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Analysis of Essential Facilities and Housing Structures for Earthquake Preparedness in Dhaka City

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Abstract

Earthquakes are one of the most devastating natural disasters at present in the world. Most recently, Earthquake response and related information are very significant particularly earthquakes impact on the urban communities and its infrastructure. Earthquake research can play a crucial role in a regional community to mitigate hazard and make awareness both of public and administration level. A major earthquake has been forecast for Bangladesh in the near future due to its position at the junction of three continental plates. Should an earthquake occur, it is expected to be devastating, particularly in the capital city of Dhaka, due to a large number of high-rise buildings constructed on relatively unstable ground and the high population density of the metropolitan area. Of primary concern is the fact that such a massive earthquake would be very difficult for the government and non-governmental organizations to handle, due to the low quality of local infrastructure. In this paper first chapter, we use statistical methods to identify correlations among the occupancy classes, essential facilities, and population density in both of Dhaka North City Corporation (DNCC) and Dhaka South City Corporation (DSCC). Correlation analysis shows that medical care and emergency response are positively weak correlated in DNCC but DSCC areas negatively correlated except for commercial area (Medical care) and industrial area (emergency response). Multiple regression analysis indicates that the potential to efficiently respond to a disaster is relatively low concerning the emergency response and medical care facilities in both of DNCC and DSCC area. The findings reveal that essential facilities in DSCC are fewer than those of DNCC and it is necessary to set up more essential facilities both in areas, particularly in DSCC area.

The damage done in earthquake disasters is correlated to the types of housing structures that are present. In the last two decades of urbanization in Dhaka, rapid growth without proper planning has been a major concern. The second chapter in this study we evaluate the performance of the decision tree and random forest techniques to predict structures' vulnerability factors for buildings as a step towards improving earthquake disaster preparedness. Applying the decision tree algorithm to locations (wards) in Dhaka North City

Corporation (DNCC) and Dhaka South City Corporation (DSCC), we observed some important predictors of earthquake damage. Decision tree analysis reveals that the most important predictor for structures that fare well in earthquakes is the use of reinforced concrete, and a common factor among the most vulnerable structures is the soft story building style in the DNCC and DSCC areas. The random forest technique also showed reinforced concrete as being the most important factor for lowering the risk for housing structures, with the model having a 24.19% out-of-bag (OOB) error. As for vulnerability, soft story construction was a significant factor in estimating earthquake susceptibility (40.32% OOB error). The findings reveal that building materials in the DNCC are stronger than those in the DSCC but soft story buildings are more common in the DNCC, which make it one of the weakest parts of the area and point to the need to make plans to seismically retrofit soft story buildings.

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Chapter 1
Introduction

1.1 Introduction

Dhaka, the capital city of Bangladesh, has become part of a group of the megacities in the world. The city situated at the bank of the Buriganga river in the middle part of the country and it covers an area of 321 sq km having a population of approximately 14 million as the primary city in Bangladesh. Due to the unplanned civilization starting more than 400 years ago, many buildings in the old part of the city are non-engineered structures (Rahman et al. 2015). Major earthquakes such as Bengal Earthquake in 1885 (also known as Manikganj Earthquake), 1897 Great Indian Earthquake and 1918 Srimangal Earthquake (Table 1) affected in the Dhaka city significantly. These earthquakes have caused the explicit scene of earthquakes for hazard vulnerability assessment the city (Khan 2016). Most of the earthquakes (Figure 1) in the Indo-Burmese arc took place through reactivation on the pre-existing defects of the Indian plate (Khan 2016). Bangladesh has been Occurred by five major earthquakes (Figure 1) with magnitude 7 or greater in the last 150 years and among two earthquakes had their epicenters within Bangladesh, while others were not far away from Bangladesh border (Islam et al. 2010). The historical seismicity and new shocks occurred in Bangladesh, and adjoining areas point out that the country is at high seismic risk. The existing urban trend and rapid urbanization process of Bangladesh have caused raising commerce, economy, education, politics and accommodate a large population (Jahan et al. 2011). As a natural consequence, many buildings in the urban areas of Bangladesh lack earthquake resistant design. Recurrence of similar earthquakes can, therefore, cause catastrophic implications in densely populated urban areas of Bangladesh. Even moderate earthquakes close to the metropolitan cities can cause great havoc (Al-Hussaini et al. 2015).

Dhaka is arising as one of the largest and speedily growing megacities of the developing world and from 2016 to 2030 city population will expect approximately 27 million (United Nations World Urbanization prospect 2016).

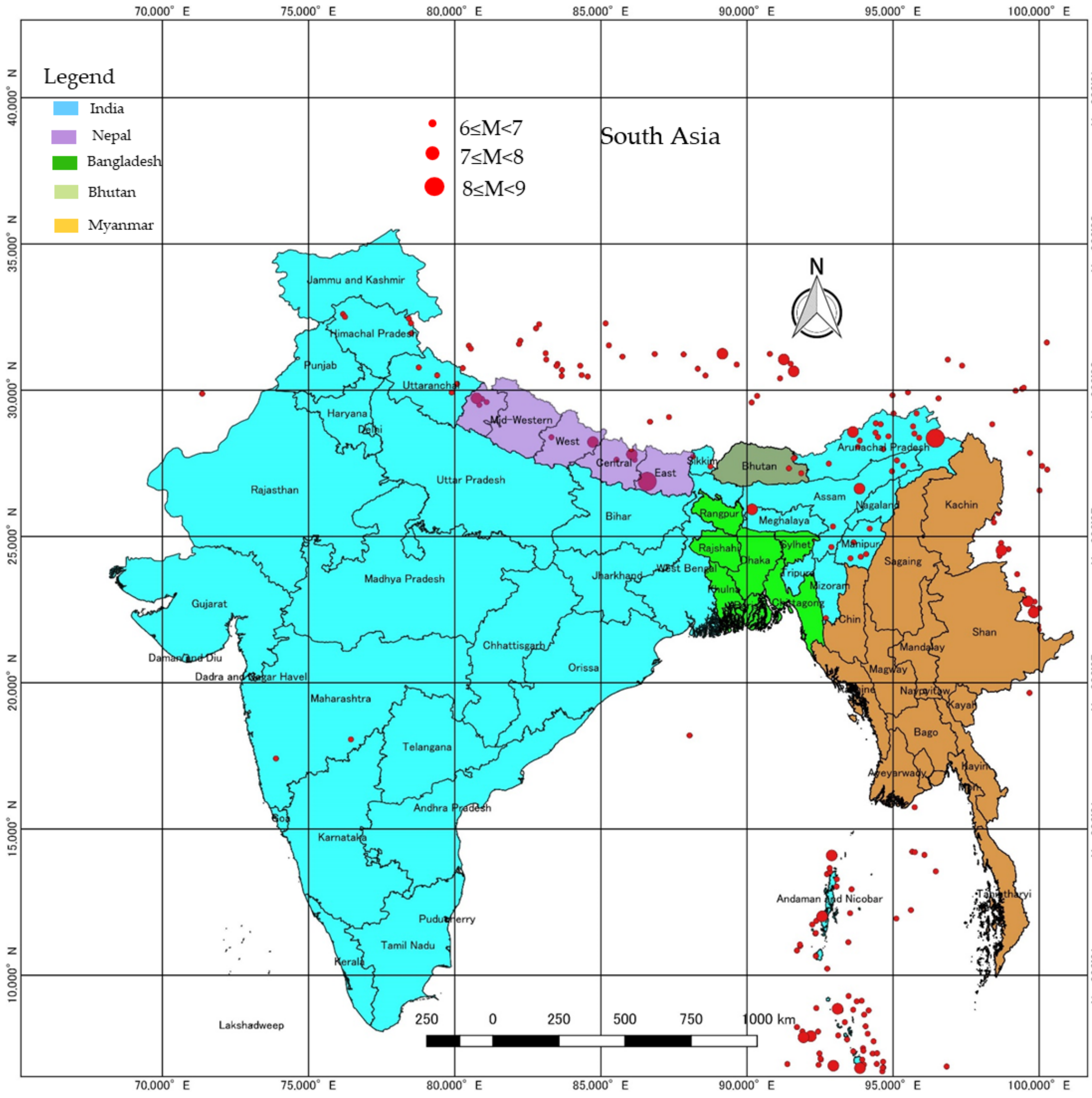

Figure 1.1 Earthquakes in around South Asia (lat. 10.10-30.11, long. 72.51-99.40) (Data Source: USGS).

Dhaka is one of the seismically vulnerable cities in the world because of its location adjacent to the convergent borderline between the Eurasian and Indian Plates, unplanned urbanization, non-engineered construction practice, high population bulk, and weak emergency response system (Rahman et al. 2018, Md Ahmed and Morita 2017). The Earthquake Disaster Risk Index of Stanford University ranks Dhaka City among the world's top 20 cities that are most vulnerable to earthquakes (Khan 2016, Akhter 2010). Dhaka is one of the seismically vulnerable cities in the world because of its location adjacent to the convergent borderline between the Eurasian and Indian Plates, unplanned urbanization, non-engineered construction practice, high population bulk, and weak emergency response system (Rahman et al. 2018). In recent large magnitude earthquakes have taken place several hundred kilometers from Dhaka, namely the 2011 M=6.9 Sikkim earthquake and the 2015 M=7.8 Nepal earthquake. These earthquakes have caused long duration shaking in the capital city and created panic among the residents (Al-Hussaini et al. 2015).

In this study, we approach statistical analysis to identify the essential facilities and housing structure for earthquake preparedness in Dhaka city.

Table 1.1 List of major earthquake history in Bangladesh (USGS).

Date	Latitude	Longitude	Depth(km)	Magnitude(Richter)	Place
July 8,1918	24.599	90.853	15	7.1	Bangladesh
September 9, 1923	24.937	90.721	15	6.8	Bangladesh
July 2, 1930	25.929	90.177	15	7.1	Meghalaya, India region
May 8, 1997	24.894	92.721	34.9	6	India-Bangladesh

Source: USGS

1.2 Earthquake in Bangladesh

Bangladesh located in a seismically active zone making the occurrence of massive earthquakes a realistic possibility. The country is situated close to the junction of two subduction zones created by two having movement of tectonic plates: the Indian plate and the Eurasian plate. The Himalayan and Burmese mountain belts generated by the collision of these plates are considered as one of the most active seismic domains in the world. Moreover, the country is encircled by the Himalayan Arc, the Shillong Plateau and the Dauki fault system in the north, the Burmese Arc and Arakan-Yoma anticlinorium in the east, and the Naga-Disang-Haflong thrust zone in the northeast (Ali and Choudhury, 2001). Researchers analysis of the data on the collision of the Ganges–Brahmaputra Delta (GBD) and the Burma Arc is warranted for advancing of the nature of the accretionary prism and its seismic potential. The Mw 9.3 on 26 December 2004 ruptured 1300 km of the boundary containing the southern part of the Burma platelet. That event was not expected and has brought to the fore the potential for similar large ruptures along the rest of the Burma platelet. Lack of knowledge about these ruptures is concern for Bangladesh, with one of the highest population densities in the world (Steckler et al. 2008). The tectonic setting of India's collision with Asia is now logically well characterized from current seismicity and geodetic studies of relative motion at their plate boundaries. Earthquakes within the Indian Plate are attributable to the superposition of the northwest compressional stress of collision. Recent earthquakes indicate the sense of these combined stresses by measurement of depth and mechanisms (Bilham 2004).

An unknown fraction of the slip is likely to be absorbed by broad faults decreasing updip megathrust slip. Given these large uncertainties, we estimate a potential earthquake of Mw 8.2–9.0. Such an event would have gigantic consequences for the >140,000,000 people living within 100 km of the locked megathrust in Bangladesh and India (Steckler et al. 2016). Seismic specialists also suspect that if an earthquake with a magnitude 7.0 on the Richter scale happens in large cities of Bangladesh, there would be a large-scale human tragedy and economic disaster because of the structural failure of many buildings built in these urban centers without the use of proper construction materials and in violation of building codes. In many densely populated neighborhoods of Dhaka, highrise apartment buildings and most garment factory buildings have been constructed without open spaces and most have encroached upon the streets and roadways. As a result, the collapse of these structures will block streets, further hindering rescue operations (Paul and Bhuiyan 2010).

1.3 Earthquake effects in Dhaka

The tectonic set-up of Bangladesh, particularly its position adjacent to three converging lithopheric plates with the existence of seismogenic faults, suggests that the country, containing its capital Dhaka, must have deteriorated from severe earthquakes in the historical past (Khan 2016, Akther 2010). Earthquake hazard zoning is the first and the most crucial required step toward seismic risk analysis and mitigation policy in the densely populated city areas. Major earthquakes such as Bengal Earthquake in 1885 (also known as Manikganj Earthquake), 1897 Great Indian Earthquake and 1918 Srimangal Earthquake affected in the past Dhaka Mega City of Bangladesh significantly. These earthquakes have been considered as the clear scene of earthquakes for hazard vulnerability assessment of Dhaka Mega City (Khan 2016). That historic earthquake killed 500 people in a much smaller Dhaka, as well as subsidence at Chittagong and coastal Bangladesh, and caused metres of uplift along the Arakan coast. Together, they suggest a rupture width >200 km. The potential slip in an earthquake is unknown, but >5.5 m of convergence has accumulated over the past 400 years without a major earthquake, since the Mughal conquest of Bengal and the establishment of Dhaka as the regional capital. Whether a rupture would reach the detachment tip near Dhaka, or would be averted to the surface on a shallower splay fault farther east, could awfully impact ground shaking and devastation in that megacity. In addition, this megathrust earthquake potential is based on the observed geodetic motion and shallow design of the fold belt, and is independent of mechanism(s) driving convergence (Steckler et al. 2016). GPS-based vector diagrams suggest that current relative motions between the Indian plate and the Burma plate at the latitudes of the Dhaka domain are similar to comparative motions across the Ramree domain. Although GPS stations are too very few and scattered to fully map strain collection across the Burma plate at this latitude, this measurement is consistent with a predominance of convergence and a minimal oblique component. Farther north and east, Imphal is converging southwestward approaching Dhaka at between 11 and 20 mm/yr. This indicates significant active right-lateral strike-slip faulting or clockwise rotations at this latitude (Wang et al. 2014). After a major earthquake, aerial rescue operations (which are extremely costly and slow) might be the only recourse in some parts of Dhaka and other large cities in Bangladesh. There would also be an increased risk of fire following an earthquake, resulting from the failure of gas lines, power lines, water pipes, and sewers, as well as other infrastructure. The reconstruction of collapsed buildings and utilities and the removal of debris would likely devastate the economy (Paul and Bhuiyan 2010). The public participation is integrated into disaster management planning and community planning; the outcome is sustainable hazard alleviation. To make ensure more community involvement, assure basic responsibility at the local level and to establish that there are links between disaster management planning and community planning (Pearce 2003). The accelerated growth of Dhaka's population forced haphazard development and speedy construction of new buildings in any and every available space. Although the government of Bangladesh has developed building codes, which contain detailed guidance for earthquake- resistant design of concrete and steel structures. But, many new buildings do not have adequate provision for seismic resistance. Overall, the number of people living and working in unsafe structures in Dhaka is increasing (Paul and Bhuiyan 2010).

