According to Zhao et al., 2017 [21], 'The first step towards urban resilience planning is to ensure that affected people are evacuated quickly to safe assembly points and shelters in the wake of disasters.'

FEMA, 2017 [22] describes, 'An Evacuation Shelter serves the general population in an existing facility (or facilities), such as a school, community centre, convention centre, or church that the Authority Having Jurisdiction (AHJ) has temporarily converted for use as a shelter for disaster survivors.'

According to CDC, 2013 [23], 'Shelters provide a safe place for individuals affected by emergency events to reside. These shelters can provide a variety of services such as food, sleeping quarters, sanitation facilities, and medical care.'

Ministry of Environment, Climate Resilience, Disaster Management and Urban Renewal in the Commonwealth of Dominica, 2019 [24] explains, 'An Emergency Shelter is a place for people to live temporarily when they cannot live in their previous residence…an emergency shelter usually accommodates people fleeing a specific situation related to disasters, violence, strife, abuse. Such people often have places of permanent residence.'

Federal Emergency Management Agency of the United States Department of Homeland Security has also defined emergency shelters as mass care resources. According to FEMA, 2017 [22], an evacuation shelter provides the following:

1. Provides for the immediate needs of disaster survivors, typically for less than 72 hours

2. Provides basic life-sustaining services until the threat has passed or until shelter residents transfer or transition to a Short-Term Shelter, including:

➢ Basic food items or snacks
➢ Hydration
➢ Basic medical care
➢ Sanitation
➢ Disaster-related information

Table 5.2.1: Classification of Shelters Based on Temporal Scale

Shelter type	Immediate shelter (IS)	Short-term shelter (SS)	Long-term shelter (LS)	Permanent shelter
Time	For the first day	One day to a week	A week to a month	A month later
Required Area	Total ≥ 2000 m^2 Per capita ≥ 1 m^2	Total ≥ 10,000 m^2 Per capita ≥ 2 m^2	Per capita ≥ 3 m^2	N/A
Purpose	Preventive	Preventive	Preventive	Protective
Major functions	Provides easily prepared food, water, emergency medical care	Provides food, water, tents, emergency medical care	Provides food, water, tents, lavatories, cooking facilities, medicines, fire control, vaccinations, temporary storage	Provides housing and well-equipped living facilities

(Source: Chen et al., 2013)

Table 5.2.2: Shelter Types Based on Carrying Capability

Resource Types			Type 1	Type 2	Type 3	Type 4
Component	Metric/ Measure	Capability				
Facility	Per facility	Shelter residents	2,000 or more	500 – 1,999	250 – 499	249 or fewer
Facility	Per facility	Area	Over 80,000 sq. ft.	20,000 – 80,000 sq. ft.	10,000 – 20,000 sq. ft	Under 10,000 sq. ft.

(Source: FEMA, 2017)

Ministry of Environment, Climate Resilience, Disaster Management and Urban Renewal in the Commonwealth of Dominica, 2019 [25] has divided the evacuation shelters into two categories:

➢ Planned Camps
➢ Spontaneous or self-settled camp

Planned camps: These are places in either rural or urban locations, where displaced populations find accommodation on purposefully-built sites, to be supplied with services which may include food, water, sanitation, locations for health or medical services, the distribution of clothing or other non-food items and meetings and recreation places for cultural events. Other services such as a location for livestock or religious worship may also be made available. The use of these sites is typically exclusively for the population of the site, but exchange and interaction with the neighboring host community are highly encouraged.

Spontaneous or self-settled camps: These are set up by displaced groups, often in smaller groups of affiliated people who may self-settle in urban or rural sites on their own. These types of settlements are typically independent of assistance and exist without receiving any humanitarian interventions. Self-settled camps can be situated on state-owned, private, or communal land, usually after limited or no negotiations with the local population or private owners overuse and access. In some cases, a Camp Management Agency may operate in the vicinity and learn about their needs and attempt to assist them with operational assistance.

The distance of emergency evacuation shelters is another important criterion for better emergency evacuation shelter functioning. Omar, 2018 [5] suggests a 400-meter radius or 5-minute walking distance to be an easy distance to access the emergency evacuation shelters.

5.2.5 Methodology

The research goal of this study is to identify the emergency evacuation preparedness perception of the residents of the study area ward no. 30 (Adabar), along with infrastructural abilities to provide safe emergency evacuation. Two objectives have been developed to achieve these goals, including demography of the area, evacuation preparedness indicators, temporary shelters, and their service area characteristics. To conduct the research, a quantitative method has been applied.

This research comes from the interpretivist paradigm, which tries to understand the world from the subjective view of the individuals. The quantitative method is followed by this research, while the descriptive approach is taken. It is because to describe the problem by way of generating numerical data and data that can be explained through statistical measurements. It describes the demographic condition of the survey area, variables under emergency evacuation preparedness, temporary shelters, and their service area characteristics.

5.2.5.1 Formulating required data set

A data list is prepared for obtaining the required information to fulfill the research objectives. For this research, a data set is prepared which encompasses all the variables related to each objective. A detailed variable list has been prepared (Table 5.2.3), which emphasizes the objectives of the study. To assess the level of earthquake risk awareness and earthquake evacuation knowledge by people of different socio-economic backgrounds, the following variables and sub-variables are required:

- Demography of the residents of the study area
  - Age
  - Gender
  - Education
  - Occupation
  - Family Size
  - Monthly Income (In Taka)
- Earthquake risk awareness

- Earthquake probability assessment by residents
- Taken steps to increase earthquake knowledge
- Home is unsafe for earthquake
- Have an earthquake safety plan
- Safety measures at home

- Emergency evacuation knowledge
  - Know about quick route out of home
  - Know about post-earthquake meeting place
  - Participation in earthquake drills
  - Know the procedure for earthquake emergency evacuation
  - Know the number of emergency services
- Provision for elderly/disabled
  - Structural provision for evacuation of elderly/disabled at home
  - Access to vehicles for evacuation of elderly/disabled at home
  - Training for the elderly/disabled for emergency evacuation
  - Assistive devices for elderly/ disabled at home
  - Training of caregivers for elderly/ disabled at home for emergency evacuation
- Vulnerability of structures
  - Age of the living place building
  - The construction quality of living place building
  - Accessibility of the living place building
  - Construction Material
  - Building Height
- Self-protection ability
  - Savings for emergencies
  - Bought safety instruments at home
  - Health Insurance
  - Formal savings for general purposes
  - The ability to shift residence
- Temporary Emergency Evacuation Shelters
  - Number of Educational and Religious structures and open spaces
  - The service area of each temporary emergency evacuation shelter
  - Carrying capacity of the shelters
  - Locational Distance from Medical Centers
  - Location of each temporary evacuation shelter

Table 5.2.3: Variable Matrix for Data Collection

Objectives	Variables	Data to Be Collected	Data Collection Method
1. To assess the level of earthquake risk awareness and earthquake evacuation knowledge by people of different socio-economic background	Demography of The Residents	▪ Age ▪ Gender ▪ Education ▪ Occupation ▪ Family Size ▪ Monthly Income	Questionnaire Survey
	Earthquake risk awareness	▪ Know about earthquake probability ▪ Taken steps to increase earthquake knowledge ▪ Home safety for earthquake ▪ Have an earthquake safety plan ▪ Have Safety measures at home	Questionnaire Survey
	Emergency evacuation knowledge	▪ Know about quick route out of home ▪ Know about post-earthquake meeting place ▪ Participation in earthquake drills ▪ Know the procedure for earthquake emergency evacuation ▪ Know the number of emergency services	Questionnaire Survey
	Provision for elderly/disabled	▪ Structural provision for evacuation of elderly/disabled at home ▪ Access to vehicles for evacuation of elderly/disabled at home ▪ Training for the elderly/disabled for emergency evacuation ▪ Assistive devices for elderly/ disabled at home ▪ Training of caregivers for elderly/ disabled at home for emergency evacuation	Questionnaire Survey
	Vulnerability of structures	▪ Age of the living place building ▪ The construction quality of living place building ▪ Accessibility of the living place building ▪ Construction Material ▪ Building Height	Questionnaire Survey

	Self-protection ability	▪ Savings for emergencies ▪ Bought safety instruments at home ▪ Health Insurance ▪ Formal savings for general purposes ▪ The ability to shift residence	Questionnaire Survey
2. To find out the availability and carrying capacity of emergency evacuation places in the study area	Service Area	▪ Number of Temporary Shelters ▪ The service area of each temporary evacuation shelter	Field Survey and Secondary Data
	Carrying Capacity	▪ No of people at each temporary shelter ▪ Percentage of the population served by the temporary shelters	Field Survey and Secondary Data
	Medical Centers	▪ Availability of Medical Centers ▪ Locational distance of Medical Centers	Field Survey and Secondary Data

5.2.6 Data interpretation

The data collected from the study area through a questionnaire and the data collected from secondary sources have been analyzed in this section. The demographic data, emergency evacuation preparedness factors, temporary evacuation shelter characteristics are presented through charts, tables, graphs, and maps.

5.2.6.1 Demographic information

The first objective of this study is to find out the emergency evacuation preparedness of people from different socio-economic backgrounds. Demographic information is collected from the surveyed people and showed here.

5.2.6.2 Age of the respondents

The ages of the responders are mostly in the range of 30-39 years. The percentage is 29.5%. The second-largest response group belongs in the age range of 20-29 years, 22.98%. The age group follows it under 20 years, which is 19.58%. The lowest responders are in the age range of over 65 years, with a percentage of 6.53%.

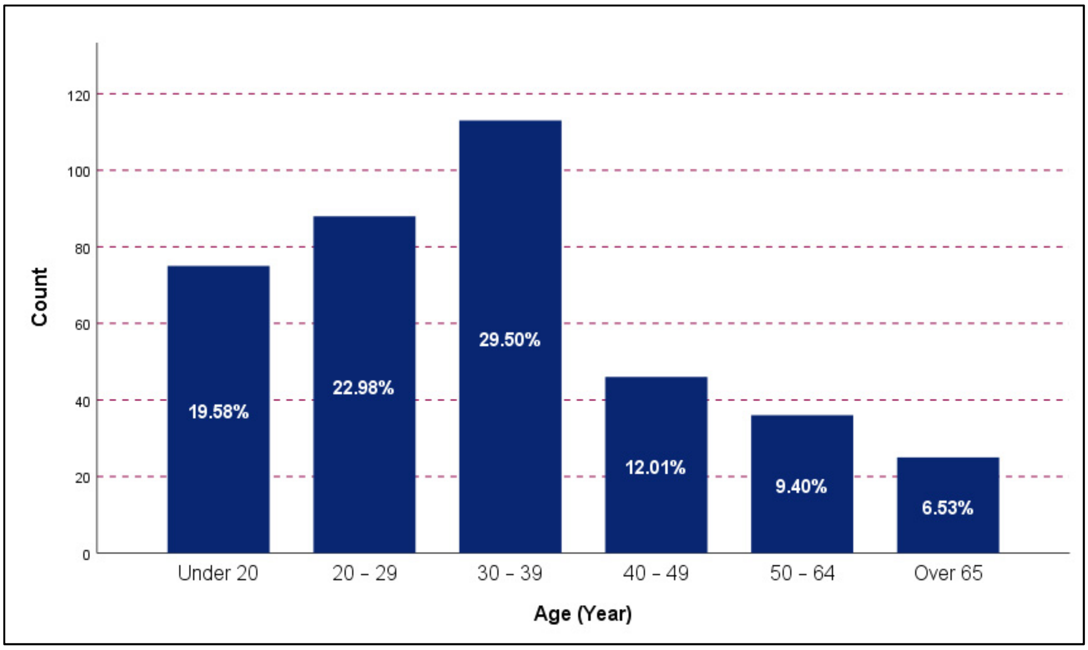


Figure 5.2.1: Age of the respondents (Source: Field Survey, 2020)

5.2.6.3 Gender of respondents

For this study, male and female responders were chosen for the response. 53% of the responders of this study were male, and 47% of responders were female.

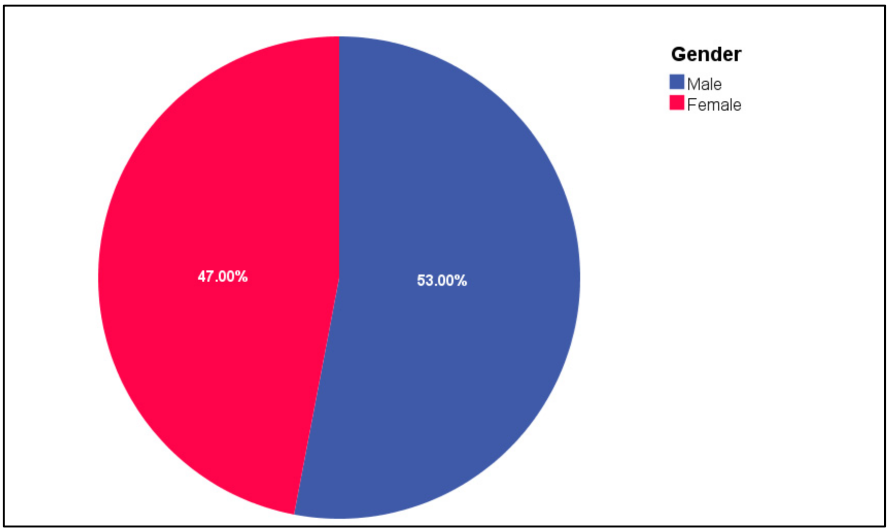


Figure 5.2.2: Gender of the respondents (Source: Field Survey, 2020)

5.2.6.4 Education level of respondents

The education level of the responders was mainly the Masters's level (24.8%). The second highest education level is below S.S.C, which is 20.37%. There were illiterate responders; also, their percentage is 14.10%.

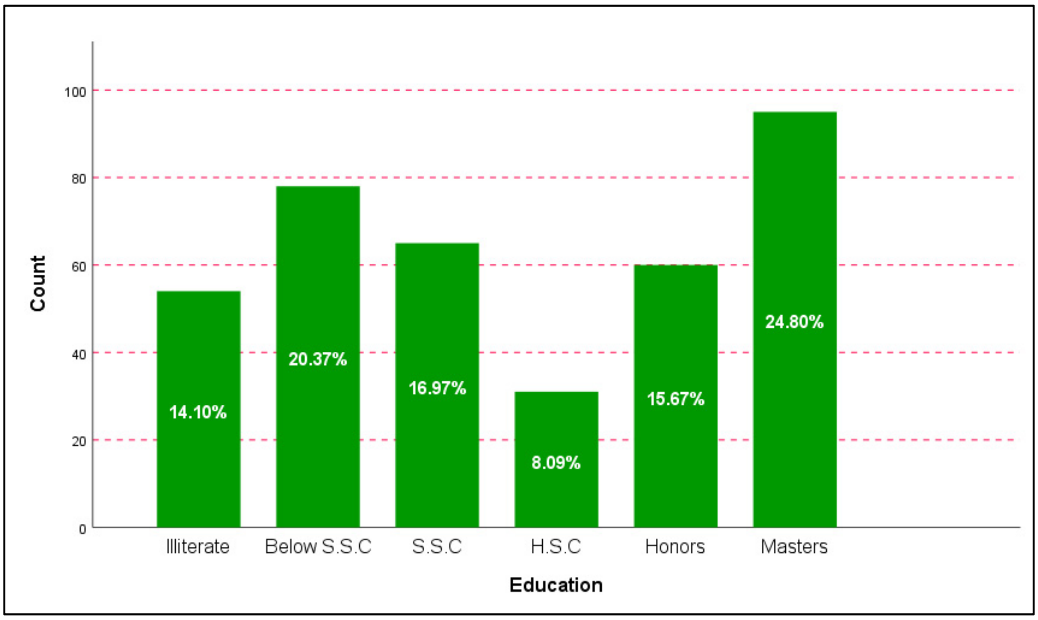


Figure 5.2.3: Education level of the respondents (Source: Field Survey, 2020)

5.2.6.5 Occupation of the respondents

Most of the responders were students (31.33%). Housewives were the second-highest responders (19.58%). Businessmen were 11.75% of the responders, and Public and Private service holders were 2.61% and 16.45%, respectively. People whose occupations were other than these were 14.62%.

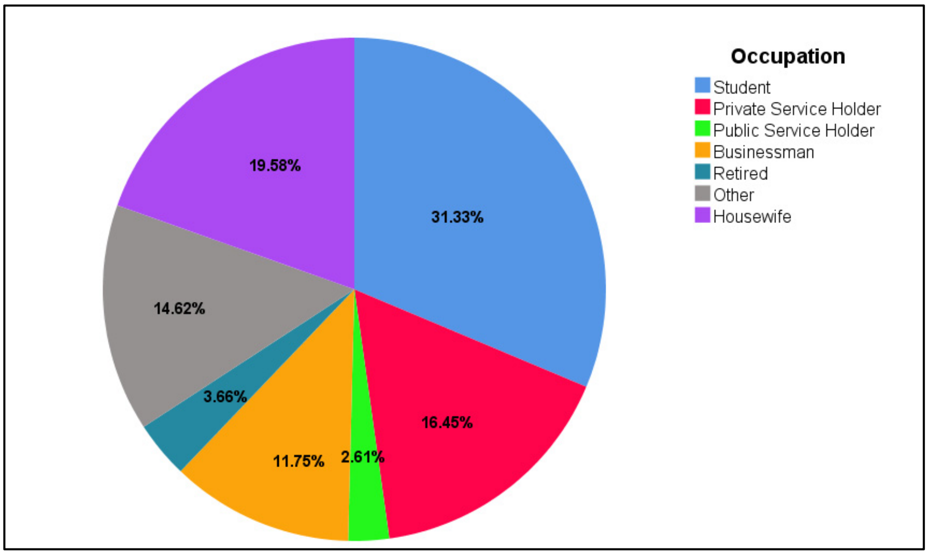


Figure 5.2.4: Occupation of the respondents (Source: Field Survey, 2020)

5.2.6.6 Family size of the respondents

40.21% of the responders belong to families who have 4 members. This is the highest percentage. The second highest is families having 3 members, which is 30.29%. 3rd highest is 5 member families, with the percentage of 12.53.

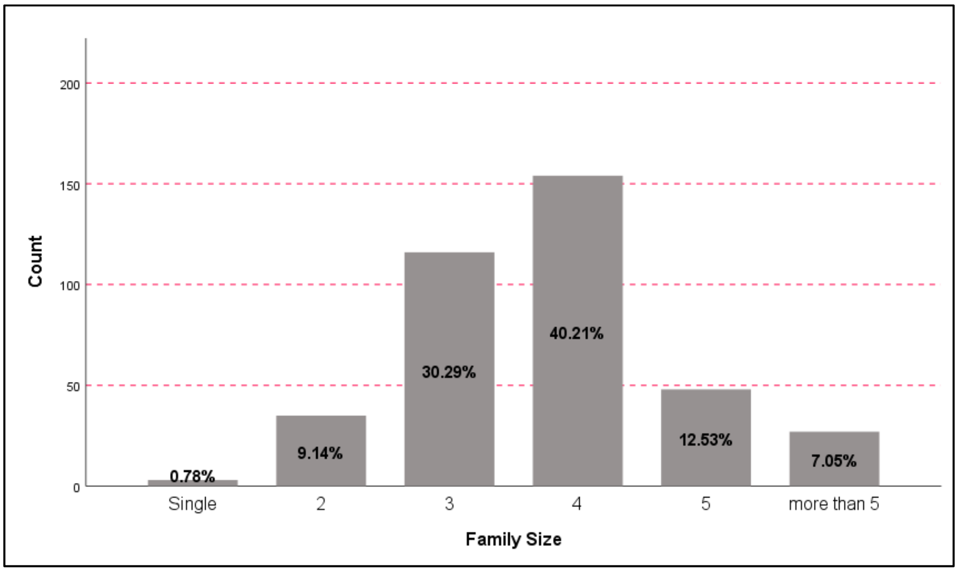


Figure 5.2.5: Family size of the respondents (Source: Field Survey, 2020)

5.2.6.7 Income of the responders families

The monthly income of most of the respondents is 26000-40000 taka, which is 30.55% of the total responders. The respondents' second-highest percentage (29.50%) have a family monthly income of 41000-55000 taka. The third-highest percentage of respondents (23.50%) have a monthly income of 11000-25000 taka. Only 7.05% of the responder' family income is less than 11000 taka.