1.4 Limitation of this study

This study is limited to the city corporation areas of the DCC and a significant number of areas outside the jurisdiction of city corporation areas are densely populated and unplanned and haphazard development is taking place over there. For example, Keraniganj one of the densely populated areas in Bangladesh with a population of more than one million, is not covered by this study despite of its adjacent location to the DCC area. Due to existing regulations in Bangladesh, it was not possible to conduct building and lifeline survey in certain areas in the DCC area, which include Dhaka Cantonment, Zia International Airport, Tejgaon Airport, Dhaka central jail, secretarial building area, presidential place area, prime minister office area, National parliament area (CDMP-2009).

1.5 Purpose of this research

These studies focused the entire Essential facilities and housing structure for earthquake preparation in Dhaka city by using statistical analysis. The purpose of this research is to understand the Critical infrastructure of which part of Dhaka City would be the worst situation in case of providing essential facilities after an earthquake. For an earthquake, preparation depends on to determine how the city's critical facilities, play crucial roles during the disaster, and what types of criteria need to be considered to lessen or minimize the catastrophic effects of a major earthquake while suggesting a new approach to the issues above. Additionally, this research cover to identify housing structures towards earthquake vulnerability in comparison to two main parts of Dhaka city. It also helps to provide valuable information about the pattern of housing structures and the results obtained have made it possible to identify the strengths and weaknesses of DNCC and DSCC. To recognize DSCC constitutes a higher hazard than the DNCC because of its old buildings, weak building materials, and soft-story structures. Finally, it is imperative to make a significant push to construct new buildings and implement seismic retrofit policies, particularly in the DSCC area.

Chapter 2

Critical infrastructure analysis for earthquake preparedness in two parts of Dhaka city

2.1 Introduction

Earthquake risk in major urban centers poses a severe challenge, as complexity in governance structures can make it difficult to implement appropriate land use planning policies, enforce regulatory regimes, and plan for earthquake readiness. With a population of approximately 15 million, Dhaka city has one of the fastest growing urban communities in the world and a sophisticated municipal governance system. Dhaka's rapid urbanization has resulted in higher vulnerability to seismic events as urban planning and public services are not keeping pace with growth (Khan 2016, Akhter 2010). There is hardly any room in the casualty wards or even other wards of the very few government hospitals in Dhaka City Corporation (DCC) for earthquake disaster. The sudden destruction and casualties caused by an earthquake demand swift action on the part of the nation's earthquake disaster management authority. There is lack of organization and trained human resources to deal with such a crisis. Identified problems include lack of earthquake awareness, lack of enforcement of building code, economic limitations and poor quality of construction materials. It would be difficult to handle disaster situation due to an absence of a national post-earthquake disaster management plan, lack of rescue and recovery equipment, small road width, lack of medical treatment facility, and lack trained workforce (Al-hussain-2003). An earthquake event has more catastrophic effects in densely built settlements, managing a disaster situation with the limited amount of medical care and emergency response capability in Dhaka city would be difficult (Md Ahmed and Morita 2017). If an earthquake or shaking occurs in Lalbagh City (DSCC-ward 29), then most deaths are the result of buildings collapse, falling debris, and objects like light or pieces of chimneys will result in many victims. Long-term mitigation measure includes: Constructing earthquake-resistant community buildings and buildings (used to gather large groups during or after an earthquake) like hospitals, prayer halls, schools and supporting non-governmental organization in various aspects of disaster mitigation, readiness, prevention and post-disaster management of Lalbagh. DSCC should prepare to be detailed seismic risk map, especially for Lalbagh City considering its high population density and weak physical structure (TUZZOHORA et al.). DSCC constitutes a higher hazard than the DNCC because of its old buildings, weak building materials, and soft-story structures (Md Ahmed and Hiroshi Morita 2018). Building damage detection after earthquake would help to rapid relief and response to disaster (Janalipour and Mohammadzadeh 2016). Sound awareness of seismic disaster risk is a necessity for ensuring the effectiveness and efficiency of seismic hazard and disaster mitigation strategies, preparedness measures, and emergency response plans (Qie and Rong 2017). The Comprehensive Disaster Management Programme (CDMP) of the government of Bangladesh (GoB) evolve maps that are describing the seismic vulnerability characteristics of the existing building stock, essential facilities and lifeline facilities in Dhaka, Chittagong, and Sylhet city corporation areas. The specialist team conducted several tasks including development of the base map, advancement of the cluster, improvement of general building stock database, development of lifeline and essential database and vulnerability analyses on the buildings, necessary facilities and lifelines (CDMP-2009).

2.2 Earthquake Vulnerability in Dhaka

Dhaka's location exposes it to direct and indirect natural disasters, notably earthquake, cyclone and flood. A significant paradigm shift in planning and governance of Dhaka is urgently required to plan for just transitions and to make it more resilient and adaptable against the disaster risk and climate change induced vulnerability (Ahmed et al. 2018). High rates of urbanization, environmental degradation, and industrial development have affected all nations worldwide, but in disaster-prone areas, the impact is even more elevated serving to enhance the range of damage from natural catastrophes such as an earthquake (Tseng and Chen 2012). Dhaka and Kolkata, although they are quite a distance from the presumed rupture area, are city collections of over 10 million each, with a large percentage of their populations living in structures that are not portable to be seismically resilient. Even if only a small fraction of this population is vulnerable to a giant tsunamigenic earthquake along the Arakan subduction zone, it seems probable that the number of lives at threat may be over a million (Cummins 2007). Historically, Bangladesh has not experienced any large damaging earthquakes. So far, all the recent major earthquakes have happened apart from major cities and have affected comparatively populated areas (Ansary and Rahman 2013).

Low-magnitude earthquakes occurred in the Proximity of Dhaka Megacity, and other seism genic pieces of evidence propose ongoing activities of faults that possibly emerge as the source of a shock. It is indispensable part to assess vulnerability status of Dhaka Megacity due to an impending earthquake (Khan 2016). Recent earthquakes very near to Dhaka with small to moderate magnitude are probably indications of its earthquake origin and vulnerability (Islam et al., 2011). Bangladesh's seismic hazard zoning map (Figure 2.1) divided into three seismic zones with zone-I, zone-II, zone-III. Dhaka lies in the zone-II while the northwest has the highest hazard (DDC -1993 a).

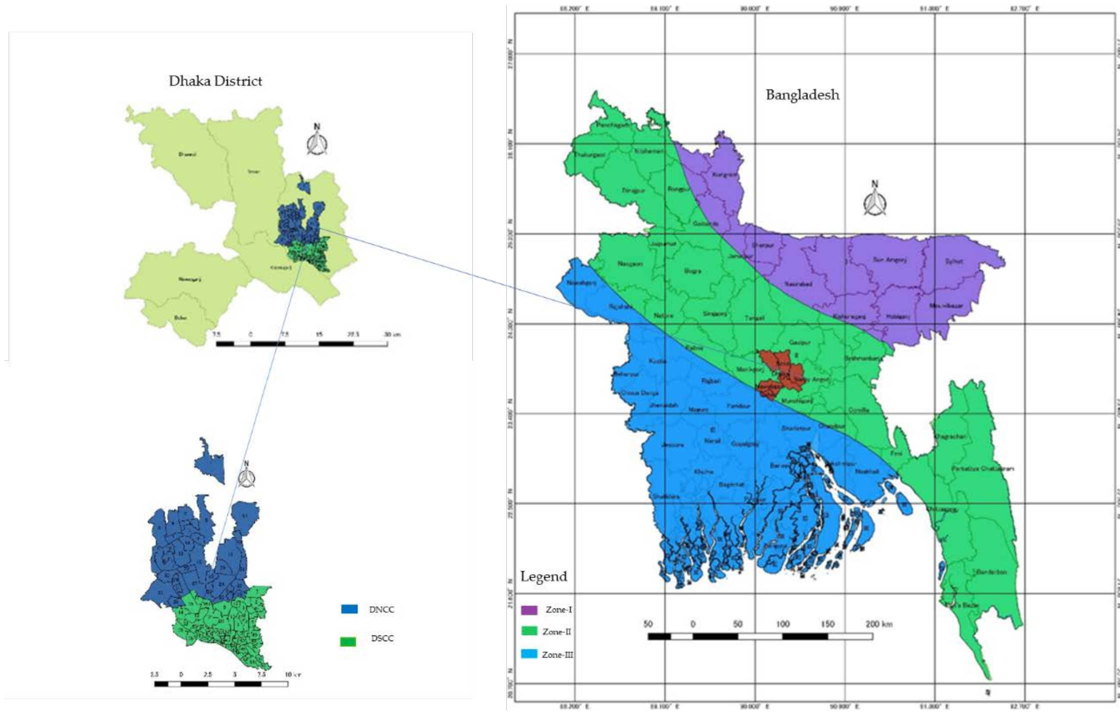

Figure 2.1 Seismic hazard zoning map of Bangladesh (BNBC-1993) and Study area.

2.3 Earthquake Disaster Management in Dhaka City

The major spotlight has been on earthquake preparedness examining particular case studies as well as limited populations that have dealt with past incidents in areas of high specific activity such as New Zealand, Japan, Turkey, Iran and Southeast Asia (Afghanistan) and more recently Nepal (Kirschenbaum et al., 2017). Recently, the New Zealand 2010–2011 Canterbury earthquake sequence severely damaged over 6000 residential buildings and disrupted the central lifelines systems of the city (Marquis et al. 2017). If large aftershocks happen during rescue and lifeline recovery activities after the main shock, there is a further possibility of secondary damages (Choi et al. 2017). After an earthquake, immediately and accurately obtaining building damage information can help to guide the implementation of the emergency rescue effectively and can reduce disaster losses and casualties. Collapsed buildings caused by an aftershock are one of the prime causes of casualties, so fast acquisition of the collapsed building information after the earthquake can play a significant role in saving lives (Zhai et al. 2016). Efficient risk communication is a crucial way to reduce the vulnerability of individuals when facing emergency risks, especially regarding earthquakes (Li et al. 2017). The mechanisms for stimulating preparedness for life-related risk experiences are unlikely to be entirely the same as for earthquake preparedness, and those particular strategies may be needed to target specific aspects of earthquake arrangement adoption (Becker et al., 2017). It is essential for hospitals to initiate effective emergency measures while facing the peak admission flow within the initial 48 hours' period. Earthquake-related injuries were mainly caused by buildings collapsing and victims being struck by objects (Kang et al., 2015).

In Dhaka, some areas are a very narrow road, old infrastructure and so working in such areas will be extremely difficult due to non-functioning of most of the essential facilities. In some cases, the demand may be higher than what is available due to additional demand created by the event. In such areas, the other facilities will help to respond to increased demand. To ease the situation certain facilities or materials are suggested to be prepositioned in such a way that such facilities can be utilized immediately after the disaster event as an alternative source (CDMP-DDC 2009). Some of the suggested facilities given below (Figure 2.2)

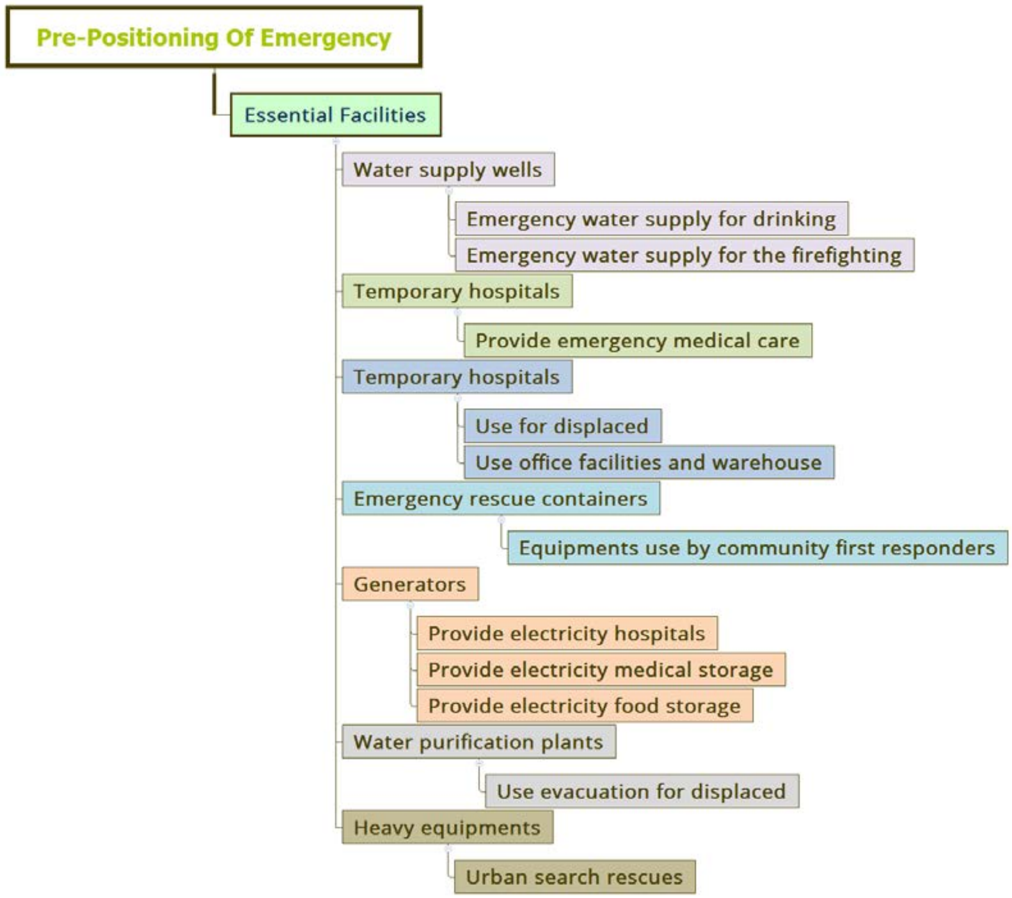

Figure 2.2 Suggested facilities of pre-positioning of Emergency (ADPC, CDMP-2009)

DCC has the responsibility to disseminate technical information related to earthquake hazards, vulnerability, and potential loss assessment data for different earthquake scenarios in the Dhaka city area. It is essential in the event of a large-scale earthquake for the DCC staff to manage relief and recovery operations in coordination and collaboration with governmental and non-governmental organizations. It should include (Figure 2.3) the organization and management of resources and responsibilities for dealing with all aspects of emergencies, in particular, preparedness, response, and rehabilitation.

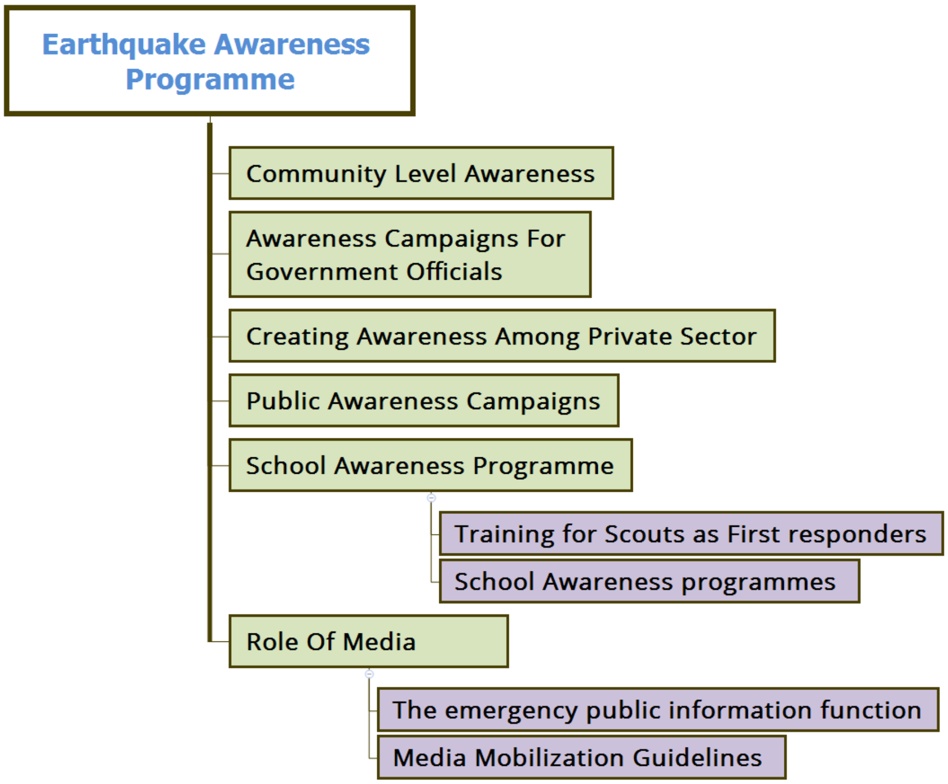

Figure 2.3 Suggested facilities of earthquake awareness programme (ADPC, CDMP- 2009)

These studies focused the entire critical infrastructure features for earthquake disaster preparation by using statistical analysis to compare the critical infrastructure and occupancy class and People location concisely. In this study correlation and multiple regression analysis are applied to analyze the relationship between the occupancy classification and essential facilities in both of DNCC and DSCC. The primary aim of this research is to understand the critical infrastructure of which part of Dhaka City would be the worst situation in case of providing essential facilities after an earthquake. Following this structure will help to determine how the city's essential facilities play crucial roles during a disaster, and what types of criteria need to be considered to lessen or minimize the catastrophic effects of a major earthquake while suggesting a new approach to the issues above.

2.4 Materials and Methods

2.4.1 Data Sources and selection of the research area

The Comprehensive Disaster Management Program (CDMP) started in 2009 by the government of Bangladesh is being implemented by the Ministry of Food and Disaster Management. The CDMP has assigned the Asian Disaster Preparedness Center (ADPC) responsibility for mapping seismic hazard and vulnerability in and around Dhaka City. This data is publicly available in the Earthquake vulnerability assessment of Dhaka, Chittagong and Sylhet City Corporation.

This research selected area in Dhaka City which divided into two parts, Dhaka North City Corporation (DNCC) with 36 wards (excluding the airport and cantonment area due to restrictions). The Dhaka South City Corporation (DSCC) with 54 wards (wards 55 and 56 not included because the data was not available). These divisions followed in this study. They cover 136.4 km2 and comprise all 90 wards of the DCC.

2.4.2 Data Analysis and mapping

The numeric values residential, commercial, industrial building, consider as independent variables. We chose the numeric value of essential facilities such as Medical care, Emergency response, Schools, Other facilities and Area of open space as a dependent variable and input in the R programming for data analysis and for mapping using QGIS software. This research applied correlation method to identify whether the variables are positive, negative or not correlated to each other. Multiple regression analysis is used to analyze how our dependent variables influenced by the group of variables (Independent variables) to predict essential facilities are significant or not in both of DNCC and DSCC area.

2.4.3 Multiple regression analysis

Multiple regression analysis was used to determine the Essential facilities in both of DNCC and DSCC. However, it is necessary to obtain the correlation between three or more variables. If one variable influenced by the combined effect of the group of other variables we get multiple correlation and multiple regression. On the other hand, if one variable influenced by another variable eliminating the linear effect of the other variable, we get partial correlation and partial regression. The multiple regression analysis equation is as follows:

$Yi = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \varepsilon$

Where,

Yi = Essential facilities (Medical care, Emergency response, Schools, Other facilities)

β_0 = Constant

X_1 = Residential building

X_2 = Commercial building

X_3 = Industrial building

ε = Error term

2.5 Results

2.5.1 Descriptive Statistics

Table 2.1 and 2.2 provides statistics for the Occupancy class, Essential facilities, Population location time, Area of open space and Other equipment. The data for Occupancy class, Essential facilities, Population location time and Area of open space and other equipment's are expressed the Number of 36 wards in DNCC (Table 2.1) and 54 wards in DSCC (Table 2.2) minimum, maximum, mean, standard deviation and standard error.

Table 2.1: Summary statistics for occupancy classification, essential facilities, population location and area of open space in DNCC area.

Location	DNCC			
	Minimum	Maximum	Mean	Std. dev.
Residential building	1143	11943	4433.78	2735.40
Commercial building	192	1521	589.67	278.06
Industrial building	3	591	89.69	131.08
Medical care	0	77	10.44	15.592
Emergency response	0	36	4.22	7.29
Schools	4	140	34.44	25.28
Other facilities	12	336	56.72	55.43
Daytime population	31126	219941	94088.97	46184.28
Nighttime Population	32197	275790	10286.63	61719.83
Area of open space	276	1244913	107457.31	264305.50
Total Occupancy class	1430	13129	5188.78	3043.28
Total Essential Facilities	31	373	105.61	69.29
Water distribution	2	24	10.89	5.38

Table 2.2: Summary statistics for occupancy classification, essential facilities, population location and area of open space in DSCC area.

Location	DSCC			
	Minimum	Maximum	Mean	Std. dev.
Residential building	213	4548	1965.94	1119.88
Commercial building	35	854	472.98	171.99
Industrial building	0	367	58.33	68.15
Medical care	0	45	5.59	8.15
Emergency response	0	9	1.74	2.43
Schools	2	82	16.93	11.85
Other facilities	9	259	51.78	43.17
Daytime population	20037	103391	56857.04	16773.98
Nighttime Population	13532	113867	59155.94	23948.06
Area of open space	91	540060	37565.50	82529.97
Total Occupancy class	400	5294	2593.13	1193.14
Total Essential Facilities	11	268	78.06	50.35
Water distribution	1	24	6.41	4.50

2.5.2 Correlation Analysis

Table 2.3 Pearson's correlation coefficient of occupancy classes and essential facilities in DNCC.

Location	DNCC		
Variable	Residential building	Commercial building	Industrial building
Medical care	0.064(p=0.80)	0.236(p=0.166)	0.233(p=0.171)
Emergency response	0.015(p=0.930)	0.112(p=0.517)	0.077(p=0.655)
School	0.602***(p=0.000)	0.671***(p=0.000	0.634***(p=0.000)
Other facilities	0.080(p=0.642)	0.215(p=0.209)	0.673***(p=0.000)

Significance level ***p<0.01; **p<0.05; *p<0.10

Table 2.3, 2.4 shows a comparison of the DNCC and DSCC by using of occupancy classes with essential facilities. As can be seen in the table 2.3, the occupancy class and medical care is a weak correlation in DNCC area, whereas DSCC (Table 2.4) area negatively correlated except commercial area ($r = 0.019$, $p > 0.893$). From these results, we can see that the relationship with emergency response is weak for the three occupancy classes both of DNCC and DSCC area (except residential area), as the p-values for all classes are greater than 0.05. In the DSCC area residential building and emergency are negatively correlated ($r = -0.113$, $p > 0.415$).

Table 2.4 Pearson's correlation coefficient of occupancy classes and essential facilities in DSCC area.

Location		DSCC	
Variable	Residential building	Commercial building	Industrial building
Medical care	-0.154(p=0.267)	0.047(p=0.736)	-0.046(p=0.740)
Emergency response	-0.113(p=0.415)	0.019(p=0.893)	0.075(p=0.588)
School	0.230(p=0.094)	0.072(p=0.606)	0.075(p=0.592)
Other facilities	-0.104(p=0.456)	0.267*(p=0.051)	0.414**(p=0.002)

Significance level ***p<0.01; **p<0.05; *p<0.10

The positive aspect of these results is that there is a significant relationship between occupancy classes and schools in the DNCC area, with a p-value less than 0.05 and that residential, commercial, and industrial buildings all have statistically significant relationships with schools. However, there is a very weak linear relationship between Occupancy class and Schools in the DSCC area and all of the case low person correlation coefficient and p-value higher than 0.05. The results show that the relationship between industrial buildings and other facilities is significant in both of DNCC and DSCC area, with a p-value less than 0.05.

Table 2.5 Pearson's correlation coefficient of occupancy classes and Population location and Area of open space in DNCC

Location		DNCC	
Variable	Residential building	Commercial building	Industrial building
Population day time	0.834***(p=0.000)	0.816***(p=0.000)	0.607***(p=0.000)
Population night time	0.950***(p=0.000)	0.768***(p=0.000)	0.407*(p=0.014)
Area of open space (m2)	-0.012 (p=0.945)	-0.070 (p=0.686)	-0.048 (p=0.7882)

Significance level ***p<0.01; **p<0.05; *p<0.10

Also, people's locations differ from day to night in the Residential, Commercial and Industrial areas. The results in Table 2.5 and 2.6 show that there is a significant relationship between occupancy classes and population locations and times both of DNCC and DSCC area. Notably, the bivariate analysis points out that the relationship between residential buildings that residential buildings and the number of occupiers at night a stable (r = 0.950) relationship in DNCC and (r = 0.937) in DSCC. Thus, it is clear that at night, both of DNCC and DSCC residents are more highly concentrated in residential buildings than during the day. On the other hand, there is no correlation between the area of open space (m^2) and residential, commercial, the industrial building which implies that the availability of open space is not linked to the location of residential, commercial and industrial areas in both of DNCC and DSCC areas.

Table 2.6 Pearson's correlation coefficient of occupancy classes and Population location and Area of open space in DSCC

Location		DSCC	
Variable	Residential building	Commercial building	Industrial building
Population day time	0.539***(p=0.000)	0.554***(p=0.000)	0.409**(p=0.002)
Population night time	0.937***(p=0.000)	0.229*(p=0.096)	0.402**(p=0.003)
Area of open space (m2)	-0.192(p=0.164)	-0.025(p=0.859)	-0.136(p=0.326)

Significance level ***p<0.01; **p<0.05; *p<0.10

2.5.3 Correlation Analysis of Scatter plot

The scatter plots below provide a visual representation of the relationship among all of the variables. For example, in Figure 2.4 we can see how Schools is linearly related with Residential building, Commercial building, and Industrial building in DNCC area. It is also noticeable that Other facilities is linearly related to Industrial building. From the scatter plots we can also see that Medical care and Emergency response do not have a clear linear relationship with Residential building, Commercial building, and Industrial building.

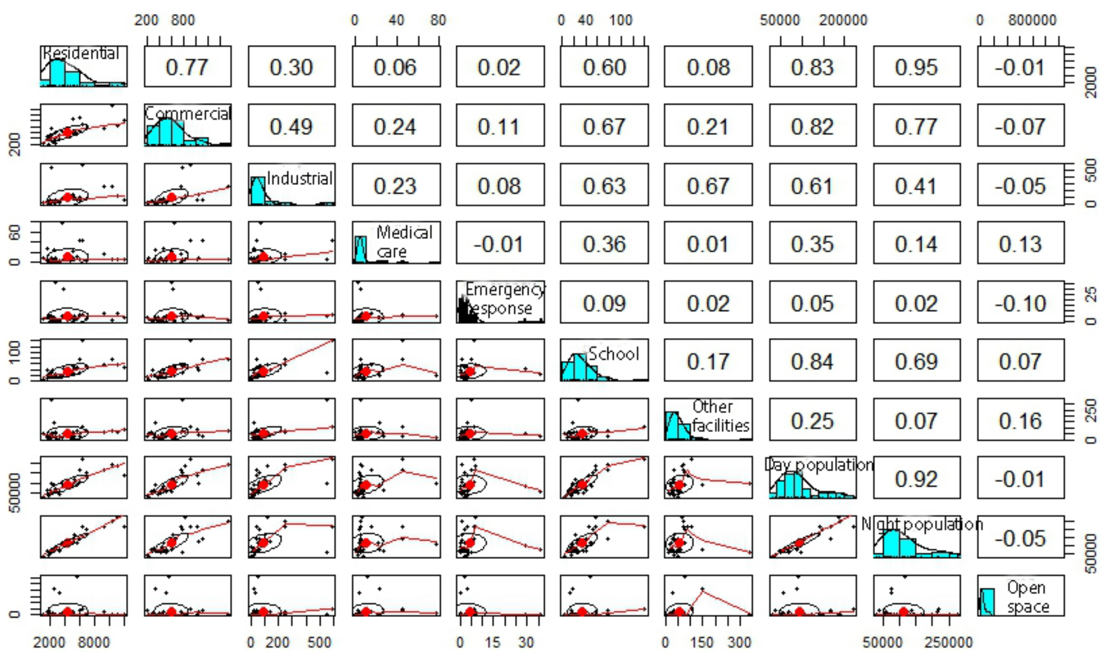

Figure 2.4: Matrix scatter plot of Residential building, Commercial building, Industrial building, Medical care, Emergency response, Schools, and Other facilities of DNCC.

The scatter plots below provide a visual representation of the relationship among all of the variables. For example, in Figure 2.5 we can see how Schools is linearly related with Residential building in DSCC area. It is also noticeable that Other facilities is linearly related to Industrial building. From the scatter plots we can also see that Medical care and Emergency response do not have a clear linear relationship with Residential building, Commercial building, and Industrial building.

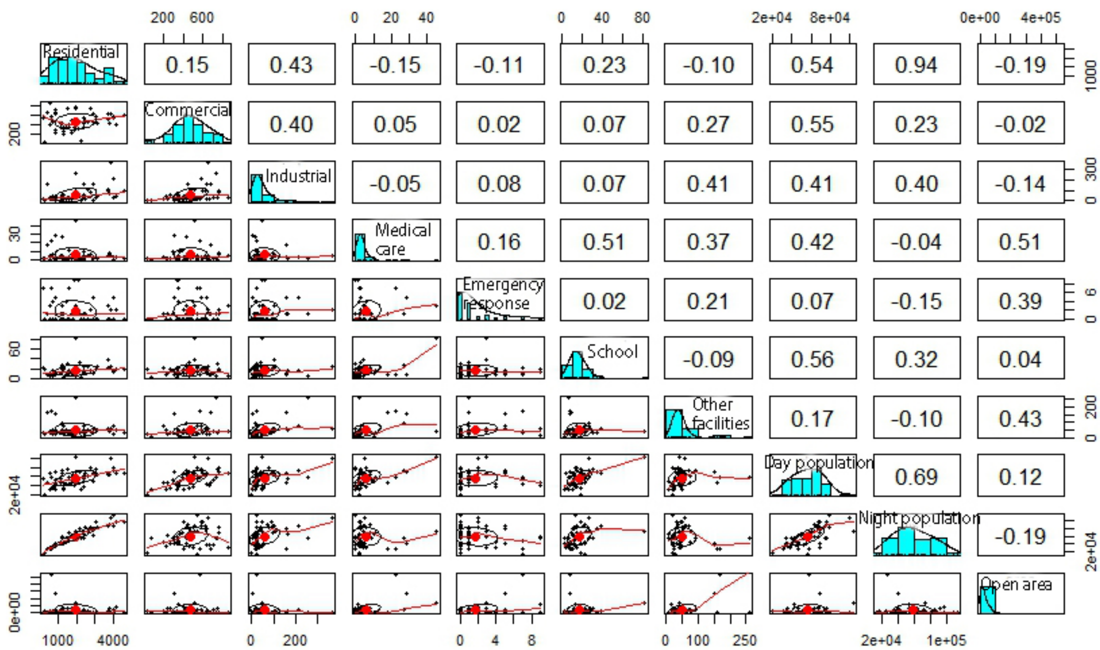

Figure 2.5: Matrix scatter plot of Residential building, Commercial building, Industrial building, Medical care, Emergency response, Schools, and Other facilities of DSCC.