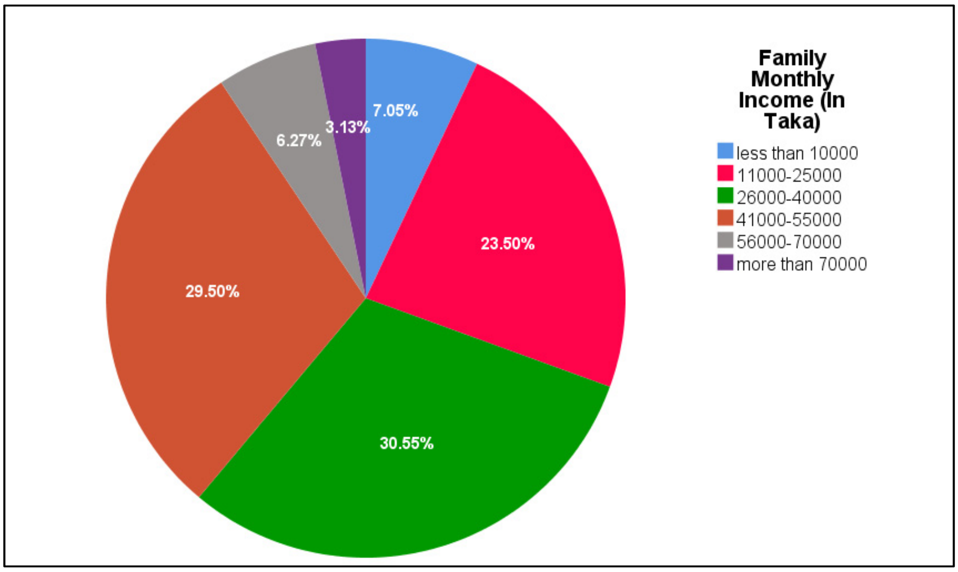


Figure 5.2.6: Family monthly income of the responders (Source: field survey, 2020)

5.2.6.8 Emergency evacuation preparedness analysis

The analysis is done through a scoring system. There are five variables under emergency evacuation preparedness. They are:

- Earthquake risk awareness

- Emergency evacuation knowledge
- Provision for elderly/disabled
- Vulnerability of structures
- Self-protection ability

Each variable has five sub-variables under it. The negative and positive responses of the sub-variables are coded from 0-1. The mean values of each sub-variable describe the condition of each sub-variable. The sum of the sub-variable mean score shows the condition of each variable.

5.2.6.9 Earthquake risk awareness

The earthquake risk awareness variable has five sub-variables. The highest score of 1 belongs to the sub-variable earthquake probability in the area. 'Safety measures are taken at home' and 'Have earthquake safety plan' sub-variables have the lowest score of 0.21. The total score is 2.36 out of 5.

Table 5.2.4: Earthquake Risk Awareness of the Responders

Earthquake risk awareness	**Mean**	**Total Score (out of 5)**
Earthquake probability in the area	1	2.36
Taken steps to increase earthquake knowledge	0.42	
Home is unsafe for earthquake	0.52	
Have an earthquake safety plan	0.21	
Safety measures are taken at home	0.21	

(Source: Field Survey, 2020)

5.2.6.10 Emergency evacuation knowledge

Under this variable, the lowest scoring sub variable is 'Participation in earthquake drills,' with a score of 0.12. 'Know the quick route out of home' and 'Know the number of emergency services' sub-variables has the highest score of 0.71. The total score is 2.23 out of 5.

Table 5.2.5: Emergency evacuation knowledge of the responders

Emergency evacuation knowledge	**Mean**	**Total Score (out of 5)**
Know the quick route out of home	0.71	2.23
Post-earthquake meeting place	0.42	
Participation in earthquake drills	0.12	
Know earthquake emergency evacuation procedure	0.17	
Know the number of emergency services	0.71	

Source: Field Survey, 2020

5.2.6.11 Provision for elderly/disabled

Poor values corresponding to the sub-variables under the Provision for the elderly/disabled variable. Among them, the highest-scoring sub-variable is ‘Access to vehicles for evacuation of elderly/disabled at home’ with a score of 0.13. The lowest scoring sub-variable is ‘Structural provision for evacuation of elderly/disabled at home’ with a score of 0.03. the total score is 0.4.

Table 5.2.6: Provision for elderly/disabled

Provision for elderly/disabled	Mean	Total Score (out of 5)
Structural provision for evacuation of elderly/disabled at home	0.03	0.4
Access to vehicles for evacuation of elderly/disabled at home	0.13	
Training for the elderly/disabled for emergency evacuation	0.06	
Assistive devices for elderly/ disabled at home	0.1	
Training of caregivers for elderly/ disabled at home for emergency evacuation	0.08	

Source: Field Survey, 2020

5.2.6.12 Vulnerability of structures

In case of vulnerability of structures, ‘Construction material’ got the highest score of 0.83. The lowest score belongs to the ‘Concerned about the construction quality of living place building’ sub variable with a score of 0.1. The total score is 1.95.

Table 5.2.7: Vulnerability of structures

Vulnerability of structures	Mean	Total Score (out of 5)
Concerned about age of the living place building	0.2	1.95
Concerned about construction quality of living place building	0.1	
Accessibility of the living place building	0.08	
Construction material	0.83	
Building Height	0.74	

Source: Field Survey, 2020

5.2.6.13 Self-protection ability

The self-protection ability variable has the ‘Savings for emergencies’ sub-variable, the lowest-scoring one, with a score of 0.2. The highest scoring is ‘Formal savings for general purposes,’ with a score of 0.83. The total score is 1.86 out of 5.

Table 5.2.8: Self-protection ability

Self-protection ability	Mean	Total Score
Savings for emergencies	0.2	1.86
Bought safety instruments at home	0.01	
Health Insurance	0.08	
Formal savings for general purposes	0.83	
Ability to shift residence	0.74	

Source: Field Survey, 2020

5.2.6.14 Total emergency evacuation preparedness score

The continuous values derived from the sub-variables under 5 variables of emergency evacuation preparedness factors are compounded into a total score which has the range of 25. The final score out of 25 is 8.8.

Table 5.2.9: Total Score of Emergency Evacuation Preparedness Factors

Emergency Evacuation Preparedness Factors	Score
Earthquake risk awareness	2.36
Emergency evacuation knowledge	2.23
Provision for elderly/disabled	0.4
Vulnerability of structures	1.95
Self-protection ability	1.86
	Total: 8.8 (out of 25)

Source: Field Survey, 2020

5.2.6.15 Temporary evacuation shelter characteristics

Temporary emergency evacuation shelters, their location, service area, served population etc. have shown in this section.

5.2.6.16 Location of the temporary evacuation shelter

The Available Temporary Emergency Evacuation Shelters are located in the west part, part of the northern and eastern area of ward 30.

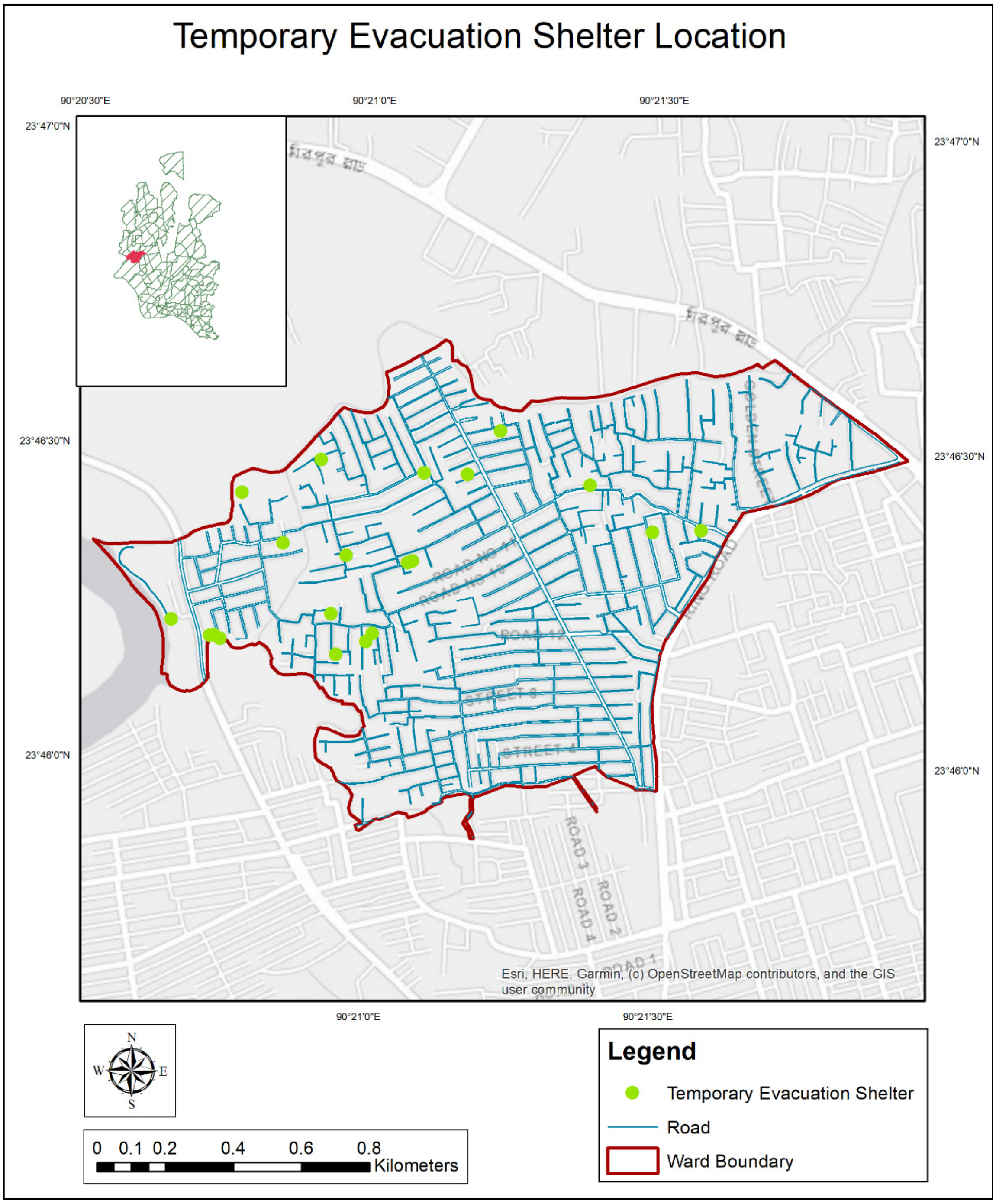


Figure 5.2.7: Temporary Evacuation Shelter Location (Source: Author, 2020)

5.2.6.17 Carrying capacity of temporary evacuation shelters

The total carrying capacity of all of the temporary evacuation shelters is 3560 persons. The highest capacity by a single temporary evacuation shelter is 621, and the lowest is 17.

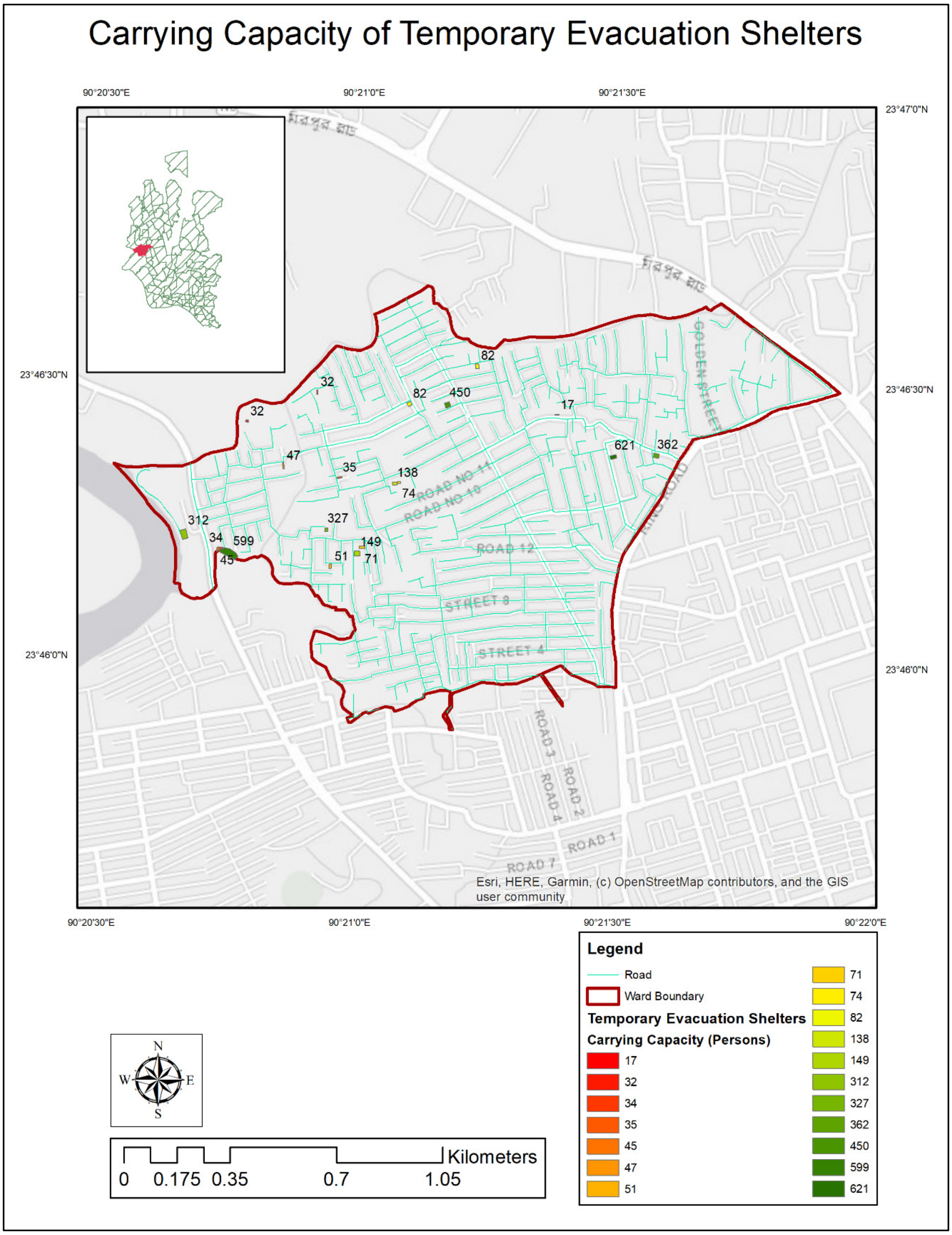


Figure 5.2.8: Carrying Capacity of Temporary Evacuation Shelters (Source: Author, 2020)

5.2.6.18 Grids covered by temporary evacuation shelters

In this study, 400 m x 400 m grids are chosen to divide the study area, considering a 5-minute walk to temporary evacuation shelters. The temporary evacuation shelters cover 9 out of 20 grids.

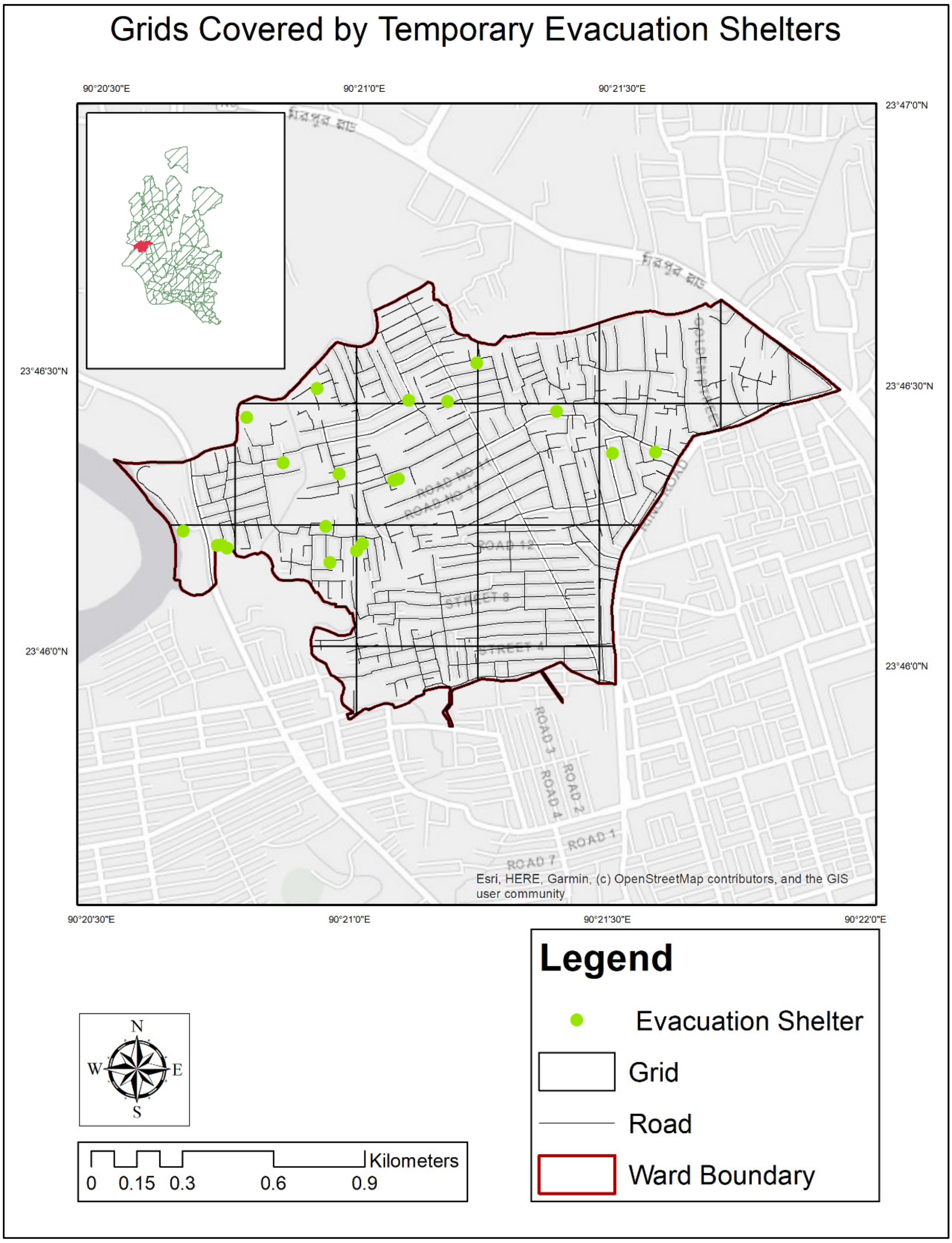


Figure 5.2.9: Grids Covered by Temporary Evacuation Shelters (Source: Author, 2020)

5.2.6.19 Service area of the temporary evacuation shelters

The service area of the temporary evacuation shelters covers the western part, northern part, and some of the eastern part of ward 30. There is no service area in the southern part of this study area.