2.6 Multiple regression Analysis

Model 1 Medical care

Table 2.7 Results of the multiple regression analysis for predicting medical care from occupancy classification variables in both of DNCC and DSCC.

Location	DNCC			DSCC		
	R^2=0.1008 F=1.196 on 3 and 32 df p>0.001			R^2=0.0287 F=0.4937 on 3 and 50 df p>0.001		
	β	t value	p value	β	t value	p value
Intercept	3.3183	0.535	0.597	6.2882	1.657	0.104
Residential Building	-0.0014	-0.980	0.335	-0.0011	-1.052	0.298
Commercial building	0.0208	1.286	0.208	0.0035	0.491	0.626
Industrial building	0.0151	0.654	0.518	-0.0008	-0.040	0.968

Significance level ***p<0.01; **p<0.05; *p<0.10

Here, R^2 = 0.1008(DNCC), 0.0287(DSCC), so we can say that independent variables explain 10% of the variability of medical care in DNCC and 2% variability of medical care in DSCC area. The p-value is greater than 0.05 both of DNCC and DSCC. Therefore, there is no statistically significant relationship between medical care and occupancy class in DNCC and DSCC.

Model 2 Emergency response.

Table 2.8 Results of the multiple regression analysis for predicting emergency response from building occupancy classification variables.

Location	DNCC			DSCC		
	R^2=0.0246 F=0.269 on 3 and 32 df p>0.001			R^2=0.031 F=0.5491 on 3 and 50 df p>0.001		
	β	t value	p value	β	t value	p value
Intercept	2.5170	0.832	0.411	2.2917	2.024	0.048*
Residential Building	-0.0004	-0.615	0.543	-0.0003	-1.160	0.251
Commercial building	0.0061	0.782	0.440	-0.0002	-0.116	0.907
Industrial building	0.0006	0.057	0.955	0.0056	0.957	0.343

Significance level ***p<0.01; **p<0.05; *p<0.10

Here, R^2 = 0.0246 (DNCC), 0.031(DSCC) means that 2.4% of the variation in the response is explained by the predictor variables in DNCC and 3.1% variation of variables in DSCC area. The p-value of this model is greater than 0.05 both of DNCC and DSCC, indicating that the predictors are not suitable for predicting the dependent variable.

Model 3 Schools

Table 2.9 Results of the multiple regression analysis for predicting schools from occupancy classification variables.

Location	DNCC			DSCC		
	R^2=0.6078 F=16.53 on 3 and 32 df p<0.001			R^2=0.056 F=0.9935 on 3 and 50 df p>0.001		
	β	t value	p value	β	t value	p value
Intercept	2.4080	0.362	0.719	10.5813	1.945	0.057*
Residential Building	0.0027	1.696	0.099*	0.0025	1.605	0.114
Commercial building	0.0210	1.212	0.234	0.0037	0.367	0.715
Industrial building	0.0834	3.372	0.002**	-0.0091	-0.319	0.751

Significance level ***p<0.01; **p<0.05; *p<0.10

For the above model, R^2 = 0.6078 (DNCC), 0.056 (DSCC) meaning that 60% of the total variability of schools are accounted for by the linear regression model based on the dependent variables in DNCC and only 5.6% of total variability of schools are accounted by independent variables in DSCC area. The predictor variables are statistically significant in DNCC area, as the p-value is less than 0.05 (i.e., the regression model is a good fit to the data) but predictor value is not significant in DSCC are as p-value is greater than 0.05.

Model 4 Other facilities

Table 2.10 Results of the multiple regression analysis for predicting other facilities from occupancy classification variables.

Location	DNCC			DSCC		
	R^2=0.4724 F=9.551 on 3 and 32 df p<0.001			R^2=0.2784 F=6.43 on 3 and 50 df p<0.001		
	β	t value	p value	β	t value	p value
Intercept	46.064	2.725	0.010*	45.330	2.616	0.011*
Residential Building	-0.0012	-0.298	0.767	-0.0131	-2.570	0.013*
Commercial building	-0.0204	-0.462	0.647	0.0281	0.855	0.396
Industrial building	0.313	4.980	0.000***	0.3263	3.588	0.000***

Significance level ***p<0.01; **p<0.05; *p<0.10

For the other facilities model, R^2 = 0.47 (DNCC), 0.27 (DSCC) means that the explanatory variables explain 47% of the variability of the dependent variable in DNCC and 27% of the variability in DSCC area. The results demonstrate that the explanatory variables are statistically significantly related to the response variable in both of DNCC and DSCC; the p-value is less than 0.05.

2.7 Discussion

Medical care

Medical care plays a crucial role in any disaster. However, sometimes medical care staffs and physicians are also affected by disasters, so their shortage or absence has the potential to become an obstacle to providing care to disaster victims. It is imperative to have an accepted consensus on the probable impacts on medical care, the vulnerability of medical personnel and facilities, and the accessibility of other resources such as potable water, electricity, and natural gas in the aftermath of tragedies. Hospital staffs and doctors thus need to be trained for work under emergency conditions. It is recommended that management and control points be established rapidly after the occurrence of a disaster, to coordinate the distribution of resources to temporary medical facilities. Creating networks between hospitals and neighborhoods can help to reduce the response time during emergencies. Concerning disaster preparedness, experiences of disaster boost disaster preparedness, while bonds with other local people assist in maintaining preparedness and residents' accessibility to medical and welfare services is also crucial in promoting the utilization of health checkups (Hasegawa et al. 2018). There is a noticeable connection between earthquake-related injury and individual behavior characteristics and so victims need mental health support from medical practitioners and the government to minimize adverse effects. The beginning response after an earthquake also played a vital role in victims' trauma; therefore, earthquake-related experience and education may prevent injuries. Self-aid and mutual aid key roles in emergency, medical rescue efforts (Kang et al. 2017).

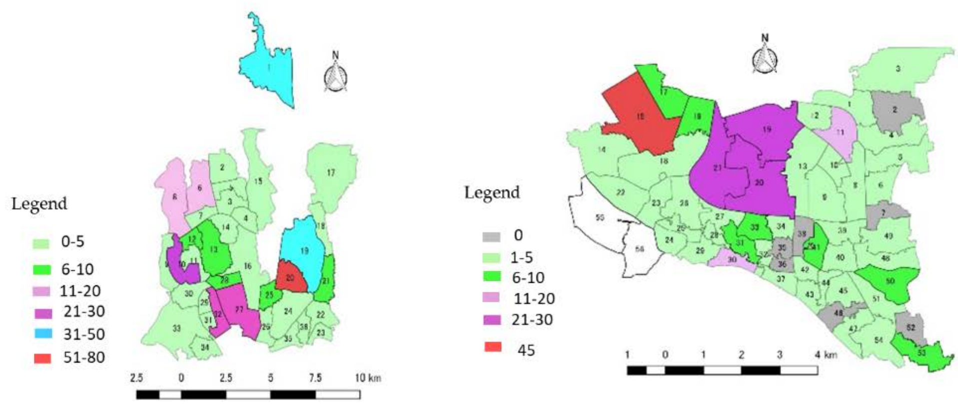

Figure 2.6 Number of Medical care in DNCC (left) and DSCC (right) area (Data source: CDMP-2009).

There are only two hospitals are found in the area of DSCC ward-29 (Tuzzohora et al., n.d.). Some hospitals, medical institutions, clinics, diagnostic centers etc. have been established both on public and private initiatives some of them are of world-class standard. The name of BIRDEM, Lab Aid, Square, United are just a few examples. However, the numbers of these medical institutions are found inadequate when considered the huge population of the city as well as those who come from outside the city to seek medical help (uddin Ahmeda and Mohuyab 2013).

Our study reveals that (Figure 2.6, Table 2.3,2.4,2.7) medical care with occupancy class is not a significant relation in both of DNCC and DSCC area. A large proportion of DNCC and DSCC residents would be unable to access medical treatment after an earthquake due to the insufficient number of hospitals mainly, DSCC area observed inadequacy number of Hospitals.

Emergency response

The vital role played by the emergency services requires that they remain operational after a catastrophe or during any other emergency situation. When an emergency happens, particularly a large-scale emergency, the emergency management system is inserted into action to handle the circumstance. Many things will need more or less immediate concentration, and abundant tasks must be taken care of both on-scene at the occurrence site and off-scene at the response organizations and within the affected society. The primary roles of police departments, fire stations, and emergency operation centers during emergency response activities, are to escort survivors to safety, provide care for the wounded, handle the dead, and provide evacuees with safe shelter, potable water, food, etc. Damage detection after earthquakes is an essential issue for the post-disaster emergency response, impact assessment and relief activities. Building damage detection is particularly crucial for identifying areas that require urgent rescue efforts and rapid relief (Gong et al. 2016, Janalipour and Mohammadzadeh 2016).

Emergency response planning should ideally determine the essential frame conditions for the emergency management that an organization should arrange for to be able to control emergencies and respond appropriately (Becker et al. 2017). In the absence of a post-earthquake disaster management plan in Bangladesh, there is insufficient rescue and recovery equipment and lack of preparedness for swift action. After the collapse of a damaged reinforced concrete frame building in Chittagong city in 1997 due to an earthquake, it took a long time to rescue an injured minor girl trapped in the collapsed building; subsequently, she died in the hospital. Narrow lanes of the city may be easily blocked by falling debris, and the already inadequate road network in the affected areas may be in disarray during an earthquake, thereby disrupting rescue and recovery operations. Whether the buildings housing the firefighting vehicles and other rescue vehicles and equipment will be able to sustain the earthquake is another question, since many of these buildings may have little earthquake resistance (Al-Hussaini-2003).

The output of correlation analysis and multiple regression analysis (Figure 2.7, Table-2.3,2.4,2.8) indicates that the number emergency response is not satisfactory level to handle the disaster situation in both of DNCC and DSCC area.

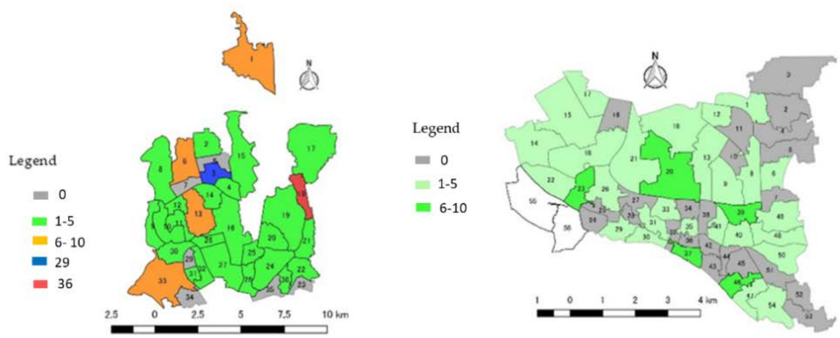

Figure 2.7 Number of Emergency response in DNCC (left) and DSCC(right) area (Data source: CDMP-2009).

Schools

After major disasters, although not ideal, school buildings can be used as temporary shelters, and for the distribution of emergency services and as evacuation points.

Two schools are available but they may not be suitable for taking shelter DSCC ward-29 (Tuzzohora et al., n.d.). It needs to host homeless people in the immediate emergency phase; then, temporary accommodations were built to host people up to the completion of the reconstruction process. Housing reconstruction affected the population returning home may be useful for future decisions and definitions of disaster recovery timing and reconstruction policy planning (Mannella et al. 2017). Barring the disaster, Dhaka North would be a prosperous city. Its educational development with the presence of many excellent private and public universities, colleges and schools, it would be a great hub of educational activities (Uddin Ahmeda and Mohuyab, 2013).

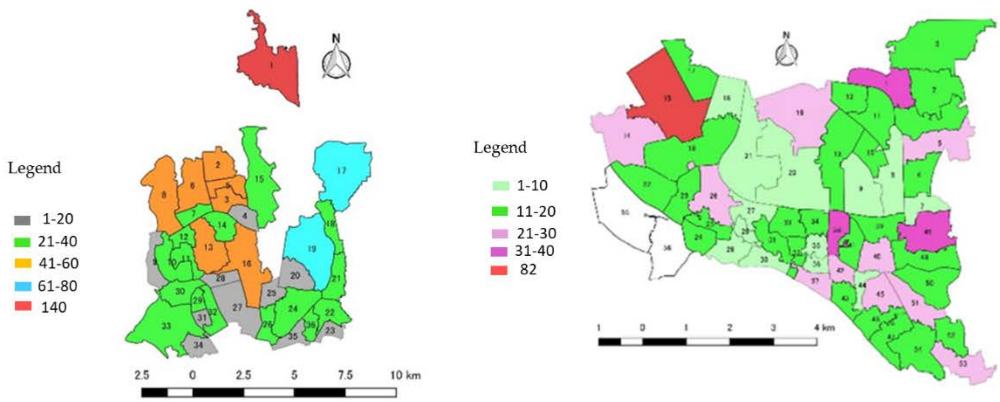

Figure 2.8 Number of School in DNCC (left) and DSCC (right) area (Data source: CDMP-2009).

From our results (Figure 2.8, Table 2.3,2.4,2.9) it observed that DNCC area Schools are the significant relation with Occupancy class but in DSCC area, not any significant relation found.

Other facilities

Manpower, equipment, materials, and power are available in different forms and quantities at other facilities. Dhaka City has equipment that can be made available for rescue operations in the aftermath of an earthquake or other disasters. Other resources include bulldozers, pay-loaders, excavators, hydraulic cranes, road rollers, dump trucks, mobile generators, forklifts, water tankers, power trailers, drain gully sweeping trucks, tractors, toilet vans, and air compressors.

From our results revealed that correlation and multiple regression analysis (Table 2.3,2.4,2.10) both of DNCC and DSCC, industrial building have a significant relation with other facilities.

2.8 Conclusions

This paper focuses on essential facilities and occupancy class in Dhaka city to facilitate earthquake preparations. This study illustrates significant findings to help identify Essential facilities towards earthquake preparedness compare to two main parts of Dhaka city. The findings of the present study indicate that medical care and emergency response facilities are poorly situated to respond to a major earthquake in both of DNCC and DSCC area. Based on these findings, more medical care and emergency response facilities should be built in both of DNCC and DSCC area, especially DSCC is the more worst situation to handle disaster situation and so need to prioritize this area to increase essential facilities. The number of schools is adequate in DNCC area than that of schools in DSCC area, but schools need to be constructed seismic retrofit to minimize damage, loss, injury and also use as a temporary shelter aftershock.

Future studies are needed to estimate the impact of the quality of medical care, emergency response, schools, other facilities in Both of DNCC and DSCC area to handle the earthquake disaster situation.

Chapter 3

An Analysis of Housing Structures' Earthquake Vulnerability in Two Parts of Dhaka City

3.1 Introduction

The capital city of Bangladesh is Dhaka, which has become one of Earth's megacities. The urban center is administered by the Dhaka City Corporation (DCC) which is split into two administrative parts, the Dhaka North City Corporation (DNCC) and the Dhaka South City Corporation (DSCC), in order to offer better facilities (see Figure 3.3). The DCC, which is the prime city in Bangladesh, covers an expanse of 321 km^2 and has a population of over 14 million. Dhaka city's history began about 400 years ago, and has proceeded without proper planning, constructed in a non-directed manner. The maximum number of buildings, both engineered and non-engineered, have been established on the artificial sand pilings along the recent floodplains of the Buriganga, Turag, Balu and Sitalakhya Rivers (Rahman et al. 2015). Most buildings were erected without the oversight of a proper earthquake disaster prevention system (Ahmed et al.). Collective consciousness regarding this problem has risen among some limited groups, but, practically, city dwellers and policy makers are not sufficiently aware of their seismic vulnerability. Nevertheless, the extent of seismic vulnerability can be minimized if the necessary steps are taken for the least earthquake-resistant buildings, since earthquakes themselves do not injure and kill people, it is the hazardous buildings that do. Thus, there is a great need for judgment regarding which of the huge number of existing buildings are more vulnerable to quakes. Most buildings have reinforced concrete frames with masonry infill. Many exhibit improper design or construction practices like the inclusion of soft stories. Several structural features are recognized as seismic vulnerability factors in buildings, including soft stories, heavy overhangs, short columns, the possibility of pounding between adjacent buildings, visible ground settlement, and topographic effects (Roy et al. 2013). When soft story mechanisms

are present, reinforced concrete buildings in ground floor columns did not perform well, causing the partial or full collapse of the building structures. Unreinforced and unconfined masonry buildings have a history of inferior performance during strong earthquakes and are responsible for most of the partial and full building collapse (Zhao et al. 2009).
Non-reinforced masonry structures are among the most vulnerable patterns of the building during an earthquake. When such a masonry structure is subjected to lateral inertial loads during an earthquake, the walls develop shear and flexural stresses. The strength of masonry under these conditions often depends on the bond between stone and mortar (or brick and mortar). This bond is often very poor when lime mortars or mud mortars are used (Adanur 2010) . Massive losses of both human lives and properties from the Nepal earthquake in 2015 demonstrate the need to strengthen masonry structures due to their poor seismic performance, as indicated by their inherent brittleness and low tensile strength (International Association for Bridge and Structural Engineering and Doboku Gakkai 2015). Seismic retrofitting is a typical example of a pre-disaster and earthquake-specific hazard mitigation measure, but its implementation is relatively difficult (Solberg et al. 2010). Seismic retrofit is applied to many Japanese buildings designed according to old seismic codes predating the major seismic code revision of 1981 (Fukuyama 2006). The reduction of structural vulnerability, introduction of solid ground-use rules and intent and construction regulations, relocation of communities, and use of public education awareness programs can help to mitigate earthquake risk (Erdik and Durukal 2008). Recently, earthquakes urban areas in Bangladesh have highlighted the urgency of pushing to strengthen these seismic deficient structures and making progress in developing various strengthening and rehabilitation techniques to boost structures' seismic performance (Sarker et al. 2011).

3.2 Earthquake Vulnerability of Dhaka's Housing Structures

Housing is essential for human beings, and there is a great need to promote the improvement of living facilities, supplementary services and community facilities. From ancient times, humans have founded settlements in Bangladesh. Building design and housing patterns in these settlements have developed and adapted to environmental, economic and social needs, and this has been guided by climatic and geographical factors (Banglapedia 2018). A strong earthquake affecting a major urban center like Dhaka, Chittagong or Sylhet may damage or demolish housing constructions and could be fatal for the entire nation. Even a small to moderate earthquake could cause severe damage to life and property, exceeding what the Dhaka City Corporation can currently handle (CDMP-2009). It is imperative to place the highest priority on recognizing the existence of the hazard and identifying vulnerable areas (Barua et al. 2016). Understanding disaster risk management holistically, focusing on all of its components, can allow us to see how a broad range of fields, including engineering science, development, government, risk management, risk communication, and local capacity can influence risk (Aitsi-Selmi et al. 2016). If an earthquake causes fault movement on the earth's surface and then creates severe ground shaking, which in turn causes buildings to collapse (as has been the case after each disastrous earthquake), the results in terms of loss of human life can be devastating (Ahmed 2014). Several hazards arising in an earthquake's aftermath may cause additional injury and loss of life and increase economic losses. In Dhaka, hazard incidents related to earthquakes seem particularly to include fire and debris generation (ADPC, CDMP -2009). The main negative impact of quakes is the full or partial collapse of buildings in which people may be crushed or trapped. The situation becomes particularly difficult in multi-level buildings, specifically those constructed from heavy materials such as brick and concrete. Some houses in slum areas in Dhaka are built of lightweight materials such as sheeting, timber and bamboo and are usually one to two stories high. These types of houses do not pose a very high risk of killing or seriously injuring people in an earthquake. Yet, increasingly, brick is being used to build the walls of homes in slums. It is frequently poorly designed and lacks reinforcement, and homesteaders occupy old dilapidated buildings. Such buildings pose a high risk in strong earthquakes (Ahmed 2014). Unreinforced masonry buildings perform poorly in earthquake movement because of their inherent brittleness, lack of tensile strength, and lack of ductility. In other words, they lack the properties provided by the steel reinforcement in reinforced masonry. Under earthquake forces, when a gap occurs in masonry, consequent earthquake pulses can trigger uncontrolled displacement, resulting in partial or total collapse of masonry units or walls. In most of these events, demolition and replacement of the masonry structures are not possible for various reasons, like orders for preservation of buildings of historic importance, or the fact that the damaged buildings serve as dwelling places in poor communities, etc. (Roy et al. 2013). An earthquake event has more catastrophic effects in densely built settlements; thus, managing a disaster situation with the limited medical care and emergency response capabilities in Dhaka city would be difficult (Ahmed and Morita 2017). Therefore, it is significant that the government recognizes how to encourage households to be involved in preparing for earthquakes (Nakagawa 2017).

3.3 Earthquake Concern in Dhaka

The absence of strong earthquakes in Bangladesh for more than 80 years has left the present generation unaware of the possibility of a severe earthquake. As a natural result, many buildings in the cities of Bangladesh were not designed to resist earthquakes. There is universal consensus among national and international experts about the potential for a large magnitude earthquake happening in the area at any time because of stress buildup in fault systems caused by the northward drift of the Indian Plate. Assessment of seismic risk is a primary priority for the country. To this end, studies are striving to assess hazards and to determine measures for mitigating them based on the degree of risk they are estimated to pose (Al-Hussaini et al. 2015). Bangladesh's seismic hazard zoning map (see Figure 1) is divided into three seismic zones with seismic coefficients of 0.04 g, 0.05 g, 0.08 g (g = acceleration due to gravity). Dhaka lies in the 0.05 g zone while the northwest has the highest hazard risk (DDC-1993). Earthquake risk increases towards the north and east, creating a seismic threat in all parts of the state. The five fault lines that lie under Bangladesh are presented in Table 3.1 (URP-Phase -1).

Occurrences of small-magnitude earthquakes near Dhaka Megacity and other seismogenic evidence suggest that continuing activity on these faults may produce a substantial earthquake. Assessing the exposure of Dhaka Megacity to an impending earthquake is essential(Khan 2016).

The building stock in Dhaka is susceptible to collapse by ground shaking or simply due to gravitation because of inadequate enforcement of building code regulations and the absence of robust construction standards. Its vulnerability is intensifying due to rapid urbanization and increasing pressure on land, which are making Dhaka the most densely inhabited city on the globe. Historical records (see Figure 3.2) from 1918 to 2018 (January) in and around Bangladesh (from 21.24° to 26.6° latitude and 88.06° to 92.483° longitude) show 236 earthquakes of magnitudes ranging from 4 to 8 (USGS).

Due to insufficiently developed infrastructure and preparedness in Chittagong and Dhaka, the results of a repeat of the AD1762 earthquake would be devastating (Alam and Dominey-Howes 2014). The total population and population density in Dhaka and Chittagong have risen at least tenfold since the first census in AD1872 to the most recent in AD2011 (Barua and Ansary 2017; BBS-2012; Rizvi-1969; Rizvi-1970). A fuller understanding of the expected overall seismic performance of code-compliant buildings is required to minimize the disaster (Del Gobbo et al. 2017). The building inventory in Dhaka city is classified into two groups: unreinforced brick masonry (URM) buildings and reinforced concrete (RC) buildings. URM buildings have been noted to have very poor seismic resistance and they can be even more dangerous if they are four or more stories high, or are built on five-inch walls, which is not uncommon in Dhaka. RC construction can also be vulnerable if earthquake-resistant design provisions are not employed. This has been fully evident in recent earthquakes in Bhuj and Izmit (Al-Hussaini 2003).

Table 3.1 Fault Line Sources and Estimated Maximum Magnitude.

Source	**Estimated Maximum Magnitude**
Madhupur Fault	7.5
Dauki Fault	8.0
Plate Boundary Fault 1	8.5
Plate Boundary Fault 2	8.0
Plate Boundary Fault 3	8.3

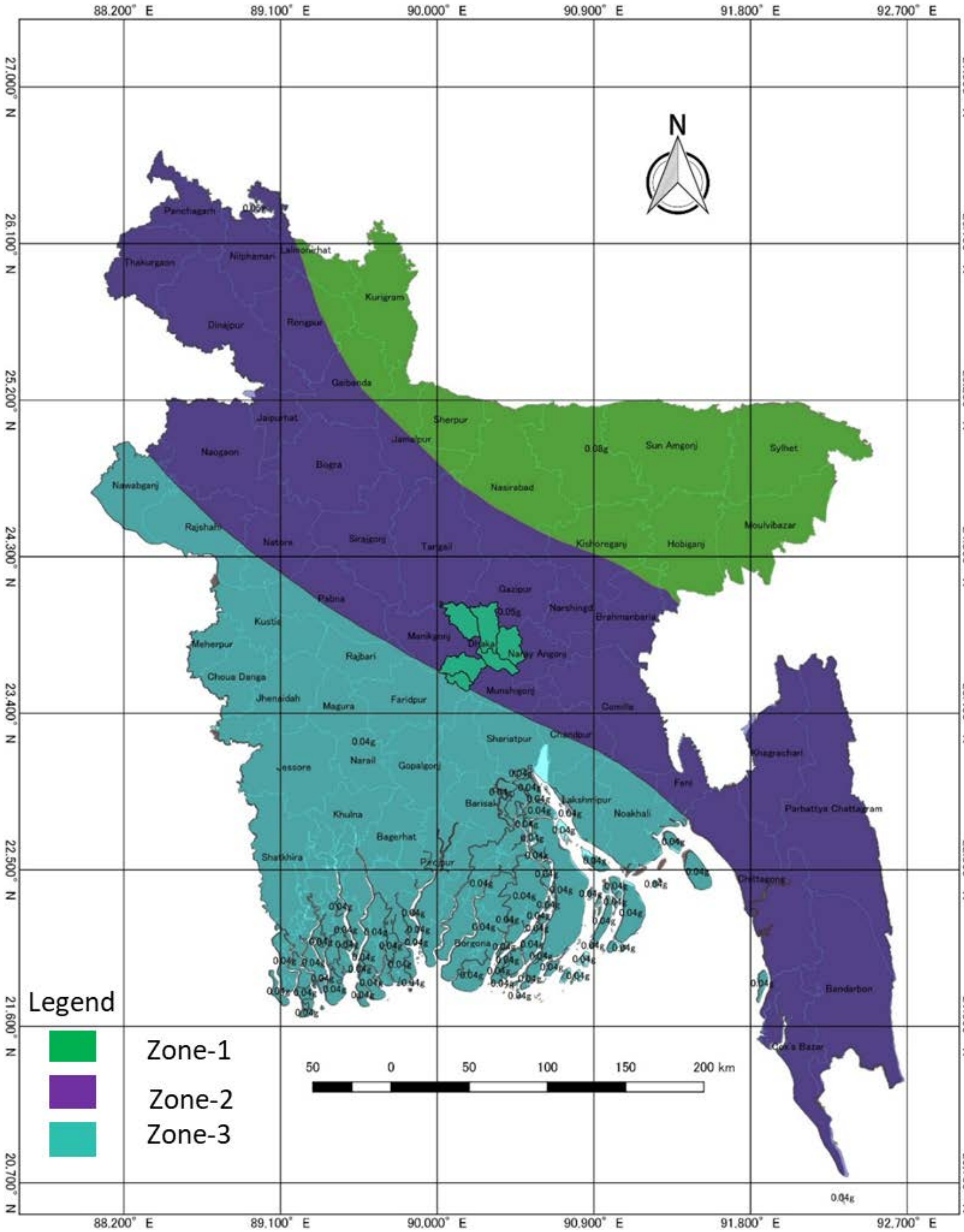

Figure 3.1 Seismic hazard zoning map of Bangladesh (BNBC-1993).