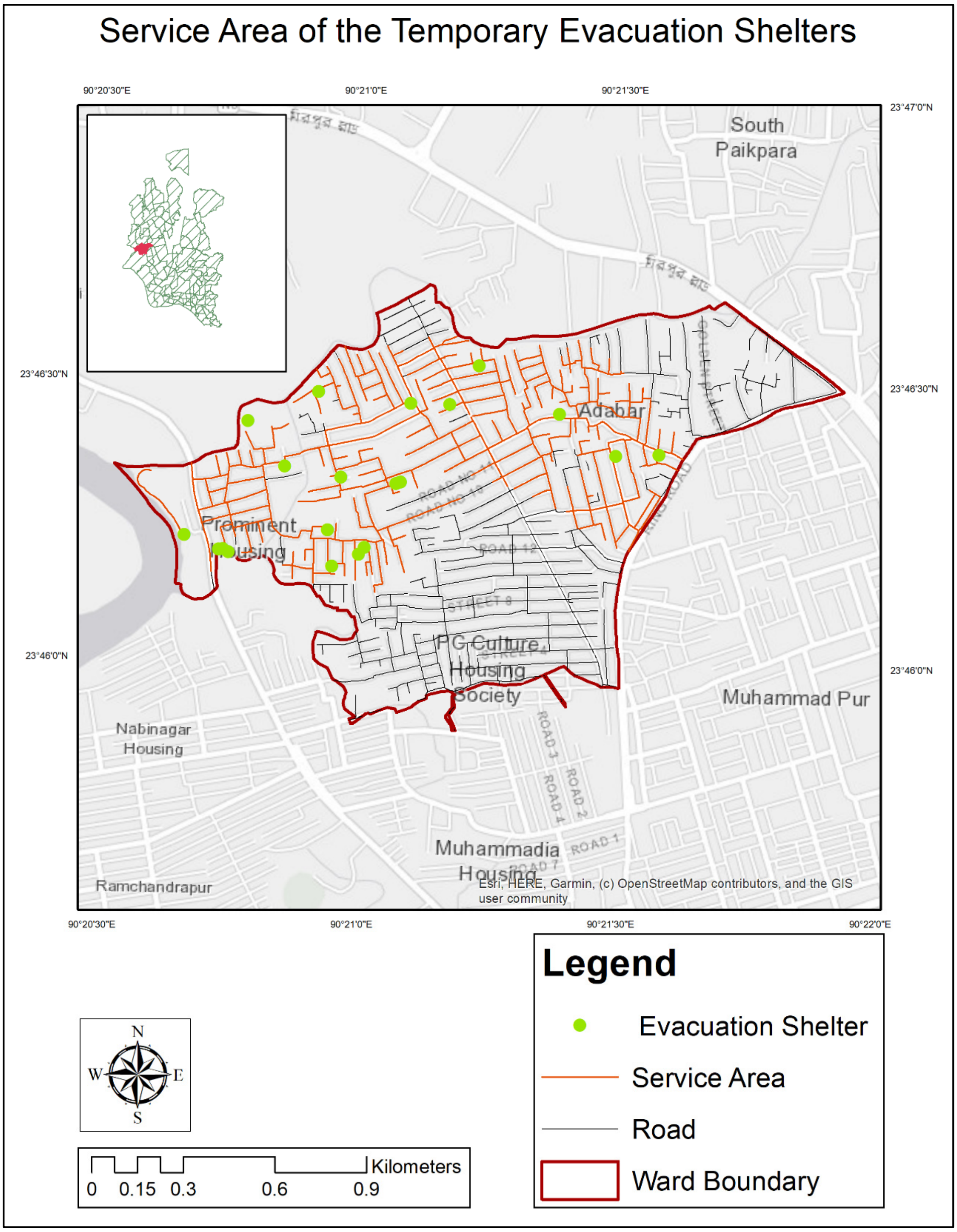


Figure 5.2.10: Service Area of the Temporary Evacuation Shelters (Source: Author, 2020)

5.2.6.20 Presence of medical centers

Close proximity to medical centers is beneficial to temporary evacuation shelters. In the study area, 3 medical centers are present which can serve the temporary evacuation shelters.

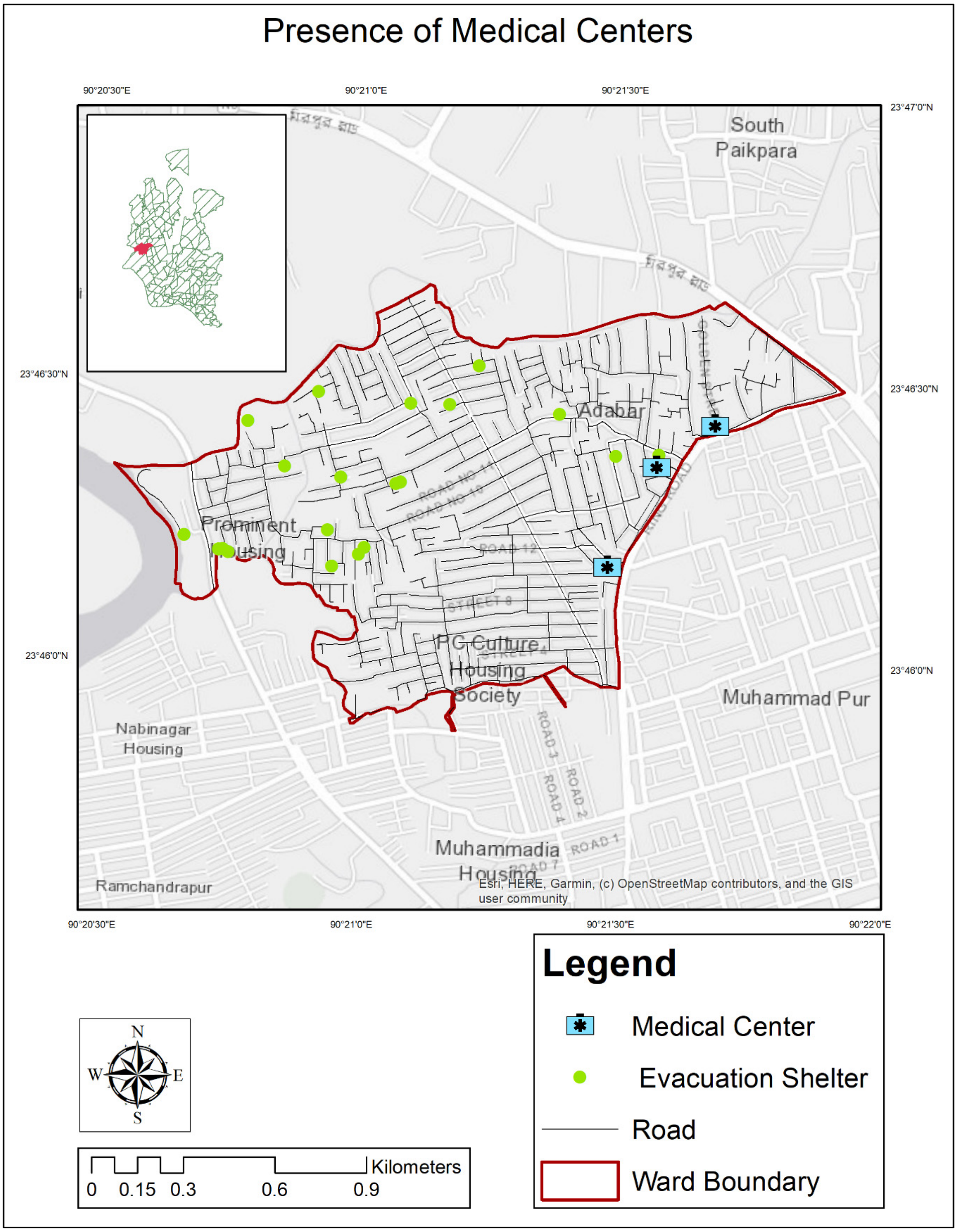


Figure 5.2.11: Presence of Medical Centers (Source: Author,2020)

5.2.6.21 Temporary evacuation shelters and socio-economic condition

The Socioeconomic condition of the residents of ward 30 varies from person to person, and the concentration of people with high socio-economic and low socio-economic conditions essentially divides the area into two parts. The northern part of the area has a higher concentration of people with the low socio-economic condition. Temporary evacuation shelters also exist there with a high number.

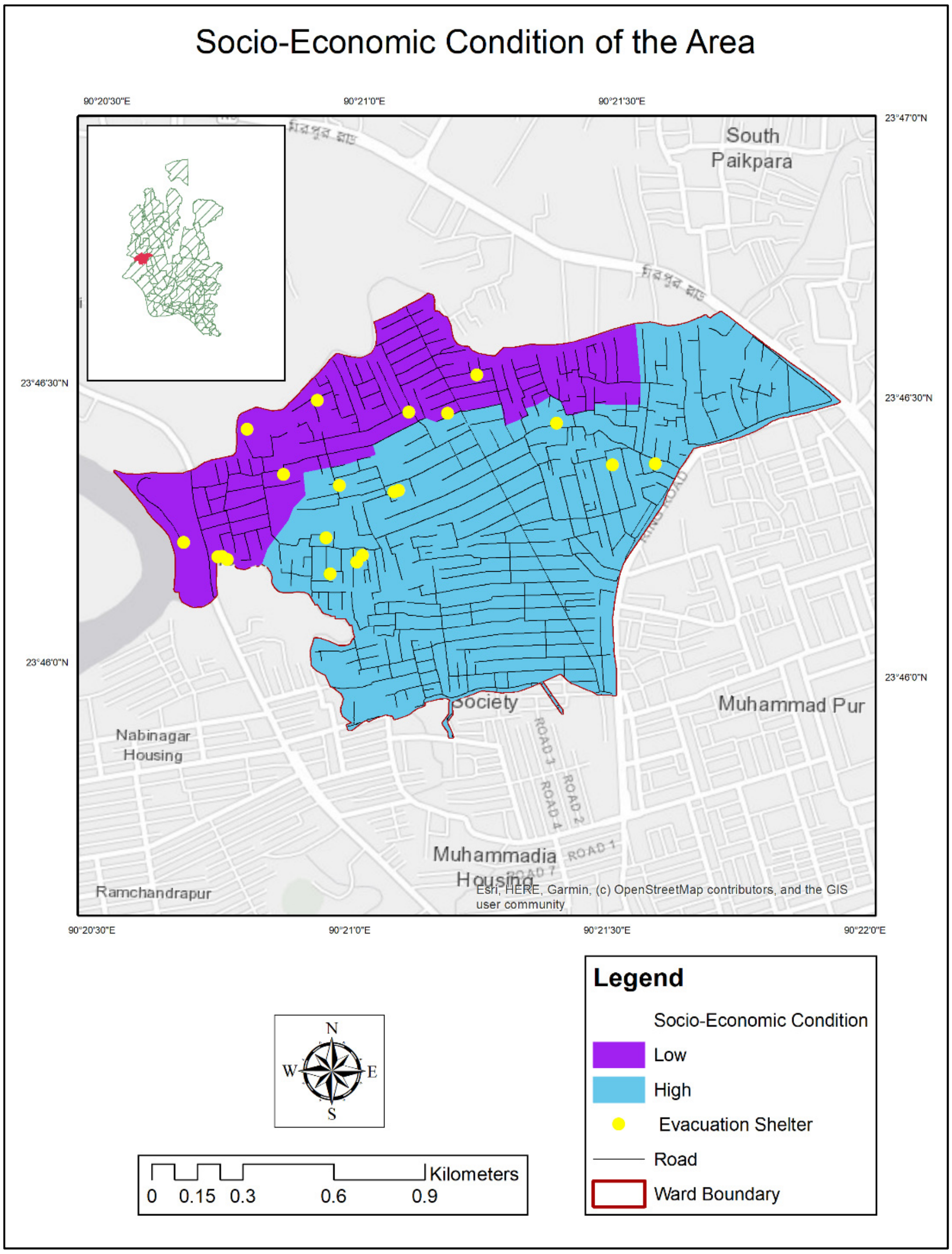


Figure 5.2.12: Temporary Evacuation Shelters and Socio-Economic Condition (Source: Author, 2020)

5.2.7 Results and Discussions

This section explains and discusses the information analyzed in the previous section. The research objectives fulfillment requires the findings from the analysis of the emergency evacuation preparedness factors and temporary evacuation shelter characteristics. This section discusses the findings of each variable under the emergency evacuation preparedness factor, along with emergency evacuation shelters and their service area characteristics.

5.2.7.1 Demography of the responders comparison

The demography of the responders is compared to the demography of the region the responders reside in. The data given below is for the Dhaka district. When compared, it is clear that some demographic components match with the district's demographic components, and some do not. The of people surveyed for this research is relatively younger than the district demography. The education level is also much higher than the average of the Dhaka district. Although, the gender ratio is almost equal. The average income range of the residents is lower than the average income of Dhaka city, but the average family size is almost equal.

Table 5.2.10: Comparison of the demography of the residents

Demography Components	**Demography Information of the Responders**	**Demography Information of Dhaka**
Age Range (20-49 years)	64.49%	53.46% [bbs, 2011]
Education (S.S.C. and Higher)	65.53%	36.08% [bbs, 2011]
Gender Ratio	Male 53%, Female 47%	Male 54% Female 46% [bbs, 2011]
Average Income	The median range of 26000-40000 taka	55000 taka [UNDP, 2015]
Average Family Size	4	4.3 [bbs, 2011]

(Source: Author)

5.2.7.2 Perception on emergency evacuation preparedness

The perception of emergency evacuation preparedness comes from the sub-variables under the variables of emergency evacuation preparedness. The data was recorded as yes or no response and was coded 1 or 0 accordingly. The mean values of each sub-variables give the perception towards each sub-variables of emergency evacuation preparedness. The compound score of each sub-variable under each variable gives the overall emergency evacuation preparedness score. The sub-variables under the variables are evaluated in this section.

5.2.7.3 Earthquake risk awareness

This variable has five sub-variables. They are: Earthquake probability in the area, Taken steps to increase earthquake knowledge, Home is unsafe for earthquake, Have earthquake safety plan And Safety measures taken at home.

- All of the responders know that there is an earthquake risk in the area. Unanimously, they feel that their area is vulnerable to earthquakes.
- Although the risk is prevalent, less than half of the responders have taken steps to increase their knowledge of earthquake safety.

- Half of the respondents believe that their home is not safe from an earthquake. So, their homes are vulnerable to earthquakes.
- Very few respondents have a safety plan for an earthquake.
- Again, very few respondents have taken safety measures of any length at home for an earthquake. Most of them are not prepared.

The earthquake risk awareness variable shows that, although people know about earthquakes and their associated risks, most do not have any sort of precautionary measures against earthquakes.

5.2.7.4 Emergency evacuation knowledge

Under the emergency evacuation knowledge variable, the five sub-variables are: Knowing the quick route out of the home, Post-earthquake meeting place, Participation in earthquake drills, Knowing earthquake emergency evacuation procedure and Knowing the number of emergency services.

- Most of the respondents know about the quick route out of the home in an earthquake.
- Although, more than half of the respondents do not know about the post-earthquake meeting place.
- Almost all of the respondents have never participated in any earthquake drills.
- Almost all of the respondents do not know emergency evacuation procedures during an earthquake.
- Most of the respondents know the number of emergency services.

The earthquake evacuation knowledge variable reveals that only a small percentage of people have participated in an earthquake drill, implying that fewer people are familiar with emergency evacuation protocols in the event of an earthquake.

5.2.7.5 Provision for elderly/disabled

This variable has the following sub-variables: Structural provision for evacuation of elderly/disabled at home, Access to vehicles for evacuation of elderly/disabled at home, Training for the elderly/disabled for emergency evacuation, Assistive devices for elderly/ disabled at home, Training of caregivers for elderly/ disabled at home for emergency evacuation.

- The structural provision for evacuation of the elderly/disabled is almost non-existent in the study area.
- Very few families have access to vehicles for evacuation of the elderly/disabled at home.
- There is almost no training for the elderly/disabled for emergency evacuation at home.
- Assistive devices, which help the elderly/disabled at home to evacuate, is not present in the study area
- Almost all families who have caregivers for the elderly/disabled are not trained for emergency evacuation.

Overall, the provision for the elderly/disabled for earthquake emergency evacuation is deplorable in the study area.

5.2.7.6 Vulnerability of structures

This variable has five sub-variables. They are: Concerned about age of the living place building, concerned about the construction quality of living place building, Accessibility of the living place building, Construction material and Building Height.

- Very few numbers of responders are concerned about the age of the building they live in.

- Almost all of the responders are satisfied with the construction quality of the buildings they live in.
- Most of the responders are concerned about the accessibility of the buildings they live in.
- Most of the responders do not worry about the construction material of the buildings they live in.
- Most of the responders are not concerned with the height of the building they live in.

The vulnerability of the structures variable shows that People are mostly concerned about the accessibility of their buildings. Other sub-variables are satisfactory to most of them.

5.2.7.7 Self-protection ability

This variable also has five sub-variables. They are Savings for emergencies. Bought safety instruments at home, Health Insurance, Formal savings for general purposes, Ability to shift residence.

- Most of the responders do not have to save for emergencies.
- Almost none of the responders has brought safety instruments for an earthquake.
- Very few responders have health insurance.
- Although, formal saving for general purposes is done by most of the responders.
- Most of the residents can shift residence.

So, the self-protection ability variable shows that most people of the study area are generally capable of having general savings and shifting residence but lack health insurance, emergency savings, and safety instruments.

The perception of emergency evacuation preparedness shows that the materialistic preparation for emergency evacuation is not present in the study area. The buildings people live in are in satisfactory condition to the residents. Although, accessibility of them remains a matter of concern.

5.2.7.8 Condition of the temporary evacuation shelters

The temporary evacuation shelters were chosen based on the given categories:

- Structure use type- Educational facilities and religious facilities.
- Structures built after 1993- considering their age limited to under 30 years and assuming that they followed the Bangladesh National Building Code,1993.
- Open Spaces of the study area

5.2.7.9 Presence of temporary evacuation shelters

There are 20 sites in the study area that could be used as temporary evacuation shelters. There are 18 educational facilities and 2 open spaces among them. Because of their mixed-use nature - the existence of commercial usage and religious site in the same structure – religious constructions were not chosen.

5.2.7.10 Carrying capacity of temporary evacuation shelters

The temporary evacuation shelters are located sparsely in the study area. Their total carrying capacity is 3560 persons. The total population of the study area is 186639. The temporary evacuation shelters can serve only 1.9% of the total population.

5.2.7.11 Service area of temporary evacuation shelters

The temporary evacuation shelters are located in the western, northern, and some of the eastern parts of the area. The service area of the temporary evacuation shelters covers those parts of the area only. The western part of the study area is not covered by the service area of the temporary evacuation shelters.

The area was divided into 400m x 400 m grids to visualize the coverage of temporary evacuation shelters within a 5-minute walk. Only 9 grids out of 20 grids are covered by 20 temporary evacuation shelters, showing overlap of coverage yet sparsity of location. The service area of the temporary evacuation shelters covers the areas where a high concentration of people with low socio-economic status is present. The temporary evacuation shelters do not cover many areas with high concentration of people with high socio-economic status.

5.2.8 Conclusion

Ward 30 of Dhaka North City Corporation has been developed over a long period of time. It has both planned and unplanned areas. The earthquake emergency evacuation process in this area becomes more complicated because of it. It is evident from the findings that the emergency evacuation preparedness of the people of Ward 30 is poor and lacks important components, reducing the area's resilience significantly. The structural provision for temporary evacuation is also poor. The people living in the area are also vulnerable due to a lack of knowledge about emergency evacuation. The situation can be improved by taking steps that serve both long-term and short-term strategies.

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Chapter 6 Development of Building Prioritization Method for Seismic Retrofitting

6.1. Introduction

In this study, building prioritization is a technique to determine priority buildings, specifically for the purpose of seismic retrofitting. In many countries/regions of the world with seismically active zones, seismic retrofitting has become a popular and effective strategy to reduce damage in the occurrence of a devastating earthquake. Earlier, seismic retrofitting has been applied mostly in developed countries to enhance seismic performance of existing building. Because seismic retrofitting allows to improve the condition of an existing building by enhancing seismic performance at a considerably low cost than demolition and reconstruction, this concept is becoming popular in developing countries as well.

In a densely constructed city like Dhaka, it is a difficult decision to determine buildings for seismic retrofitting. Every building of the city differs based on their structural condition. Seismic performance is generally considered to be the prime component for retrofitting prioritization. However, other components should also be considered irrespective of buildings and their performance. Considering other components will facilitate the optimal outcome of retrofitting procedure. Using seismic performance in line with other component for the buildings, requires a prioritization system. Among all the RC buildings of Dhaka city, not all of them requires the same attention for seismic retrofitting. It is a devious task to determine the buildings needed to be retrofitted based on the fact that there is a number a of components. Hence, determination of buildings to be retrofitted should be done by using a prioritization technique.