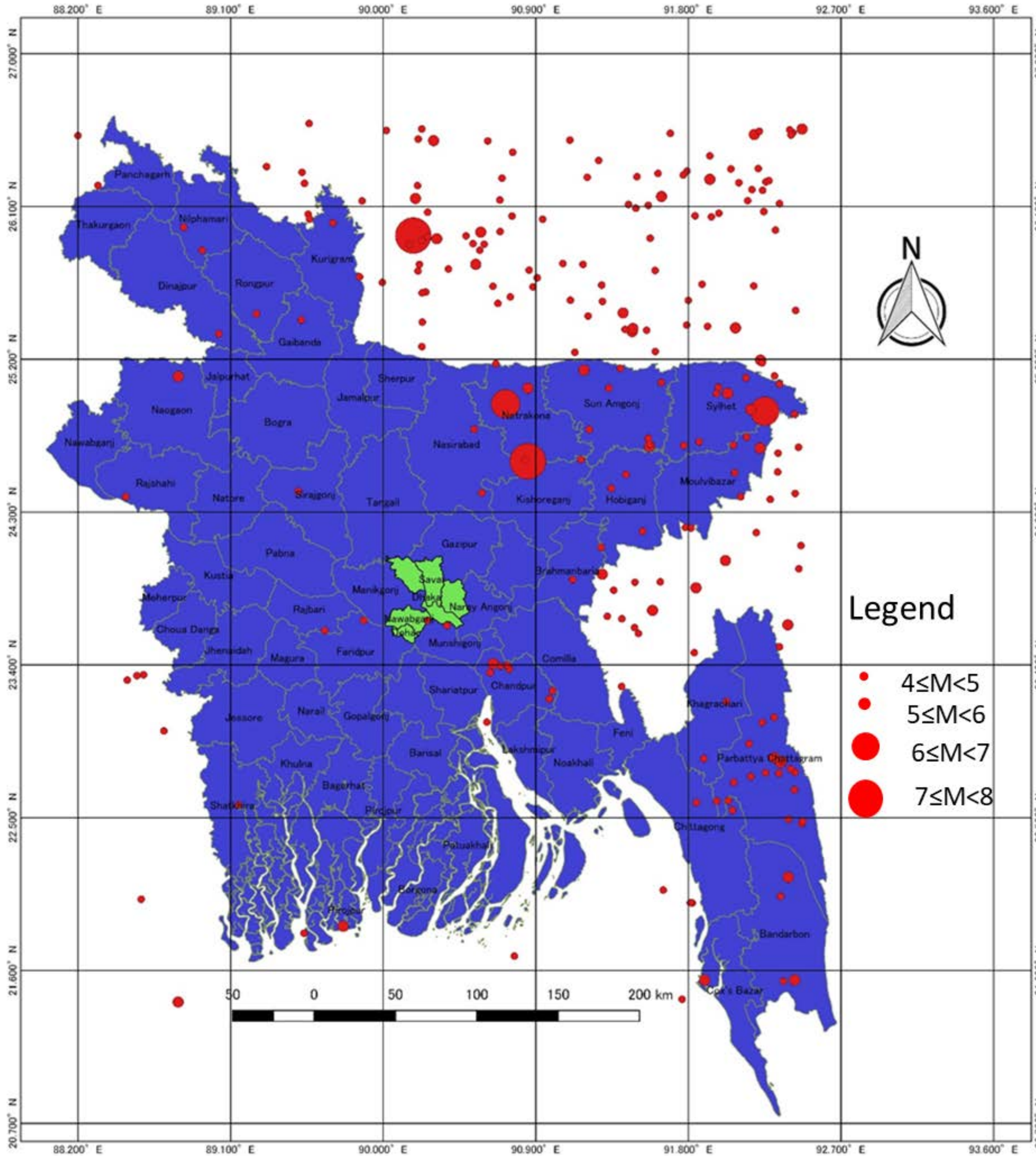

Figure 3.2 Earthquakes in and around Bangladesh (latitude 21.24–26.6, longitude 88.06–92.483) (Data source: USGS).

Recent events serve as shocking indicators of the extreme vulnerability of the constructed environment in Dhaka. One example is the collapse of the Rana Plaza building in Savar on 24 April 2013 and the deaths of the 1127 people it caused, which was deadliest event recorded in a serial publication of structural failures in the metropolis. A report commissioned by the Ministry of Home Affairs concluded that poor site location, sub-standard building materials, and illegal construction were responsible for this collapse (URP-Phase 1). This dreadful incident received worldwide attention and brought forward diverse issues concerning millions of workers, employers, brands and consumers—the entire supply chain in the ready-made garments sector (RMG) of Bangladesh (Barua and Ansary 2017). Such buildings are evidence of a poor infrastructure that needs to be boosted to make sure structures are resilient through a variety of different initiatives (Ansary and Barua 2015). To mitigate earthquake damage, we need to ensure the safety of structures under earthquake loading. Dynamic effects have been brought into consideration in design codes of many nations around the globe, often using zoning maps based on geological assessments of seismic hazards, which are embodied in construction codes or regulations (Ansary and Rahman 2013). Thus, it is significant that the government recognizes how to deftly encourage households to be involved in preparing for earthquakes (Nakagawa 2017).

3.4 Dhaka North City Corporation (DNCC)

In 2011, the government divided DCC into Dhaka North City Corporation (DNCC) and Dhaka South City Corporation (DSCC) through the local government amendment act 2011. The DNCC consists of 36 wards (see Figure 3.3), covering approximately 95.76 square kilometers, with a population of almost 3.74 million (BBS-2012, DNCC). The DNCC is an essential part of the Dhaka megacity, having its own administration, and is a familiar institution of recent Dhaka. During the last forty years, the city has undergone rapid, radical change, not just in its physical shape, but also in terms of its internal physical workings. The DNCC consists of plots, open places, rural agricultural spaces, low ground, water bodies, parks that have been transformed into building areas, places for commercial structures, built-up land, and so on (uddin Ahmeda and Mohuyab 2013).

3.5 Dhaka South City Corporation (DSCC)

The DSCC consists of 56 wards (see Figure 3.3), covering approximately 44.6 square kilometers, with a population of almost 2.8 million. Its 56 wards cover Azimpur, Magbazar, Malibagah, Motijheel, Jatrabari, Kotwali, Sutrapur, Bangsal, Wari, Gendaria, Lalbagh, Hazaribagh, Dhanmondi, Shahbagh, New market, Khilgaon, Kamrangirvhar and other areas (BBS-2012, DSCC). Natural disasters like earthquakes will probably cause catastrophic effects in the old parts of Dhaka because people will either be inside the remains of a tumbled building or will not be able to reach any post-disaster shelters. This total area is void of proper open spaces, and public buildings are in very indigent condition, so people there would have no suitable option for post-disaster shelters (Ansary and Barua 2015). Old Dhaka is at high risk of earthquake disaster because of the obsolete and dilapidated building structures in which many people live. In addition, unauthorized high-rise buildings are a massive threat for those dwelling in them. Because of the multipurpose uses of its buildings and the presence of flammable substances, the vulnerability of the Shakhari Bazar (DSCC wards 35 and 36) is higher than that of the Segunbagicha (DSCC ward 20) and Uttara areas (DNCC ward 1). On the other hand, Uttara is less vulnerable than Segunbagicha with respect to multipurpose buildings. Building structures in Shankhari Bazar are mostly centuries old. Half of the buildings are at least 51 years old and five percent are almost 350 years old. In contrast, in Segunbagicha and Uttara, most of the buildings are less than 10 years old (Ferdous and Rahman 2015). In addition, the densely built city fabric, consisting of vulnerable aged and unreinforced masonry buildings and narrow streets, makes it more vulnerable to earthquakes. A socioeconomic survey of 210 households was conducted in what was previously ward 68 (current DSCC ward 32) of the older part of Dhaka city to estimate social vulnerability and to delineate existing conditions in the target area. The socioeconomic status of the study area illustrates that the area is in between the low and middle-income groups, and if a disaster struck in this area, most of them would suffer losses. The expected loss is unpredictable and financial assistance would be required from outside individuals, governments and foreign agencies (Jahan et al.2011). A recent building survey funded by the Bangladesh Ministry of Science and Technology research grant, conducted in parts of Sutrapur, Lalbagh and West Dhanmondi (in the DSCC) reveals a concentration of multi-storied URM buildings in the older part of the city. While the percentage of URM buildings in the Sutrapur area of the old city was found to be roughly 65%, in the relatively new West Dhanmondi area, it was approximately 42% (Al-Hussaini 2003). The earthquake performance of cities can be upgraded by changing their functional characteristics through urban transformation, land-use planning, and boosting the quality and redundancy of the infrastructure (Erdik and Durukal 2008). This will require careful coordination between different groups such as the police, armed forces, volunteers, professionals, engineers, firefighters, rescue personnel, utility personnel, medical personnel, media, social workers and post-disaster relief personnel (Al-Hussaini 2003).

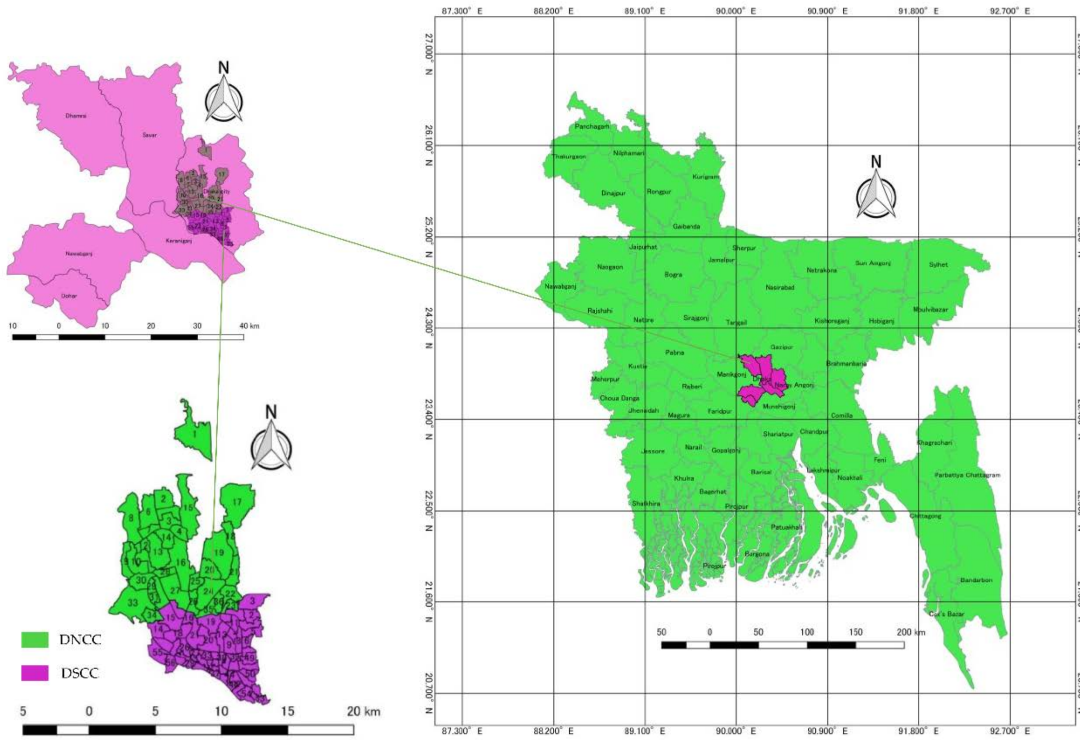

Figure 3.3 Bangladesh location map and study area.

3.6 Materials and Methods

3.6.1 Data Sources and Selection of the Research Area

The Comprehensive Disaster Management Program (CDMP) started in 2009 by the government of Bangladesh is being implemented by the Ministry of Food and Disaster Management. The CDMP has assigned the Asian Disaster Preparedness Center (ADPC) responsibility for mapping seismic hazard and vulnerability in and around Dhaka city. This data is publicly available in the Earthquake vulnerability assessment of Dhaka, Chittagong and Sylhet City Corporation. In this research, we chose the variables, one of which was structural type, which includes: reinforced concrete (RC), lightly reinforced concrete (LC), masonry brick in cement mortar with a concrete floor (BC), masonry brick in cement mortar with a flexible roof (BF), and tin shed bamboo (TSB). For building age, we categorized three age groups: less than 10 years, 10–30 years and over 30 years. Finally, for earthquake vulnerability factors we chose: the presence of a soft story, the presence of a heavy overhang, pounding between adjacent buildings, and topographic effects.

Dhaka city is divided into two parts, Dhaka North City Corporation (DNCC) with 36 wards (excluding the airport and cantonment area due to restrictions) and Dhaka South City Corporation (DSCC) with 54 wards (wards 55 and 56 were not included because the data was not available). These divisions are followed in this study. They cover 136.4 km^2 and comprise all 90 wards of the DCC.

3.6.2 Data Analysis and Mapping

The numeric values for structural type, building age and earthquake vulnerability factors are independent variables. Whether or not a structure is in the DNCC or DSCC was input as a categorical variable in the R programming for data analysis and for mapping using QGIS software. This research applied a machine-learning decision tree algorithm and a random forest algorithm to predict which parts of the DCC are most vulnerable to earthquakes. The main advantages of the decision tree and random forest techniques for predicting grouped or multiple variables that we applied in this research are that they produce easily understandable results for any city as to which parts are more vulnerable to earthquakes and that readers can reproduce the analysis. The authors prepared all of the maps using of shape files in QGIS software.

3.6.3 Decision Tree

A decision tree is a graph that uses a branching method to demonstrate every possible outcome of a decision. Decision trees can be drawn by hand or created with a graphics program or specific software. Programmatically, they can be used to assign monetary/time or other values of possible outcomes so that decisions can be automated. Decision trees are used in data mining to simplify complex strategic challenges and variables into a form normally denoted by circles. Decision trees are easy to understand and can be used to classify both categorical and numerical data, but the output attributes must be categorical (Zhao and

Zhang 2008). Each categorical predictor is inputted into the model as a single entity and the model decides how to group or split the values. Initially, all categorical predictors are decomposed into binary variables. These binary variables are considered independently, thus forcing a binary split into the categories (Kuhn and Johnson 2013). The best variables are selected to split the categories, and the decision tree also defines cut-off levels or rules and the split accordingly. This process is applied recursively to the subgroup until the decision tree is finished, as defined by various stopping criteria (Atkins et al. 2007).

In both our decision tree and random forest analyses, we took the wards of the DNCC and DSCC as the response variable for all of the models, and the predictor variables are the housing structure type, building age and vulnerability factors. The analysis was done using R studio. To examine the earthquake vulnerability of Dhaka city's housing structures, we categorized them into reinforced concrete buildings, lightly reinforced concrete buildings, masonry brick in cement mortar with concrete floors, masonry brick in cement mortar with flexible roofs, and tin and bamboo sheds as explanatory variables. Building ages were grouped into those built less than 10 years ago, those that are 10 to 30 years old and those over 30 years old as an independent variable in order to see the role building age plays in earthquakes. Finally, earthquake vulnerability factors such as soft stories, the presence of heavy overhangs or short columns, pounding of adjacent buildings, and topographic effects were used as predictors to tell which factors most effect vulnerability. For the decision tree analysis, we partitioned our dataset into 80% for the training set and 20% for the validation set. We used data from 76 wards for training data and 14 wards for validation data.

3.6.4 Random Forest

Random forest is a new entry in the field of data mining and is designed to produce accurate predictions that do not over fit the data. Random forest is an ensemble of unpruned classification or regression trees, induced from bootstrap samples of the training data, using random feature selection in the tree induction process (Breiman 2001). For the random forest technique, a total of 36 wards in the DNCC and 54 wards in the DSCC were divided into two groups, training (70%) and testing (30%) respectively. Training sets were used to construct the random forest classification model, while test sets were selected to be used to verify the performance of the constructed model.

3.7 Results

3.7.1 Decision Tree

3.7.1.1 Housing Structure

From our training data, we can see (Figure 3.4) that the most important predictor of the variation in this model is reinforced concrete buildings (RC). Starting at node 1, if the number of RC buildings is less than or equal to 2713 and the number of tin and bamboo sheds (TSL) is less than or equal to 278, proceed to node 3. Then if there are 1381 or less RC buildings, go to node 4 where 26 wards were predicted accurately within the DSCC. Wards in node 5 area predominately in the DSCC, while those in node 6 were predominately in the DNCC. In those wards, there are more than 2713 RC buildings. Eleven wards in the DNCC were predicted accurately here. Our validation data correctly predicted 12 out of 14 DNCC wards with only two wards being predicted as belonging in the DSCC.