After the 'Rana Plaza' tragedy in 2013, concept of seismic retrofitting has been applied in some buildings of Dhaka. Application of retrofitting on these buildings has been done either by considering only seismic performance of those buildings or randomly. It is now a well-known fact that occurrence of a high magnitude earthquake can cause extensive damage to the lives and properties of the city. Hence, it is needed to retrofit buildings on a priority basis to minimize damage with optimum outcome. And a seismic retrofitting prioritization method for the RC buildings can ensure optimality of outcome.

This chapter comprises of detailed method for seismic retrofitting prioritization framework for Dhaka city. This prioritization framework is considered from the viewpoint of individual buildings and intend to set priority among those buildings. Main consideration of this chapter is to focus on different aspects regarding buildings. AHP (Analytic Hierarchy Process), a decision-making process has been employed for the purpose of prioritization. The final result of this chapter provides with a hierarchical priority ranking of building.

6.2. Analytic Hierarchy Process (AHP)

6.2.1. Concept of AHP

The Analytic Hierarchy Process (AHP) is decision making technique, developed by T. L. Saaty [1] that facilitates the objective mathematics to process the undeniably subjective and differing personal preferences in making a decision. Fundamentally, AHP works by setting priorities and decision is needed to be taken among a number of elements which are termed as alternatives. The decision maker should know the problem and the specific purpose to make the decision. Criteria and sub criteria are needed to be determined to evaluate the alternatives. Priority ranking of the alternatives by creating priorities for the selected criteria is done to weigh the priorities of the alternatives. Attainment of overall ranks of the alternatives is a strategic task. This technique is applicable to both intangible criteria and tangible criteria. This feature makes it widely acceptable as a decision-making technique.

6.2.2 Why AHP?

At the implementation phase, the main concern will involve the choice of buildings to be retrofitted. The probable questions might include for retrofitting, 'Which locality shall be chosen?', 'If it shall be residential building or community facilities?', 'What shall be the standard of choosing buildings?' etc.

This chapter aims to relate and find out the answer to this kind of questions to some extent. It is hypothesized that choosing a building for seismic retrofitting depends not only on structural parameter of a building, but also on other parameters (eg: social, geographical, economic etc.).

Setting importance among the parameters is required to determine the buildings for seismic retrofitting. Only one parameter makes it easier to take decision for choosing buildings for seismic retrofitting. When multiple parameters with varied characteristics are involved, task of determining buildings for seismic retrofitting becomes complex and elaborate. In this instance, attainment of an outcome from these varied parameters requires a systematic approach.

In the context of Bangladesh, there is no specific standard that works on determining and addressing the need of a building to be retrofitted on priority basis. Random selection of buildings might not optimize the result of seismic retrofitting from city perspective. Purpose of seismic retrofitting is related to damage which also concerns human/people. Therefore, the choice of building type to be retrofitted is strongly related to people and their perception. They are the stakeholders who are going to contribute and be benefitted or affected. From this perspective, it is only logical to consider people's perception in making decisions for determining priority buildings for seismic retrofitting by unification of the varied aspects.

AHP is a decision-making procedure which allows to decide by making a hierarchy among the desired choices a decision maker has. And the decision is made by considering people's perception or opinion on that matter. AHP allows to take people's perception on a specific issue upon importance and degree of importance by using a pairwise comparison matrix. This method can confirm the respondent's consistency in making choices and works on reducing cognitive errors to reduce decision biases. But it also deals with some issues that are being criticized by experts.

There are many multi-criteria decision-making techniques to solve a decision problem. Characteristics of each technique makes them appropriate or preferred for solving specific decision problem. AHP, despite having being criticized, has been considered for this research. because of some specific reasons. AHP is preferred because of,

a. the ability to quantify the qualitative attributes which made it more desirable for this research

b. the unique way to structure a problem in hierarchical form from goal to alternatives makes is easily understandable.

c. the flexibility to be unified with other techniques.

d. its ability to make relative measurements by using a ratio scale.

6.3. Approach to AHP

6.3.1. Measurements of AHP

R.W Saaty stated in 1987,

> "Cognitive psychologists have recognized for some time that there are two kinds of comparisons, absolute and relative. In absolute comparisons alternatives are compared with a standard in one's memory that has been developed through experience; in relative comparisons alternatives are compared in pairs according to a common attribute. The AHP has been used with both types of comparisons to derive ratio scales of measurement. We call such scales absolute and relative measurement scales, respectively." [2]

Hence, two types of measurements are available for the decision makers to make decision and set priority among the alternatives.

Relative measurement is based on pairwise comparisons among the components of a set reference to a common feature or attribute. This measurement is essential in the cases where there are no specific measures or standards for making priority decision for the alternatives. When it comes to the alternatives, addition of new ones introduces new dimension to the overall framework. This, fundamentally rescales the criteria levels and has the ability to rank reversal of previous orders. On the other hand, absolute measurement requires a standard to compare elements for the bottom level of the framework. Ranking of alternatives remain unaffected with the addition of new alternative to the system[3].

6.3.2. Principles of AHP

There are three principles associated in solving the problem using AHP. They are, decomposition, comparative judgements and synthesis of priorities[2]. The process starts with decomposition principle which is applied by structuring a problem into a hierarchy of goal, criteria, and decision alternatives from top level to bottom level. The first level is the goal, the mid-levels correspond to criteria, sub-criteria and further divisions and the final level corresponds to the decision alternatives. The second principle is applied after structuring the hierarchy. This principle is associated with the construction of comparison matrix, where elements of a level are compared with each other with respect to a shared element in the level above. For example, alternatives are compared with each other with respect to their shared criterion. Since, this method is based on decision making, it requires the judgements of participants. Synthesizing the priorities by using judgements from the second level to the last level is the third principle. The comparison process facilitates with the weights which are basically priorities in AHP. Two types of priorities are derived on the process; local priorities and global priorities. Local priorities are derived from the comparison from their corresponding element/criteria; whereas global priorities are derived by accumulating all the local priorities.

6.3.3 Structure of AHP

The overall procedure of AHP can be divided into a number of steps which are linked to the three principles of AHP (shown in figure 6-1). The fundamental is to create the structure of AHP framework consisting of goal, criteria (and divisions, if any) which should reflect the following concerns:

- **Goal (Level 1):** The decision to be made by following the whole process.
- **Criteria and its sub divisions (Intermediate levels, eg:2,3,4):** The factors creating link between the goal and alternatives.
- **Alternatives (Final level):** The solution is decided from this level. They are subjected to be influenced with respect to their corresponding level above [4].

In this process, there are no specific standard for selecting goal and criteria. It is recommended to go in brainstorming session with experts to identify those. Otherwise, taking assistance from previous literatures also might help in deciding goal and criteria [5]. Although the model can accept infinite numbers of elements at each level, it is only ideal to take only a limited number of criteria and alternatives to maintain correctness of the achieved result. This limit is seven with a variation of two [6]. Structuring the AHP hierarchy framework with the factors of lowering importance leads to the creation of pairwise comparison matrix. The matrix is a rectangular array with equal number of elements subordinate to its corresponding element from above where the experts register their judgements. Experts or decision makers provide their judgement on each pairwise comparison by using the fundamental comparison scale developed by Saaty. This scale converts descriptive preference of relative importance into numbers which basically is a ratio scale. Table 6-1 shows the comparison scale developed by Saaty. This scale allows the experts/decision makers to express their relative preferences of an element over the other for a pair in the pairwise comparison matrix.

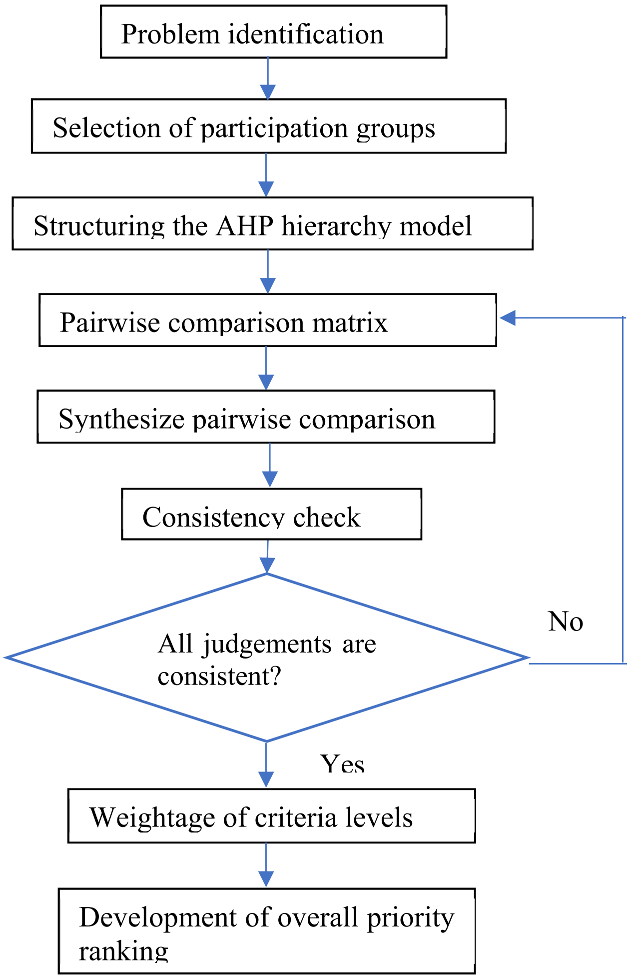

Figure 6.1: Fundamental steps of AHP

For this research, judgement was collected by using questionnaires and then they were converted to a pairwise comparison matrix similar to the one shown below:

$$A= \begin{array}{c|cccc} & A_1 & A_2 & & A_n \\ \hline A_1 & 1 & a_{12} & \ldots\ldots & a_{1n} \\ A_2 & 1/a_{12} & 1 & \ldots\ldots & a_{2n} \\ \ldots\ldots & \ldots\ldots & \ldots\ldots & \ldots\ldots & \ldots\ldots \\ A_n & 1/a_{n1} & 1/a_{n2} & \ldots\ldots & 1 \end{array}$$

Source: Based on Saaty (1987)

Here, $A_1, A_2, \ldots, A_n$ are the elements, a_{ij} (i, j=1, 2,…, n) is the a judgement for the corresponding elements and A is a positive reciprocal matrix. In the next step, the matrix is normalized by using geometric mean method. The sum of normalized row values facilities the calculation of eigen vector.

Table 6.1: Saaty fundamental scale

Intensity of importance on an absolute scale	**Definition**	**Explanation**
1	Equal importance	Two activities contribute equally to the objective
3	Moderate importance of one over another	Experience and judgement strongly favor one activity over another
5	Essential or strong importance	Experience and judgement strongly favor one activity over another
7	Very strong importance	An activity is strongly favored and its dominance demonstrated in practice
9	Extreme importance	The evidence favoring one activity over another is of the highest possible order of affirmation
2, 4, 6, 8	Intermediate values between two adjacent judgements	
Reciprocals	If activity i have one of the above numbers assigned to it when compared with activity j, then j has the reciprocal value when compared with i	
Rationals	Ratios arising from the scale	If consistency were to be forced by obtaining n numerical values to span the matrix

Source: Saaty, 1987

In the next step, it is checked if there are any inconsistencies present in the judgement of the decision makers. In AHP, it is not aimed to get 0 consistency, as it is normal to have inconsistency in human judgement. Hence, AHP allows some degree of inconsistency to check the reality (ideally, less than 10%). Inconsistency or CR (consistency ratio) is derived from the ratio of CI (consistency index) and RI (Random index). RI is the consistency of a reciprocal matrix that was derived from a sample size of 500 [2]. The value of RI depends on the dimension of the matrix as shown in table 6-2.

$$CR = \frac{CI}{RI}$$

Table 6.2: Random index values

n	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
RI	0	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49

Source: Saaty, 1987

CI is derived by using the largest eigenvalue, λ_{max} by using the following equation; where n is the number of elements in the matrix and λ_{max} should be greater or equal to n.

$$CI = \frac{(\lambda\text{max} - \text{n})}{(n-1)}$$

If inconsistencies are over the set limit, then the judgements should be reconsidered and need to be either revised or removed. After checking consistency of the judgements, overall performance of the alternatives is computed to get the priority ranking.

6.4. Development of AHP Framework and Problem Structuring

In this study, both absolute and relative type of AHP measurements have been used to make rank of priority buildings. Absolute measurement of AHP has been used for the prioritization framework of buildings where number of targeted buildings can be changed with demand. On the other hand, relative measurement has been used to get priority standard of a parameter for the prioritization framework. Jointly, these two measurements provided the overall prioritization system.

AHP involves a step-by-step proceeding to get the priority ranking for making the final decision. Three main stages have been distinguished during the decision-making process for this research. These three steps involve other detailed steps. The first stage involves structuring the decision problem that requires to be solved by deciding upon a specific decision. The second stage involves evaluation of the decision matrix by evaluating the criteria and its divisions, alternatives etc. The final step involves synthesizing the result for making the concluding decision. These three stages are prepared in contrast to the three principles of AHP. Development of the building prioritization system using absolute measurement has been discussed first in the following.

Structuring the problem involves with defining the decision problem and setting up the goal followed by decomposing the problem. Three steps have been recognized for this stage that has effect on structuring the model.

6.4.1. Defining the goal

In case of limited resources, it is the best to choose the optimized option to fulfill the objective of any development process. In a portfolio of buildings, which are the buildings that will help in minimizing damage by seismic retrofitting is the issue to be addressed in the context of Dhaka city. This study has documented this issue as the decision problem. Hence, the goal for the this AHP structure is to find out the best choice of buildings that are suitable for seismic retrofitting. Goal is set at the top level of the decision hierarchy.

6.4.2. Setting up the decision alternatives

Decision alternatives are the last tier of an AHP framework model. For the building prioritization model, number of targeted alternatives are not fixed. Here, the buildings that are considered for seismic retrofitting can go through the prioritization system and the number of buildings can change according to demand. For this study, 15 buildings have been set as targeted ones for seismic retrofitting prioritization. These 15 buildings are selected based on availability of related data for retrofitting prioritization. Details of the selected 15 buildings are in the following table:

Table 6.3: Targeted buildings for seismic retrofitting prioritization

Building ID	Ward no.	Floor no	Area(m2)	Use	Building Occupancy
Building A	DNCC 1	6	280	COM10	Residential
Building B	DNCC 31	6	209	RES3B	Residential
Building C	DNCC 24	5	358	COM2	Commercial
Building D	DNCC 4	5	107	COM10	Residential
Building E	DSCC 13	9	524	RES3C	Residential
Building F	DNCC 5	1	114	COM4	Commercial
Building G	DNCC 13	5	103	IND6	Industrial
Building H	DSCC9	6	295	RES3B	Residential
Building I	DNCC 9	6	153	RES3B	Residential
Building J	DNCC 10	4	286	RES2B	Residential
Building K	DNCC 11	6	187	COM10	Residential
Building L	DNCC 16	4	102	COM10	Residential
Building M	DSCC 03	3	159	REL1	Community facility
Building N	DSCC 26	6	118	RES2B	Residential
Building O	DSCC 15	6	599	RES3C	Residential

6.4.3. Identification of evaluation criteria

Evaluation criteria are placed in the second tier of an AHP structure. This is actually the first level of intermediate level in case there are other sub-division of criteria. There are three levels of criteria (criteria and sub-criteria) identified for the purpose of this research. All the criteria, and sub-criteria are subjected to be measured qualitatively. Number of criteria and number of sub-criteria for each cluster remained within five to keep the decision structure easily perceivable by the respondents [9].

Table 6.4: Evaluation criteria for the AHP hierarchical model

Levels	Evaluation criteria			
Criteria (level 2)	Improvement of seismic resistance based on cost-effectiveness	Vulnerability at ward level	Building importance	
Sub-criteria (level 3)			User number	Building occupancy
Comparison standard	-High -Moderate -Low	-High vulnerability -Moderate vulnerability -Low vulnerability		

6.5. Details of Evaluation Criteria

The evaluation criteria and its divisions are all set from the viewpoint of improving seismic resilience of the city based on cost effectiveness, location and functional viewpoint of the buildings. They should also express the decision alternatives to solve the problem. Type of functionality and user types are the two initial criteria, where each of them is divided into sub-criteria. Definition and justification of these criteria are as follows:

- Improvement of seismic resistance based on cost-effectiveness:

  It is required to maintain balance in resources and their allocation in any development work. In a similar way, it is very important to assess the relation of cost for seismic retrofitting. This criterion is based on the fact that if seismic retrofitting is performed on a building, how cost-effective it will be. To achieve a certain level of seismic capacity (seismic capacity index Is, a Japanese evaluation technique for measuring seismic performance of a reinforced concrete building), cost of seismic retrofitting should be acknowledged. For example, if same amount of money is spent on A and B building for seismic retrofitting, then building should be chosen according to achieved seismic capacity. It needs to be mentioned that, cost-effectiveness has been derived considering the seismic capacity of some buildings in Dhaka.

  Three comparison standards have been determined for comparing the alternative buildings for seismic retrofitting based on cost-effectiveness. They are; highly cost-effective, moderately cost-effective and lowly cost-effective.

- Vulnerability at ward level:

  Seismic vulnerability can be different on different location. In Dhaka, building and their surroundings are different based on their location. Along with a building's capacity, surrounding condition of a building contributes to the vulnerability condition of a building. Vulnerability here has been defined by considering building density, open space facility, hospital facility, evacuation condition etc.

- Building importance:

  Besides building density and cost-effectivity of seismic retrofitting, characteristics of a building and its component should also be considered for seismic retrofitting. Depending on the objective and perspective of any research or project, importance of a building can differ. For this research, building importance is defined here by the number of persons who use the building and occupancy type of the buildings. Improvement of seismic performance of a building will help mostly in reducing fatal consequences and maintain functionality during and after a disaster. Hence, user number and building occupancy plays a very important role in reducing damage.

  -User number:

  Depending on user number a building's importance can vary in terms of seismic retrofitting. Here, user number means the number of persons who uses a building in different time of a day. They might be regular, frequent or occasional users of that building.

  -Occupancy type:

Occupancy type contributes to the importance of a building given the fact that each occupancy type differs from each other by their intensity of use. Retrofitting a building of a specific occupancy type might reduce damage compared to the damage of other kinds of occupancy types. The occupancy types have been selected from the GIS database of the city in order to bring all the buildings under the prioritization system for seismic retrofitting. According to the GIS database of DAP, seven occupancy types are determined; residential, education and research, institutional, health facilities, commercial, industrial and community facilities.

6.5.1. Improvement of seismic resistance based on cost-effectiveness

Seismic retrofitting is done to a building based on its seismic performance. In Japan, seismic capacity Index(Is) is derived to understand a building's seismic performance. Susumu Takahashi and his colleagues[7] figured out a way to examine effectiveness of retrofitting based on cost. They examined first level of seismic capacity index for 582 buildings and developed damage ratio for these buildings. Bangladesh has a history of mild earthquakes. Fortunately, there has been no high magnitude earthquakes that created severe damage to the buildings of the city. As a result, no damage ratio has been developed solely for Dhaka based on the related earthquakes. Takahashi et. al.[7] created a damage ratio based on Taiwan earthquake scenario. Using the damage ratio, they derived retrofit effect and developed an equation to determine cost-effectiveness by using retrofit effect and retrofit cost.

For this study, retrofitting cost-effectiveness has been taken into consideration for having the optimum result for with minimal cost.

6.5.2. Improvement of seismic resistance based on cost-effectiveness

The main consideration for seismic retrofitting should always be upon seismic performance of buildings. In chapter 3, seismic performance for all the RC buildings of Dhaka city has been derived by an equation for understanding seismic capacity of building in a statistical manner. From this evaluation, density of these 'high risk' buildings in the wards are considered to evaluate vulnerability of the wards of the two city corporations. Three vulnerability categories have been decided based on the density of high-risk buildings; high vulnerability, medium vulnerability and low vulnerability. Distribution of wards according to their vulnerabilities.

Table 6.5: Wards and their vulnerability level

Vulnerability type	**DNCC**	**DSCC**
Low vulnerability	8, 10, 4, 27, 18, 19, 24, 26, 23	18, 19, 20, 21, 27, 24, 7, 8, 9, 10, 11, 40, 44, 48, 49, 50, 51, 53
Moderate vulnerability	17, 15, 2, 6, 7, 9, 11, 12, 13, 28, 20, 21, 9, 29, 31, 32, 33, 25, 36, 35	14, 15, 16, 17, 22, 55, 57, 56, 25, 26, 28, 29, 30, 43, 46, 54, 1, 2, 4, 5, 6, 13
High vulnerability	1, 3, 5, 14, 16, 30, 34, 22,3	3, 23, 39, 45, 47,12

Density is deemed important for choosing buildings for seismic retrofitting in this study. In that sense, location of priority buildings in the city is kept under consideration to develop the prioritization system for seismic retrofitting.

6.5.3. Building importance

Importance of a building is defined in this study by their usage/occupancy and users. Assessment of building importance is as vital as assessing seismic performance of a building for seismic retrofitting. For example, retrofitting a building with zero occupancy would bear no efficiency. Again, optimum outcome isn't achievable by retrofitting a building that doesn't contribute to reduce overall damage condition in the time of disaster. Hence, different building occupancy bears different kind of importance in the time of disaster along with user ratio.

The priority of building occupancy is decided based on perception of people. Their perceptions have been put together by using a different AHP framework using relative measurement. Priority ranking of building occupancy based on the relative measurement will be used on the prioritization system framework to obtain ranking of priority buildings for seismic retrofitting.

Like a general AHP structure, this AHP structure has the three components; goal, criteria and alternatives. Details of the relative measurement used for this research is given below:

6.5.3.1. Goal

Goal of this part is to develop a priority ranking for building occupancy categories.

6.5.3.2. Choice of alternatives

The alternatives are finite in nature and from these alternatives the decision will be made. The number of alternatives is limited within 7, which ensures the practical application of the model. For this hierarchical model, occupancy types of Dhaka city are set as the decision alternatives. The occupancy types are determined according to the primary building use data from GIS database (RAJUK). Table 6-6 shows the detailed facility use under each occupancy type based on the database. In this research, these building occupancies have been considered as the alternatives. Apart from these, there are some other types of occupancy that are kept out of the hierarchical model as they won't serve the purpose effectively. In some cases, it is tough to match their application with context (eg: mixed use).

Table 6.6: Occupancy types and detailed facility uses

Occupancy type	Detailed facility uses
Residential	Single dwelling, multi dwelling, hostel, quarters, informal housing, residential care homes
Education and research	School, college, university, madrasa, research institute, training institute
Institution	Governmental office, local government office, international office, non-governmental offices, other institutions
Health facilities	Community health, hospital, rehabilitation center, research institute
Commercial	Building material, commercial, general retail, heavy retail, hotel, bank, customer care, dental care, diagnostic center, office, food and drink, market, refuelling station, restaurant, salon, super shop, warehouse, wholesale and storage
Industrial	Agro based industry, chemical, cottage industry, readymade garments, factory, food manufacturing, godown, leather, metal, paper, pharmaceuticals, plastic, rubber, textile, reused food factory, reused goods factory
Community facilities	Mosque, community center, emergency and security, recreational, religious, social organization, utility services

It would have been ideal if the building occupancies could be selected from BNBC (2006) and defined accordingly. Instead of considering BNBC, the current GIS database (RAJUK) has been referenced in this issue as the prioritization framework could be extended to further step. While defining each alternative, BNBC (Volume 1, part 3, chapter 2) has been considered initially. Building occupancy classification in BNBC is different from the classification used in the current GIS database. Some of the occupancies overlap with each other in GIS database, hence the definition of the two sources is not same. So, the definition is provided according to the GIS database with reference to BNBC (where it is possible) and also from BNBC directly (where it is possible). The definitions of each building occupancy can be understood by the definitions stated below.

- **Residential buildings:** According to BNBC (2006), “This occupancy type shall include any building or portion thereof providing sleeping and living accommodations to related or unrelated groups of people, with or without independent bathroom, cooking or dining facilities, except any building classified under Occupancy C (institution for care) or D (health care). This occupancy shall be subdivided as follows: single family dwelling, two family dwelling, flats or apartments, mess, boarding houses, dormitories and hostels, hotels and lodging house.” The definition is almost the same as the GIS database (RAJUK); except hotels are considered as commercial occupancy in the current GIS database (refer to table 4-1).
- **Educational facilities:** According to BNBC (2006), “This occupancy type shall include any building or portion thereof in which education, training and care are provided to children or adults.” This definition matches the definition of GIS database.
- **Institution:** There is no specific definition for institution type occupancy use in BNBC. According to the database, any building that provide office activities and are not related to any personal gain can be considered as institution type building occupancy.

- **Health facilities:** Definition of health facilities provided in BNBC is almost the same as the details provided in the GIS database. According to BNBC (2006), "Buildings under this occupancy group shall include those used for purposes of providing medical care, diagnostic facilities and treatment to persons suffering from physical discomfort, in which sleeping accommodation may or may not be provided." Additionally, some research institutions are included in the definition for this research.
- **Commercial (Office and mercantile):** In BNBC, there is no specific definition for commercial uses. Definition of office and mercantile occupancy together expresses commercial occupancy. So, compositely, any building type that provides facility for any business activity, transaction, paper works and documentations, maintaining accounts and records for administrative or consulting services, banking, activities for business purposes and professional training, display and sale of merchandises shall be considered as commercial facility.

- **Industrial (Industrial and storage):** The buildings might contain hazard potential of the contents and the processes of the industry. Additionally, the buildings that are used primarily for storage or sheltering of goods, wares, merchandises, vehicles or animals also fall in this group. This is also a composite definition generated from industrial and storage type occupancy in BNBC.

- **Community facilities (Assembly and utilities):** This occupancy type shall include any building to install any type of equipment to provide support service Also, it includes, buildings where groups of people assemble for recreation, amusement, social, religious, political, cultural, travel and similar purposes (A composite definition of assembly and utilities type building occupancy from BNBC).

6.5.3.3. Identification of evaluation criteria

Evaluation criteria are placed in the second level of an AHP structure. This is actually the first level of intermediate level in case there are other sub-division of criteria. There are three levels of criteria (criteria, sub-criteria and sub-sub-criteria) identified for the purpose of this research. All the criteria, sub-criteria, sub-sub-criteria are subjected to be measured qualitatively. Number of criteria and number of sub-criteria for each cluster remained within five to keep the decision structure easily perceivable by the respondents(Hummel et al., 2014). Table 6-7 shows the evaluation criteria to be measured for the AHP model with three levels.

Table 6.7: Evaluation criteria for the AHP hierarchical model

Levels	Evaluation criteria			
Criteria (level 2)	Type of functions		Types of users	
Sub-criteria (level 3)	Importance of functionality	Susceptibility to aftershock	Children	All kind of users
Sub-sub-criteria (level 4)	Evacuation facilities			
	Critical facilities			
	Regular use			

The evaluation criteria and its divisions are all set from the viewpoint of functionality and casualty in the time of disaster. They should also express the decision alternatives to solve the problem. Type of functionality and user types are the two initial criteria, where each of them is divided into sub-criteria. Definition and justification of these criteria are as follows:

- Types of Functions:

This criterion is supposed to explain the role of each occupancy type during or after an earthquake. Since, this study is related to the purpose of seismic retrofitting, functionality in the time of earthquake specifically became the focus. This criterion is sub-divided into two types:

  - Importance of functionality in the time of earthquake:

    The time during or after an earthquake is very critical to any community since this time involves various critical activities like evacuation, rescue, first-aid action etc. So, it is necessarily important to consider the functionality of a facility in the situation mentioned above. Depending on the type of function, this sub-criterion is sub-divided into three types.

    > Evacuation facilities: The facilities (pre-determined/can be transformed) where people can take shelter during or after the occurrence of a damaging earthquake. Such as: religious facilities, schools with play grounds etc.

    > Essential services: These services include the facilities that provide emergency services during or after the occurrence of an earthquake. Such as: hospitals, fire stations

    > Regular use: These facilities might or might not contribute to any important service during an earthquake. Rather, they will go on with their regular use. Such as: residential, commercial etc.

  - Susceptibility to aftershock: Secondary disasters often follows a damaging earthquake. Fire, explosion and poisonous gas diffusion are some of the very common secondary disasters in this regard. Therefore, they should be given consideration. For example: chemical industries are susceptible to fire hazard, explosion and diffusion of poisonous gases.

- Types of users:

The ability to understand the severity of a situation and move in the time of an earthquake is very crucial. Mostly, elderly people, children and people with special abilities and people with disability are supposed to be vulnerable in this perspective. So, it is necessary to determine the priority based on user type. In the used dataset, there are no occupancy types that specifically distinguish the facilities that are used by elderly people and people with special ability and disability. In this case, it might not bring any effective solution to the final result even if they are considered. Therefore, this sub-criterion couldn't be sub-divided by taking them into consideration.

  - Children: Some building occupancy specifies the use by children and young people in the used database. In Bangladesh, 18 is the age limit for being considered as children. They become vulnerable in most cases because of the inability to make rational decision. Also, effect of a disaster (specifically earthquake) doesn't end with the immediate effect. They impose a long-tern effect on children from various perspective. So, it becomes a matter of consideration if those buildings are needed specific attention to prevent extensive damage.

- All kind of users: Apart from the children specified building occupancy, the other building occupancies are used by all kinds of user, regardless of age, sex, occupation etc. Casualty can become a critical issue for this building occupancy in the time of a disaster.

6.5.3.4. Evaluation of AHP framework: Relative measurement

The prerequisite for achieving the second principle is to build the AHP structure by the finalized goal, criteria and alternatives. Figure 6-2 shows the AHP framework with five levels. Prioritization of building occupancy types is achieved by group decision making effort for the purpose of this research. Each respondent provides their opinion by comparing the criteria and its divisions, and alternatives. Individual judgement from different respondents is aggregated into group judgement. And before synthesizing the results, inconsistencies were checked for the justification of the model.

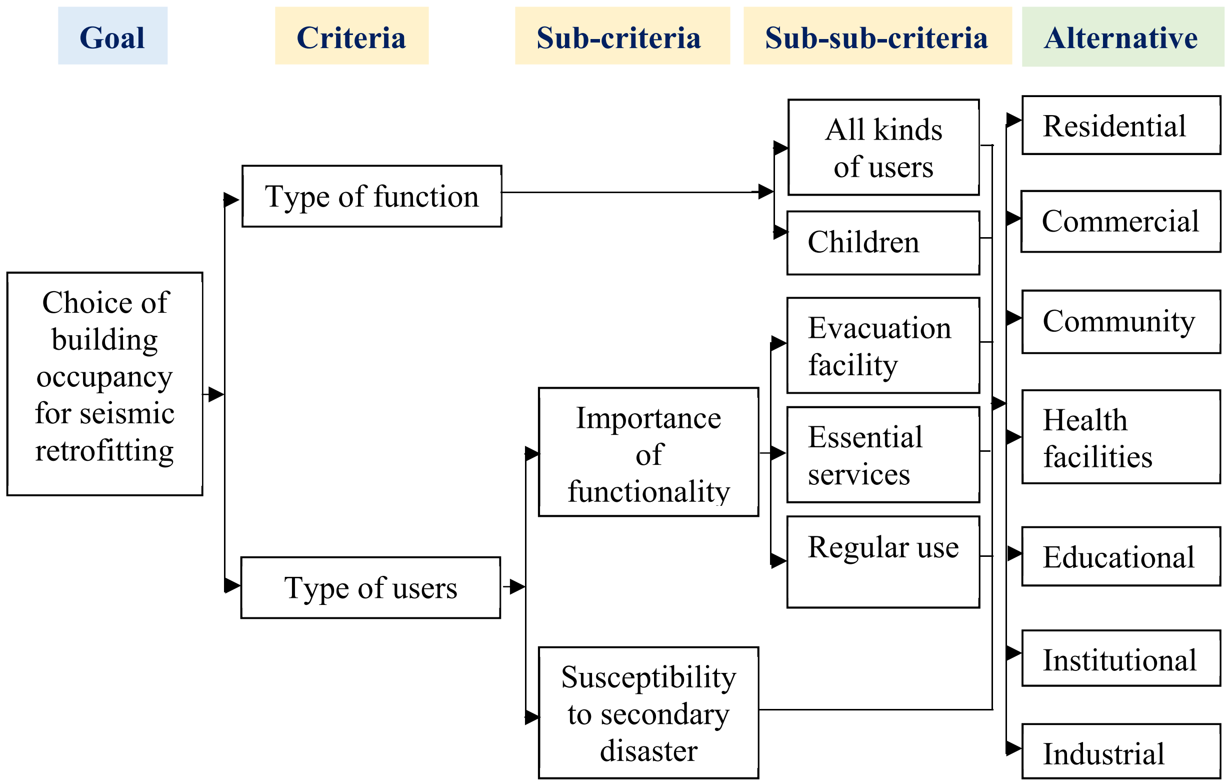

Figure 6.2: Hierarchical decision structure of relative measurement of AHP

6.5.3.5. Data collection: Questionnaire survey

The process requires the participation of stakeholders for making comparative judgements on different levels of the hierarchy. For this research, data was collected by conducting an E- survey.

- Questionnaire preparation:

  Another questionnaire was prepared to carry out survey for AHP process to obtain relative judgement from the participants. Since, this is an E-survey, it was tried to make the purpose of the research easily understandable to the participants. The participants were requested to deliver their judgements by comparing the relative importance of the components in the provided questionnaires. Each participant filled up 132 pairwise comparisons which complies the n(n-1)/2 rule provided by Saaty (1980).

- Definition of participants:

  Initially, three stakeholder groups were thought to be involved in the process by conducting a series of group session. These groups represent different sections of society; policy makers, practitioners, and community people. Because of unavoidable condition, the survey was decided to conduct an E-survey by involving only one group. Among these three stakeholder groups, practitioners were considered for conducting the survey. Practitioners are thought to be a bridge between the policy makers and common people. It is assumed that a rational and accurate decision can be obtained from the judgement of practitioners. In this attempt, questionnaires were distributed among the selected practitioners through email. A total of 6 practitioners were willing to be the participant of the survey. A brief introduction of the participants is provided below in table 6-8.

Table 6.8: Participant's profile for relative measurement of AHP

Name	**Age**	**Profession**	**Affiliation**	**Institution**
Participant #1	38	Teaching	Assistant professor	DURP, Chittagong University of Science and Technology
Participant #2	35	Teaching	Assistant professor	DURP, Jahangirnagar University
Participant #3	34	Teaching	Assistant professor	DURP, Jahangirnagar University
Participant #4	42	Teaching	Professor	DURP, Bangladesh University of Science and Technology
Participant #5	43	Teaching	Professor	DURP, Bangladesh University of Science and Technology
Participant #6	48	Teaching	Professor	DURP, Bangladesh University of Science and Technology

6.5.3.6. Aggregation of individual judgements

Among different ways of collecting judgements, this research adopted the way of collecting individual judgements, rather than consensus voting as a group on the pairwise comparison. Aggregation of judgements can be done in this stage as well as during the decision-making stage. If group aggregation takes place in evaluation stage, it is done by aggregating the participants choice for each pairwise comparison and synthesizing the result for only one decision matrix. The group mean of each pairwise comparison is processed further to get the decision as a whole. If aggregation takes place in the later stage, it means that the judgements of individual person are computed individually, and the final result is been aggregated for making the final decision. Geometric mean should be used for both approaches (Saaty, 2008). For the purpose of this research, individual responses have been aggregated to observe the variation of final result for both cases.

6.5.3.7. Inconsistency analysis

Inconsistency is a measure of AHP that ensures reliability of the judgements obtained from the pairwise comparison matrixes. It indicates the degree of logical soundness in contrast to the other comparisons. Inconsistency is calculated after receiving (in case of individual judgements)/ computing (in case of group aggregation) each set of pairwise comparison. In this research, these pairwise comparisons include comparison of criteria, paired comparison of sub-criteria for each cluster, paired comparison of sub-sub criteria within each cluster and paired comparison among the alternatives each sub-sub-criterion/sub-sub criteria. Judgements with a lower inconsistency (<0.1) is very much desirable, within 0.1 to 0.2 is workable. Inconsistency over 0.2 point is objectionable and requires to be altered or discarded. In the cases of inconsistency over 0.2 (ideally 0.1), it is advised to reconsider or reform those judgements to the point that inconsistency level goes below the threshold limit. Threshold limit is set at 0.2 for the cases of this research. Since the biggest matrix is a 7×7 matrix, it is hard to obtain an inconsistency below 0.1.

For the calculation of this AHP framework, a software named Super Decision v3.2 is used for group aggregated judgements. Inconsistencies were obtained from this software as well. For the judgement regarding group aggregation, the inconsistencies were corrected where inconsistencies went over the threshold value.

6.5.3.8. Decision-making: Ranking the alternatives

This is the last stage of the whole decision-making process. Overall priorities are obtained for the alternative building occupancies. Alternatives are attained in two forms; the ideal form and the normal form. For ideal form, the alternative building occupancy with value 1 is the top priority alternative which possess the highest value in normal form. Alternatives with higher priorities are considered to be more valued and are preferred in decision-making procedures. For group-decision making, Saaty (2008) says,

> *"Two important issues in group decision making are: how to aggregate individual judgements in a group into a single representative judgement for the entire group and how to construct a group choice from individual choices. The reciprocal property plays an important role in combining the judgements of several individuals to obtain a single judgement for the group. Judgements must be combined so that the reciprocal of the synthesised judgements is equal to the syntheses of the reciprocals of these judgements. It has been proved that the geometric mean, not the frequently used arithmetic mean, is the only way to do that. If the individuals are experts, they may not wish to combine their judgements but only their final outcomes obtained by each from their own hierarchy. In that case one takes the geometric mean of the final outcomes. If the individuals have different priorities of importance, their judgements (final outcomes) are raised to the power of their priorities and then the geometric mean is formed."*

In this research, every individual has been given the same priorities of importance. So, geometric mean is formed in a normal way. But group aggregation is done in two ways: by combining the judgements of the individuals and by combining their outcomes, to observe the variation of final result. Finally, only the result that has been obtained by combining the outcomes has been counted for final decision-making.

6.5.3.9. Outcome

It was expected to obtain a priority ranking from this AHP framework. The final outcome facilitates with a priority ranking for the building occupancies. Outcome for each step is stated below.

- Priority alternative by combining individual outcomes:

In this method, the relative judgement for each pairwise matrix for all participants is combined by using geometric mean. This generates only one AHP matrix which is then synthesized for final priority ranking. This is the selected approach to decide the prioritized building occupancy type. With variation in case of other ranks, health facilities are the prioritized building occupancy in this approach as well which is shown in table 6-9.

Table 6.9: Ranking of building occupancy by for aggregation of individual outcomes

Name	**Normal**	**Ideal**	**Rank**
Health facilities	0.23	1	1
Industrial	0.18	0.8	2
Community facilities	0.14	0.61	3
Education and research	0.14	0.61	4
Residential	0.13	0.58	5
Institutional	0.09	0.38	6
Commercial	0.08	0.36	7

Health facilities is the specified building occupancy that should be prioritized for seismic retrofitting. While in other literatures, schools are given the most priority mostly, in the context of Dhaka city, health facilities are given priority.