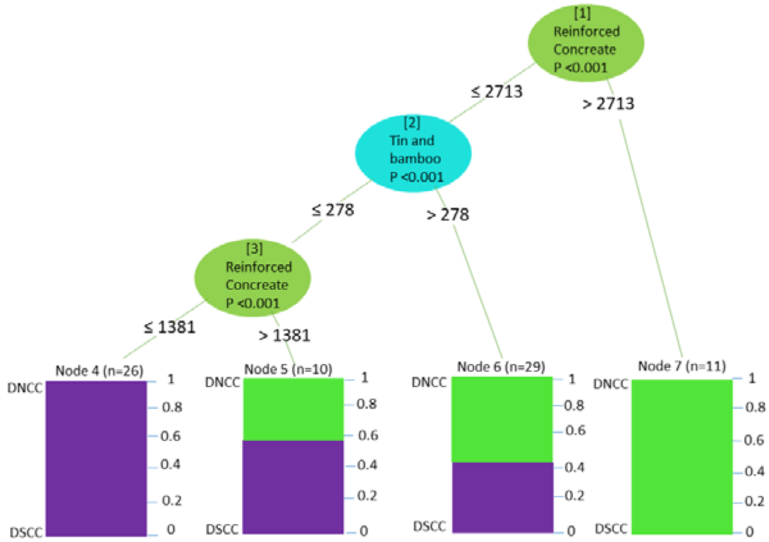

Figure 3.4 Decision tree for housing structure type in Dhaka city.

3.7.1.2 Building Age

In this case (see Figure 3.5), if there are more than 968 buildings that are 10 to 30 years old, then go to node 5. This accurately predicts 75% of the 29 wards in the DNCC. If there are fewer than 968 buildings of that age, then move to node 2. If there are 1107 or fewer buildings over 30 years old, move to node 3. The algorithm correctly then predicts about 90% of the 30 DSCC wards. From the validation data, seven of the 14 wards were predicted to be in the DNCC and seven were predicted to belong in the DSCC.

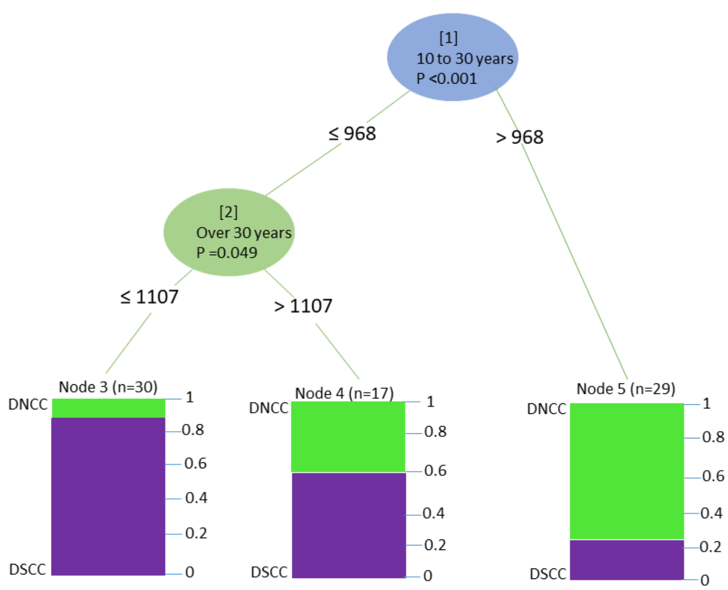

Figure 3.5 Decision tree for building age in Dhaka city.

3.7.1.3 Earthquake Vulnerability Factors

The most significant predictor (see Figure 3.6) here is the presence of a soft story. If there are fewer than 935 soft story buildings, go to node 2 where 80% of 47 DSCC wards were predicted accurately. However, if there are more than 935 soft story buildings, then we go to node 3, where 75% were classified as being in the DNCC. We can predict from our validation data that out of 14 wards, six wards are predicted to be in the DNCC and eight are predicted to belong in the DSCC.

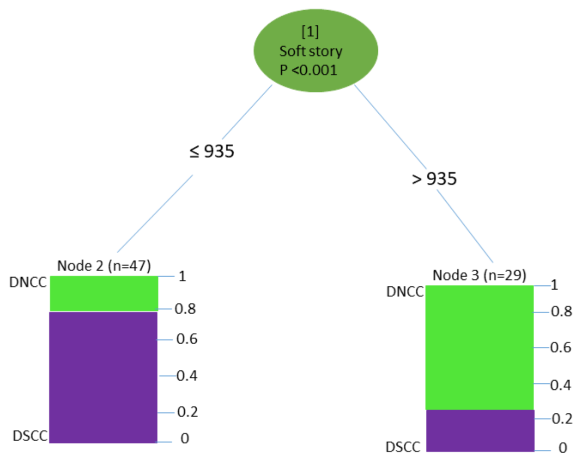

Figure 3.6 Decision tree for vulnerability factors in Dhaka city.

3.7.2 Random Forest

3.7.2.1 Housing Structure

The out-of-bag error (OOB) suggests that, when the resulting model is applied to new observations, the answer will be in error 24.19% of the time. This indicates that 75.81% of the results are accurate, which would indicate a reasonably good model. We observed that, of the 30% of the data set aside for testing from the confusion matrix (28 wards), six wards from DNCC and 13 wards from DSCC were classified correctly. The accuracy of the random forest model for the test data was 0.6786.

Figure 3.7 shows that, in the initial stages, errors were higher, but as the number of trees increased, they dropped slowly overall.

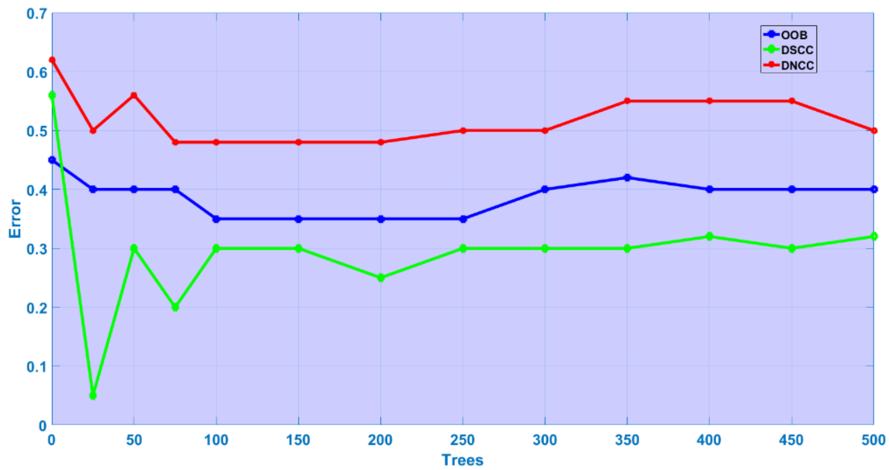

Figure 3.7 Overall random forest model error rates: out-of-bag (OOB) (black line); Dhaka North City Corporation (DNCC) (red line) and Dhaka South City Corporation (DSCC) (green line).

The random forest technique offers a simple way to measure variable importance for each of its features, affording insights into the interaction between those features and the model's prediction accuracy. Variable importance is a measurement of how much influence an attribute has on prediction accuracy. There are two methods of measuring it in a random forest: Gini importance and permutation importance. A list of important variables in the model represents each class of activity. The importance of the variables considered, based on the mean decrease in the Gini index, is presented in Table 3.2.

Table 3.2 Variable importance of housing structure.

Variable	**Mean Gini Decrease**
Reinforced concrete building	7.107414
Lightly reinforced concrete building	5.385688
Brick in cement mortar with concrete floor	5.945903
Brick in cement mortar with flexible roof	4.944385
Tin and bamboo mixed	6.594351

The most important attributes are of reinforced concrete buildings and tin and bamboo mixed structures, which carry the most influence in the model.

3.7.2.2 Building Age

The OOB, as presented in Figure 3.8, suggests that when the resulting model is applied to new observations, the answer will result in an error 32.26% of the time. This indicates that 68.74% of the results will be accurate, which would indicate a reasonably good model. Out of the 30% of the data set aside for testing, (28 wards), seven wards from the DNCC and 13 wards from the DSCC are classified correctly, implying an accuracy of 0.7143 on the test data. A list of the modelled categories is shown in Table 3.3. The building age range of 10 to 30 years is the most important.

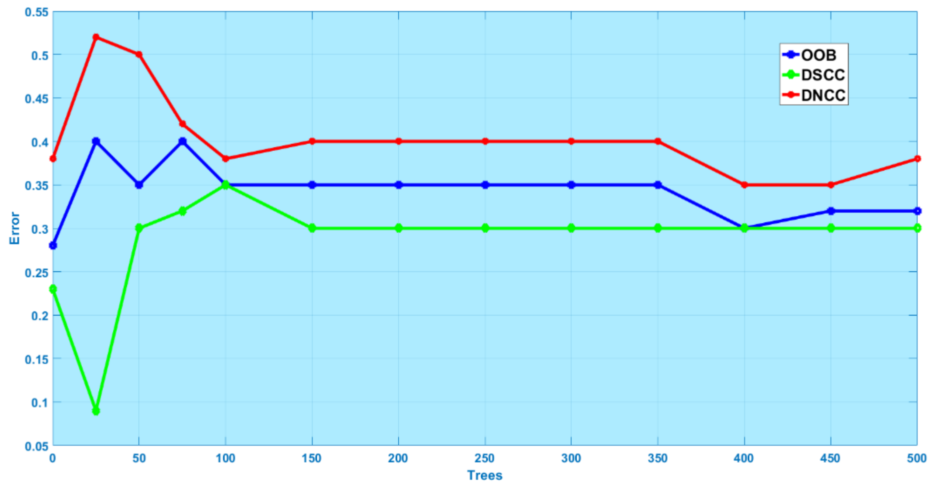

Figure 3.8 Overall random forest model error rates: OOB (blue line); DNCC (red line) and DSCC (green line).

Table 3.3 Variable importance of building age.

Variable	Mean Gini Decrease
10 years	9.965379
10–30 years	10.390261
Over 30 years	9.566955

Figure 3.8 indicates that, as the number of trees increases, the OOB error rate decreases, particularly in the DSCC, and after 200 trees the OOB error rate becomes constant. The DNCC OOB error rate still fluctuated slightly after 400 trees, becoming stable after 450 trees.

3.7.2.3 Earthquake Vulnerability Factors

The OOB error for these factors suggests that when the resulting model is applied to new observations, the answer will result in an error 33.87% of the time (66.13% accuracy, indicating a reasonably good model). Here, we can see that, out of the 30% test holdout data for 28 wards, seven wards from the DNCC and 10 from the DSCC are classified correctly, and the accuracy of the random forest model on the test data is 0.6071.

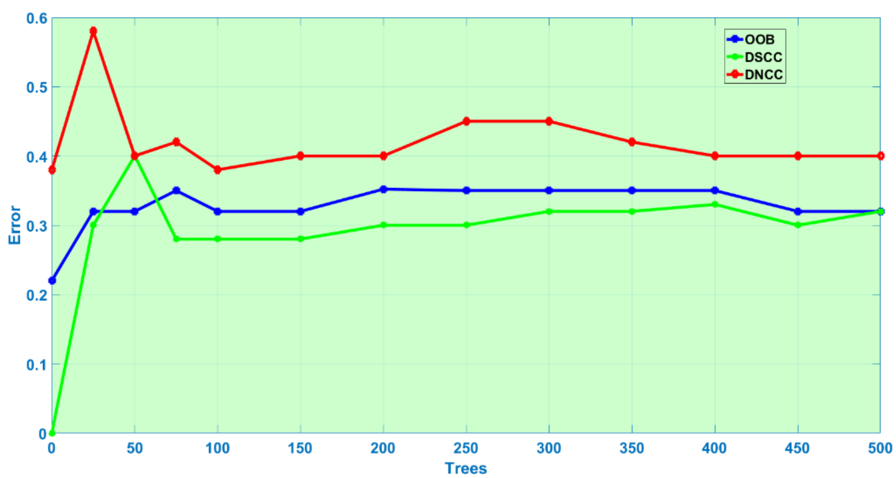

Figure 3.9 Overall random forest model error rates: OOB (blue line); 1, DNCC (red line) and 2 DSCC (green line).

As shown in Figure 3.9, the final random forest model was built from 500 trees. The OOB error rate decreased quickly as the number of trees increased up to 350. After that, the error rate becomes constant. As described in the discussions above of variable importance for building age and structure type, for vulnerability factors, we found the presence of short columns and heavy overhangs to have the most influence in the model (see Table 3.4).

Table 3.4. Variable Importance of earthquake vulnerability factors.

Variable	**Mean Gin Decrease**
Soft first story	6.911157
Heavy overhang	7.043463
Short columns	7.693125
Pounding effects	6.615364
Topographic effects	1.714052

3.7.3 Discussion

3.7.3.1 Structural Type

Reinforced concrete (RC) structures are built of concrete, which responds rather weakly to tensile forces and is quite brittle. These structures are enhanced with a reinforcement of higher tensile strength and/or ductility. RC is concrete that is made with pieces of metal inside it to make it stronger. Reinforcing schemes are usually designed to resist tensile stresses in particular regions of the concrete that might cause unacceptable cracking and/or structural failure. Modern reinforced concrete can include varied reinforcing materials made of steel, polymers or alternate composite material along with its standard rebar. RC may also be prestressed to improve the behavior of the final structure under working loads (Reinforced Concreate Wikipedia 2018).

In the last twenty years, urban development has sparked a widespread construction boom in the DNCC, and very recently new high-rise buildings and skyscrapers have changed Dhaka's Northern landscape. Different real estate companies have constructed a variety of high-rise apartment buildings either by purchasing land from the owners or demolishing existing one- or two-story buildings (Mohuya 2011). However, inadequate infrastructure and the existence of many vulnerable buildings has resulted in a serious threat of collapse in old areas of Dhaka (DSCC) (Ansary 2015).

Our study reveals (see Figure 3.4 and Table 3.2) that for structure type, the presence of reinforced concrete buildings is the most important predictor. These are more common (see Figures 3.4 and 3.9) in the DNCC, which can tolerate small or medium earthquakes. In the DSCC, on the other hand, less than half the buildings in an area are likely to be RC-type structures. Therefore, the DSCC is much more vulnerable to earthquake disasters with respect to housing structure types. Still, we highly recommend applying seismic retrofits in both areas to mitigate earthquake disasters.