6.5.4. Definition of Ratings

In absolute measurement of AHP, an individual alternative is ranked in terms of rating intensities for each of the criteria or sub criteria. The criteria or sub criteria are additionally subdivided into a level for intensities. Intensity is described as a criterion’s range of variation. Variation ranges of a criterion facilitate the distinction of ranking the alternatives for that very criterion. Intensities are expressed by ratings and each criterion has ratings listed under it upon necessity. Intensity describing ratings can vary in number and type; eg: one type can be, high, moderate and low. These ratings are compared and prioritized to define their relative importance. In short, each lowest level criterion or sub-criterion of an AHP framework are subdivided into indicator categories which in term facilitates the ranking of alternatives in absolute measurement of AHP.

In this research, both absolute numbers and indicator categories have been used to define their concerning criteria/sub-criteria for the purpose of determining priority buildings. The indicator categories for the last levels were initially determined as the following:

>Improvement of seismic resistance based on cost-effectiveness: ‘high’, ‘moderate’ and ‘low’
>Vulnerability at ward level: ‘high vulnerability’, ‘moderate vulnerability’ and ‘low vulnerability’
> User number: ‘0-20’, ‘21-60’, ‘61-150’, ‘151-300’, ‘above 300’

>Building occupancy: ‘health’, ‘industry’, ‘commercial’, ‘education’, ‘residential’, ‘institution’, ‘commercial’

In one case, absolute numbers expressing the last level has been thought to be used instead of indicator categories. This has been applied for expressing user density.

For user number, only residential user number can be determined by using household number and number of units of a building. It is hard to forecast user number for all occupancy types. It is thought to use user density to have a more specified and detailed prioritization via user number. User density is defined as number of users using a facility in 24 hours. Unit of user density is set as person/square meter/hour. Changes in these components finally led the indicator categories for the last levels to be determined as the following:

>Improvement of seismic resistance based on cost-effectiveness: ‘high’, ‘moderate’ and ‘low’

>Vulnerability at ward level: ‘high vulnerability’, ‘moderate vulnerability’ and ‘low vulnerability’

> User density: absolute number derived from ‘user number/ (floor area*24)’

>Building occupancy: ‘health’, ‘industry’, ‘commercial’, ‘education’, ‘residential’, ‘institution’, ‘commercial’

6.6. Evaluation of AHP Framework: Absolute Measurement

As per the prerequisites for achieving the second principle, AHP structure for absolute measurement has been finalized and built according to previous discussion of this chapter. Figure 6-3 shows the AHP framework with three levels; goal, criteria and sub-criteria. As this structure follows the absolute measurement, number of alternatives might be infinite as the alternatives are changeable. Prioritization of buildings are achieved by group decision making effort for the purpose of this research. Perceptions have been taken from the respondents for the criteria and sub-criteria.

Each respondent provides their opinion by comparing the criteria and its divisions. Individual judgement from different respondents is aggregated into group judgement and weightage for criteria and sub-criteria has been derived for further prioritization of buildings.

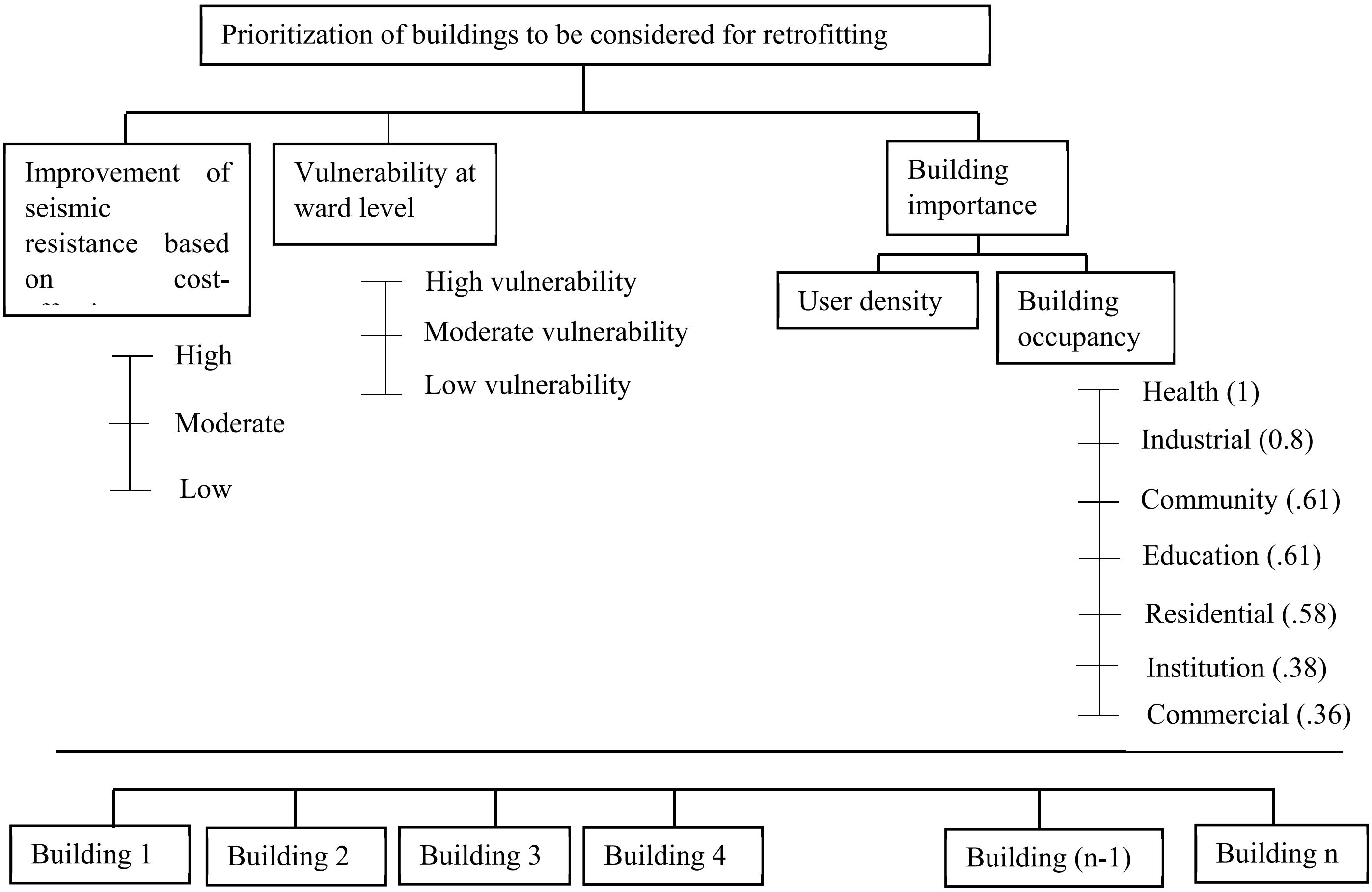

Figure 6.3: Hierarchical decision structure of absolute measurement of AHP

6.6.1. Data collection for absolute measurement: Questionnaire survey

To get the standards for indicator categories, another questionnaire survey has been performed thinking that the process requires the participation of stakeholders for making comparative judgements on indicator categories of the hierarchy. Hence, data was collected by conducting an E- survey.

- Questionnaire preparation:

  Questionnaire was prepared to carry out survey for AHP process to obtain relative judgement from the participants. An E-survey is thought to be performed considering the world pandemic situation. Like the relative measurement of AHP, it was tried to make the purpose of the research easily understandable to the participants. The participants were requested to deliver their judgements on the indicator categories by comparing the relative importance of the components in the provided questionnaires.

- Definition of participants:

  Since this survey is to determine standards for the indicator categories, only practitioners were thought to be involved in the process as it is assumed that a rational and accurate decision standard can be attained from the judgement of practitioners. In this attempt, questionnaires were distributed among the selected practitioners of relevant fields through email. The questionnaire was distributed to around 50 practitioners. A total of 16 practitioners were willing to be the participant of the survey within a period of approximately one and half month. A brief introduction of the participants is provided below in table 6-10.

Table 6.10: Participants profile for absolute measurement of AHP

Name	Age	Profession	Designation	Institution
Participant #1	29	Urban planning	Assistant Town Planner	Dhaka South City Corporation (DSCC)
Participant #2	28	Urban Planning	Assistant Town Planner	United Group
Participant #3	29	Urban Planning	Town Planner	United Group
Participant #4	28	Urban Planning	Assistant Town Planner	Rajshahi Development Authority (RDA)
Participant #5	32	Urban Planning	Assistant Town Planner	RAJUK
Participant #6	43	Teaching	Professor	DURP, Bangladesh University of Engineering and Technology
Participant #7	33	Urban Planning & DM	Project Manager	United Group
Participant #8	32	Urban Planning	Manager	Fortis Group
Participant #9	35	Academician	Assistant Professor	DURP, Chittagong University of Engineering and Technology
Participant #10	31	Academician	Lecturer	Chittagong University of Engineering and Technology
Participant #11	31	Academician	Assistant Professor	DURP, Chittagong University of Engineering and Technology
Participant #12	32	Academician	Assistant Professor	Chittagong University of Engineering and Technology
Participant #13	42	Academician	Professor	DURP, Bangladesh University of Engineering and Technology
Participant #14	48	Academician	Professor	DURP, Bangladesh University of Engineering and Technology
Participant #15	28	Urban Planning	Assistant Urban Planner	Dhaka South City Corporation (DSCC)
Participant #16	39	Urban Planning	Consultant	LGD/JICA

6.6.2. Weightage factor derivation

Upon receiving the individual responses from the respondents. Aggregation of judgements can be done in this stage as well as during the decision-making stage. Group aggregation has been taken place in evaluation stage and it is done by aggregating the participants choice for each pairwise comparison and synthesizing the result for only one decision matrix. The group mean of each pairwise comparison is processed further to get the decision as a whole.

The responses were given input in superdecisions2.0 software for deriving the rating for column priorities along with standard for indicator categories. During the process, all aggregated responses were found to be consistent for the analysis. All consistency values remained below 0.01. After deriving the rating values, the AHP structure becomes:

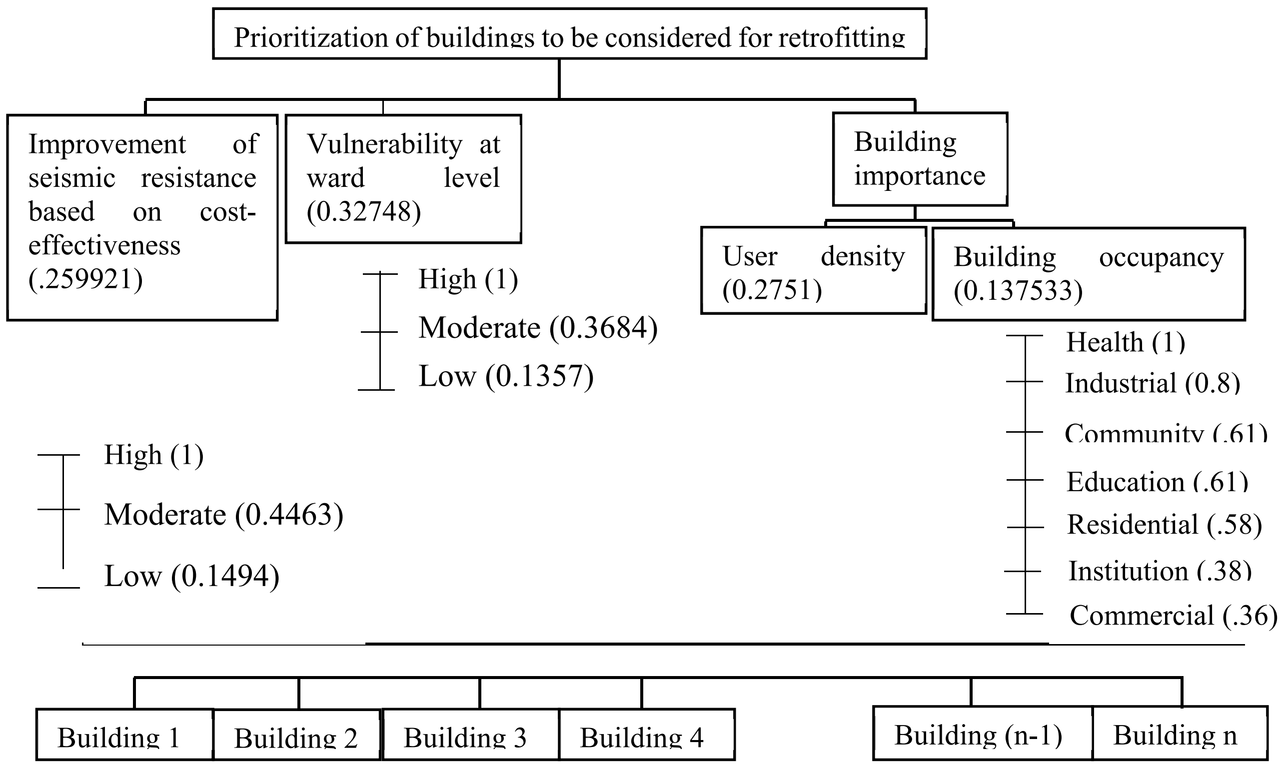

Figure 6.4: Hierarchical decision structure of absolute measurement of AHP with obtained weightage

Based on these ratings of criterion and their categories, ranking of alternatives has been obtained. Fifteen buildings from the buildings stock of 582 building samples have been taken for application of the retrofitting prioritization methodology. The ranking of the buildings is shown in the table below:

Table 6.11: Priority ranking with absolute measurement of AHP

Building ID	**Ward no.**	**Building area**	**Cost-effectiveness (0.26)**	**Location (0.3275)**	**Building occupancy (0.138)**	**User density (0.2751)**	**Total**	**Priorities**	**Rank**
Building A	DNCC 1	1680	Low	Highly vulnerable	Residential	0.00124	0.4464	0.09736	3
Building B	DNCC 31	1254	Low	Moderately vulnerable	Residential	0.001994	0.2398	0.05230	11
Building C	DNCC 24	1790	Low	Lowly vulnerable	Commercial	0.000745	0.1330	0.02900	15
Building D	DNCC 4	535	Moderate	Lowly vulnerable	Residential	0.001947	0.2407	0.05251	7
Building E	DSCC 13	4716	Low	Moderately vulnerable	Residential	0.001414	0.2396	0.05226	13
Building F	DNCC 5	114	Moderate	Highly vulnerable	Commercial	0.005482	0.3167	0.06907	4
Building G	DNCC 13	515	Moderate	Moderately vulnerable	Industrial	0.008091	0.2636	0.05750	5
Building H	DSCC9	1770	Low	Lowly vulnerable	Residential	0.001295	0.1634	0.03564	14
Building I	DNCC 9	918	Low	Moderately vulnerable	Residential	0.002269	0.2399	0.05231	10
Building J	DNCC 10	1144	Moderate	Lowly vulnerable	Residential	0.002367	0.2409	0.05253	6
Building K	DNCC 11	1122	Low	Moderately vulnerable	Residential	0.0026	0.2400	0.05233	9
Building L	DNCC 16	408	High	Highly vulnerable	Residential	0.004596	0.6684	0.14578	2
Building M	DSCC 03	477	High	Highly vulnerable	Community facility	0.00428	0.6725	0.14666	1
Building N	DSCC 26	708	Low	Moderately vulnerable	Residential	0.004708	0.2405	0.05246	8
Building O	DSCC 15	3594	Low	Moderately vulnerable	Residential	0.001681	0.2397	0.05228	12

According to the developed prioritization method for RC buildings, building no. "M" is on top of priority ranking system, building no. "L" is second on priority list and building no. "A" is on third.

The detailed procedure of deriving ranking order would help further to apply the method in other buildings. Calculation to derive ranking order is given below for a better understanding. Building "A" is taken to exemplify and demonstrate the process of building prioritization.

Step 1: It is required to know about a building's information regarding,

- Number of stories
- Floor area
- Location in the city (ward no.)
- Average user number per hour
- Building occupancy type
- Wall area ratio
- Column area ratio

Step 2: Calculation of cost-effectiveness

Value of cost-effectiveness starts from deriving effectiveness value. Cost-effectiveness has been defined as effectivity of retrofitting per unit cost. Hence, cost-effectiveness should be calculated from the equation below. If C-Eff is cost-effectiveness, this is to be derived by the following equations. Firstly, effectivity is calculated by equation (1) and then cost-effectiveness is calculated by equation (2).

$$\text{Eff} = nA1\Delta r = nA1(r(ex.\,IS) - r(ex.\,IS + \Delta IS))\ [7] \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

n= Number of floors of the building

$A1$= Area of the first floor of the building (m2)

Δr= Damage rate reduction (> 0) (%)

$ex.\,IS$= IS value before reinforcement

ΔIS= IS value increased by reinforcement

$$\text{C-Eff} = \text{Eff}/\text{Cost}[7] \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

Cost is derived from the following equation.

$$\text{Cost}= Cf \times \Sigma(n - i + 1)A_1 \times \frac{n+i}{n+1} \Delta I_{si} \text{ (i range from 1 to n)}[7] \ldots\ldots\ldots (3)$$

Cf= 120 BDT/kN[7]

w= Weight supported by the i floor (11 KN/m^2)[8]

Cost-effectiveness is categorized in three categories considering cost-effectiveness value of 582 buildings. Based of the highest cost-effectiveness value, cost-effectiveness categorized are defined as the following.

Highly cost-effective: 0-0.047

Moderately cost-effective:0.048-0.093

Lowly cost-effective:0.093-0.14

Step 3: Determining vulnerability status of the building's locality

Location of the building in the city carries the vulnerability status of the building. Ward vulnerability is defined in chapter 3, where vulnerability is categorized in four categories. Vulnerability status of the ward where the subjected building is located, is necessary to know the rank of the building.

Step 4: Knowing number of users in 24 hours

Number of users can very in different time of a day. Finding out the number of users of a building in 24 hours will provide user density. Number of users, and total floor area of a building will provide user density of a building in 1 hour.

Step 5: Calculation of priorities

Weightage of each criterion and weightage of respective categories are multiplied and then summed to derive priority value for this building.

For building A,

Total= (weightage value for cost-effectiveness) × (weight for low cost-effectiveness) + (weightage value for location of building at ward level × weight for highly vulnerable wards) + (weightage value for building occupancy) × (weight for residential building use) + (weightage value for user density) × (value for user density)

$$= (0.26 \times 0.1494) + (0.3275 \times 1) + (0.138 \times 0.58) + (0.2751 \times 0.00124)$$

$$= 0.4467$$

So, priority value= $\frac{Total\ weightage\ value\ of\ Building\ A}{Sum\ of\ total\ weightage\ value\ of\ the\ sample\ buildings}$

$$= \frac{0.4467}{4.5852}$$

$$= 0.0974$$

6.7. Conclusion

Dhaka, being the capital city of Bangladesh, houses majority of urban population as well as important infrastructures. The centralized nature of the city made it one of the densest cities of the world. In this context, earthquake risk makes Dhaka vulnerable in terms of physical, infrastructural, social, economic damage etc. It is reported in CDMP that the massive damage will be done by the destruction of the buildings from earthquake. Recent occurrences of mild earthquakes made it more apparent that it is high time we made our infrastructures capable to withstand such seismic occurrences.

In Dhaka, not in all cases, building owners followed the rules of BNBC during construction. As a result, it is assumed that Dhaka will face huge destruction due to earthquake. Retrofitting is a way to increase seismic capacity of structures and building physical resilience of a city. The huge number of buildings makes it difficult to decide which kind of buildings to retrofit first. Generally, seismic capacity of a building should be considered for seismic retrofitting. Alongside seismic capacity, there are other factors to be considered to optimize the outcome of seismic retrofitting. In the context of Dhaka city, it is not possible to determine seismic capacity of all buildings. To address this problem, it is thought to make a prioritization system for the buildings to be retrofitted considering improvement of seismic retrofitting based on cost-effectiveness, vulnerability of the ward where the building is located and importance of building according to their occupancy and user number. The priority buildings are determined by using both types of AHP measurement; relative and absolute.

The prioritization system provides ranking of the input buildings to prioritize for seismic retrofitting. It will enable in determining the priority buildings for seismic retrofitting. It will facilitate the decision makers to make a decision in an optimized manner.