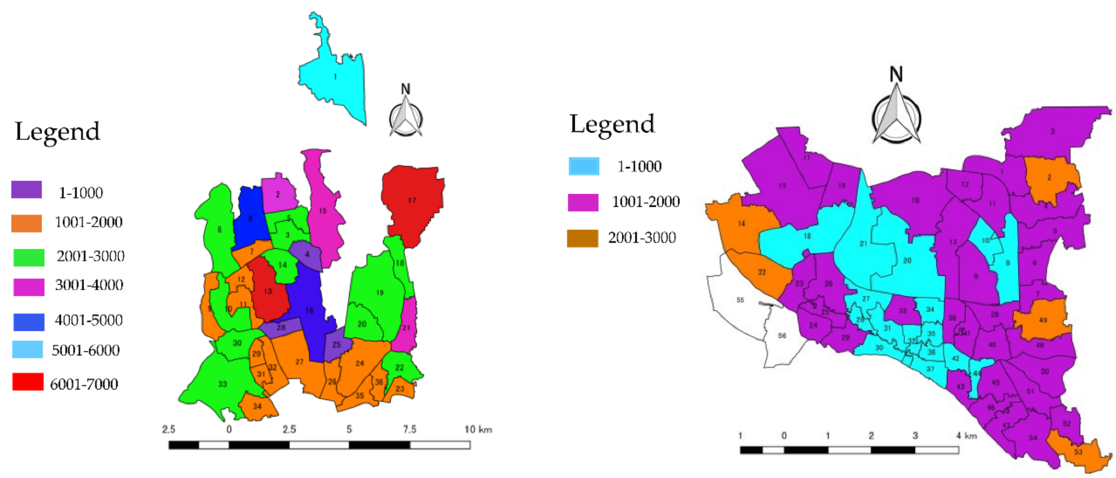

Figure 3.9 Number of reinforced concrete buildings in the DNCC and DSCC (Data source: CDMP-2009).

Lightly reinforced concrete buildings (LC) are the RC structures that employ only the minimum structural members to sustain gravity loading. The columns in these buildings are small and they have heavy overhangs (CDMP-2009). Lightly reinforced concrete columns are common in many old buildings and are widespread in current detailing practice in areas with lower seismicity. From a conventional design perspective, this structural type has very low lateral load and drift capacity.

Masonry brick in cement mortar with a concrete floor (BC) buildings have concrete slabs, structural masonry walls and no confined reinforced concrete columns (CDMP-2009). The concrete used in these buildings is made by mixing cement, sand, small stones, and water. Its stability and durability, which varies widely, can also be a liability, and concrete floors are very hard. Many masonry buildings that have been subjected to catastrophic earthquakes have collapsed or suffered severe damage due to inappropriate design, improper material production or application mistakes. Nevertheless, many masonry buildings, particularly historical ones, have survived earthquakes with little or no damage, while many new reinforced concrete structures in the same location have been cracked or heavily damaged. Therefore, if masonry buildings can be designed to resist earthquake and constructed with excellent quality materials, they could survive earthquakes. Although masonry buildings vary in different earthquake zones, the damage they suffer from earthquakes can usually be classified (Doğangün et al. 2008).

Buildings in the masonry brick in cement mortar with a flexible roof (BF) category are quite similar to those with concrete floors. However, due to the lack of a stiff diaphragm that confines the masonry wall, they exhibit poorer seismic behavior (CDMP-2009). Flat roofs exist all over the world and each area has its individual traditional or preferred materials. In warmer climates, where there is less rainfall and frost is unlikely, many flat roofs are simply made of masonry or concrete, which is inexpensive, good at shielding the warmth of the sun and easy to build (Passmore 1904).

The tin shed bamboo (TSB) category ranges from very simply constructed open-sided tin roofed structures to large wood or bamboo-framed sheds with shingled roofs, windows and electrical outlets. Tin shed construction may have metal or plastic sheathing over a metal frame. Tin sheds and bamboo houses are less vulnerable to earthquakes.

We also discovered (see Figure 3.4 and Table 3.2) from the decision tree and random forest analysis that, after RC buildings, TSB structures are the second most important predictor for earthquake hazard, and performed better in the DSCC area than in the DNCC area. One essential factor here is that these types of house are not built adjacent to other structures, avoiding the indirect effects of contact during earthquakes.

3.7.3.2 Building Age

Building age is divided into three categories as follows: (1) less than 10 years old; (2) 10–30 years old; and (3) over 30 years old. Buildings from the last 10 years are new. Particularly, in recent years' real estate companies have built many residential buildings. The many buildings from 10 to 30 years old are also part of Dhaka's building boom of the last two or three decades. Our results (see Figure 3.5 and Table 3.3) reveal that having buildings from 10 to 30 years is the most important predictor. This was particularly significant in the DNCC since these buildings are less vulnerable than those over 30 years old. These newer buildings (see Figure 3.10) are more common in the DNCC than in the DSCC.

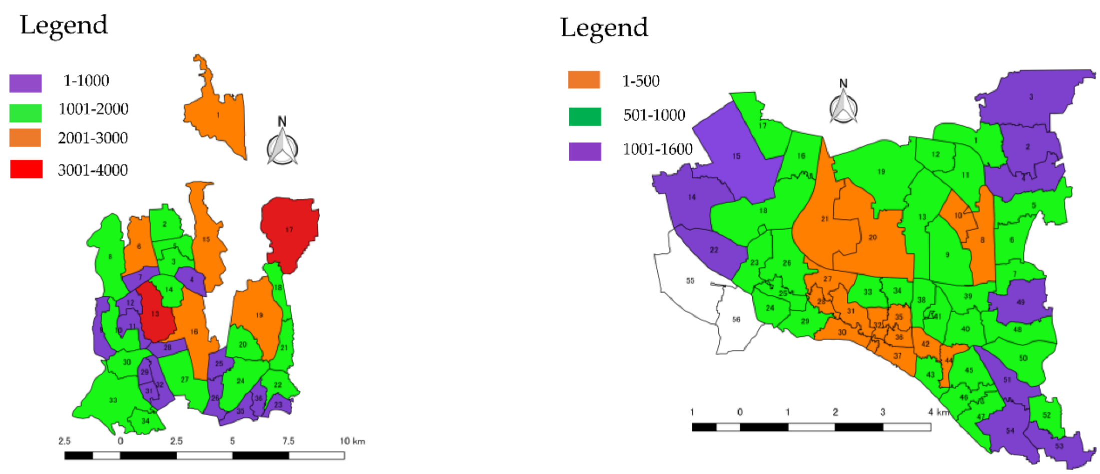

Figure 3.10 Numbers of buildings 10 to 30 years old in the DNCC and DSCC (Data source: CDMP-2009).

Buildings constructed more than 30 years ago are quite old and were designed without earthquake engineering considerations, so are more vulnerable to earthquakes. Some of the urban areas in Old Dhaka (DSCC) are several hundred years old and the people living in them are at risk of the closely-packed, congested buildings being obliterated (Ansary 2015).

We found that Old Dhaka (DSCC ward 32) was emphasized by the maximum number of respondents having aged and/or damaged buildings (Jahan et al.2011).

The result reveals that buildings over 30 years old, having aged and not having been engineered correctly in the first place, are more vulnerable during earthquake events. From our analysis (see Figure 3.5), there are more of these buildings in the DSCC than in the DNCC. We, therefore, recommended that design and constructed methodologies be upgraded to improve these outdated buildings and mitigate earthquake disasters, particularly in the DSCC.

3.7.3.3 Vulnerability Factors

According to level 1 of the Turkish method for earthquake disaster abatement, there are five factors that affect a structure's vulnerability: a soft first story, heavy overhang, short columns, pounding effects and topographic effects.

Soft story buildings are seen in both residential and commercial areas, where the soft stories are often at ground level. A soft story is a floor that is significantly more pliable and weaker than the other floors. First stories are used as stores and commercial spaces, particularly in the central part of cities. These areas are surrounded by glass windows, or sometimes have a single masonry infill at the rear. During an earthquake event, the presence of a soft story significantly increases deformation and puts the whole burden of energy dissipation on the first-story structural elements, as opposed to allocating it over the entire height of the building. Many failures and collapses can be attributed to the increased deformation precipitated by the presence of soft stories (Bruneau 2002).

Weak construction, defective building design (pillars, columns and foundations), damage from congested electric cables and other factors increase earthquake vulnerability in DSCC ward 32 (Jahan et al.2011).

Our decision tree results (see Figure 3.6) for earthquake vulnerability factors indicated more soft story buildings in the DNCC than in the DSCC and, indeed, more of them are being built (see Figure 3.11) in the DNCC area. To lower the hazard, we highly recommend reconstructing these sorts of buildings or applying high performance fiber reinforced cementitious composite **(**HPFRCC) devices to their structures to mitigate earthquake damage (Fukuyama 2006).

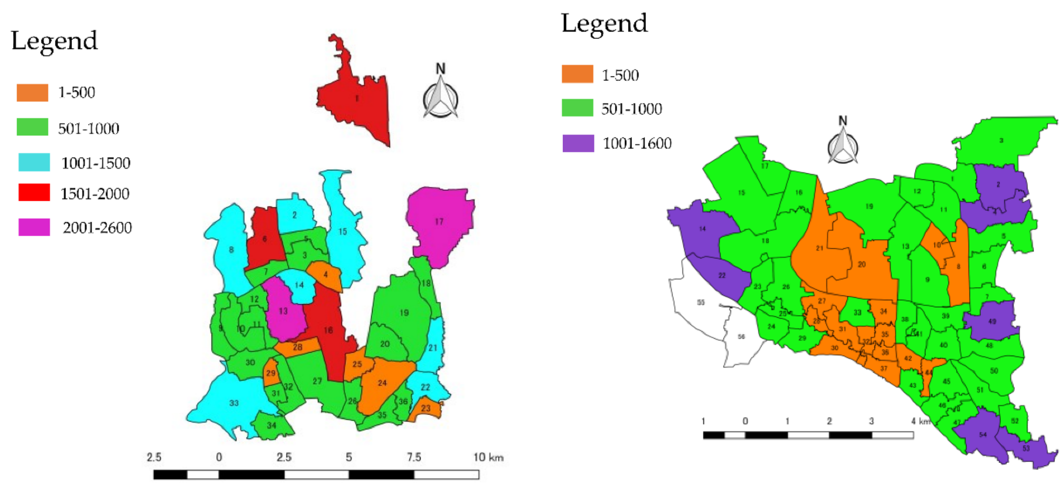

Figure 3.11 Numbers of soft story buildings in the DNCC and DSCC (Data source: CDMP-2009).

Heavy overhanging floors in multistory buildings leads to inconsistency in stiffness and mass distribution. From the viewpoint of earthquake engineering, these irregular plan shapes are undesirable because they cause an unsuitable dynamic behavior when subjected to horizontal earthquake ground motion. For example, torsional moment in buildings increases during an earthquake because of the asymmetric distribution of mass and stiffness (CDMP-2009).

The pounding of adjacent buildings also causes structural damage. Proper distances should be maintained between adjacent buildings in order to reduce these catastrophic effects. In some areas where a series of buildings are constructed side by side, the outside edges of buildings on the end may be forced outward, resulting in severe damage, while inner buildings are protected from such extreme lateral deformation (Otani 2004).

Topographic implications may also enhance ground motion intensity on hilltops during earthquakes. For example, most buildings located on steep slopes (greater than 30 degrees) have discontinuous foundations that can transfer the ground movement distribution evenly to the structural components above.

3.7.4 Conclusions

Rapid urbanization without proper planning and unregulated population migration have created zones in Dhaka city where the earthquake hazard is quite elevated. In a disaster like a medium-sized earthquake in or around Dhaka, the catastrophic effects would be unthinkable. This paper examines housing structures and vulnerability factors in Dhaka city in order to facilitate earthquake preparations. This study presents significant findings to help identify housing structures towards earthquake vulnerability in comparison to two main parts of Dhaka city. We believe that our study will provide valuable information about the pattern of housing structures and the results obtained have made it possible to identify the strengths and weaknesses of DNCC and DSCC. Based on our analysis, we found that the DSCC constitutes a higher hazard than the DNCC because of its outdated buildings, weak building materials, and soft-story structures. Thus, it is of utmost importance to make a significant push to construct new buildings and implement seismic retrofit policies, particularly in the DSCC area. In the DNCC area, there is a need to apply HPFRCC devices to soft-story buildings to mitigate future earthquake hazards. Future studies are required to understand the seismic retrofit imposed on housing infrastructure both in the DNCC and DSCC area during post-disaster recovery. Additionally, further studies are needed to estimate the quality of housing materials and to increase public awareness of earthquake safety.

Chapter 4

Conclusion

To mitigate the earthquake hazard need to ensure the safety the housing structures and set up essential facilities. Effective earthquake education is imperative to make awareness for necessary steps. For proper disaster management, recognition of the existence of the hazard zone is considered an essential task. In previous, some research had done about specific wards earthquake vulnerability assessments in Dhaka city. In this study, we approach new way for earthquake preparedness analysis that focuses the whole Dhaka city essential facilities and housing structure for earthquake preparedness and find out concisely robust and weakest area compare to two main parts of Dhaka city. The findings of this research lack of emergency response, medical care and poor construction house can push to policymakers to take appropriate decision regarding earthquake disaster management strategies in this prime city of Bangladesh. As individual level such as the landlords, physicians, firefighters and other responsible professions along with local people working together can play an important role to lessen the disaster impacts in the local area. Additionally, this research also illustrates the general people responsibility during the earthquake, what to do if an earthquake hits, where to get shelter, where to phone for help, etc. should be undertaken daily in different television, radio, newspaper, talk show. The policy issues regarding disaster like an earthquake could be handled mostly at the national level, but planning and implementation issues are to be processed at the local community level. The earthquake hazards can never be resisted, but increasing capacity of essential facilities and improving housing structures can reduce the severe damages of the earthquake disaster in Dhaka city as it reduces the risk and vulnerability.

This paper focuses on critical and housing structures in DCC to facilitate earthquake preparations. In this paper, the second chapter illustrates significant findings to help identify Essential facilities towards earthquake preparedness compare to two main parts of Dhaka city. The findings of the present study indicate that medical care and emergency response facilities are poorly situated to respond to a major earthquake in both of DNCC and DSCC area. Based on these findings, more medical care and emergency response facilities should be built in both of DNCC and DSCC area, especially DSCC is the more worst situation to handle disaster situation and so need to prioritize this area to increase essential facilities. The number of schools is adequate in DNCC area than that of schools in DSCC area, but schools need to be constructed seismic retrofit to minimize damage, loss, injury and also use as a temporary shelter aftershock. Future studies are needed to estimate the impact of the quality of medical care, emergency response, schools, other facilities in Both of DNCC and DSCC area to handle the earthquake disaster situation.

Rapid urbanization without proper planning and unregulated population migration have created zones in Dhaka city where the earthquake hazard is quite elevated. In a disaster like a medium-sized earthquake in or around Dhaka, the catastrophic effects would be unthinkable. In this paper third chapter examines housing structures and vulnerability factors in Dhaka city in order to facilitate earthquake preparations. This study presents significant findings to help identify housing structures towards earthquake vulnerability in comparison to two main parts of Dhaka city. We believe that our study will provide valuable information about the pattern of housing structures and the results obtained have made it possible to identify the strengths and weaknesses of DNCC and DSCC. Based on our analysis, we found that the DSCC constitutes a higher hazard than the DNCC because of its old buildings, weak building materials, and soft-story structures. Thus, it is of utmost importance to make a significant push to construct new buildings and implement seismic retrofit policies, particularly in the DSCC area. In the DNCC area, there is a need to apply HPFRCC devices to soft-story buildings to mitigate future earthquake hazards. Future studies are required to understand the seismic retrofit imposed on housing infrastructure both in the DNCC and DSCC area during post-disaster recovery. Additionally, further studies are needed to estimate the quality of housing materials and to increase public awareness of earthquake safety.

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