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Chapter 7 The Improvement in Citizen Awareness of Low-Frequency Hazards after a Disaster Risk Reduction Town Walk – A Case Study in the Tejturi Bazar Area of Dhaka City

7.1 Introduction

7.1.1 The importance of "disaster risk reduction town walks" for low-frequency disaster

We live with various hazards such as earthquakes, floods, and tsunamis. For citizens to live a safe and secure life, it is important to take appropriate measures against these hazards. Various measures, both structural and non-structural, are being undertaken for hazards that occur frequently in the region, as both public and private sectors maintain a high awareness of disaster risk reduction. Therefore, even if a disaster of a certain scale occurs, the damage can be controlled. On the other hand, in both public and private sectors, the awareness of disaster risk reduction is not necessarily high with regard to low-frequency hazards, and sufficient disaster risk reduction measures are not being taken. Therefore, when such a hazard occurs, the damage is larger than the scale of the hazard, which may result in a large-scale disaster.

To prevent such a situation, it is important to raise awareness of disaster management in the public and private sectors, and to prevent the spread of damage by taking effective measures.

One of the important measures to reduce the damage caused by earthquakes is seismic retrofitting. Although it is costly, in countries where earthquakes occur frequently, such as Japan, the government provides subsidies, and each building owner bears to spend a certain amount of money to carry out the retrofitting work. This has been effective as a measure against earthquake disasters. However, if earthquakes are a low-frequency hazard, governments rarely provide subsidies for seismic retrofits, and owners rarely invest in them, either. This is especially true when the public and private sectors have no economic margins, as is the case in developing countries.

Therefore, to prepare for such low-frequency hazards, it is necessary for both the public and private sectors to properly understand the risks, raise disaster risk reduction awareness, and take appropriate measures accordingly. In particular, the owner of the building is primarily responsible for it, so it is important to improve the owner's awareness of disaster risk reduction and to encourage them to do seismic retrofitting of the building.

One of the measures to raise the disaster risk reduction awareness of building owners is the "disaster risk reduction town walk." This is an activity in which local people receive information on earthquakes, walk around the town to understand the dangers in it, and think about improvement measures, which they expect to be eventually realized. The town walk itself does not require a large budget, so if it can attract a larger investment from the private sector, a safer town can be created with a small administrative budget.

7.1.2 Previous studies

Faupel et. al. (1992) [1] examined the impact of participation in disaster education programs generally, the impact of hurricane experience as a type of education, and the impact of participation in earthquake-specific education programs to determine whether there is any transference of knowledge across agent types. They found that participating in a disaster education program is strongly related to preparedness measures, while participation in earthquake-specific education programs is not a significant predictor of either planning or response when controlling for other variables.

Rahman et al. (2018) [2] applied the concept of „Participatory Vulnerability Reduction" to the community of Dhaka city, which had been identified in a research as one of the most vulnerable areas of the city for earthquake. PVR consists of the following three steps: assessment of earthquake vulnerability, assessment of community capacity and development of the strategy to overcome the vulnerability. They finally found that the participatory methods can be successfully applied to draw more in-depth findings in participation of local community who possess the best knowledge about themselves.

Newport et al. (2003) [3] described how the Society for National Integration through Rural Development in India was involved in local communities when developing disaster mitigation measures. They showed how the participation of the community in resource identification, capabilities, coping mechanisms, and vulnerability assessments would be more effective in the planning of a sensible and practical system, and more suitable for the needs of the community.

Yoshida et al. (2009) [4] carried out the town walking program for disaster risk reduction and illustrated the effects of collective watching and participatory mapping on the engagement of school children and communities in risk reduction activities. Though the program itself is similar to the program carried out in this study, the target area as well as the effect measurement target is different from the present study.

Saito et al. (2017) [5] clarified that the outcomes for disaster management activities in the local community include improved risk perception, disaster management activities, and disaster awareness for residents. They also identified the issues in planning and continuing community disaster management activities after deciding to make a disaster management plan.

In addition, Nakagawa (2015) [6] identified the effectiveness of the experience-based disaster education program utilizing ICT in the practical activity of "Ishinomaki Tour -Remember 3.33-," a kind of town walking program for disaster prevention, developed after the 2011 Great East Japan Earthquake.

However, no study has yet clarified the effectiveness of a disaster risk reduction town walk in developing countries in improving the residents' awareness of disaster risk reduction and their willingness to retrofit buildings.

7.1.3 Objectives of this study

The purpose of this study is to clarify how residents' awareness of disaster risk reduction and the cost-bearing consciousness of building seismic retrofitting have been improved by disaster risk reduction town walking.

Accordingly, the following two research questions are set. First, will disaster risk reduction town walk change people's awareness of earthquakes and seismic retrofits? As mentioned above, the cost of implementing a disaster risk reduction town walk is not high, so if such an event causes a change in people's consciousness, it would be valuable to implement it actively. The second question is, what kind of people are particularly affected by disaster risk reduction town walks? By clarifying this point, it will be possible to narrow down the places where town walks are carried out and the number of participants who can be invited, which means that a more efficient and effective project implementation and a more significant achievement of the objectives will be possible. This is the basic information necessary for effectively promoting countermeasures against low-frequency earthquake hazards.

7.1.4 Target and methods used in the study

The study was conducted in the Tejturi Bazar area in Dhaka, Bangladesh. The target residents were 14 building owners and residents in the area. The number of people surveyed was not necessarily sufficient. However, given the low awareness of low-frequency risks in developing countries, it is inevitable that the number of participants will be limited at first. In fact, when developing countries are used as a field, it is important to search for the truth by stacking multiple (albeit somewhat incomplete) data rather than by aiming for perfect data from the beginning.

The target disaster risk reduction town walk was the Town-Watching Program (TWP) conducted by SEEDS Asia.

The survey method was a hearing survey followed by a questionnaire survey. The survey was conducted in July 2018.

Regarding willingness to pay (WTP), we used a multiple-choice system rather than a questionnaire design that repeats alternatives, which is considered a better method. This is because the survey time was limited and it was necessary to use a simple survey method in consideration of the ability of the respondents, so that changes in responses before and after the TWP could be grasped accurately.

7.2 Contents of Town-Watching Program

The Town-Watching Program was developed based on UNISDR's Town-Watching Handbook (Shaw and Takeuchi, 2009) [7] and modified to suit the situation in Dhaka city [8].

As regards learning systems, town-watching falls in the experiential learning category, which needs to be complimented by lectures (using text books, videos and other related information sources), and presentations (using different workshop tools). The objectives of town-watching are to increase children's and adults' awareness of disaster risk reduction and preparedness.

The TWP mainly consists of three parts. The first part is walking around the area. Each group walks around the predetermined area, finds the designated locations, takes notes, and takes photographs. The second part involves making a map by each group of each of the locations found, and add explanation and pictures to the map. The last part is the presentation. Each group makes a presentation of what they found in front of all the participants, and the other groups ask questions of the group making a presentation. If there are no questions, the chair asks questions. The chair makes comments and provides a summary.

7.3 Basic Information about the Participants and their Buildings

7.3.1 Attributes of the participants

Regarding the age of participants (Figure 7.1), middle-aged people in their 30s and 40s made up the majority, eight people (57%). Five young people were under the age of 30 (36%). There was only one person aged 50s or older.

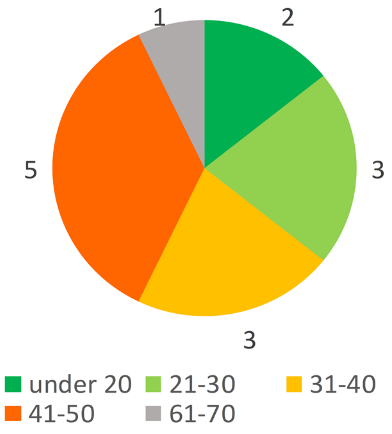

Figure 7.1 Age of the participants

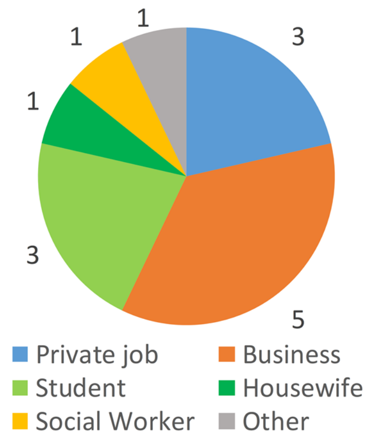

Figure 7.2 Occupation of the participants

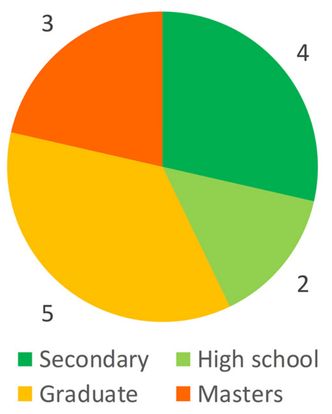

Figure 7.3 Educational background of the participants

In terms of occupation (Figure 7.2), five people said "business" (36%), while three people each said "private job" or "student."

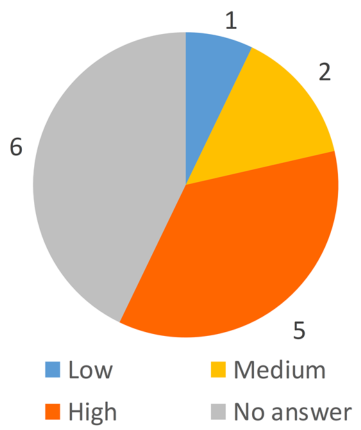

Figure 7.4: Income of the participants

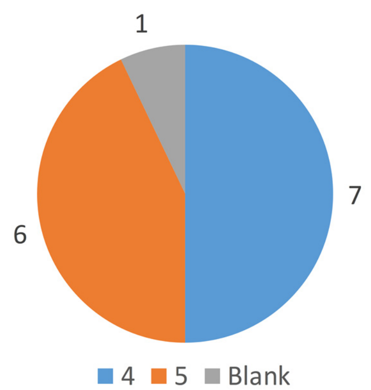

Figure 7.5: Number of family members of the participants

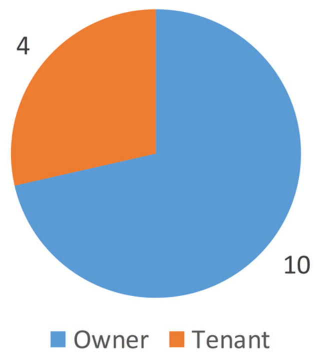

Figure 7.6: Real estate right of the participants

Regarding educational background (Figure 7.3), five (36%) graduated from college, and three (21%) completed master's degrees, more than half in total. Considering that the university enrollment rate in Bangladesh is 18% (UNESCO, 2017) [8], this is a very high value. Four people had a secondary education (29%).

Regarding income (Figure 7.4), they responded subjectively on a three-point scale. Six people (43%, the highest percentage) said "no answer," while five respondents said their income was "high" (36%).

For the number of family members (Figure 7.5), 13 respondents (93%) answered "4" or "5." As for real estate rights (Figure 7.6), ten were owners and four were renters.

7.3.2 Attributes of owned/rented buildings

Regarding the age of the buildings (Figure 7.7), responses varied with five (36%) reporting "fewer than 10 years," and two each saying "10-20 years," "20-30 years," "30-40 years," and "40-50 years."

As for the structure (Figure 7.8), all of them live in reinforced concrete buildings. All had between five and nine floors, indicating that all were medium-rise buildings. Regarding rebuilding (Figure 7.9), 11 people (79%) answered that they did not consider rebuilding, and three people (21%) said they would rebuild “within 10 years.”

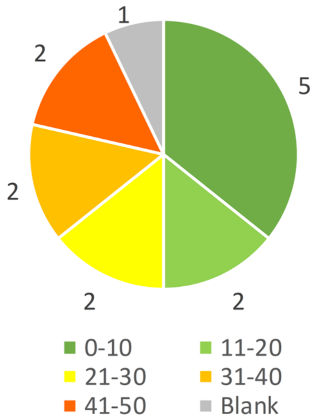

Figure 7.7: Building age (year)

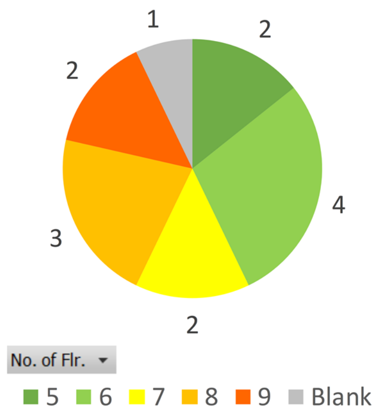

Figure 7.8: Number of floors of the building

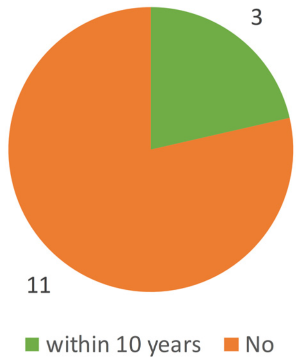

Figure 7.9: Plan of rebuilding

7.4 Changes in the Awareness of Disasters

7.4.1 Changes in the awareness of earthquakes

Before the TWP, 10 (71%) said that they were “very worried” about an earthquake, while four (29%) were “little worried” and no one was “not worried” (Figure 7.10). This suggests that they had a certain perception of the danger of earthquake hazard in the first place. In contrast, after the TWP, one (7%) still answered “little worried,” but the rest (93%) answered “very worried.” This suggests that the implementation of the TWP increased the awareness of earthquake hazards.

Analyzing their responses according to the age of the building in which they reside (Figure 7.11), the proportion of respondents who answered “little worried” is relatively high when the building is no more than 20 years old, while most of the respondents who reside buildings more than 20 years old answered “very worried.” It was found that the residents of older buildings had relatively less fear of earthquake, though their awareness changed due to the TWP.

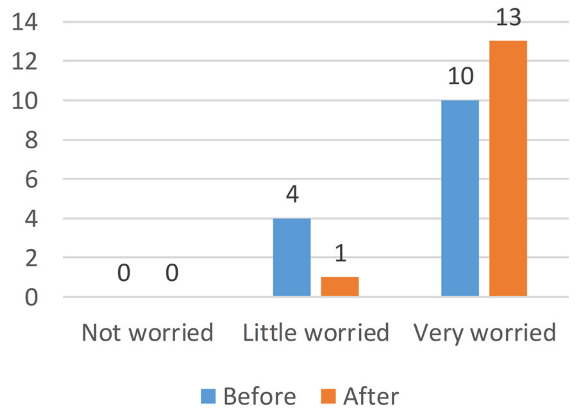

Figure 7.10: Worried about earthquake

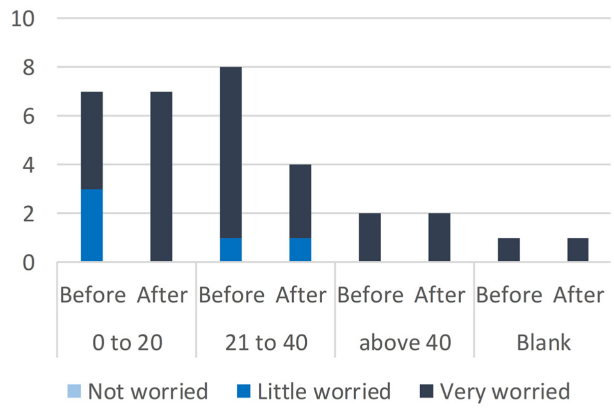

Figure 7.11: Worried about earthquake by own building age

7.4.2 Changes in the awareness about buildings

Before the TWP, the majority, 9 (64%) were "little worried," while two were "not worried" (14%), and only three were "very worried" (21%) (Figure7.12). However, the TWP reduced the number of "not worried" to 0, while the number of "very worried" increased significantly to 11 (79%). The TWP, therefore, changed the awareness of residents who consider their buildings safe.

A cross-analysis of this with earthquake awareness (Figure 7.13) reveals that only one person answered "very worried" about both the earthquake and his own building. The remaining nine people answered "very worried" about the earthquake and "not worried" or "little worried" about their buildings. This shows that many citizens consider their own buildings to be safe even if they have anxiety about earthquakes in general.

Looking at this by building age (Figure7.14), six out of seven residents (86%) living in a building less than 20 years old answered either "not worried" or "little worried," while two people living in a building more than 40 years old both answered "little worried." It can be said that there is no clear correlation between the age of the building and the residents' concerns about their own building.

In terms of educational background (Figure 7.15), those who answered "not worried" initially were all secondary school graduates, while those who answered "very worried" were all college graduates. The higher the educational background, the higher the awareness of earthquakes. In addition, all four secondary graduates became "very worried" after the TWP, suggesting that such community programs are likely to be effective with those with a low educational background.

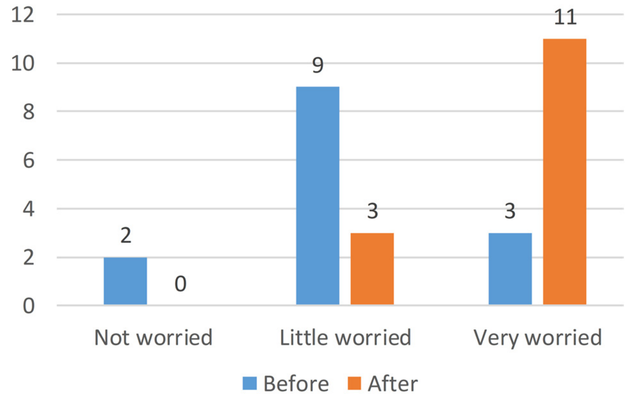

Figure 7.12: Worried about own building

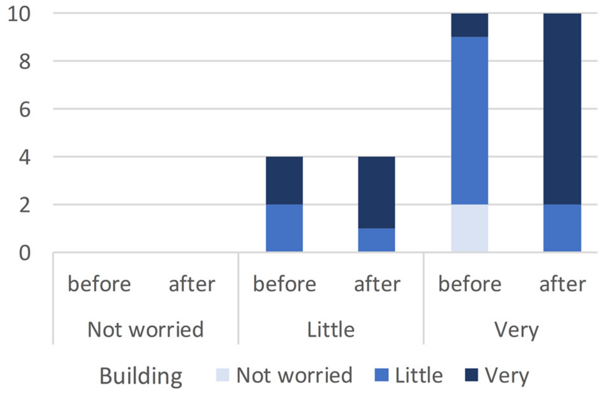

Figure 7.13: Worried about own building and earthquake

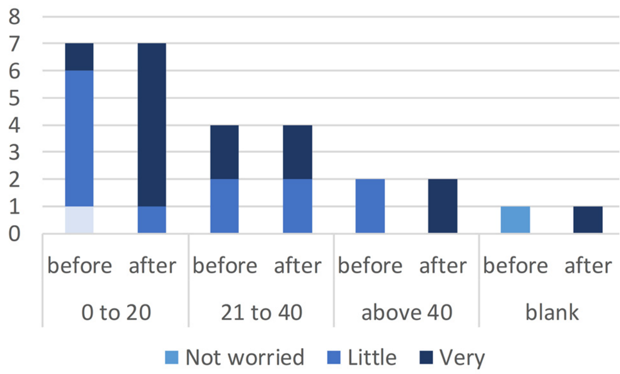

Figure 7.14: Worried about earthquake by own building age

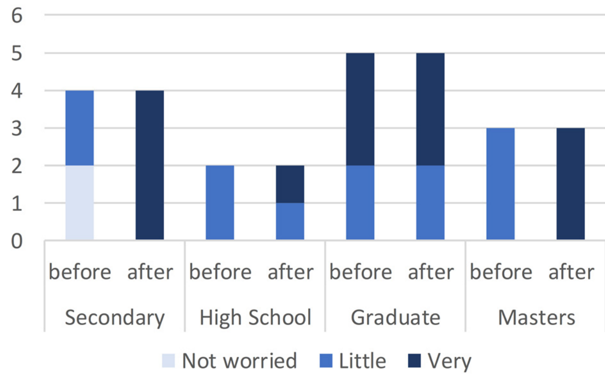

Figure 7.15: Worried about earthquake by education

7.4.3 Changes in WTP for seismic retrofits

Regarding seismic retrofitting, questions were asked about four cases: the possibility of building collapse being 80%, 60%, 40%, and 20% due to seismic retrofitting. There were seven options: willing to pay 200 Bangladeshi Taka (TK)/sq. ft. or less, 200-400 TK/sq. ft., 400-600 TK/sq. ft., 600-800 TK/sq. ft., 1,000-1,200 TK/sq. ft., and 1,200 TK/sq. ft. or more. In calculating the average, the median of each range was taken. In addition, we calculated "1,200 TK/sq. ft. or more" as 1,400 TK/sq. ft. Therefore, the average value may be lower than the actual value.

First, looking at the WTP by collapse probability (Table 7.1), it can be seen that WTP increases as the collapse probability decreases, both before and after the TWP. It can also be seen that the TWP increases due to the TWP regardless of the probability of collapse. This is characteristic of the rate of increase in WTP. Once the probability of collapse reaches as high as 80%, it increases by only 8%, and there is almost no effect of TWP. On the other hand, if the collapse probability can be reduced to 40% or less, the increase rate was more than 70%, which illustrates that the TWP has a large effect on increasing the WTP. In particular, when the probability of collapse could be reduced to 20%, the modal class after TWP was 1,200 TK/sq. ft. or more (six persons). The t-test shows that the population mean is different, with a significance level of 1%, when the probability of collapse is 20% and 40%. If safety can be ensured by seismic retrofitting, it can be said that the willingness to pay a certain amount has been fostered to a considerable degree by the TWP.

Table 7.1: WTP for seismic retrofit by collapse probability before and after TWP

Collapse Risk (n=13)	Avg. WTP before TWP (TK/sq. ft.)	Avg. WTP after TWP (TK/sq. ft.)	Difference	t-test * : P<0.05 ** : P<0.01
80%	192	208	16 (+8%)	
60%	330	423	93 (+28%)	
40%	346	615	269 (+78%)	**
20%	577	992	415 (+72%)	**

Regarding the measures to reduce the probability of collapse to 20%, looking at changes by age (Table 7.2), those who were under 30 years old showed relatively high values from the beginning, such as the two people indicated their WTP more than 1,200 TK/sq. ft.; the number increased further after the TWP, and all of them selected 800 TK/sq. ft. or more. On the other hand, all those aged 30-50 selected 800 TK/sq. ft. or less from the beginning, and four out of eight people still chose 800 TK/sq. ft., even after the TWP. Middle-aged people were more reluctant to retrofit after the TWP compared to younger people.

Table 7.2: WTP for seismic retrofit by age before and after TWP (20% collapse risk)

Age	Avg. WTP before TWP (TK/sq. ft.)	Avg. WTP after TWP (TK/sq. ft.)	Difference	t-test * : P<0.05 ** : P<0.01
Under 30 (n=5)	780	1,200	420 (+54%)	
30-50 (n= 8)	450	850	400 (+89%)	**
Over 50 (n=1)	1,400	1,400	0 (0%)	

Next, looking at this in relation to educational background (Table 7.3), in the case of junior and senior high school graduates, 3 out of 4 people had a willingness to pay less than 400 TK/sq. ft. before the TWP, and the average amount was 533 TK/sq. ft., which was 21% lower than 675 TK/sq. ft. of college graduate or higher. However, after the TWP, the average has risen to 1,000 TK/sq. ft., which is 4% higher than 963 TK/sq. ft. for college graduate or higher. The amount (rate) of increase was 288 TK/sq. ft. (43%) for college graduate or higher, while that for junior high and high school graduates was 467 TK/sq. ft. which accounts for nearly double. For these junior high school graduates, the WTP after TWP is significantly higher (significance level 5%) than before TWP. It can be seen that though lower educated people were more skeptical about earthquake countermeasures compared to higher educated people, their awareness has increase drastically after the TWP.

Table 7.3: WTP for seismic retrofit by educational background before and after TWP (20% collapse risk)

Educational background	Avg. WTP before TWP (TK/sq. ft.)	Avg. WTP after TWP (TK/sq. ft.)	Difference	t-test * : P<0.05 ** : P<0.01
Middle and high school graduates (n=6)	533	1,000	467 (+88%)	*
College graduates or higher (n=8)	675	963	288 (+43%)	

Next, looking at the relationship with the building age (Table 7.4), it can be seen that the residents living in the 21-40 years old buildings had the highest WTP both before and after the TWP. Comparing the growth before and after the TWP, the residents of the building 40 years or older, which showed the lowest WTP before the TWP, was 800 TK/sq. ft. after the TWP, which accounts for quadruple. In addition, the WTP of residents of buildings with relatively young age has also increased by 51%, a very high growth rate. Thus, it can be seen that the TWP is particularly effective for residents of relatively new and old buildings who had low WTP. However, the sample size of residents living in buildings older than 40 is two, which is not reliable enough. This point needs to be examined by increasing the number of samples in the future.

Table 7.4: WTP for seismic retrofit by building age before and after TWP (20% collapse risk)

Building age	Avg. WTP before TWP (TK/sq. ft.)	Avg. WTP after TWP (TK/sq. ft.)	Difference	t-test * : P<0.05 ** : P<0.01
0-20 (n=7)	643	957	314 (+49%)	
21-40 (n=4)	900	1,100	200 (+22%)	
40- (n=2)	200	800	600 (+300%)	-

Regarding the relevance to the worry about the earthquake before the TWP (Table 7.5), those who previously answered “little worried” had a low WTP, as low as 500 TK/sq. ft.. However, it increased more than twice by 575 TK/sq. ft. (115%) after the TWP to 1,075 TK/sq. ft.. On the other hand, the residents who answered “very worried” had a higher WTP of 660 TK/sq. ft. than that of “little worried” before TWP. However, after the TWP, it increased by only 280 TK/sq. ft. (42%) to 940 TK/sq. ft., which is lower than those who answered “little worried.” The TWP therefore has a particularly large effect on people who are not worried about earthquakes.

Table 7.5: WTP for seismic retrofit by worries about earthquakes before and after TWP (20% collapse risk)

Worry about earthquakes before TWP	Avg. WTP before TWP (TK/sq. ft.)	Avg. WTP after TWP (TK/sq. ft.)	Difference	t-test * : P<0.05 ** : P<0.01
Little worried (4)	500	1,075	575 (+115%)	
Very worried (10)	660	940	280 (+42%)	

7.5 Discussions and Conclusions

In this study, which aimed at clarifying how cost-consciousness regarding building seismic retrofitting improved after the disaster risk reduction town walk, we set the following two points as research questions: 1) how people's awareness of earthquakes and seismic retrofitting are changed by the disaster risk reduction town walk, and 2) what kind of attributes in people are particularly affected by it. The following summarizes the conclusions made in this study.

As for the first point, it became clear that people's consciousness about earthquakes, seismic retrofitting, and the cost burden to them was changed by the disaster risk reduction town walk. A particularly clear effect was seen for better seismic retrofitting, with an improvement to 20% and 40% collapse probability. Examining the benefit/cost ratio, this TWP has had the effect of increasing the expense of seismic retrofitting of 269 TK/sq. ft. (for a 40% collapse risk) to 415 TK/ sq. ft. (for a 20% collapse risk) for 14 participants. Assuming that the housing area per owner is 1,000 sq. ft., the TWP had the effect of improving 3.8-5.8 million TK/TWP. This can be evaluated as being significantly higher than the cost of a single TWP, even if we take it into consideration that the results of the questionnaire can be overstated. It is expected that the effect will be further enhanced if the number of participants increases.

Regarding the second point, the impact on the WTP for seismic retrofitting was particularly affected by having less education, by being younger, by whether they are residents of newer or older homes, and by not being worried about earthquakes. It is therefore important to encourage people in these groups to participate in the TWP from the viewpoint of improving the TWP's efficiency.

Two points, however, remain unanswered by this study. The first point ifs the accuracy of the results. It can be presumed that those who participated in this TWP have higher disaster risk reduction awareness than ordinary people. In addition, the questionnaire regarding the WTP uses a hypothetical scenario, and the result may be significantly higher than an actual scenario. Due to the characteristics of the participants and the survey method, there may be errors in the results. This point, therefore, needs to be corrected in the future for greater accuracy. The second point, related to the first point mentioned above, is how to increase the number of the people surveyed. This time we had a very limited sample size of 14 people, and that number needs to be increased for the results to be generalized.

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Chapter 8 Urban Planning Strategies and Policy Framework to Make Dhaka City Resilient against Earthquake

8.1 Visioning Seismic Resilient City

Ultimate vision of this endeavor is to gradually develop efficient and effective urban planning strategies to make cities safer and more resilient against disasters- particularly earthquake. Pursuing of this vision is not an isolated work, it needs multi-stakeholders' efforts as its nature of multilayered works involved.

Following interventions are extremely necessary to make Dhaka city resilient;

a) Seismic hazard responsive land use planning and enforcement of that plan;
b) Construction of seismic responsive buildings in compliance with building construction rules and code;
c) Evaluation of the building distribution by seismic performance in the city;
d) Prioritization of public and private building for retrofit;
e) Knowledge sharing with community about community resilience and retrofitting;
f) Strong integrated effective disaster risk governance (Legal, Institutional, and Execution);
g) Resilience oriented investment of resources to make city safer and resilient.

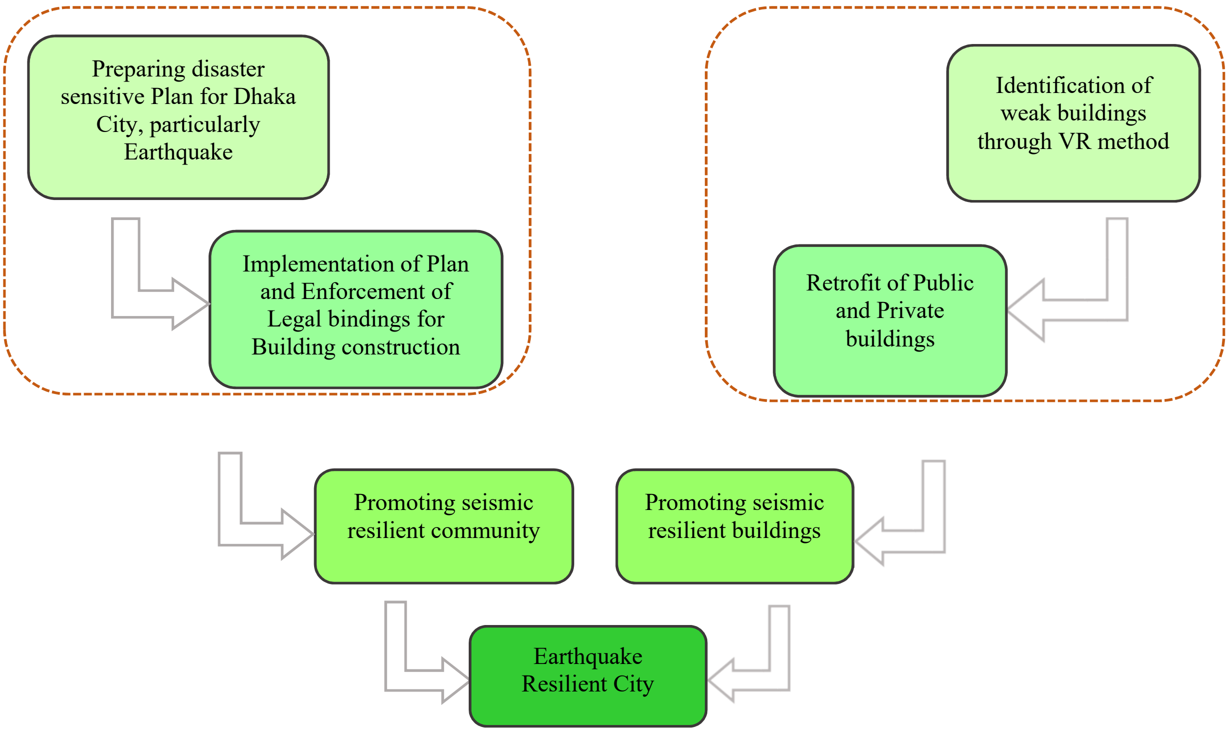

Figure 8.1: Vision of building Earthquake Resilient City (own illustration)

Making a city resilient is a long term endeavor that city authorities and the citizen must pursue with combined efforts keeping a vision ahead. Above schematic diagram (Figure 8.1) shows us the process of developing an earthquake resilient city in comprehensive manner.

8.2 Where to Focus for Building Seismic Resilient City?

Development of efficient and effective urban planning strategies to make cities safer and more resilient against disasters

- **Earthquake Responsive Urban Planning:** Plan Preparation: City development authority need to consider all the shocks and threats related to earthquake in the city including seismic fault lines, geology, land formation and soil condition of the city. Plan must be prepared on the considering the finding of the above-mentioned investigation to reduce the seismic vulnerability of Dhaka city. **Chapter Two** of this guidebook elaborately explained the gravity of considering the geological matters in urban planning.

- **Enforcement of Formulated Plan and Policy**

- **Building distribution of seismic performance**: As a part of improving seismic resilience of the city, chapter 3 of this guidebook guides through a process developing a method for identifying the buildings with low seismic performance using Japanese Standard. The method of estimating seismic performance helped in addressing 'building condition' in understanding the city's overall seismic condition.

- **Prioritization of Building for Retrofit**: For improving seismic resiliency of Dhaka city, it is required to improve seismic performance of the buildings through seismic retrofitting. Random selection of buildings for seismic retrofitting might not help in achieving efficiency. Buildings should be prioritized for retrofitting to maximize efficiency as a part of improving seismic resiliency.

- **Compliance of Building Rules and Code**

- **Revision of Contingency Plan:** Earthquake Contingency Plan (ECP) was prepared in 2009 under the Comprehensive Disaster Management Programme (CDMP). It was solely prepared for the unified Dhaka city corporation to withstand the adversity of an earthquake. In this document it clearly mentioned that twenty-seven (27) stakeholder organizations are directly related to execute the plan. However, most of the stakeholder organizations are unaware of this plan. Disowning such a plan merely indicate the lack of interest among the organizations.
- **Advocacy and informing community**

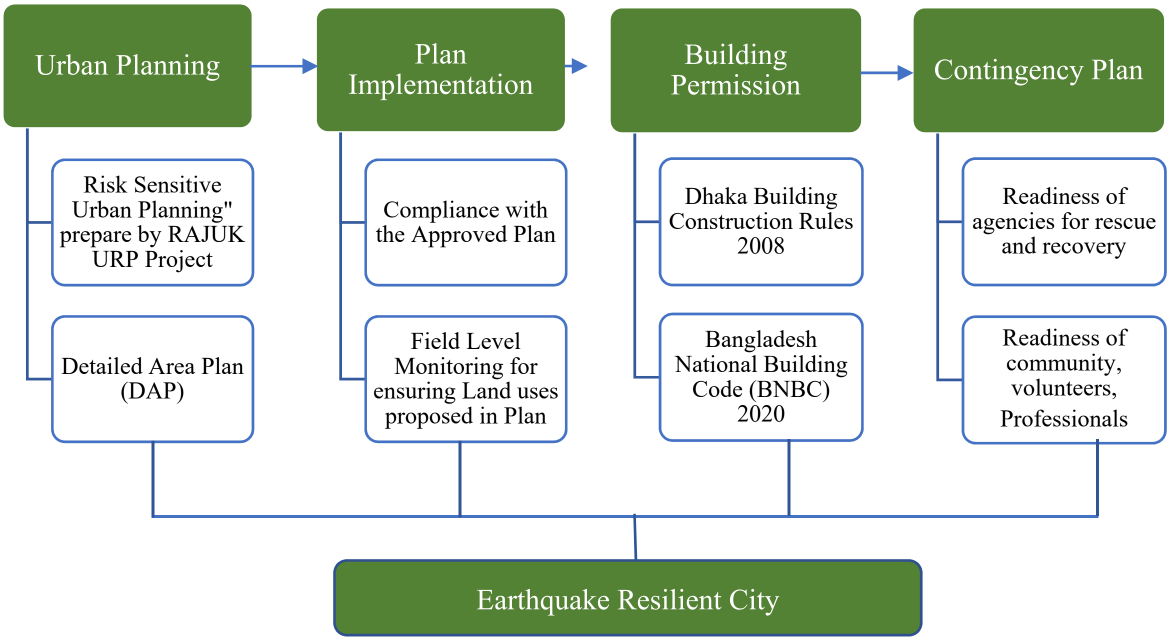

Figure 8.2: Flow Chart of Promoting Dhaka an Earthquake Resilient City

8.3 Measures to be Taken to Improve City's Resilience

Here is the summary of policy interventions need to be taken for building a seismic resilient Dhaka city.

SL No	Existing Situation	Necessary Policy Intervention
1.	**Urban Planning**	
	Risk Sensitive Urban Planning" prepare by RAJUK URP Project:	Under preparation, need to finish it timely and approve it timely.
	Detailed Area Plan (DAP):	Prepared, waiting for approval
2.	**Plan Implementation**	
	Compliance with the Approved Plan:	• Ensure the implementation of land uses proposed in DAP, it will help to develop a resilient city.
	Field Level Monitoring for ensuring Land uses proposed in Plan: At present, weak governance of RAJUK and corrupted field level monitoring system allowing violation of building plans.	• Accountable and transparent governance in building construction system.
3.	**Building Permission Process**	
	Building Construction Rules 2008: • Various investigations reveal that, in Dhaka city a big number of buildings are constructed deviating the plan	We suggest 3 points to reinforce in the Building construction rules which is NOW under the process of revision; • strengthening the field level monitoring system to stop violation of plan

	• Only the architectural plan is approved by RAJUK, Structural design is not approved by the authority Both the reasons increasing the vulnerability of the city as per as earthquake is concerned.	• compelling the building owners to taking the "occupancy certificate" before starting the buildings to use. It will ensure the compliance of the building construction as per the approved plan from RAJUK. • To reduce the building vulnerability, new section should be added in the Building Construction Rules that, structural design has to approved by RAJUK.
	Bangladesh National Building Code (2020): Though BNBC 2020 was approved in 2020, government has not taken yet any realistic step to implement this code. BNBC 2020 proposed establishment of separate authority named "Bangladesh Building Regulatory Authority" to regulate building construction all over Bangladesh to ensure the quality of building construction.	We are proposing to take immediate actions to implement BNBC 2020 with following priority actions: • Establishment of Bangladesh Building Regulatory Authority • Commencement of continuous training program for professionals, construction workers and rescue volunteers to build resilient cities.
4.	**Contingency Plan**	
	Readiness of agencies for rescue and recovery: from an assessment it has been found that agencies like; City corporation, hospitals, agencies of rescue operation don't have minimum readiness to handle an earthquake incident.	We propose to prepare a new contingency plan and explicitly defining the role and responsibilities of the local government institutions and agencies of emergency rescue operations.
	Readiness of community, volunteers, Professionals	Conducting training program for community, volunteers, Professionals (engineers, planners, medical staffs) to inform them their role and responsibilities and preparation during an earthquake.
5.	**Information dissemination and informing community**	
	There are no other alternative than engaging the community and knowledge sharing in the process of building a resilient city. Need to share the outcomes of this project: • how quickly an owner can know his building vulnerability by our VR method; • status of area vulnerability where a person lives • Retrofit process and tentative cost	What are the measures: • knowledge sharing meetings with the community at ward offices • meeting the ward level community-based organizations • preparing booklets and flyers in very easy understandable language in Bangla • Advertisement and awareness message in popular media.

8.4 Concluding Remarks

Only good research, excellent city plan, sufficient rules and regulations are not enough to have a safe and resilient city. It is more important to implement the plan and enforce the rules formulated to achieve the objectives and the mission of resilience. Therefore, we need to focus on some of the following strategies:

a) Knowledge sharing with community about community resilience and retrofitting;
b) Strong integrated effective disaster risk governance (Legal, Institutional, and Execution)
c) Resilience oriented investment of resources to make city safer and resilient.